

Rediscovery and Discussion on Contemporary Ahupua‘A Implementation: A Self-Sufficiency Assessment in South Maui, Hawaii, Utilizing Geographic Information Systems

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Abstract

In contemporary times, land and resource management is inefficient and unsustainable, leading to global issues such as climate change. Though many solutions have been explored, they neglect ancient land management techniques, such as those in the Hawaiian Islands, exemplified by the ahupua‘A system. Projects at Kahikinui on Maui and King’s Landing on the Island of Hawai‘I both demonstrate the integration of the ahupua‘A system into modern-day society and the characteristics of the lands being utilized. However, the current body of knowledge has not identified specific areas in drought-prone South Maui that should be the first to reimplement the ahupua‘A system and effectively ‘test’ its benefits. To fill this gap, technology, in the form of geographic information systems, was used to identify the ahupua‘A with the lowest self-sufficiency ratio (SSR), determined from analysis of three distinct resources. The study identified the ahupua‘A of Waiakoa as having the lowest SSR of ~2.17%, while the ahupua‘A of Kōheo 1-2 had the highest SSR of ~254.10%. These findings indicate that the area within the Waiakoa ahupua‘A boundary is the primary candidate for a pilot implementation of the ahupua‘A system to address critical resource deficiencies.

Key Words: ahupua‘A; self-sufficiency; GIS; South Maui; traditional land management; drought

1. Introduction

Climate and other temperature-related changes have plagued the world, especially close-to-sea populations. These variations in climate—temperature, precipitation, and sea level—over recent years have been linked to shifts in natural resources (Pau et al., 2012). The future of these resources depends on proper management and considering many possibilities (Safeeq & Fares, 2012). With this in mind and the goal of preserving the environment, research on climate change’s impact on how natural resources are used and produced, and on potential solutions to these issues, is critical to an optimistic future. The ominous and

unfavorable future necessitates research beyond conventional methods, which may involve adapting traditional land management practices to either revert or improve existing environmental conditions.

In line with drought conditions, the Hawaiian Islands, and especially Maui, have been linked in previous years to climate-driven changes, with the South and Central Maui region identified as experiencing “severe drought” (Mair et al., 2024; National Drought Mitigation Center et al., 2024). In pre-Western-contact times in Hawaiʻi, the islands thrived in agriculture and self-sustainability, whereas after Western colonization, the islands lost 80% of endemic species due to mass human contact and an increased footprint (Gon et al., 2018). Given the benefits of pre-human practices, traditional approaches may need to be better understood, as exemplified by recent educational efforts to teach these practices to younger generations. These management techniques can be applied beyond the classroom and have proven effective in mitigating climate change-related damage among coastal communities when implemented in some form (Kaneshiro et al., 2005; Vaughan & Vitousek, 2013). The potential within these practices, fueling further interest in the subject and the lack of current utilization of traditional land management, necessitates research on their implementation. This gap in the literature and knowledge underscores the need for a systematic methodology to determine how to implement traditional land management techniques. The technological advancements of the twenty-first century have enabled anyone to create models using online geographic information systems (GIS) and have paved the way for their use in land management and conservation efforts. Taken together with GISs, traditional land management techniques have been used to some extent in previous research, but studies on how technology can further determine where and potentially how GISs can be used to implement such practices are lacking (Winter & Lucas, 2017). The issue regarding climate change in drought-prone areas, paired with the lack of GIS usage in ahupuaʻA location identification, raises the question: Which ahupuaʻA in South Maui is best suited for implementing traditional Hawaiian land management techniques to optimize self-sufficiency in water, vegetation, and livestock resources?

2. Literature Review

2.1 Traditional Land Management Practices

Traditional and indigenous land management practices have been central to human life since the dawn of civilization. These practices that encompass traditional ecological knowledge (TEK) worldwide have proven to share characteristics with adaptive land management, which enables a reactive approach to societal change (Berkes et al., 2000). The ability of traditional land management practices to adapt, linked with the extensive knowledge systems that Polynesia, particularly in this case, the Hawaiian Islands, possesses, demonstrates a realm of study (Berkes et al., 2000; McMillen et al., 2014). In pursuit of this paper’s goal, the

foundation of indigenous and traditional land management as a productive and effective method for preserving, conserving, and maximizing land production necessitates a deeper understanding of the practices of the Hawaiian Islands and their storied culture.



