Research Article

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Analysing the sustainability of swamp buffalo (*Bubalus bubalis carabauesis*) farming as a protein source and germplasm

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Abstract: The swamp buffalo is a valuable genetic resource and an important source of animal protein in Indonesia. Unfortunately, their population is decreasing due to problems attributed to conventional farming systems. The objective of the study was to examine the sustainability of swamp buffalo farming and identify the attributes that influence its sustainability. Data were collected through a focus group discussion involving experts and business actors in swamp buffalo farming and a survey on buffalo farmers. The study examined 52 attributes within 6 dimensions: ecological, economic, social, technological, institutional, and welfare dimensions. The data were analysed using multidimensional scaling through the Rapid Appraisal for Swamp Buffalo technique. The results of the study demonstrate that swamp buffalo farming in Hulu Sungai Utara (HSU), Hulu Sungai Selatan (HSS), and Hulu Sungai Tengah (HST) districts in South Kalimantan province has sustainability indices of 51.70, 53.13, and 48.87%, respectively. This study identified 12 leverage attributes that are very influential to the sustainability of swamp buffalo farming, i.e., climatic conditions, land suitability, marketing, income from swamp buffalo farming, mutual assistance, education level, processing technology, reproduction technology, the role of local government, capital institutions, programs from central government, and farmers' welfare. Swamp buffalo farming in HSU and HSS is moderately sustainable, while in HST, it is less sustainable, suggesting improvement in the key factors influencing the sustainability of swamp buffalo farming. This study offers valuable insights for the government in formulating policies and programs for developing swamp buffalo farming and conserving swamp buffalo germplasm.

Keywords: germplasm, multidimensional scaling, meat source, sustainable farming, swamp buffalo

1 Introduction

The livestock subsector significantly contributes to livelihoods and food security in various parts of the world but has suboptimal performance in several developing countries, including swamp buffalo in Indonesia. In 2021, the world buffalo population was approximately 203.94 million, among which 98.16% were in Asia, mainly India and Pakistan [1]. Water buffalo can be classified into river buffalo (*Bubalus bubalis*) and swamp buffalo (*Bubalus bubalis carabauesis*). The difference between the two types of water buffalo lies in the number of chromosomes, phenotypic characteristics, and the location where they develop [2–5]. The swamp buffalo population is only about 20.51% of the total water buffalo population. Moreover, the present state

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of the swamp buffalo in the Southeast Asian region remains poorly understood compared to the river buffalo [6].

In developing countries such as Indonesia, livestock provides a valuable food source, income, and employment [7]. Swamp buffalo serves as a food source to support achieving the target of national meat self-sufficiency. Its contribution plays a significant role in realising a steady meat supply for the nation [8]. Buffalo is an excellent animal as a converter of low-quality fibrous feed into meat and milk and can utilise coarse feed more efficiently than cows [9,10]. Moreover, it produces more total solids in meat and milk while requiring less management input [10,11]. Another valuable characteristic of buffalo is its adaptability to the environment and its more disease-resistant ability, so it can adapt in areas where other ruminants cannot develop [12].

Swamp buffalo is recognised as one of the genetic sources of livestock in Indonesia that has been stipulated as the South Kalimantan buffalo family by the Ministry of Agriculture through Decree Number 2844/Kpts/LB.430/8/2012 dated August 10, 2012. The South Kalimantan buffalo family is a wealth of local Indonesian buffalo genetic resources that need to be protected and conserved through various efforts. Despite their high phenotypic consistency, swamp buffalo populations exhibit geographic distinction and low gene transmission [3]. The swamp buffalo population in Indonesia has not been well recorded, but the largest concentration is believed to be in South Kalimantan.

