Historical Land Use and Land Cover Change of the Lake Tempe Region: A Multi-source Data Landscape Reconstruction

Syahruddin Mansyur [1, 2, 3] *, **Nur Ihsan Djindar** [3, 4, 5], **Wasita Wasita** [1],
Imam Hindarto [1], **Nani Somba** [1], **Hasrianti Hasrianti** [6], **Moh. Ali Fadillah** [7],
Hamka Naping [2], and **Sofyan Setia Budi** [4]

AFFILIATIONS

1. Research Center for Environmental Archaeology, Maritime Archaeology, and Cultural Sustainability, National Research and Innovation Agency, Jakarta, Indonesia.
2. Department of Anthropology, Hasanuddin University, Makassar, Indonesia.
3. Collaboration Research Center for the Archaeology of Sulawesi, Hasanuddin University, Makassar, Indonesia.
4. Department of Archaeology, Hasanuddin University, Makassar, Indonesia.
5. Antwerp Cultural Heritage Sciences Research Group (ARCHES), University of Antwerp, Antwerpen, Belgium.
6. Research Center for Prehistoric and History Archaeology, National Research and Innovation Agency, Jakarta, Indonesia.
7. Department of History Education, University of Sultan Ageng Tirtayasa, Banten, Indonesia.

 * Corresponding authors:
   syah021@brin.go.id

ABSTRACT

Lake Tempe, situated in the Wajo Regency, is an ancient lake in Indonesia that plays a crucial role in the socio-historical evolution of Southern Sulawesi. The Lontara manuscript, a significant source of regional history, highlights Lake Tempe as a vital resource for adjacent communities. Contemporary narratives of Lake Tempe, however, are overshadowed by recurrent flooding attributed to accelerated sedimentation leading to lake shallowing, which impedes its capacity to manage the inflow from tributary rivers. This study aims to offer a historical perspective by reconstructing the landscape and detailing the evolution of land use and land cover (LU/LC) in the Lake Tempe region, thus enhancing our understanding of the lake's current conditions. We compiled an array of historical and archaeological data, including manuscripts, archival maps, and satellite imagery, spanning the 13th to 20th centuries. Our approach involves historical LU/LC modeling to provide an intricate depiction of the landscape evolution in the Lake Tempe area. Moreover, we presented modeled projections of LU/LC alterations over approximately 86 years (1930-2016). The analysis reveals that pre-20th century landscape dynamics in the region were influenced by several factors: demographic shifts due to local migration, interplay among local elites over natural resource control, and integration into global trade networks from the 13th century onwards. These elements collectively spurred deforestation during periods of agricultural expansion. Starting in the early 20th century, the agricultural development policies of both the Dutch Colonial and the Republic of Indonesia's governments further accelerated land conversion for distinct agricultural purposes. This historical narrative underscores the fact that centuries of anthropogenic activity have been central to the hydrometeorological challenges faced throughout the Lake Tempe region.

1. INTRODUCTION

South Sulawesi has seen a significant conversion rate of paddy fields for alternative uses in Indonesia. According to a study conducted on the conversion of paddy fields in rice production centers across the country, South Sulawesi ranked first outside Java and Sumatra, with a conversion rate of 3,562 ha/year (Mulyani et al., 2016). These findings pose a serious threat to national food security, as indicated by the results of land conversion studies in rice production centers in Indonesia (Mulyani et al., 2016). Furthermore, the 2018 study by the Central Bureau of Statistics revealed a decrease of 0.65 million ha in the area of rice fields in Indonesia when compared to the land area in 2017 (CNN Indonesia, 2018). The region surrounding Lake Tempe is one of the main agricultural production centers and food reserves in South Sulawesi Province. Agricultural activities in this area have been ongoing for a considerable amount of time

and have become the primary means of subsistence for the local population. Agricultural activity is one of the driving factors contributing to land use and land cover change (LU/LC).

The interplay between agriculture and land-use changes is a complex and longstanding phenomenon. Historical analyses, such as those by Redman (1990, 1999) and Alfonsina et al. (2015), have demonstrated that agricultural practices play a pivotal role in altering LU/LC. Tracing back human agricultural endeavors around the world revealed a sporadic but significant presence spanning 12,000 to 4,000 years ago, as noted by Bellwood (2005). The genesis of these land-use changes can be traced to the domestication and cultivation of food crops, and the adaptation of early humans to sustain their livelihoods. This pattern of change has been progressively shaped by agricultural intensification and subsequent expansion. As argued by Axtell et al. (2002) and Bithell et al. (2009), these developments were largely in response to demographic growth, culminating in marked landscape transformations and consequent environmental impacts.

Extensive research has been conducted in Indonesia to understand landscape transformations resulting from agricultural activities, employing a spectrum of analytical perspectives. These include historical and contemporary LU/LC models. Various studies involving regional analyses have been conducted in this domain. For example, Wahyuni et al. (2014) investigated LU/LC changes in the Dairi Regency, North Sumatra, from 2003 to 2013. Similarly, Susanti et al. (2020) analyzed land alterations in the Upper Serayu Watershed, Central Java, using advanced techniques, such as remote sensing and geographic information systems. Sudrajat et al. (2021) examined the socioeconomic impact of converting land into palm oil plantations in the North Kayong District of West Kalimantan. Supriatna et al. (2022) identified the factors that contribute to changes in land-use in the Martapura and Maluka watersheds of South Kalimantan. Recently, Ambarwulan et al. (2023) projected future land use and cover in the Cisadane Watershed of West Java to identify the potential consequences for deforestation and food security.

In addition, Nganro et al. (2021) predicted future LU/LC trends in Makassar City, South Sulawesi, whereas Santoso et al. (2017) examined paddy field conversion patterns in Subang Regency, West Java. Verawaty et al. (2023) modeled Land Use and Cover Changes (LUCC) in Deli Serdang Regency, North Sumatra. In the field of environmental archaeology, Sulistiyo & Fakhri (2023) provided insights into the malacofauna from the Cappa Lombo Site, contributing to environmental reconstruction and an understanding of subsistence strategies in South Sulawesi's Bontocani highland karst region. Murdaningsih et al. (2016) conducted a spatial analysis of changes in agricultural land-use in the Indramayu Regency, West Java, emphasizing its role in supporting food self-sufficiency.

However, in the context of South Sulawesi, despite notable contributions such as Caldwell & Lillie (2004), who also focused on Lake Tempe, there remains a notable gap in comprehensively synthesizing multi-source data from diverse perspectives, including historical (manuscripts, ancient maps, and oral traditions), archaeological, and environmental data. Although some studies have been conducted in this region, such as Caldwell and Lillie (2004), there is a noticeable gap in the literature. Recognizing the complexity of LU/LC change, Lambin et al. (2003) suggested the importance of local-scale analysis to gain an understanding of a typical eco-region. Generally, reconstructions of land cover composition and structure leverage multiple methods and integrate various data sources for a more holistic understanding. Yang et al. (2014) proposed a novel approach involving multiple-source and multidisciplinary analysis. This method merges different reconstruction techniques ranging from

historical document analysis, historical maps and imagery, archaeological remains, and natural archives to develop model-based reconstructions. The application of this multi-source and multidisciplinary framework enables a more comprehensive depiction of land-use and cover changes (Yang et al., 2014:755). Consequently, in reconstructing landscape alterations and the historical trajectory of LU/LC in the study area, a dual approach was adopted. This encompasses both multiple-source reconstruction and multidisciplinary analysis, acknowledging the limitations inherent in single-method LU/LC analyses.

At its core, this article aims to provide an overview of landscape reconstruction and to detail the history of LU/LC changes in the Lake Tempe region and its vicinity. The primary objectives were to gain a more comprehensive understanding of the phenomena occurring in the Lake Tempe region and to trace the history of vegetation and landscape changes from around early Holocene to more recent developments from the 13th century to the 21st century. This article discusses and elucidates the environmental background of Lake Tempe and the history of the agricultural landscape in the Lake Tempe region up to the 20th century and performs LU/LC model-based landscape reconstruction for the period 1930-2016.

2. MATERIALS AND METHODS

2.1 Study area

This research delves into the landscape evolution of the area surrounding Lakes Tempe and Sidenreng, focusing on the historical sweep of change across what were once the realms of the Kingdoms of Wajo, Sidenreng, and Soppeng. These domains have evolved into today's administrative divisions of Wajo Regency, Sidenreng Rappang Regency, and Soppeng Regency, which are part of the governmental structure.

Figure 1. Multilayered historical and toponymical maps of Lake Tempe and Lake Sidenreng regions. This map delineates the geographical scope of the study area, incorporating the territories of the former Kingdoms of Wajo, Sidenreng, and Soppeng, which are now redefined as

administrative regencies. It features significant sites and place-names derived from the Cenrana, Soppeng, and Sidenreng Manuscripts, illustrating the intersection of historical narratives with the present-day landscape. Each site was marked in correspondence with its documented historical significance and cultural heritage. The inset maps provide a contextual overview of the location of the study area within Indonesia and on Sulawesi Island.

The study region, historically composed of various political kingdoms, is now characterized by its lowland topography and rich water resources, contributing to its reputation as a base for agricultural fertility. It is a legacy that traces back to its recognition as a major rice production center by European observers since the 16th century (Pelras, 1983). Presently, ancient wanuas, once political units under the royal dominion, have transitioned into contemporary settlements, retaining their historical nomenclature and continuing to thrive as vibrant communities.