FIGURE 1: *Maui AhupuaʻA Boundaries (Maui Nui AhupuaʻA Project, n.d).*

A primary example of TEK in the Hawaiian Islands is the ahupuaʻA, once used as land divisions that split the islands into sections based on a “mountain-to-sea” cultivation system. This system was that of a hierarchical organization as the islands, mokupuni, were divided into larger moku, subdivided into various ahupuaʻA, that in themselves contained ‘ili, communities and towns on their own (Gonschor & Beamer, 2014; Kaneshiro et al., 2005). The ahupuaʻA system enabled the “makaʻāinana” or “commoners” to have access to all of the resources provided by the land, including the forestry, agriculture, and marine life (Minerbi, 1996).

2.2 Current AhupuaʻA and Characterization

The existing literature on the specific characterization of land suitable for implementing ahupuaʻA systems is limited, with only a few statewide initiatives and projects. Nevertheless, a substantial body of knowledge warrants pursuing such a study. These ahupuaʻA projects are typically “homestead” projects for Native Hawaiians and are operated by the Department of Hawaiian Home Lands (DHHL), a government agency formed to manage Hawaiʻi’s lands intended for Native Hawaiians, with a particular project on Hawaiʻi Island at King’s Landing, adopting a model

FIGURE 3: *Kahikinui Homestead and Conservation Land Layout. The image depicts land allocations for various uses, such as silviculture (controlled forestry regeneration), watershed conservation, grazing, and homestead properties for Native Hawaiians (Department of Hawaiian Home Lands, 2011).*

The DHHL has contributed further to the goal of ahupuaʻA in a contemporary setting by developing homesteads on Kahikinui, Maui, a former ahupuaʻA, as depicted in Figure 3. With the selection of Kahikinui to be conserved and develop self-sufficiency by its occupants through the ahupuaʻA system, it was noted that Kahikinui was initially “āina maloʻo” or “[dry] land” (Department of Hawaiian Home Lands, 2011; Minerbi, 1996). These cases in which ahupuaʻA systems are revitalized demonstrate which characteristics should be discussed when planning where an ahupuaʻA should start, as they have all seen success in recent years of use. For research purposes, a degraded ahupuaʻA lacking resources will be regarded as a high-priority region for ahupuaʻA development and as “best suited.” This study utilizes a need-based normative framework to define “suitability.” While a high-SSR may indicate overproduction and, therefore, be seen as a successful model of existing resources, it does not represent a critical site of intervention. Equating the lowest SSR as the candidate-region “best suited,” the research prioritizes areas of greater vulnerability and foreign reliance. This is grounded in the idea that traditional land management is needed in places where modern systems are failing. A degraded region, in turn, allows for a more rigorous test of the ancient techniques in the region’s self-sufficiency restoration.

2.3 Self-Sufficiency

When investigated from an ecological and environmental perspective, self-sufficiency and sustainability are terms frequently used to describe and express an environment or community’s conscious development while maintaining human and ecological order (Vehkamäki, 2005). Despite this, the study will focus only on self-sufficiency, as these are quantifiable and verifiable results that are not heavily dependent on societal success or other non-quantifiable variables, unlike sustainability. Whereas sustainability is the measure of a community’s long-term dependency on outside resources and encompasses a variety of social and economic aspects in addition to environmental, self-sufficiency is a community or region’s ability to produce within or above the means their population requires, often being directly linked to the environment (Beltran-Peña et al., 2020; Gon et al., 2018; Günther, 2003; Velten et al., 2015). Under these circumstances, self-sufficiency is measurable and can be determined, hence its usage in this study. Such is evident from self-sufficiency rates, which estimate how much of a community’s population it can provide for

based on production, importation, and exportation (Godenau et al., 2020). Self-sufficiency and its subsequent metrics—vegetation, livestock, and water management—are shown to operate together within a region, either through direct self-sufficiency rates or through indirect production measures that affect export and import dependence (Godenau et al., 2020; Soltani et al., 2020).

The most significant and essential variable to be assessed in the study is the self-sufficiency of water resources, given the importance of water to the emergence and continuation of life (Westall & Brack, 2018). Through a self-sufficiency-minded lens, water has proven vital to a community's overall success, with some communities facing self-sufficiency challenges and resorting to alternative water-harvesting methods (Rygaard et al., 2011). Furthermore, the need to evaluate a community's overall self-sufficiency in water is exemplified by the complexity of water usage beyond mere domestic consumption, including thermoelectric, irrigation, and public supply, among other categories (Rehkamp et al., 2021).