The genetic diversity of swamp buffalo is extensive [13], and Indonesia has a significant genetic stock of native swamp buffalo that exhibits good cross-regional adaption. However, its population and genetic quality are declining [14]. In the last two decades, the swamp buffalo population in Indonesia has declined sharply, from 2,459,434 in 2003 to 1,170,209 in 2022, meaning there has been a population decline of 52.42%. The same phenomenon occurred in South Kalimantan province, from 37,550 to 21,055, or a population decrease of 43.93%. Hence, buffalo meat production decreased sharply, from 40,639 tons to 21,120 tons nationally and from 756 tons to 397 tons for South Kalimantan [15].

Several studies reported factors causing the decline in the population of swamp buffaloes in South Kalimantan. Grazing land conversion into oil palm plantations and other purposes has reduced forage availability and caused damage to the swamp ecosystem [7,11]. Climate change also negatively impacted forage availability [16,17]. On the breeding aspect, a study reported that low female productivity is an essential factor that causes the decreasing population of swamp buffalo [18]. It is exaggerated by the high rate of calf mortality and diseases [7,16,17]. Other factors that negatively impact the swamp buffalo population in South Kalimantan are lack of capital, institutional capacity, and direction from the group leaders, as well as low access to information sources and lack of expertise in buffalo processing [16,17].

Besides having the potential to reduce animal-based food, which is essential for maintaining food security, the decline in the buffalo population also threatens the sustainability of buffalo germplasm in Indonesia. This condition requires the conservation of existing germplasm to prevent the loss of buffalo genetic resources. Currently, limited studies are available on the sustainability of buffalo farming. A previous study shows that, in general, Moa buffalo development in Moa Island, Maluku province, is multidimensionally sustainable [19]. It is sustainable in socio-cultural and economic dimensions. However, it is less sustainable in the ecological dimension. Another study concludes that traditional buffalo farming in Muaro Jambi district, Jambi province, is less sustainable, as shown by all less sustainable dimensions studied (ecological, economic, and socio-cultural) [20]. So far, to the best of our knowledge, studies have yet to examine the sustainability of swamp buffalo farming in South Kalimantan province.

The multidimensional scaling (MDS) technique has been popularly used to assess sustainability. Moreover, it has been widely used to determine the sustainability status of various agricultural commodity development such as garlic [21], cacao [22], corn [23], beef cattle [24,25], dairy cattle [26,27], buffalo [19,20], shrimp [28,29], coffee [30], rice [31–33], rice and duck [34], oil palm [35–37], red chilli [38], ornamental plant [39], microalgae [40], and black soldier fly [41]. Because agriculture sustainability is a complicated term, its meaning is multidimensional and open to interpretation in various ways [30]. Previous studies on sustainability mostly use ecological/environmental, economic, social, technological, and institutional dimensions. Some other studies use ethics, marketing, and political aspects in the analysis. However, those studies hold different opinions on the number and what dimensions to employ. The selection of dimensions is usually based on the objective of the study and is sometimes seen as region-specific.

The study on the sustainability of swamp buffalo farming in South Kalimantan is crucial, considering that the region has the largest population of swamp buffalo and is expected to experience a significant decline. Furthermore, knowing what factors should be considered to sustain buffalo farming is necessary. The swamp buffalo is one of the meat sources and germplasms owned by Indonesia, so its sustainability must be protected. Based on this background, this study aims to assess the sustainability of swamp buffalo farming in South Kalimantan province and identify the key factors influencing its sustainability. This study adds the welfare dimension to the five commonly used dimensions mentioned. The reason for this addition is that the future sustainability of livestock production depends on the welfare of both farmers and livestock [12]. The results of this study offer valuable insights to the government in formulating policies and programs for developing swamp buffalo farming and conserving swamp buffalo germplasm in Indonesia, especially in South Kalimantan province.

2 Methods

2.1 Study area

This study was carried out between August and December 2022 in South Kalimantan province, covering three districts: Hulu Sungai Utara (HSU), Hulu Sungai Tengah (HST), and Hulu Sungai Selatan (HSS) (Figure 1). The study locations were selected purposively considering the following reasons: (1) They are areas where the South Kalimantan buffalo family has been legalised through the Decree of the Ministry of Agriculture Number 2844/Kpts/LB.430/8/2012 dated August 10, 2012; (2) they are areas with a high swamp buffalo population in South Kalimantan; and (3) they have the same agroecosystem, namely, the swampland.