2.2 Data source

Our multi-source approach to reconstructing historical LU/LC integrates natural archives, archaeological findings, historical documents, and maps. Natural archives offer insights into paleoenvironmental conditions, while archaeological data reveal human impacts on landscapes. Historical maps and images sourced from VOC, Dutch East Indies documents, 1979 satellite imagery, and 2016 RBI landform maps provide primary data for understanding landscape changes.

2.2.1 Data sources for landscape reconstruction

For landscape reconstruction, we utilized primary data such as ancient Dutch maps (17th-18th centuries) and Lontara manuscripts detailing the histories of the Sidenreng and Wajo Kingdoms. Secondary data encompasses publications on archaeological, historical, and environmental studies, offering perspectives on paleovegetation, cultural landscapes, and human development in the Lake Tempe area.

2.2.2 Data sources for land use and land cover history

LULC analysis relies on primary data from topographic maps, satellite imagery, and land cover maps, covering 1930-2016. The archival topographic maps from the *Topografiche Inrichting*, part of the "*Gouvernement Celebes en Onderhorigheden*" series, depict various land features at a 1:25,000 scale. Satellite imagery from the 1979 KH-9 mission covered the southern region of Sulawesi Island, offering high-resolution surface images (Surazakov & Aizen, 2010). Finally, the RBI landform maps from the Indonesian Geospatial Portal provide recent land cover data.

2.3 Data analysis

In this phase, we applied Yang et al.'s (2014) multiple-source and multidisciplinary analysis method for a comprehensive reconstruction of historical land-use and land cover. This approach integrates diverse methods including document-based, historical maps, image-based, archaeological remains, natural archives, and model-based reconstruction. We utilized Bugis manuscripts, specifically the Lontara, as a historical source with significant value regarding the occupation of land around Lake Tempe. Additionally, we identified archaeological remains, including the concentration and distribution of ancient settlement sites, based on structural, substructural, and artifactual data that aligned with land-use for agriculture and settlement. Our analysis spans two key periods: the pre-20th century and the 20th century (1930-2016). The earlier period utilized a variety of historical documents and maps, whereas the latter period's analysis was grounded in 1930 topographic maps, satellite imagery from 1973 to 1980, and 2016 landform maps. This methodological approach allowed us to develop a nuanced understanding of landscape changes, encompassing both land cover and

land-use over these distinct periods.

2.3.1 Data preprocessing

In the data preprocessing stage, we employed specific techniques for different data types. For the archival topographic maps, we used ArcGIS Desktop 10.8.1, applying the WGS 1984 World Mercator coordinate system for georeferencing. Ground Control Points (GCPs) were established using major road networks, and the Polynomial Affinity type was used to minimize distortion. The digitization process involved extracting key land cover classes from the maps, and ArcGIS was used to calculate the land area changes.

Satellite imagery analysis underwent a process similar to that of georeferencing and digitization. The key difference was in cropping the imagery to match the coverage areas of the archival maps. This process was aided by overlaying the vector data from the maps onto the imagery to assist in land cover interpretation. For the RBI Land Cover Maps, we aligned their coordinate system with the other maps and merged the data into a single layer, cropping it to the designated analysis area.

2.3.2 Harmonization of land cover categories

To study LU/LC changes effectively, we addressed the challenge of varying classification systems by standardizing categories across different data sources. Recognizing the diversity in classification systems, such as those by the United States Geological Survey (USGS), European Space Agency (ESA), or the Ministry of Environmental Affairs and Forestry, Indonesia, we adopted the National Standardization Agency's classification (Badan Standarisasi Nasional, 2014). This hybrid definition of LU/LC offers the flexibility needed for our research.

Table 1. Land cover and land use classifications were used.

Code	Name	Description
1	Agricultural Land	Land cover, consisting of fields, orchards, and farmland. Clearings (patches) within forest areas are also included in this category.
2	Lake	Permanent water bodies formed naturally on land, usually characterized by distinct boundaries between water bodies and land, and relatively deep-water bodies (National Standardization Agency 2014, 14).
3	Forest	Land cover, consisting of tree vegetation, both homogeneous and heterogeneous species.
4	River	Natural flowing water bodies in elongated basins.
5	Swamp	Land areas around lakes, whether permanent or affected by lake level fluctuations, characterized by relatively shallow water and thick, extensive mud deposits.
6	Settlement	Built-up areas containing human-made structures and buildings.

Based on these land cover categories, the land cover classification system in the three map data sources from different periods was adjusted to include six categories. The harmonized results are listed in Table 2.

Table 2. Harmonization of Land Cover Categories

Code	Archival Topographic Maps 1930	Satellite Image 1979	Land Cover Map 2016
1	Paddy Fields, Farmland	Agricultural Land	Paddy Fields, Orchards
2	Lake	Lake	Lake

Code	Archival Topographic Maps 1930	Satellite Image 1979	Land Cover Map 2016
3	Vegetated area	Forest	Forest, Dry Forest, Wet Forest, Scrubland.
4	River	River	River
5	Swamp, Wetlands	Swamp	Marsh
6	Village	Settlement	Buildings, Settlements

We adjusted the land cover categories from our three map data sources (archival topographic maps, satellite imagery, and land cover maps) to align them with the six standardized categories. This harmonization simplifies the comparison and analysis across different periods and data sources. The harmonized categories included agricultural land, lakes, forests, rivers, swamps, and settlements, ensuring consistency in our land-use and land cover analysis.

2.3.3 Characteristics observed

Our analysis of land cover changes around Lake Tempe focused on specific characteristics to effectively monitor landscape dynamics. These include (1) calculation of the land cover area in square kilometers and its percentage of the total area, (2) tracking additions and reductions in land cover categories over time, (3) identifying land cover conversions, (4) maintaining records of areas with consistent land cover since 1930, and (5) calculating the rate of change per category in km²/year.

2.3.4 Data processing

Data processing utilized 'Terrset v.18.31,' which is a comprehensive geospatial modeling and analysis tool developed by Clark University (Eastman, 2020). The primary module used was the Land Change Modeler (LCM), which facilitates the analysis of land cover changes between two points of time. To align with LCM requirements, vector data from preprocessing were converted to raster format using ArcGIS 10.8.1 and then imported into Terrset as '.rst' files for analysis. This process enabled detailed observations of land cover changes for the periods 1930-1979 and 1979-2016.

3. RESULTS AND DISCUSSIONS

3.1 Environmental background of Lake Tempe and its surroundings

Lake Tempe is a basin formed by geological processes resulting from the tectonic activity of the Walennae fault. Geologically, this area is often referred to as the Sengkang Basin or Walennae Depression (Suyono & Kusnama, 2010) and is also known as the Tempe Depression (Whitten et al., 1978), Tempe Basin (Cholik & Anggraeni, 1994), or Cenrana Valley/Walennae Valley (Caldwell, 1995; Bulbeck & Caldwell, 2000 and 2008; Caldwell & Wellen, 2017).

During the Pleistocene epoch, sea levels were approximately 25 m higher than they are today, suggesting that the Tempe depression area was likely submerged under the sea at that time (de Klerk, 1983; Whitten et al., 1978; Giesen et al., 1991). Situated on the Australian and Asian continental plates (van Bemmelen, 1949), Lake Tempe was a water body that separated the northern and southern parts of Sulawesi Island during this period (Nugraha et al., 2019: 111). During the Holocene, plate collisions caused the area around the lake to rise (van Bemmelen, 1949), forming three basins: Lake Buaya, Lake Sidenreng, and Lake Tempe (Pelras, 2006).

Over time, geological processes have gradually transformed the northern part of the Sengkang Basin from a tidal and deltaic to a fluvial environment. The upper

sequence of basin sediments is predominantly composed of fluvial deposits (Suyono & Kusnama, 2010). The sedimentation process, influenced by the hydrological system in which the major rivers flow in this region, has led to the deposition of alluvial sediments in these lowlands. Consequently, this has turned the area into fertile agricultural land.

Lake Tempe, which currently exists in terms of topography and hydrology, is interconnected with Lake Sidenreng. Together, these lakes form an inseparable system, covering a maximum area of 35,000 ha. Lake Tempe itself spans about 13,000 hectares, with depths varying from 5.5 meters during the rainy season to between 0.5 and 2 meters in the dry season. It serves as the confluence for several tributaries, including the Tancung, Lababo, Baru, Menreli, Wettee, and Minraleng Rivers, flowing from south to north. The eastern part of Lake Tempe is bordered by a range of hills, namely Bulu Menje, Bulu Cepo, Bulu Nepo, Bulu Pattirosompe, Bulu Wage, and Bulu Pattiro. To the southeast lies the Bulu Topompangi and Bulu Malongo hills, while the southern area encompasses the floodplains of the Walannae and Towaroe Rivers. The western side is defined by the Bulu Mangewo, Bulu Bakae, and Bulu Lapobangi hills, and the northern part includes the floodplains of the Bila River and its branches (Syahriwati 2004: 1-2, 14).