Though contributing significantly less to a society's success, livestock, particularly beef in this study, plays a significant role in a community member's diet and lifestyle. The significance is exemplified by its predominant share in the daily diet, at 26.16% (Mititelu et al., 2024). Considering the complexities of such a variable and measurement, it must be noted that a notion claiming that determining livestock self-sufficiency is a nuanced and multifaceted problem exists (Kaufmann et al., 2022). Additionally, these complexities extend to societal development, with growing and significant adherence to non-meat diets, such as vegan or vegetarian. These non-conventional diets must be acknowledged in the contemporary setting, as practicing communities demonstrate that no diet is standard, and this also invites the argument that the inclusion of meat hinders sustainable development (Dwyer, 1991; Henning, 2011). Given the intricacies, the research will only aim to answer the earlier question based on population consumption needs and disregard the production resource needs or the ethics of including meat in diets. These complexities, taken together with the large portion of the diet devoted to meat, are compounded by the reality that many communities worldwide cannot meet the demand for livestock and, in turn, lack self-sufficiency in livestock production (Gebru, 2001; Ripoll-Bosch et al., 2013). Hence, livestock's role in a community's overall self-sufficiency is significant and a major determinant of how much a population can provide for itself (Gebru, 2001).

Particularly in Hawai'i, vegetable and fruit consumption is a large portion of the diet and accounts for the majority of locally produced food, combining for 26% and 36.9% of the total food produced in Hawai'i (Loke & Leung, 2013; Shintani et al., 2001). This high demand and further high production, relative to other food groups, necessitate consideration of both fruits and vegetables in this study. Prior research further underscores the need to investigate a valuable resource to a community, such as fruits

in Bosnia and Herzegovina, which can translate to Hawaiʻi’s dependence on fruits and vegetables (Ostojčić et al., 2019). The possibility of communities providing for themselves with fruits and vegetables is a potential one, but, as outlined, it necessitates “substantial changes in dietary patterns and land use” (McCarthy et al., 2023, p. 1). With these substantial changes, an opportunity for ahupuaʻA and traditional Hawaiian land management could facilitate such a self-sufficient idea. Furthermore, despite their inherent differences in shape, utilization, and nutrition, the categories of fruits and vegetables were consolidated for ease of data collection and analysis, with further consideration of prior practices conducted by other researchers (Ostojčić et al., 2019).

2.4 Spatial Management and Modeling on GIS

The development of knowledge in traditional land management is limited in current research, which is why geographic information systems (GISs) are being implemented. GIS is a technology used to capture geographic information, represent data in terms of relationships, and create new relationships and data (Chrisman, 1999). These GISs have seen success in the land management category for decades, including the management and categorization of Brazilian lands by their suitability for various agricultural or livestock activities, thereby enabling further development and the preservation of biodiversity (Ramalho-Filho et al., 1997). This success, coupled with numerous other land management practices, demonstrates the ability of GIS to measure the usability of certain land, characterize land based on given relationships, and create new data to be interpreted by the user (Matthews et al., 1999; Ramalho-Filho et al., 1997; Taghvaye Salimi et al., 2008).

The application of GISs to land management practices, such as the ahupuaʻA within the Hawaiian archipelago, is viewed in the current literature, and there is a body of research containing success with the technology. Winter and Lucas (2017) use GIS to create spatial models that partition the island of Kauai into distinct bio-cultural and social-ecological zones, respectively (Winter et al., 2018). The models created not only show a gap within the current body of knowledge—being that no GIS has been used to locate the most suitable area for ahupuaʻA management—but they also suggest the potential within GIS and Hawaiian land management practices, despite the information being traditional and historical records (Winter & Lucas, 2017). Taken together with outside information regarding the use of GIS worldwide to measure land use, GIS can serve as an essential tool for locating the region of interest.

The contributions of traditional Hawaiian land management—ahupuaʻA—the lack of self-sufficiency in some communities, and advancements in technology lead to the essential question: Which ahupuaʻA in South Maui is best suited to implement traditional Hawaiian land management techniques to optimize self-sufficiency in water, vegetation, and livestock resources?