2.2 Data collection

The study was conducted with a structured survey approach involving 60 swamp buffalo farmers selected through multistage sampling. In addition, a focus group discussion was conducted involving 15 experts, namely, researchers, extension workers, district service representatives, provincial service representatives, academicians, business actors, and the private sector. Experts in this study have the knowledge and master the aspects studied; commit to the problem under investigation; have a reputation and position in accordance with the field under study; are neutral, honest, and open

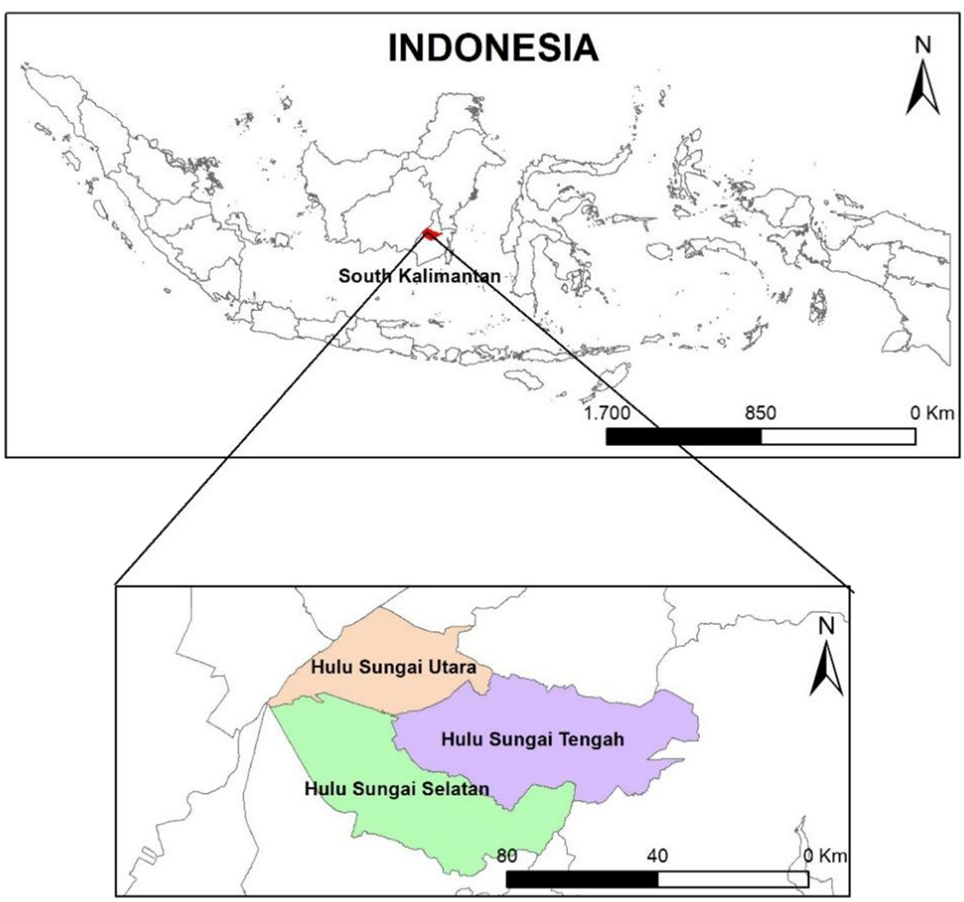

Figure 1: Map of the study area.

about research topics and able to accept input/opinions from other respondents.

The concept of sustainability adopted in this study used 6 dimensions with 52 attributes (Table 1). The answer choices used a score of 1–5 with the following criteria: 1 = very weak, 2 = weak, 3 = medium, 4 = strong, and 5 = very strong [42,43]. The description of each variable is presented in Appendix.