The morphology of the southern peninsula of Sulawesi Island clearly shows a topographical distinction between the northern, central, and southern regions. The northern topography consists of mountains that appear to connect with the mountainous regions of Central Sulawesi, with Latimojong Peak being the highest. In contrast, the southern part features a series of mountains aligned centrally, similar to the backbone of the southern peninsula, with Mount Bawakaraeng and Mount Lompobattang in the south exhibiting the highest peaks. The central area between these two sides consists of lowlands, which receive river flows from both the north and south.

The climatic conditions of a region are influenced by various factors, primarily rainfall, and the annual distribution of wet and dry months. Data from the past 30 years indicate changes in climatic conditions. According to RePPProT (1988), the annual rainfall recorded at the Parepare station was 2,078 mm, and at the Sengkang station, it was 1,593 mm (Giesen et al., 1991). However, data from 2018 showed an increase in annual rainfall to 1,832 mm at Pare-pare (Satu Data Pemerintah Kota Parepare, 2021) and 2,146 mm at Sengkang (BPS Kabupaten Wajo, n.d). The distribution of wet and dry months helps define a region's agro-climatic system. According to Oldemann & Darmiyati (1977), the zones were differentiated based on the number of wet (> 200 mm) and dry months (< 100 mm). According to this system, the Lake Tempe area and its surroundings are categorized as a zone where wet months occur consecutively for zero–two months, and dry months for up to six consecutive months (Giesen et al., 1991).

The environmental conditions of Lake Tempe, as recorded in the written sources, were confirmed through palynological investigation reports at three lake depression locations: the eastern shore of Lake Tempe, Lake Buaya to the north, and Rawa Lampulung to the east. Paleovegetation records from the eastern shore of Lake Tempe have been dominated by freshwater vegetation since at least 4,400 years ago. Pollen diagrams from Lake Tempe revealed a transition from lowland forest to open grassland vegetation dominated by grasses and shrubs. Conversely, Lake Buaya exhibited a vegetative shift from open fields to lowland forests. In contrast, pollen diagrams indicated that Rawa Lampulung was once covered by mangrove vegetation. This cover underwent a sudden change approximately 2,600 years ago and was replaced by open plain vegetation, such as grasses and shrubs (Whitten, 1978; Gremmen, 1990). These findings suggest that the area, located approximately 4 km east of Lake Tempe, was submerged in seawater approximately 7,100 years ago. Furthermore, historical

accounts of a large lake are likely to refer to the annual flooding recorded by Manuel Pinto in a document from 1548 (Caldwell & Lillie, 2004).

3.2 A brief history of agricultural landscapes before the 20th century, with specific reference to the Lake Tempe region

Neolithic culture is often cited as the root of agricultural emergence in human civilization. Experts suggest that the spread of the Neolithic culture began around 11,000 to 10,500 BP in the Southwest Asia region. Neolithic sites with archaeological findings associated with rice grains have been estimated to date back to at least 8,500 BP in East Asia, specifically in the Yangzi Basin in China (Bellwood, 2005). Another significant site is Shangshan in Zhejiang Province, China, where rice grain findings have been dated between 9,000 and 11,000 BP (Jiang, 2005; Gross & Zhao, 2014). South Asia is also noted as a region of origin for rice cultivation, particularly at Lahuradewa in the Ganges Plains of India, where rice phytoliths have been indicated to originate from around 9,000 BP (Saxena et al., 2006; Tewari et al., 2003; Tewari et al., 2008). These two regions were subsequently identified as the origins of the two primary rice variants, japonica and indica (Khush, 1997; Fuller, 2011; Bellwood, 2005).

Natural archives, particularly palaeobotanical and ethnobotanical records, along with other traces of human activity, have become early indicators of the history of agricultural landscape formation in various regions. Agricultural landscapes have also shown historical records of human land use for hundreds or even thousands of years. The Yangzi and Yellow River basins in China, with their fertile agricultural landscapes, have been the homeland of the Qing Dynasty rulers for 300 years, from the 17th to the 20th century (Bellwood, 2005). Similarly, the terraced rice landscapes of Honghe Hani have been cultivated for 1300 years since the Tang Dynasty (685 – 704 AD) in Yunnan Province, Southern China (Guo & Zhang, 2015; Zhang et al., 2016), irrigated rice fields in Burma (Myanmar), Southeast Asia (Luce, 1940; Reid, 1995: 97), as well as the terraced rice landscapes of the Cordilleras in the Philippines and the rice fields with the cultural heritage of the Subak system in Bali, Indonesia (Dharmiasih, 2020; Unesco Word Heritage Convention, 2022).

On the southern peninsula of Sulawesi Island, the roots of agricultural systems can be traced back to Neolithic sites along the Karama River in Mamuju, such as the Kalumpang, Kamansi, and Minanga Sipakko sites. One of the oldest and most recent findings in Southeast Asia regarding early evidence of rice cultivation in Sulawesi was discovered at the Minanga Sipakko site around 3,500 BP (Deng et al., 2020). Another finding by Glover (1985) included rice grains from a cave in Maros dating back to 500 AD. Both discoveries provide insights into the early beginnings of rice farming in South and West Sulawesi.

Written sources, such as the La Galigo Manuscript, derived from the oral traditions of the ancient Bugis people, provide information about the existence of water channels connecting the peninsula. Additionally, 16th-century accounts by Manuel Pinto depict the presence of a giant lake (Pelras, 2006; Caldwell & Lillie, 2004), likely referring to Lake Tempe. The environmental conditions of Lake Tempe before human settlement were described in the early parts of the Lontara Sukkuna Wajo as dense forests inhabited by various animals, such as wild pigs, deer, buffalo, and various bird species. Moreover, swamps surrounding the large lake served as habitats for various fish species and crocodiles (Abidin, 1979:81).

The environmental conditions of Lake Tempe, as depicted in historical texts, were corroborated by palynological investigation reports from three lake depression sites: the eastern shore of Lake Tempe, Lake Buaya to the north, and Rawa Lampulung to the east. Paleovegetation records from the eastern shore of Lake Tempe have been

dominated by freshwater vegetation for at least 4,400 years. The pollen diagram of Lake Tempe indicates a transition from lowland forest to open grassland vegetation dominated by grass and reeds. Conversely, Lake Buaya exhibits a vegetative shift from open fields to lowland forests. Unlike these two locations, the pollen diagram for Rawa Lampulung showed mangrove vegetation coverage. Approximately 2,600 years ago, this vegetation abruptly changed to open plain vegetation, such as grasslands and reeds (Whitten, 1978; Gremmen, 1990). These paleovegetation records suggest that the area approximately 4 km east of Lake Tempe was submerged in seawater approximately 7,100 years ago. The description of a large lake by Manuel Pinto in the 1548 record (Caldwell & Lillie, 2004) likely refers to an annual flooding phenomenon rather than a permanent lake.

The Lontara manuscript also details the wanua (settlement) units scattered around Lake Tempe. The *Lontara Attoriolong* from the Sidenreng Kingdom mentions wanuas specifically tasked with managing the kingdom's agricultural affairs (*Palili noe rakkalana*), including Massepe, Alekkuang/Allakuang, Teteaji, Liseq, Wala, Sereang, Liwuwu/Lawawoi, Arateng, and Tellang (Druce, 2009; Latif, 2012). Meanwhile, *Lontara Sukkuna Wajo* references a *limpo* (region) designated for farmers, namely, Limpo Bettempola (Abidin, 1979; see also Macknight, 1983).

3.3 Analysis of pre-20th century landscape reconstruction

Landscape reconstruction before the 20th century in the Lake Tempe region relied heavily on archaeological findings, where the presence of rice fields was evident in various discoveries at key sites. These sites offer unique indications of settlement patterns, ritual sitess, and burial practices (Mansyur et al., 2022), with rice cultivation being a central element in their respective chronologies based on ceramic data and radiocarbon dating. The significance of rice fields is further highlighted by their annotations on historical maps, emphasizing their centrality in the kingdoms or the main wanuas. Table 3 summarizes these findings, covering toponyms, site indications, and chronologies, with sources including Druce (2009) and Caldwell & Bulbeck (2008).

Table 3. Summary of research results and dating findings for archaeological sites in the Lake Tempe region and its vicinity.