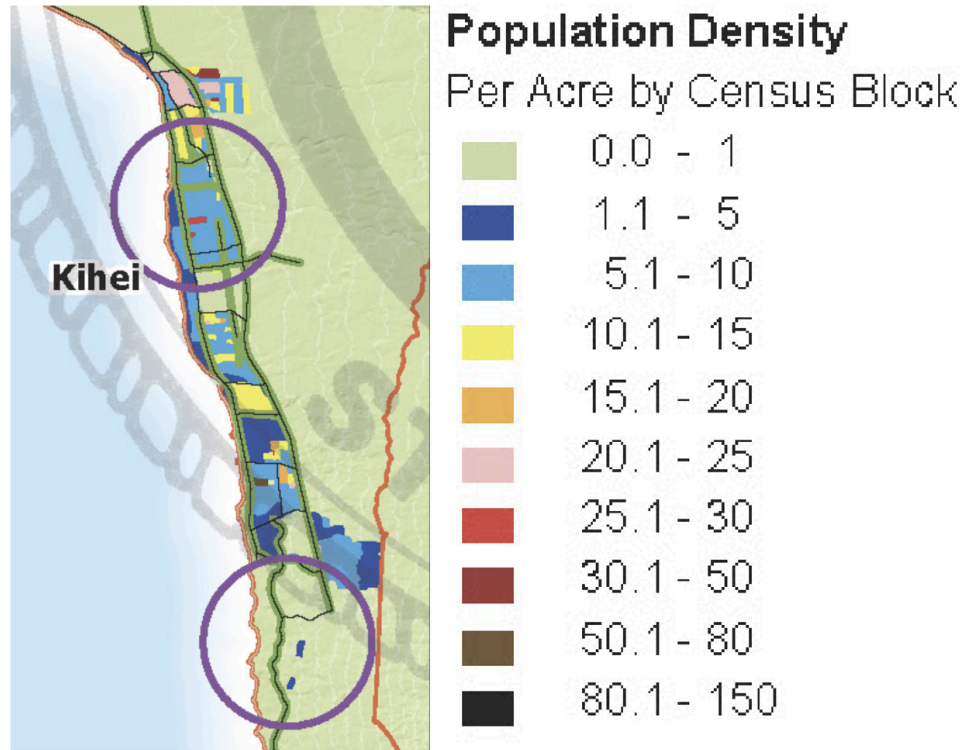


FIGURE 4: *The population densities of South Maui are demonstrated on the map to the left, while the legend for such color variation and significance is shown to the right of the map (County of Maui, 2012).*

Through an understanding of self-sufficiency and the current population densities of Kihei based on the Maui Plan, shown in Figure 4, an initial hypothesis was developed: the ahupuaʻA of Waiakoa or Kaʻoonoʻulu will be the least self-sufficient due to their high population demands and similar production to other South Maui ahupuaʻA, and, in turn, most desirable area to begin ancient Hawaiian land management practices.

3. Methodology

To achieve the project goal of identifying the area of South Maui most suitable for implementing traditional Hawaiian land management practices, online geographic information systems and public datasets were used. The entire project was conducted through comparative analysis. Comparative analysis focusing on quantitative data was chosen for its ability to analyze numerous variables within a dataset—a multidimensional approach to various entities (Gupta et al., 2008; Lex et al., 2010). This analysis method identified similarities, differences, and patterns between variables, which were chosen to manipulate otherwise distant entities regarding the research at hand. In particular, comparative analysis has been used in the geospatial and geographical fields to analyze data using geographical information systems (GIS), such as for landslides and environmental degradation (Ali et al., 2021; Gupta et al., 2008).

Additionally, the comparative analysis enabled relative weights to be assigned to the values produced; this study yielded a favorability of 50% overall for SSR to water, 26.3391% for beef, and 23.6608% for vegetables and fruits. These specific food weights were derived from empirical dietary data; according to Mititelu et al. (2024), beef constitutes approximately 26.16% of the average daily diet, and vegetables and fruits 23.50%. These weights were slightly adjusted to 26.3391% and 23.6608% to maintain a proportional 50/50 balance between water and food resources (Martin et al., 2020; Mititelu et al., 2024).