2.3 Data analysis

Data analysis was done using MDS through the Rapid Appraisal technique for Swamp Buffalo (Rap-SwampBuffalo). This approach was adopted and developed from the Rapid Appraisal method for Fish [44–46] to assess the sustainability of swamp buffalo farming, which is determined through the following stages:

(1) Assess the dimensions and attributes of sustainability. This study used 6 dimensions with 52 attributes.

(2) Perform a scored assessment on the attributes. The attribute score values will form an X matrix (n x p), where n is the number of regions and their reference points, and p is the number of attributes used. The scores are then standardised for each attribute score using the following formula:

$$X_{ik}\mathrm{sd} = \frac{X_{ik} - X_k}{s_k}, \tag{1}$$

where, X_{ik}sd = the ith regional standard score (including reference points) = 1, 2, …, n for each kth attribute = 1, 2, …, p, X_{ik} = the ith standard score (including reference points) = 1, 2,., n for each kth attribute = 1, 2, …, p, X_k = the mean score on each kth attribute = 1, 2, …, p, and S_k = standard deviation of scores for each kth attribute = 1, 2, …, p.

The shortest distance from the Euclidian distance was calculated using equation (2) and then projected into a two-dimensional Euclidian space (d12) based on the regression formula in equation (3) [44,46]. The regression process used the ALSCAL algorithm to make iterations so that the intercept value in the equation was equal to zero (a = 0). Thus, equation (3) becomes equation (4). The repetition process was stopped when the stress (S) value was <0.25. The S value was attained based on equation (5).

$$d_{12} = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2 + \cdots}, \tag{2}$$

$$d_{12} = a + bD_{12} + e, \tag{3}$$

$$d_{12} = bD_{12} + e, \tag{4}$$

Table 1: Dimensions and attributes used in analysing the sustainability of swamp buffalo farming in South Kalimantan, 2022

No.	Ecological	Economic	Social	Technological	Institutional	Welfare
1.	Feed availability	Swamp buffalo productivity	Family labour	Feed technology	Extension institution	Farmers' welfare
2.	Utilisation of livestock waste	Capital	Access to technology	Housing technology	The role of local government	The role of buffalo from the economic aspect
3.	Land fertility	Swamp buffalo ownership status	Household size	Reproduction technology	The role of the central government	The role of buffalo as a food source
4.	Climate change/condition	Swamp buffalo business scale	Education	Disease technology	Input institution	Regional buffalo program
5.	Water availability	Marketing	Mutual assistance	Breeding technology	Group dynamics	Buffalo program from the central government
6.	Land suitability	Income from swamp buffalo farming	Community empowerment	Processing technology	Capital institution	Public health
7.	Distance to the grazing area	Feasibility	Land conflict	Communication technology	Farmer group/union	
8.	Land availability	Labour availability	Farmers' behaviour	Internet network	Marketing institution	
9.	Rearing system	Profit				
10.	Land carrying capacity	Credit				
11.	Disease outbreak					
12.	Swamp buffalo health level					

$$S = \sqrt{\frac{1}{m}\sum_{k=1}^{m}\left[\frac{\sum_i \sum_i (D_{ijk} - d_{ijk})2}{\sum_i \sum_j d_{ijk}^2}\right]}. \quad (5)$$

(3) Assess and determine sustainability index and status. The sustainability status category for the sustainability of swamp buffalo development in South Kalimantan refers to the following sustainability index categories: 0.00–25.00 (not sustainable); 25.01–50.00 (less sustainable); 50.01–75.00 (moderately sustainable); and 75.01–100.00 (highly sustainable), as adopted by Rachman et al. [33].

(4) Conduct a sensitivity (leverage) analysis to determine the sensitive attributes that strongly influence the sustainability of swamp buffalo farming. This analysis was based on the priority order of changes in the RMS ordination on the *x*-axis. If the RMS has a significant value, it means that the role of this attribute is getting more prominent toward the sustainability status (more sensitive).