No	Toponyms	Site Indications and Chronology	Administrative and Geographical Regions	Sources
1.	Watang Sidenreng	Indications: Ancient settlement, ritual sites, and old graves Chronology: 13th century (ceramic data)	Sidrap, West of Lake Tempe	Druce (2009: 259)
2.	Wengngeng	Indications: Settlement Chronology: 14th century (ceramic data)	Sidrap, West of Lake Tempe	Druce (2009: 259)
3.	Bulubangi	Indications: Settlement and pre-Islamic jar burials Chronology: 13th century (ceramic data), 570±60 BP (charcoal dating)	Sidrap, Northwest of Lake Tempe	Druce et al. (2005)
4.	Belokka	Indications: Settlement and old graves	Sidrap, West of Lake Tempe	Druce (2009: 259)

No	Toponyms	Site Indications and Chronology	Administrative and Geographical Regions	Sources
		Chronology: 13th century (ceramic data)		
5.	Allangkanangnge ri Latanete (Sarapao)	Indications: Settlement, old graves, and rice phytolith findings Chronology: 11th-12th century (ceramic data), 820±60 BP / calibrated 13th century (C-14 dating of shell samples)	Wajo, South of Lake Tempe	Caldwell & Bulbeck (2008)
6.	Wajo-Wajo, Boli, Lappadeppa, and Attunuang.	Indications: Core sites of the Wajo Kingdom Chronology: 14th-17th century (ceramic data)	Wajo, East of Lake Tempe	Fadillah et al. (2020)
7.	Tosora	Indications: Capital of the Wajo Kingdom Chronology: 13th-19th century (ceramic data at Geddong and Old Mosque sites)	Wajo, East of Lake Tempe	Mahmud, (2001) and Duli (2010)
8.	Cinnotabi, Wajo Wajo, Cina Riaja, and Bukit Cina	Indications: Wanua and core sites of the Wajo Kingdom, pre-Islamic graves Chronology: 15th century (Guandong ceramics), 14th-15th century (Lapaukke Graves), 13th century (ceramic data)	Cina Riaja Village, Lapaukke Village, Wajo, East of Lake Tempe	Mahmud, (2001) and Duli (2010)
9.	Battempola	Indications: Core site of the Wajo Kingdom, ancient village (Limpo), structures Chronology: 15th century (ceramic data)	Wajo, East of Lake Tempe	Mahmud, (2001) and Duli (2010)
10.	Tuwa (Kp. Menge)	Indications: Core site of the Wajo Kingdom, ancient village (Limpo), trade center? Chronology: 15th century	Wajo, East of Lake Tempe	Mahmud, (2001) and Duli (2010)
11.	Talo Tenreng (Kp. Ciung and Kp. Ta')	Indications: Core site of the Wajo Kingdom, ancient village (Limpo), tala' farming settlements (pananrang passari)? Chronology: 15th century	Wajo, East of Lake Tempe	Mahmud, (2001) and Duli (2010)

No	Toponyms	Site Indications and Chronology	Administrative and Geographical Regions	Sources
12.	Situs Cilellang, Situs Tobattang	Indications: Settlements and megalithic sites Chronology: 735±40 BP (Cilellang Site) and 605±30 BP	Southeast of Lake Tempe	Hasanuddin (2017)

Radiocarbon dating of shell samples from the analysis area confidently indicates that, as detailed in Table 3, the earliest human activity dates back to approximately the 13th century. This era marks the commencement of trading activities catalyzed by the Bugis community's access to trade goods, such as textiles and ceramics (Bulbeck & Caldwell, 2008). The chronology's inception is anchored at the Allangkanangnge Site, which is posited as the site of the Cina Kingdom's palace. Scholars acknowledge the Cina Kingdom, an early Bugis kingdom in South Sulawesi, as the most ancient and influential in the northern part of the peninsula, located around the Lake Tempe and Lake Sidenreng regions. The geographical positioning of Lake Tempe and its environment was strategic for controlling maritime trade routes while offering a fertile agricultural valley. This is corroborated by radiocarbon dating, with ceramic fragments at Allangkanangnge further confirming habitation from the 13th to the mid-17th centuries (Caldwell & Bulbeck, 2008; Caldwell & Wellen, 2017; Bulbeck et al., 2018). The Allangkanangnge site is located at the northern extremity of a molasse hill extending north-south, southeast of Lake Tempe (Caldwell & Bulbeck, 2008). This site is also recognized as a potential early site for rice cultivation, as evidenced by the discovery of phytoliths and rice husks, with findings suggesting that such cultivation dates back to the 13th century (Bulbeck & Caldwell, 2008).

Additional sites, such as Cilellang and Tobatang, located southeast of Lake Tempe, also bear evidence of 13th-century habitation through radiocarbon dating. Both sites are situated along the same hill range, extending south of Allangkanangnge. Archaeological findings suggest that early settlements in the Lake Tempe region were primarily located in highland or hilly areas, possibly for security reasons, to mitigate the risk of flooding from the Walennae River (Hasanuddin, 2017).

The transformation of the natural landscape around Lake Tempe and Sidenreng into settlements and agricultural areas is a complex process influenced by multiple factors. Initially, fertile lowland regions, characterized by their wetland agricultural landscapes, attracted early settlers because of their suitability for rice cultivation. This availability of fertile soil led to gradual tilling of land for rice fields, which in turn supported population growth. As the population increases, the need for structured social systems and resource management has spurred the development of complex societies. This process saw the rise of civilizations such as the Wajo, Soppeng, and the Ajatappareng Confederation (encompassing Sidenreng, Rappang, Sawitto, Suppa, and Alitta), with Wajo and Sidenreng emerging as major kingdom centers due to their strategic geographical proximity to the lakes.

Importantly, integration into international commerce was marked by the presence of imported goods, facilitated by these kingdoms' access to trade routes, further accelerating social complexity and economic development. This inter-regional contact has also influenced the globalization of agricultural techniques, commonly referred to as the agricultural revolution. This began in southern China and spread to Southeast Asia in the 13th century (Elvin, 1973: 121; Reid, 1995: 96). This exposure not only enhanced local wealth but also influenced the cultural and political structures of

societies around Lake Tempe, Sidenreng, and Buaya.

Archaeological findings have led to the hypothesis that the Wajo Kingdom's heartland emerged in the early 14th century, particularly in areas east of Lake Tempe, such as Wajo-wajo, Boli, Lapadeppa, and Attunuang (Fadillah et al., 2020). Conversely, the Bulubangi Site, located west of the lake, is thought to have been the nucleus of the Sidenreng Kingdom around the 14th century, or at least before the 17th century (Druce et al., 2005). Furthermore, another radiocarbon dating estimate places the Bulubangi Site in the 16th-17th century, situated in the lowlands near Lake Sidenreng or northwest of Lake Tempe (Druce, 2005). The evolution of the settlement landscape has also been documented in Soppeng's historical records, highlighting a significant event in the early 14th century when We Tekkewanua, the ruler of Soppeng and Suppaq, relocated hill-dwelling communities to expand farmland around Lake Tempe (Caldwell & Wellen, 2017). These data, combined with the topographical context of each site, underscore the progression of settlements from hilltops to lowland areas adjacent to the lakes.

Key insights into the distribution of settlements and toponymic origins are derived from the Lontara manuscripts, notably *Lontara'na Simpurusia* and *Attoriolonna Soppeng*. These documents trace the genealogies of rulers in Cina, Soppeng, and Sidenreng. According to Caldwell (1988), the genealogies of Cina and Soppeng rulers commenced around 1300 AD, while those of Sidenreng began around 1500 AD (Caldwell, 1988: 170). Additionally, the *Lontara Sukkuna Wajo* manuscript delineates the genealogy of Wajo Kingdom rulers, dating back to approximately 1400 AD (Abidin, 1979).

Table 4. Settlement Toponymy Based on Ancient Manuscripts.

Genealogy of the Cenrana Valley	La Galigo Manuscript	Lontara *Attoriolong*
Balubu Tua	Soppeng ri Aja	Sidenreng (Watang
Lompoq	Soppeng ri Lau	Sidenreng)
Tampangeng	Lempang-lempang	Massepe
Marioriawa	Saqbamparu	Allakuang
Pammana	Paccing	Guru
Lompuleq	Tempe	Liseq
Ganra	Wage	Teteaji
Alliwengeng	Teamusuq	Wala
Telleq	Limpomajang	Arateng
Kebo	Lampoko	Wanio
Marioriawao	Lompengeng	Wette'e
Baringeng	Canru	Amparita
Wawolonrong	Ganra	Bilokka
Tinco	Balangnipa	
Tetewatu	Pationgi	
Pattojo	Salotungo	
Amali	Buludua	
Atakka	Lamuru	
Marioriwawo		
Buneq		
Taq		

A detailed analysis of the Genealogy of the Cenrana Valley manuscript by Caldwell & Wellen (2017) revealed numerous toponyms, including Balubu, Tua, Lompoq, and Tampangeng. Among these, Lompoq and Tampangeng were situated within the study area. Lompoq, located north of Sengkang City, is identified as the origin site of the Cina Kingdom's founder, Tomanurung Simpurusia (Bulbeck & Caldwell, 2000), while Tampangeng lies south of Sengkang. Furthermore, the Kronik Wajo (Lontara Sukkuna

Wajo) and Lontara'na Simpurusia cite key settlements like Tempe, Wage, Tampangeng, and Sengkang as central to Cina's power. These locations are primarily to the east of Lake Tempe, with the Cenrana River flowing towards the Bay of Bone (Caldwell, 1988: 46; Caldwell & Wellen, 2017).

The La Galigo manuscript, which delineates the Cina Kingdom, lists several toponyms associated with the kingdom, including Soppeng ri Aja, Soppeng ri Lau, Lempang-lempang, Saqbamparu, Paccing, Tempe, Wage, Teamusuq, Limpomajang, Lampoko, Lompengeng, Canru, Ganra, Balangnipa, Pationgi, Salotungo, Buludua, and Lamuru (Kern, 1989; Caldwell and Wellen, 2017). Within the scope of this study, notable place-names are Saqbamparu, Tempe, Wage, Limpomajang, and Canru. The Soppeng manuscript, compiled in the late 17th century, introduces additional toponyms, such as Lamuru, Marioriwawo, Goagoa, Pattojo, Ujumpulu, Lompengen, Baringeng, Tanah Tengah, Appanang, Belo, Ganra, Bekkeq, Leworeng, Marioriawa, and Citta (Caldwell, 1988; Druce, 2014). Marioroawa and Leworong were pertinent to the study area.