3.1 Data Harvesting

Options were heavily weighed during the initial process as to how data harvesting would be conducted. The chosen method was to conduct online searches, leveraging multiple search engines to locate academic journals and a variety of publicly available datasets. This was selected over a survey questionnaire that could be distributed to varying residences corresponding to their respective ahupuaʻA for various reasons. Primarily, the survey was disregarded due to time constraints and, in most cases, the redundancy of the information that could be collected. Furthermore, surveys, particularly questionnaires in both open- and closed-ended formats, have issues with reliability, accuracy, and nonresponse (Beegle et al., 2012; Converse & Traugott, 1986; Stratton, 2015). After determining the procedure to harvest data, key terms including, but not limited to, a combination of: “vegetation,” “fruit,” “vegetables,” “water,” “livestock,” “meat,” “consumption,” “production,” or “rainwater,” paired with either “Maui,” “Maui County,” or “Hawaii” were used. The specific inclusion of the vocabulary, as mentioned above, was key to achieving significant and valuable results for the project’s completion, explicitly identifying a community’s needs and production outputs in the first place. Resources on the search terms were filtered out for multiple reasons: year, data completeness (with data for the entire study area), and redundancy. A significant amount of the labor-intensive research occurred at this junction, as a large majority of the publicly available data, though accessible, was challenging to find and turned out to be a tedious task; this particular instance was notable with the variety of sources on Maui County’s “Document Center” and Hawaiʻi’s “Statewide GIS Program.”

3.2 Filtering Resources

Upon filtering through numerous resources, only a select few resources met the criteria and were valuable to the study, whilst not overcomplicating the topic. These sources needed to be, at a minimum, a dataset on a particular variable’s consumption and another on local production. Following filtering, the two or three remaining datasets for each variable were processed and formatted for use in the geographic information system ArcGIS Online. ArcGIS was selected for

the given research due to its ability to model numerical and spatial relationships with exceptional success (Pimpler, 2017; Szewrański et al., 2017).

3.3 Formatting Datasets

The data formatting was conducted through various processes dependent on the original, ‘raw,’ composition. Due to the limited scale of the research’s area of study, data in the form of a shapefile—a specific format for point, polyline, and polygon mapping to allow for visualization of geographic features—was not available for the variables tested, which would have made analysis simple (Hu et al., 2015). Hence, most data was provided as tables from extensive reports and datasets produced by the County of Maui and its departments. If the dataset was for a district, subdistrict, or larger area, such as the island of Maui, a map with polygon(s) was created in ArcGIS using geographic correlations based on current boundaries.

3.4 Spatial Analysis

Following the importation, formatting, and creation of dataset maps in ArcGIS, spatial analysis was performed in various forms and capacities. For variables provided on a per capita basis, population estimates from census data were used to calculate consumption or production per household, using tax maps. Other methods with spatial analysis in mind were conducted, such as for variables based on land size—such as vegetable and fruit production and beef production—“summarize within” analysis allowed the calculation of specific land characteristics and zoning. Once values in terms of totals for households were calculated, ahupuaʻA boundaries were overlaid, and the “summarize within” tool, precisely the “sum” function, was used to add the specific household estimates together within each ahupuaʻA. Once total consumption and production estimates were obtained for each ahupuaʻA, the “join count” tool combined these two values into a single map for each variable.

Given that most consumption and production data were not included with import and export values, the self-sufficiency ratio was calculated differently from that of the common body of knowledge (Godenau et al., 2020). Instead, it was simply a ratio of the production to consumption, which would measure how much of an ahupuaʻA’s population’s consumption needs it could meet.

$$SSR_{\text{Raw}} = \frac{\text{Domestic production}}{\text{Domestic Consumption}}$$

Once raw SSR values were calculated for each ahupuaʻA, the South Maui Community Plan boundary was overlaid to allow viewing only the study area.

3.5 Data Resolution and Spatial Limitations

The spatial resolution of the production data primarily relies on large-scale averages reduced from county and state-level datasets. In turn, much of the variability between the ahupua‘A boundaries (the upland and sea) is homogenized. The homogenization was necessary because quantifiable public datasets or research on differences in resource availability within an ahupua‘A and its terrain do not currently exist. However, certain variables, such as pastureland and hardiness zones, allowed for more specific analysis. In such cases, high-resolution land-cover data was available with greater precision.

3.6 Data Normalization and Scale

To align the GIS model’s results with Maui’s modern agricultural realities, a normalization method was developed. Preliminary spatial analysis indicated a pronounced favorability for vegetable and fruit SSR relative to what is currently observed at the state and county levels (Loke & Leung, 2013; U.S. Department of Agriculture, National Agricultural Statistics Service, 2025). To correct this, a scaling ratio (r) was derived by comparing the reported SSR (SSR_{Reported}) to the average raw SSR calculated in the model (SSR_{AvgRaw}). This scaling ratio ensures that the model’s raw findings are calibrated against the modern established yields for Hawai‘I, preventing the GIS results from overestimating rates. The final self-sufficiency rate was calculated as follows:

$$SSR_{\text{Final}} = \frac{SSR_{\text{Reported}}}{SSR_{\text{Avg Raw}}} \times SSR_{\text{Raw}}$$

This value was then applied to all the individual ahupua‘A SSRs, along with the variable-dependent percentage outlined in this paper’s methodology. SSR values would finally be compiled into a singular map, adding the SSR values of each variable together to get an “overall SSR.”