(5) Perform Monte Carlo analysis in the Rap-SwampBuffalo method to estimate the random error rate in the model resulting from the MDS analysis for all dimensions at 95% confidence level. The smaller the value difference between the MDS and Monte Carlo analysis results, the better the Monte Carlo model produced by the Rap-SwampBuffalo method. The goodness of fit in MDS is reflected in the values of S and coefficient of determination (R^2). A low S value denotes a good fit, while a high S value denotes the opposite. With the Rap-SwampBuffalo approach, a good model is indicated by an S value of less than 0.25. The R^2 value close to 1 indicates that the attributes used to examine a dimension are reasonably accurate [46].

3 Results and discussion

3.1 Regional overview

Table 2 shows that HSS has the largest area and swampland area. Meanwhile, HSU has the smallest area but has the highest percentage of swampland area compared to the other two districts. The environmental conditions are ideal for the growth and development of swamp buffalo farming. HSU is a swamp buffalo-producing centre in South Kalimantan with the highest location quotient value of 9.65, compared to HSS (1.24) and HST (1.16). HSU has the largest swamp buffalo population in South Kalimantan, much larger than the other two districts. Larger swamp areas can provide greater forage, positively affecting the sustainability of swamp buffalo development [47].

Table 2: Swampland area and buffalo population in the three study locations in South Kalimantan, 2021

No.	Items	District		
		HSU	HSS	HST
1.	Area (km^2)	892.70	1804.94	1770.77
2.	Swampland area (km^2)	32.95	46.94	21.32
3.	Swampland percentage (%)	37	26	12
4.	Buffalo population (head)	10,501	602	646
5.	Swampland area to buffalo population ratio	3.14	77.98	33.00

HST has the smallest percentage of swampland area compared to the other districts. Moreover, the area is primarily used for agricultural development, such as food crops, horticulture, and biopharmaceuticals. The swampland in this district is mainly shallow to medium-depth swampland area used for planting food crops, resulting in the limited land availability for swamp buffalo farming. The district focuses more on developing beef cattle, sheep, and pigs due to the abundance of agricultural waste that can be used to feed these animals.

Over the last 12 years (2010–2021), the buffalo population in HSU has increased by approximately 20.90, or 1.74% per year, from 8,686 to 10,501 heads [47]. Unfortunately, the swamp buffalo population in HSS decreased sharply by 82.74, or 6.9% per year (from 3,488 to 602 heads). Similarly, in HST, there was a decrease of 71.80, or 5.98% per year (from 2,291 to 646 heads). However, over the past 5 years (2017–2021), swamp buffalo meat production in HSU decreased by 50.41%, from 367,380 to 182,199 kg. A remarkable decrease in swamp buffalo meat production happened in HSS (41.10%), from 23,224 to 32,769 kg. A slight decrease (5.34%) in meat production occurred in HST, from 75,865 to 71,811 kg.

The swamp buffalo population in South Kalimantan decreased due to various factors, including limited forage, land conversion, snail pests that consume forage, diseases, and reproduction issues that hinder its development. Several problems, such as inadequate management, a lack of quality feed, a shortage of superior bulls, and insufficient livestock health services, also limit swamp buffalo productivity [48]. Moreover, farmer group performance is not optimal, leading to difficulties when problems arise. Therefore, strengthening farmers' organisations with strong bargaining power is needed to increase the swamp buffalo population while improving breeding abilities [49].