According to the genealogy of Sidenreng's rulers, as analyzed by Druce (2009; 2014) in Lontara Attoriolong, eight *wanua passeajingeng*, or main wanuas that constitute the central kingdom, are mentioned, with the exception of Aliwuwu and Lawawoi, the existence of which remains uncertain. The Sidenreng Kingdom had a significant impact on the political and economic landscape of the Lake Sidenreng region, and the growth of these wanuas underscores the importance of the lake in this regard. Among the surviving wanuas are Sidenreng (Watang Sidenreng), Massepe, Allakuang, Guru, Liseq, Teteaji, Wala, Arateng, Wanio, Wette'e, Amparita, and Bilokka. The region is also characterized by major rivers, such as the Bila River, which flows from the north to the lakes, and is integral to highland wanuas, such as Bila, Bulucenrana, Botto, Barukku, Bettoa, Baraqmamase, Baraja, and Kalempang, which are located north of Lake Sidenreng. Additionally, smaller rivers, such as Sidenreng, Empagae, and Walatedong, are noteworthy.

Figure 2. *Top left*: Approximate area covered in "Kaart van een gedeelte van de Westkust tusschen R. Labakang en de Baay van Para Para, en aan de Oostkust tusschen R. Kayoe en de Hoek Tjipoe" by J.M. Aubert, circa 1752. *Bottom left*: Map of the Northern part of South Sulawesi with North oriented to the left, approximate scale 1:215.000. *Right*: Magnified section of the map showing Lake Tempe and its surrounding region during the 17th-18th century. Source: Nationaal Archief, 1752.

The reconstruction of the landscape in Lake Tempe and its surrounding regions was substantially aided by Dutch historical maps. These visual documents are chiefly sourced from the book *'Grote Atlas van de Verenigde Oost-Indische Compagnie deel 3: Indische Archipel en Oceanie*,' a compilation by Roever and Brommer, and published by Atlas Maior in 2008. This publication includes two pivotal maps of the Lake Tempe and Lake Sidenreng areas dated to 1693 and 1745, respectively (Roever & Brommer 2008: 162-163 and 166). The toponyms depicted in these maps (Figure 2) provide a visual representation of the landscape of the Lake Tempe area during the late 17th and 18th centuries.

While the 17th-century maps of the Danau Tempe region may not encompass every toponym or wanuas within the territories of the Wajo and Sidenreng Kingdoms, they offer a clear illustration of the settlement patterns that evolved along the rivers bordering the lake. This depiction aligns with archaeological findings and historical records, suggesting that rivers play a crucial role in the development and sustainability of these settlements. For instance, the Walennae and Cenrana Rivers, prominent features in historical narratives, are known to have facilitated trade and communication between the highlands and lowlands, impacting agricultural practices and settlement distribution. On the other hand, the mid-18th-century maps continue to showcase the distribution of human settlements in the vicinity of Danau Tempe and Danau Sidenreng. These maps not only highlight the importance of rivers as vital conduits linking central settlements but also facilitate the integration of environmental resources between highland and lowland areas around the lake. The annotation of rice fields on these maps further underscores their centrality in the kingdoms or the main wanuas, indicating how the strategic positioning along these waterways supported agricultural expansion and economic growth.

This section elucidates the transformative impact of human settlements and agricultural practices on the landscape around Lake Tempe and Lake Sidenreng before the 20th century. Through archaeological evidence and historical mapping, we observed how early communities shaped the region through the strategic use of rivers for trade and agriculture. The positioning and expansion of settlements, driven by the cultivation of rice and other agricultural practices, not only altered the natural landscape but also laid the groundwork for complex societal structures within the Wajo, Soppeng, and Sidenreng Kingdoms.

In the next section, we extend our analysis to the 20th century, employing historical LU/LC modeling to track the continued evolution of this landscape from 1930 to 2016. This section provides a quantitative assessment of how historical land use has changed. Through this modeling, we aim to offer a perspective on the impact of human activity on the region's land cover, thereby deepening our understanding of the ongoing interactions between human and environmental dynamics in the Lake Tempe area.

3.4 Landscape reconstruction based on historical land use/land cover modeling 1930 – 2016

Landscape reconstruction using historical LU/LC modeling has offered a nuanced understanding of landscape changes over time. This analysis was facilitated by employing 20th-century topographic maps and satellite imagery. We utilized maps from three key years, 1930, 1979, and 2016, each notable for their high level of accuracy. Our focus was on various elements, such as settlements, agricultural areas, forests, wetlands, rivers, and lakes, to effectively reconstruct land cover in the study area.
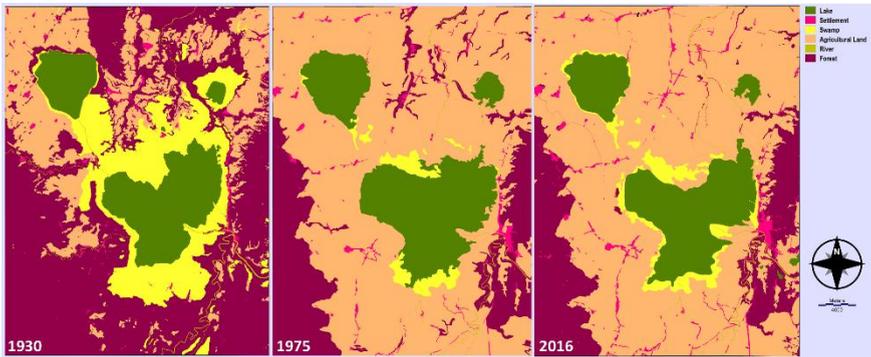
Figure 3. Sequential Land Cover Maps Displaying Changes from 1930 to 2016 in the Lake Tempe Region highlight the transformation of natural ecosystems into agricultural and settlement areas over an 86-year period.
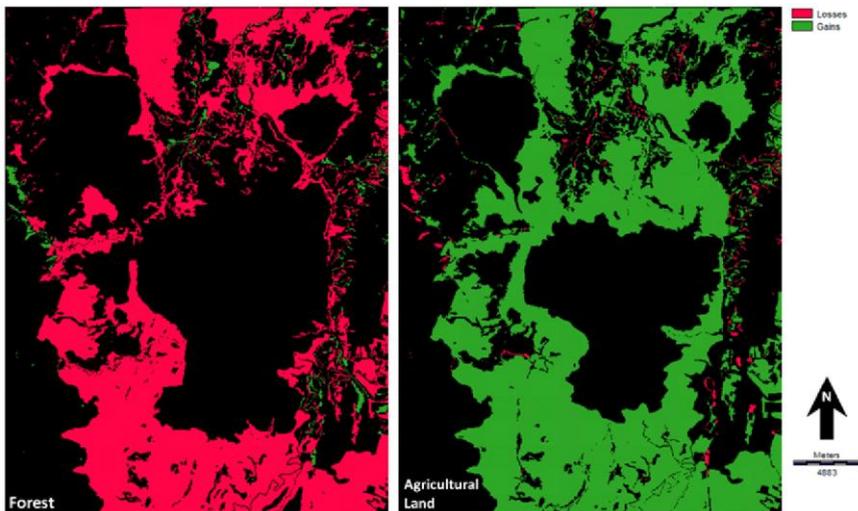

Figure 4. Offers a striking visual representation of the significant landscape transformation in the region surrounding Lake Tempe from 1930 to 1979. This graphical depiction serves as a vivid illustration of the changes and developments in the area's land cover over this nearly half-century period. The left side of the map illustrates the forested areas lost (shown in red), which indicates a substantial decrease in forest coverage over the 49-year period. In contrast, the right side of the map displays the emergence of new agricultural land, depicted in green, highlighting the expansion of agricultural development within the same timeframe. Notably, the overlay of red on the green areas signifies the gains and losses of land cover, with the red strokes indicating areas in which the forest was replaced by agricultural land. These visual data corroborate the trend towards agricultural expansion at the expense of forest land, reflecting broader environmental and socioeconomic changes in the region.

Capturing the progressive transformation of the land cover of Lake Tempe from 1930 to 2016, Figure 3 offers a vivid illustration of landscape change over time. In 1930, the region was characterized by a vast expanse of forested areas, with significant marshlands and prominent lakes. Agriculture and settlements are present but are less extensive. By 1979, the landscape exhibited a shift, with a marked reduction in forestland and an expansion of agricultural areas, reflecting increased agricultural activity. Settlements have grown, whereas marshlands have declined. The map from 2016 underscores a continued trend: agricultural lands dominate much of the region,

expanding considerably, while forest areas have been further reduced. Settlements show additional growth, although not as extensive as agricultural expansion. Lakes and rivers maintain their presence, indicating the persistence of aquatic ecosystems amid these substantial terrestrial changes. This series of maps visually demonstrates the significant human influence on the region's landscape, with a shift from natural forests and marshlands to predominantly agricultural land. The enduring presence of lakes and rivers amid these changes highlights the complex interplay between natural water bodies and human land-use over time.
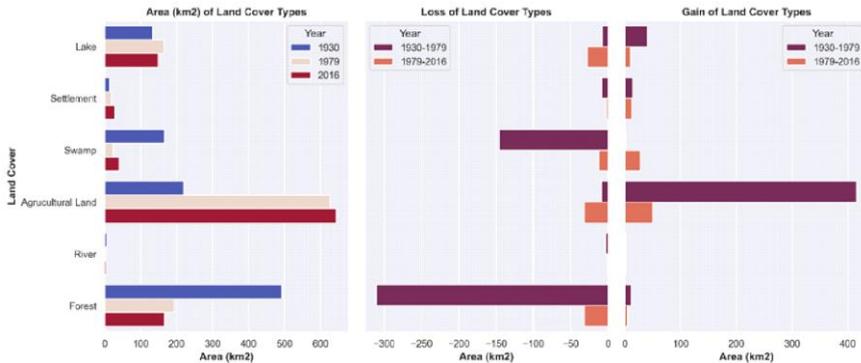
Figure 5. Changes in Land Cover Types in the Lake Tempe Region from 1930 to 2016 illustrate the area (in square kilometers) of different land cover types across three periods (1930, 1979, and 2016) and the net gains and losses of land cover types between two-time intervals (1930-1979 and 1979-2016).