Variable	Raw Data Source	Processing Method	Output
Vegetables & Fruit	USDA NASS (2025)	Calculate lbs/acre based on Maui Hardiness Zones	Potential Yield
Beef	HDOA (2022)	Applied “Retail Weight” percentage from Greiner (2003)	Lbs of beef/year
Water	Maui Water Dept. (2023)	Sustainable yield vs. average consumption per subdistrict	Gallons/day

Population	U.S Census (2024)	2020-2024 Estimates applied to TMK Parcels	Consumer Demand
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FIGURE 5: *The above table illustrates the sample process of the data (for each variable) from the raw data, how it was processed, and the output gained from the processing.*

4. Results

Following the normalization process, the spatial analysis of South Maui’s ahupua‘A revealed significant disparities in self-sufficiency.

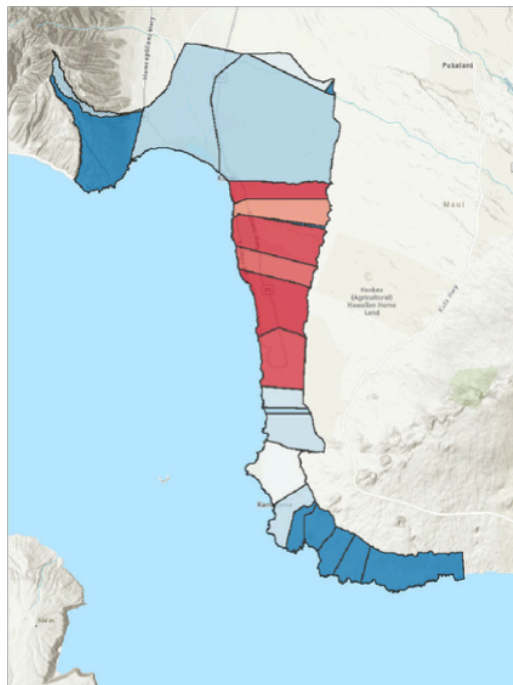


FIGURE 6: *A spatial analysis model of the “overall SSR” was created for the South Maui Community. The red represents a lesser SSR, and the blue represents a higher SSR for that respective ahupua‘A.*

These findings, as shown in Figure 5, indicate that the ahupua‘A of Waiakoa exhibited the lowest SSR of 2.17087%. Conversely, the ahupua‘A of Kōheo 1-2 demonstrated the highest SSR of 254.09741%. This exceptionally high value in Kōheo 1-2 is primarily due to its unique demographics; as it is a narrow sliver of land with minimal residential population (estimated <5), its resource-to-person ratio is disproportionately inflated. Additionally, the high SSR of Kōheo 1-2 could place it in an export-economy setting, given its proximity to resource-deficient regions and its high production relative to demand. Based on characteristics of other contemporary ahupua‘A-like

developments, these results support the prediction that reintegration efforts should be prioritized in Waiakoa to address the resource deficit (Department of Hawaiian Home Lands, 2011; Minerbi, 1996).

Ahupua'A	Population (est.)	Water SSR	Beef SSR	Veg + Fruit SSR	Total SSR
Ka'oono'ulu	~1,914	0.016764282	0.007753791	0.003664890	0.028182962
Waiakoa	~6,726	0.018972750	0.001603375	0.001132583	0.021708708
Kōheo 1-2	~2	0.016764282	1.867660403	0.656549371	2.540974056
Papa'anui	~192	0.047699499	0	0.030451011	0.078150510

FIGURE 7: A summary table of key ahupua'A SSR levels is displayed above. The orange represents Ka'oono'ulu, one of the ahupua'A included in the hypothesis. The blue represents the Waiakoa ahupua'A, the lowest SSR found in the study. The green represents the Kōheo 1-2 ahupua'A, the highest SSR found in the study. The red represents the Papa'anui ahupua'A, an ahupua'A representing the median of the dataset.