The diagram above reveals significant transformations in land cover over an 86-year period, as analyzed using the Land Change Modeler (LCM). In 1930, forests dominated the landscape, covering 492.11 km² (47.81%), followed by agricultural lands. By 1979, agricultural land had expanded dramatically to 626.44 km² (60.86%), becoming the predominant land cover at the expense of forests, which had decreased significantly to 192.91 km² (18.74%) due to extensive deforestation. This trend continued into 2016, with agricultural land reaching 644.59 km² (62.62%) and forests further diminishing to 166.10 km² (16.14%). Meanwhile, the swamp areas experienced a resurgence, increasing to 38.77 km² (3.77%). The graphs highlight both gains and losses in land cover, offering insights into the region's evolving agrarian landscape. From 1930 to 1979, the most substantial changes included an increase in agricultural land and a decrease in forestland, reflecting intensified agrarian practices and ongoing deforestation. The Marshlands also saw reductions due to the conversion for agricultural use. The period from 1979 to 2016 showed a stabilization in land-use dynamics, with a continued yet slower pace of agricultural expansion and a moderate rate of forest loss, which may indicate a saturation of land available for agriculture. Additionally, the modest increase in settlement areas underscores population growth and its impact on land-use, particularly in the eastern region of the lake, where the city of Sengkang, the capital of the Wajo Regency, is located. This comprehensive analysis underscores the profound anthropogenic impacts on the landscape, with agricultural expansion as the primary driver of land-cover change in the region.

4. CONCLUSION

This study demonstrated that the reconstruction of the landscape in the Lake Tempe region, based on multi-source data and multidisciplinary analysis, revealed significant

vegetation and landscape changes spanning thousands of years. The integration of three primary data sources—historical documents, historical maps and images, and natural archives—complements each other to provide a comprehensive picture of landscape reconstruction in the analyzed area, which is further enhanced by the multidisciplinary analysis model.

The vegetation and landscape changes in and around Lake Tempe have been ongoing since at least the late Holocene. Freshwater vegetation dominated the eastern shore of Lake Tempe approximately 4,400 years ago, whereas the northern part, where Lake Buaya is located, transitioned from open-field vegetation to lowland forests. Meanwhile, Rawa Lampulung, situated approximately 6 km east of Lake Tempe, was dominated by mangrove vegetation and submerged in seawater approximately 7,100 years ago, which then transitioned to open plain vegetation approximately 2,600 years ago.

From the 13th to the 15th centuries, the land cover in almost the entire Lake Tempe area transitioned from forests and swamps to residential landscapes and agricultural land. This transformation was marked by the formation of wanuas as recorded in the Lontara manuscripts, indicating a period of population growth and local migration from mountainous regions to form settlements in lowland areas. This significant expansion of residential space and agricultural development has fostered the growth of the Wajo, Soppeng, and Sidenreng kingdoms.

By the 17th and 18th centuries, the landscape featured low-lying areas with scattered residential developments and rice paddies along the lake's periphery and riverbanks. Since the early 20th century, there has been a significant expansion of cultivated land, accelerating particularly towards the end of the 20th century and into the 21st century. This period witnessed an increase in agricultural land cover, a decrease in forest cover, and fluctuations in the coverage of lakes, marshes, and waterways.

Our methodological approach, inspired by Yang et al. (2014), integrates these diverse data sources to provide a richer and more accurate picture of historical land change. This approach allows for the quantitative analysis of land cover changes and offers a means to spatially contextualize these changes over large temporal scales. By leveraging historical maps for spatial precision and satellite imagery of recent changes complemented by archaeological insights into human settlement patterns, we gained a nuanced understanding of how human activities have shaped the landscape.

The utilization of ancient manuscripts such as Lontara to derive toponyms has supported the reconstruction of human occupation patterns and associated land-uses. However, a key limitation arises from the geospatial representation of toponyms as points, rather than the polygons typically used for LU/LC data. This discrepancy highlights the challenges in delineating precise areas of historical land-use. Furthermore, historical maps, while invaluable, often come with limitations, such as errors in scaling and spatial accuracy. These maps cannot be directly overlaid onto modern maps owing to varying cartographic standards. Although some maps were crafted based on textual descriptions and may lack precise details, they provide essential insights into the general landscape conditions of past periods and assist in pinpointing the toponyms mentioned in ancient manuscripts.

In contrast, modern topographical maps from the early 20th century, which adhere to contemporary cartographic standards and are based on aerial photographs and detailed terrestrial surveys, offer a more reliable basis for georeferencing. Nonetheless, the need for terminology harmonization arises due to differing conceptualizations of land-use and land cover typologies across time, essential for developing a continuous and accurate land cover model. Although historical satellite imagery is a valuable

resource for landscape reconstruction, it is underutilized because of its limited spatial and temporal coverage and often lower resolution. When available, this imagery is instrumental in corroborating land cover changes depicted in other historical data sources, despite its limitations.

This study contributes to the discourse on land-use and environmental change, demonstrating the value of historical reconstructions in informing sustainable land management practices. This study offers an alternative model for landscape reconstruction analysis applicable to regions with rich historical and cultural contexts. This reveals that pre-20th century landscape dynamics in the Lake Tempe area were influenced by anthropogenic activities, such as local migration, interrelations among local elites over natural resource control, global trade networks, and environmental modifications for agricultural purposes. These factors have triggered deforestation and the reduction of wetlands, with potential long-term effects on habitats, hydrological cycles, and climate conditions. As we move forward, refining these methodologies to adapt to new data sources and advances in technology will continue to provide valuable insights into the complex interactions between humans and their environments. This research offers a broader temporal perspective on the present-day occurrence of land conversion, which has not only resulted in a decrease in arable land but also transformed the historical backdrop of the agricultural landscape.

REFERENCES

Abidin, Z., (1979). *Wajo Pada Abad XV-XVI: Suatu Penggalian Sejarah Terpendam Sulawesi Selatan dari Lontara* [Doctoral Dissertation]. Universitas Indonesia.

Alfonsina, L., Mas, J. and Valle, N. T., Torres, P. S., & Folan, W. J. (2015). Modeling Historical Land Cover and Land Use: A Review fromContemporary Modeling. *ISPRS International Journal of Geo-Information, 4*(4), 1791-1812. https://doi.org/ 10.3390/ijgi4041791

Ambarwulan, W., Yulianto, F., Widiatmaka, W., Rahadiati, A., Tarigan, S. D., Firmansyah, I., & Hasibuan, M. A. S. (2023). Modelling land use/land cover projection using different scenarios in the Cisadane Watershed, Indonesia: Implication on deforestation and food security. *The Egyptian Journal of Remote Sensing and Space Science, 26*(2), 273-283. https://doi.org/10.1016/j.ejrs.2023.04.002

Aubert, J. M. (1745). "Kaart van Zuid-Celebes, Noordelijk Deel/Map of South Celebes, Northern Part." Ms on paper. Grote atlas van de Verenigde Oost-Indische

Compagnie. Voorburg, Netherlands: Atlas Maior. Nationaal Archief. Accessed at https://www.nationaalarchief.nl/onderzoeken/archief/2.14.97/invnr/11.3/file/ GAVOC-III%20Dig%20(Pagina%20166)

Axtell, R. L., Epstein, J. M., Dean, J. S., Gumerman, G. J., Swedlund, A. C., Harburger, J., ... & Parker, M. (2002). Population growth and collapse in a multiagent model of the Kayenta Anasazi in Long House Valley. *Proceedings of the National Academy of Sciences, 99*(suppl_3), 7275-7279. https://doi.org/10.1073/pnas.092080799

Badan Standardisasi Nasional. 2014. Klasifikasi Penutup Lahan - Bagian 1: Skala Kecil dan Menengah (SNI 7645-1:2014). Jakarta: Badan Standardisasi Nasional Indonesia.

Bellwood, P. (2005). *First farmers: The origins of agricultural societies*. Blackwell Publishing.