To evaluate the statistical significance of the findings, a 95% confidence interval was calculated for the mean of all 23 analyzed ahupua'A. The mean was determined to be 59.489%, with a standard deviation of 88.752%, and a confidence interval of [21.110%, 97.869%]. Notably, the ahupua'A of Waiakoa (SSR of 2.17%) falls well below the lower bound of the confidence interval. This exemplifies that Waiakoa is a statistical outlier ($p < 0.05$). This p-value reinforces the ahupua'A's selection as the priority site for resource management intervention, as it exceeds the expected regional variance.

Ahupua'A	Model's SSR (Rank)	33/33/33 SSR (Rank)	75/12.5/12.5 (Rank)
Waiakoa	0.021708708 (23)	0.013560486 (20)	0.006087292 (23)
Kama'ole	0.021830223 (22)	0.012864835 (23)	0.007088385 (21)
Papaka Kai	2.370461547 (2)	1.368043623 (1)	0.700165397 (2)
Kōheo 1-2	2.540974056 (1)	0.852579446 (6)	1.487005044 (1)

FIGURE 8: The SSRs of the ahupua'A were calculated under different variable weighting to return the SSRs as shown in the table above. The

ahupuaʻA of Waiakoa and Kamaʻole are featured for their consistently low SSR rankings. The ahupuaʻA of Papaka Kai and Kōheo 1-2 are included because of their consistently high SSR rankings. The lower the ranking, the greater the self-sufficiency, and vice versa.

4.1 Sensitivity Analysis

To further evaluate the model, a sensitivity analysis was performed (shown in Figure 8). Under an equal-weighting scenario, Waiakoa ranked as the 4th lowest SSR. However, when the weight of water was adjusted to 75%—reflecting the environmental reality of South Maui’s drought—and the remaining 25% split between beef, vegetables, and fruit, Waiakoa was the lowest SSR again. This indicates that, while other ahupuaʻA face food shortages, Waiakoa’s status as the candidate for reimplementation is driven by a critical water insecurity.

5. Discussion

Given the self-sufficiency results of the study and taking into account similar characteristics to those of the developing Kahikinui ahupuaʻA on Maui and other homestead projects, efforts to recreate a system of ahupuaʻA should be highly considered in Waiakoa, South Maui (Department of Hawaiian Home Lands, 2011; Minerbi, 1996). The results support the initial hypothesis that Waiakoa would rank among the least self-sufficient regions. While the hypothesis was originally broad in identifying both Waiakoa and Kaʻoonoʻulu as candidates, given their large populations and the corresponding higher relative demands, the data specifically highlight Waiakoa’s 2.17% SSR as the most critical resource deficit to address. Moreover, these research ventures to establish a system of ancient Hawaii aim to aid the drought-ridden environment of modern-day Hawaii, particularly South Maui. This aid is achieved by identifying the potential within the return of the ahupuaʻA system, which thrived with endemic species, and where it may be most beneficial (Gon et al., 2018). The results of this study, in turn, fill the current gap in the body of knowledge with a new understanding of where ahupuaʻA implementation should take place and a preliminary methodology for addressing the topic.

Beyond the metrics of self-sufficiency, the designation of Waiakoa as a priority region for ahupuaʻA implementation carries significant social and political weight. By using GIS to validate the needs of indigenous resource management, this study supports the Department of Hawaiian Home Lands and local organizations advocating for Native Hawaiian land rights. Through such an intersection of technological development and social necessities, a restorative justice approach can be formed, ultimately returning lands to productive, self-sustaining use for the local community.

5.1 Limitations

Despite the study’s success in identifying an area of South Maui with the lowest SSR and the best spot to implement an ahupuaʻA-like system,

numerous limitations exist in the results and methodology. Such a restriction is evident in the selection process and in the availability of sources on consumption and production, as these sources often lacked detailed information on their methods and measurements. An error due to such an issue can be illustrated by the need to use available pastureland acreage, paired with current beef production statistics for pounds collected per cow in Hawaii. As a result, some of the data may have been used inconsistently with how it was initially collected and with the areas each dataset represented. Regardless, the data provided through the selection process still reflected the general patterns of self-sufficiency in their respective regions, but should be addressed, as future research may find obstacles in the data collection process that could hinder achieving 100% accuracy.

Additionally, the study's chosen variables, water, beef, and vegetables and fruits, pose a potential limitation in the accuracy of an ahupuaʻA's self-sufficiency ratio. This may occur because relatively few variables are considered compared to the actual magnitude of resources that affect a population's reliance on outside sources. It must be recognized that, given the scale of the study at the high school level, it would be difficult to collect community-wide data on resource use and production for all potential variables. Whilst this may hold, given the scholarly nature of the research, all potential limitations must be duly noted.

Furthermore, within the study, a limitation regarding per capita estimates and totals per ahupuaʻA is the lack of information on local consumption trends, as well as on the method of population measurement: tax maps and 2020 census data. Although this problem was apparent throughout the research, it was determined that, using household estimates per tax parcel centroid and broader consumption per capita estimates, consumption or production trends could still be identified and used to create self-sufficiency ratios. Despite the promise of the selected method, the limitation shall be addressed even if the hindrance was not met in this study.

5.2 Future Directions

The results of this study have the potential to influence community managers and urban planners to push directly for the development of an ahupuaʻA resurgence in contemporary Hawaiʻi, particularly in South Maui's Waiakoa ahupuaʻA. Additionally, when considering incorporating ahupuaʻA land management, the results may be interpreted differently depending on the value of SSR characteristics in the implementing area, whether a higher or lower SSR is valued more highly. Adopting such a method of land use, sharing, and general environmental management may lead to various benefits for adopting communities, such as the careful and practical use of resources to avoid over-consumption beyond the means a community can produce. In doing so, a region may become less dependent on external sources, a trend especially prevalent in Hawaiʻi, given the island chain's isolated nature. Through a less "mainland-dependent"

HawaiʻI, communities can keep money circulating throughout the state and create an economy centered around a local commodity rather than the current economy based on tourism and outside spending. Furthermore, by understanding what a particular region can produce, population and community development can be better planned, which in turn may reduce resource depletion and environmental degradation. This ecosystem degradation is essential to address in the coming years, with climate change and HawaiʻI's unique, close-to-sea population among the concerns, which underscores the importance of identifying resource-abundant areas.

In terms of future research, the study opens various development opportunities. A possible future venture in studying how Lahaina could implement ahupuaʻA or traditional Hawaiian land management in rebuilding the historic town following the 2023 Fires could occur. Research on the use in rebuilding could lead to more resilient environments, which Lahaina and other fire-prone communities need.

Another such opportunity could be to shift to a greater variety of studied resources, potentially more contemporary ones, to address waste management or renewable energy capacities. Additionally, experimental research into the specific engineering and implementation methods of ahupuaʻA in contemporary society needs to be conducted on a larger scale. This needs to occur, as the modern environmental and social conditions are far different from those of the nineteenth century and earlier HawaiʻI (Gon et al., 2018). For these reasons, the social aspect in modern HawaiʻI could be researched to identify the population willing to at least restore ancient ahupuaʻA land divisions or management. Beyond the aforementioned research opportunities, the study area could be expanded, as the ancient ahupuaʻA boundaries extended far beyond the coastline and into the reef area, which this study failed to address (Minerbi, 1996). An understanding of the present marine resources under safe withdrawal measures and their extent could be highly pertinent to incorporating ahupuaʻA in HawaiʻI, given the dependence on aquatic life and seafood.

5.3 Conclusions

The SSR results per ahupuaʻA found in this study reflect a growing body of research on environmental degradation and resource use. As a result, the research expands beyond Kagawa's stated importance of rain-fed agriculture in drought-prone environments; instead, the research identifies the particular ahupuaʻA in a specific drought-prone area that could utilize an ahupuaʻA system—an example of rain-fed agriculture—the most. By adding this study's results to the body of literature, urban planners can make informed decisions about land management and practices. This happens because, while prior research has implemented ahupuaʻA-like management in communities across the islands, particularly in drought-prone and isolated areas, there remains a gap in the body of knowledge on where ahupuaʻA can be established in more populous and contemporary societies, such as that of South Maui. With this in mind, the study finds that, for populous, dense, and modern South Maui, ahupuaʻA

should first be implemented in the Waiakoa ahupuaʻA, given its relatively low SSR of ~2.17087%. Additionally, the study sought to bridge the gap in the literature on GIS's potential for land management decisions, as although Winter utilized the technological capabilities of GIS to identify ahupuaʻA bio-cultural zones, no research had been conducted on determining where to begin ahupuaʻA in a modern sense. Hence, this study enabled GIS to be used to a greater and more varied extent than previously. Furthermore, these findings are critical to addressing climate change and environmental issues in today's society, enabling future research and regional assessments to seek a modern-day adaptation of the ancient Hawaiian ahupuaʻA system that incorporates technological elements and relies on GIS, as exemplified in this study.

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