Bithell, M., & Brasington, J. (2009). Coupling agent-based models of subsistence farming with individual-based forest models and dynamic models of water distribution. *Environmental Modelling & Software, 24*(2), 173-190. https://doi.org/10.1016/j.envsoft.2008.06.016

BPS Kabupaten Wajo. (n.d). Curah Hujan Stasiun Ongkoe (Milimeter), 2017-2018. Retrieved from https://wajokab.bps.go.id/indicator/151/85/1/curah-hujan-stasiun-ongkoe.html (Accessed February 2, 2024)

Bulbeck, D., & Caldwell, I. (2008). Oryza sativa and the origins of kingdoms in South Sulawesi, Indonesia: Evidence from rice husk phytoliths. *Indonesia and the Malay World, 36*(104), 1-20. http://doi.org/10.1080/13639810802016117

Bulbeck, D., & Caldwell, I. (2000). *Land of iron: The historical archaeology of Luwu and the Cenrana Valley: Results of the origin of complex society in South Sulawesi Project (OXIS)*. Centre for South-East Asian Studies, University of Hull.

Bulbeck, D., Caldwell, I., Druce, S., Hakim, B., & Macknight, C. (2018). Imported tradeware ceramics and their relevance for dating socio-political developments in South Sulawesi, with special reference to the Allangkanangnge ri Latanete site. In O'Connor, S., Bulbeck, D., & Meyer, J. (Eds.), *The Archaeology of Sulawesi: Current Research on the Pleistocene to the Historic Period* (pp. 269-286).

Caldwell, I. (1988). *South Sulawesi A. D. 1300-1600: Ten Bugis Texts.* [Doctoral Dissertation] The National University of Australia.

Caldwell, I. (1995). Power, state and society among the pre-Islamic Bugis. *Bijdragen tot de Taal-, Land-en Volkenkunde/ Journal of the Humanities and Social Sciences of Southeast Asia, 151*(3), 394-421. http://dx.doi.org/10.1163/22134379-9000 3038

Caldwell, I., & Lillie, M. (2004). Manuel Pinto's inland sea: Using palaeo-environmental techniques to assess historical data from South Sulawesi. In Keates, S. G., & Pasveer, J. M. (Eds.), *Modern Quaternary Research in Southeast Asia (Volume 18): Quaternary Research in Indonesia* (pp. 259-272). CRC Press.

Caldwell, I., & Wellen, K. (2017). Finding Cina: A new paradigm for early Bugis history. *Bijdragen tot de taal-, land-en volkenkunde/Journal of the Humanities and Social Sciences of Southeast Asia, 173*(2-3), 296-324. http://dx.doi.org/10.1163/22134 379-17302004

Cholik, F., & Anggraeni, M. S. (1994). *Research and needs for integrated management of Lake Tempe presented in AARD/FAO National Workshop on sustainable development of Lake Tempe basin, Ujung Pandang, Indonesia, 4-7 July 1994.* Agency for Agricultural Research and Development, Ministry of Agriculture, Indonesia.

CNN Indonesia. (2018). *BPS, Sebut Luas Lahan Pertanian Kian Menurun*. CNN.

Accessed on January 12, 2024 from https://www.cnnindonesia.com/ekonomi/20181025153705-92-341433/bps-sebut-luas-lahan-pertanian-kian-menurun

De Klerk, L.G. (1983). *Zeespiegels, riffen en kustvlakten in Zuidwest-Sulawesi, Indonesia: Een morfogenetisch – bodemkundige studie (Sea levels, reefs and coastal plains of Southwest Sulawesi, Indonesia: A morphogenetic-pedological study'. On the Holocene evolution of the Spermonde Archipelago coral reefs and adjacent SW Sulawesi coastal region)* [Doctoral Dissertation]. University of Utrecht.

Deng, Z., Hung, H., Carson, M. T., Oktaviana, A. A., Hakim, B., & Simanjuntak, T. (2020). Validating earliest rice farming in the Indonesian Archipelago. *Scientific Reports, 10*(1), 1-9. https://doi.org/10.1038/s41598-020-67747-3

Dharmiasih, W. (2020). Cultural Landscapes in the Asia-Pacific: Re-focusing UNESCO Designation on Community Participation. *Forest and Society, 4*(2), 271-279. https://doi.org/10.24259/fs.v4i2.10028

Diessen, J. R. van, Günter Schilder, G. J. Knaap, A. G. de Roever, Bea Brommer, Jos J. L. Gommans, and Isaac de Graaff. (2006). "*Grote atlas van de Verenigde Oost-Indische Compagnie*." Voorburg, Netherlands: Atlas Maior.

Druce, S. (2014). Dating the tributary and domain lists of the South Sulawesi kingdoms. In Ampuan Haji Brahim bin Ampuan Haji Tengah (Ed.), *Cetusan minda sarjana: Sastera dan budaya* (pp. 145-156). Dewan Bahasa dan Pustaka.

Druce, S. (2009*). The lands west of the lakes: A history of the Ajattappareng kingdoms of South Sulawesi 1200 to 1600 CE*. KITLV Press.

Mahmud, I., Bulbeck, D., & Druce, S. (2005). A transitional Islamic Bugis cremation in Bulubangi, South Sulawesi: Its historical and archaeological context. *RIMA: Review of Indonesian and Malaysian Affairs, 39*(1), 1-22.

Duli, A. (2010). Peranan Tosora Sebagai Pusat Pemerintahan Kerajaan Wajo Abad XVI-XIX. *WALENNAE: Jurnal Arkeologi Sulawesi Selatan dan Tenggara, 12*(2), 143-158. https://doi.org/10.24832/wln.v12i2.237

Eastman, J. (2020). TerSet Manual: Geospatial Monitoring and Modelling System. Clarks Labs, 206–219. https://clarklabs.org/wp-content/uploads/2020/05/Terrse

Elvin, M. (1973). *The Pattern of the Chinese Past: A Social and Economic Interpretation*. Standford University Press.

Fadillah, M. A., Mahmud, M. I., & Hakim, B. (2020). The Core of Wajo Confederation: Archaeological Survey in Tosora, Cinnotabi and Lamasewanua. *WALENNAE: Jurnal Arkeologi Sulawesi Selatan dan Tenggara, 18*(2), 131-148. https://doi.org/10.24832/wln.v18i2.496

Fuller, D. Q. (2011). Finding plant domestication in the Indian subcontinent. *Current Anthropology, 52*(S4), S347-S362. https://doi.org/10.1086/658900

Giesen, W., Baltzer, M., Baruadi, R. (1991). *Integrating conservation with Land Use development in wetlands of South Sulawesi.* Directorate General of Forest Protection and Nature Conservation: Asian Wetland Bureau (AWB)-Indonesia. http://dx.doi.org/10.13140/RG.2.2.35974.63045

Glover, I. C. (1985). Some problems relating to the domestication of rice in Asia. In Misra & Bellwood (Eds.), *Recent advances in Indo-Pacific prehistory* (pp. 265-274). Brill. https://doi.org/10.1163/9789004644472_041

Gremmen, W. H. E. (1990). Palynological investigations in the Danau Tempe depression, southwest Sulawesi (Celebes), Indonesia. *Modern Quaternary Research in Southeast Asia, 11,* 123-134.

Gross, B. L., & Zhao, Z. (2014). Archaeological and genetic insights into the origins of domesticated rice. *Proceedings of the National Academy of Sciences, 111*(17),

6190-6197. http://dx.doi.org/10.1073/pnas.1308942110

Hasanuddin, nfn. (2017). Situs-situs Megalitik di Kabupaten Wajo, Sulawesi Selatan. *Kapata Arkeologi, 13*(1), 83-94. https://doi.org/10.24832/kapata.v13i1.395

Ina-Geoportal. (n.d). *Peta RBI*. Accessed from https://tanahair.indonesia.go.id/portal-web/

Jiang, L., (2005). The Shangshan Neolitic site in Pujiang County, Zhejing: New evidence of rice civilization in the lower Yangtze River region (in Chinese). *Gudai Wenming Yanjiu Zhongxin Tongxun, 7,* 51-55.

Kern, R.A. (1989). *I La Galigo: Cerita Bugis Kuno.* Gadjah Mada University Press.

Khush G. S. (1997) Origin, Dispersal, Cultivation and Variation of Rice. *Plant Molecular Biology, 35,* 25-34. http://dx.doi.org/10.1023/A:1005810616885

Lambin, E. F., Geist, H. J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual review of environment and resources, 28*(1), 205-241. https://doi.org/10.1146/annurev.energy.28.050302.105459

Latif, A. (2012). *Konfederasi Ajatappareng 1812-1906, Sejarah Sosiopolitik Orang Bugis di Sulawesi Selatan* [Doctoral Disseration]. Universitas Kebangsaan Malaysia.

Luce, G. H. (1940). Everyday Life of the Early Burman. *Journal of the Burma Research Society, 30*(i), 283-335.

Macknight, C. (1983). The Rise of Agriculture in South Sulawesi Before 1600. *Review of Indonesian and Malaysian Affairs 17* , 92-116.

Mahmud, M. I. (2001). Awal Mula Wajo dan Aspek Ruang Situs Inti Wajo Abad XV-XIX Masehi. *WALENNAE: Jurnal Arkeologi Sulawesi Selatan dan Tenggara, 4*(2), 47-60. https://doi.org/10.24832/wln.v4i2.131

Mansyur, S., Fadillah, M.A., Ihsan, N., Somba, N., Hasrianti, H., Mulyadi, A., Hamado, H. (2022). Landscape of Pre-Islamic Beliefs: The Rise of Agriculture and Bugis Diaspora. *Advances in Social Science, Education and Humanities Research, Vol. 660*. https://doi.org/10.2991/assehr.k.220408.030

Mulyani, A., Kuncoro, D., Nursyamsi, D., & Agus, F. (2016). Analisis konversi lahan sawah: Penggunaan data spasial resolusi tinggi memperlihatkan laju konversi yang mengkhawatirkan. *Jurnal Tanah dan Iklim, 40*(2), 121-133.

Murdaningsih, W., Munibah, K., & Ambarwulan, W. (2017). Analisis spasial perubahan penggunaan lahan pertanian untuk mendukung kemandirian pangan di Kabupaten Indramayu. *Majalah Ilmiah Globe, 19*(2), 175-184.

Nationaal Archief. (1752). *Kaart van een gedeelte van de Westkust, tusschen R. Labakang en de Baay van Para Para, en aan de Oostkust tusschen R. Kayoe en de Hoek Tjipoe*. Manuscript map by Jean Michiel Aubert. Verzameling Buitenlandse Kaarten Leupe, 4.VEL, inv.nr. 1301. The Hague: Nationaal Archief. https://www.nationaalarchief.nl/onderzoeken/archief/4.VEL/invnr/1301/file/N L-HaNA_4.VEL_1301, accessed May 8, 2025.

Nganro, S., Trisutomo, S., Barkey, R., Ali, M., Imura, H., Onishi, A., ... & Mahamud, M. A. (2021). Prediction of Future Land Use and Land Cover (LULC) in Makassar City. *Tataloka, 23*(2), 183-189. http://dx.doi.org/10.14710/tataloka.23.2.183-189

Nugraha, M. F. I., Julzarika, A., Radjamuddin, A., Reflinur, R., Yunita, R., Enggarini, W., & Novita, H. (2019). Study of aquatic plants and ecological- physics Lake Tempe, Sulawesi Selatan. *Torani Journal of Fisheries and Marine Science, 2*(2), 105-115. https://doi.org/10.35911/torani.v2i2.7060

Oldemann, L.R. and Darmiyati, S., (1977). An agroclimatic map of Sulawesi. Contr. Centr. Res. lnst. Agric. Bogor60: 1-32.

Oldeman, L. R., & Darmiyati, S. (1977). The agroclimatic map of Sulawesi, scale 1: 2,500,000. *Contr. Centre. Res. Inst. Agric. Bulletin, 60*, 1-32.

Pelras, C. (1983). *Sulawesi Selatan sebelum datangnya Islam Berdasarkan Kesaksian Bangsa Asing. Dalam Citra Masyarakat Indonesia*. Sinar Harapan & Archipel.

Pelras, C. (2006). *Manusia Bugis* [Translated by Abdul Rahman Abu, Hasriadi, Nurhady Sirimorok]. Nalar and Forum Jakarta-Paris.

Redman, C. L. (1990). Los orígenes de la civilización. Crítica, 276.

Redman, C. L. (1999). *Human impact on ancient environments*. University of Arizona Press.

Reid, A., (1995). Humans and Forests in Pre-colonial Southeast Asia. *Environment and History, 1*(1), 93-110. http://dx.doi.org/10.3197/096734095779522717

RePPPProT, (1988). *The Land Resources of Indonesia: A National Overview Main Report*. United Kingdom-ODA NRI, Ditjen Pankim, Department of Transmigration.

Santoso, P. B. K., Widiatmaka, W., Supiham, S., Machfud, M., & Rusastra, I. W. (2017). Analisis pola konversi lahan sawah dan struktur hubungan penyebab dan pencegahannya (Studi kasus Kabupaten Subang, Provinsi Jawa Barat). *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan, 7*(2), 184-194. https://doi.org/10.29244/jpsl.7.2.184-194

Satu Data Pemerintah Kota Parepare. (April 16, 2021). Curah Hujan di Kota Parepare Tahun 2016-2020. Retrieved from https://satudata.pareparekota.go.id/index.php/2021/04/16/curah-hujan-di-kota-parepare-tahun-2016-2020/ (Accessed February 2, 2024)

Saxena, A., Prasad, V., Singh, I. B., Chauhan, M. S., & Hasan, R. (2006). On the Holocene record of phytoliths of wild and cultivated rice from Ganga Plain: evidence for rice-based agriculture. *Current Science*, *90*(11), 1547-1552. https://www.jstor.org/stable/24091834

Sudrajat, J., Suyatno, A., Oktoriana, S., (2021). Land-Use Changes and Food Insecurity around Oil Palm Plantations: Evidence at the Village Level. *Forest and Society, 5*(2), 352-364. https://doi.org/10.24259/fs.v5i2.11376

Sulistiyo, R. B., & Fakhri. (2023). Malacofauna from Cappa Lombo Site: Environmental Reconstruction and Subsistence Strategies of The Bontocani Highland Karst Region, South Sulawesi. *Kalpataru, 32*(1), 47-62. https://doi.org/10.55981/kpt.2023.1045

Supriatna, S., Hashilah, F., Mukhtar, M.K., Wardani, K.K., (2022). Determinant of Land Use Change in South Kalimantan: An Evidence from Banjarbaru City and Banjar Regency. *Forest and Society, 6*(1), 422-435. https://doi.org/10.24259/fs.v6i1.18469

Surazakov, A., & Aizen, V. (2010). Positional accuracy evaluation of declassified Hexagon KH-9 mapping camera imagery. *Photogrammetric Engineering & Remote Sensing, 76*(5), 603-608. https://doi.org/10.14358/PERS.76.5.603

Susanti, Y., Syafrudin, Helmi, M. (2020). Analisa Perubahan Penggunaan Lahan di Daerah Aliran Sungai Serayu Hulu dengan Penginderaan Jauh dan Sistem Informasi Geografis. *Bioedukasi: Jurnal Pendidikan Biologi, 13*(1), 23-30. https://doi.org/10.20961/bioedukasi-uns.v13i1.37825

Suyono, S., & Kusnama, K. (2010). Stratigraphy and Tectonics of the Sengkang Basin, South Sulawesi. *Indonesian Journal on Geoscience, 5*(1), 1-11. http://dx.doi.org/10.17014/ijog.5.1.1-11

Syahriwati, A., (2004). *Zonasi Sebaran Sedimen Danau Tempe Bagian Timur, Kecamatan Tanasitolo, Kabupaten Wajo, Provinsi Sulawesi Selatan* [Bachelor Thesis]. Universitas Hasanuddin.

Tewari, R., Srivastava, R. K., Saraswat, K. S., Singh, I. B., & Singh, K. K. (2008). Early farming at Lahuradewa. *Pragdhara, 18*, 347-373.

Tewari, R., Srivastava, R. K., Singh, K. K., Saraswat, K. S., and Singh, I. B. (2003).

Preliminaru report of the excavation at Lahuradewa, District Sant Kabir Nagar, U.P. 2001-2002. Wider archaeological implications. *Pragdhara 13,* 37 - 68

Topographische Inrichting. (1921-1931). Gouvt. Celebes en Onderh (Gouvernement Celebes en Onderhorighedeni). Accessed from https://nla.gov.au/nla.obj-234014610/view

Unesco Word Heritage Convention. (2022). *World Heritage Convention Cultural Heritage Nominated by People's Republic of China: Cultural Landscape of Honghe Hani Rice Terraces.* Unesco Word Heritage Convention.

United States Geological Survei (USGS). (n.d). *Satellite Imagery of South Sulawesi.* Accessed from https://earthexplorer.usgs.gov/

van Bemmelen, RW. (1949). *The Geology of Indonesia.* Government Printing Office.

Verawaty, I., Widiatmaka, & Firmansyah, I. (2023). Modeling of land-use and cover changes (LUCC) in Deli Serdang Regency, North Sumatra Province. *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan, 13*(2), 237-251. https://doi.org/10.29244/jpsl.13.2.237-251

Wahyuni, S., Guchi, H., & Hidayat, B. (2014). Analisis perubahan penggunaan lahan dan penutupan lahan tahun 2003 dan 2013 di Kabupaten Dairi. *Jurnal Agroekoteknologi Universitas Sumatera Utara, 2*(4), 100734. https://dx.doi.org/10.32734/jaet.v2i4.8420

Whitten, T., Henderson, G. S., and Mustafa, M., (1978). *The Ecology of Sulawesi: The Ecology of Indonesia Series Vol. IV (1st Edition)*. Gajah Mada University Press.

Yang, Y., Zhang, S., Yang, J., Chang, L. Bu, K., Xing, X., (2014). A review of historical reconstruction methods of Land Use/land Cover. *Journal of Geographical Sciences 24*(4), 746-766. https://doi.org/10.1007/s11442-014-1117-z

Zhan, G., & Jin, Z. (2015). Hani rice terraces of honghe-the harmonious landscape of nature and humans. *Landscape Research, 40*(6), 655-667. https://doi.org/10.1080/01426397.2015.1060299

Zhang, Y., Min, Q., Jiao, W., and Liu, M., (2016). Values and Conservation of Honghe Hani Rice Terraces System as a GIAHS Site. *Journal of Resources and Ecology 7*(3), 197-204. https://doi.org/10.5814/j.issn.1674-764x.2016.03.007