Currently, swamp buffaloes in South Kalimantan serve as an animal protein food source for the population and an income source for farmers. People in South Kalimantan are very familiar with consuming buffalo meat, especially for celebrations and religious events, so the demand for swamp buffalo meat is relatively high, especially in HSU. Based on the data, the slaughtering rate of swamp buffalo in HSU in 2022 was 812 heads, while the beef cattle slaughtering rate was 932. Likewise, the rate of swamp buffalo slaughtering in HSS was high compared to other districts/cities in South Kalimantan [50]. The slaughtering rate indicates the number of swamp buffaloes being slaughtered in a certain period. The swamp buffaloes slaughtered are usually local ones. These data show the importance of swamp buffalo as a source of income and food. Therefore, it is crucial to consider both internal and external factors supporting swamp buffalo development. The priority scale that needs to be considered in developing swamp buffalo farming is addressing the issues related to feed, reproductive concerns such as inbreeding, lack of selection of superior males, slaughtering of productive females and males, and livestock health problems, especially disease prevention and treatment.

3.2 Swamp buffalo farming profile

Swamp buffalo farming is generally still carried out in a traditional/conventional way. Swamp buffaloes are generally kept in places with little human intervention, such as river areas, shrubs, forest edges, and swamps. In South Kalimantan, 64% of the swamp buffaloes are reared extensively in swampland [48]. Local people call it *Kalang* buffalo, named after a specific type of stall barn (local name is *kalang*) used for the swamp buffaloes to take a rest (Figure 2). *Kalang* is made of *belangeran* wood and ironwood, which are stacked over swamp water. *Kalang* is usually built without a roof or with a partially roofed structure to separate the lactating mother swamp buffalo and the baby [51].

Swamp buffalo farming is generally a family business that has been handed down from one generation to another. Swamp buffalo farming mainly serves as the main business. However, it is a side business for others, individually and in groups. It can also be a job opportunity to run a company owned by someone else. Swamp buffalo rearing management is generally easy, simple, and practical, especially in small-scale swamp buffalo farms. Moreover, it has not applied technology and information systems. Breeding is achieved through natural mating, which can lead to inbreeding. These farms are concentrated in multiple locations and need an integrated agribusiness system.

Swamp buffalo farming in the three research locations is almost similar. Most rearing is carried out over swampland because the land area is minimal. Swamp buffaloes look for grass also by swimming to a grazing place where the water recedes so the grass is easy to reach. Swamp buffaloes generally depend on the grass that grows naturally in swamps to fulfil their nutritional requirements. Farmers do not provide grass or additional feed except for sick or newly born buffalo. The buffalo is allowed to graze in the swamp during the day and return to *kalang* in the afternoon to rest until early morning.

To distinguish one farmer's swamp buffaloes from others, farmers mark their buffaloes on the earlobes as a tear with specific patterns on the earlobe (Figure 3). Hence, they are not confused with swamp buffaloes belonging to other farmers. These marks are different for each farmer and have specific names such *as tatak, tajun hampang, tali layar, sapit hundang, belah pucuk, kait, dirik,* and many others. This mark on the earlobe is made by cutting the

Figure 2: *Kalang* (left) and grazing area of swamp buffaloes (right) in South Kalimantan.

Figure 3: An example of a mark on the earlobe of the swamp buffalo in South Kalimantan.

earlobe when the buffalo is 1 year old. The marking technology for buffaloes is carried out in a simple way and has been passed down for generations. Especially for Toraya buffaloes in Tana Toraja district, South Sulawesi province, which are reared intensively, no markings are made on the earlobes. Instead, they are only given names and necklaces around their necks so as not to spoil their appearance and, therefore, the selling price.

The amount of forage available is greatly affected by the climate. During the rainy season, the water levels rise (1.5–3 m), making it difficult to find areas with grass. The grass may also be submerged or washed away. The amount of forage available during the rainy season is reduced by about 50% due to waterlogging compared to the dry season [17,52]. Moreover, changes in swamp water levels can affect the growth and development of plants, leading to a reduction in their biomass [9]. During the long rainy season, many buffaloes become famished. Farmers often have to sell their livestock at lower prices to avoid losses from possible deaths. In the rainy season, heartworms can attack numerous swamp buffaloes, which may result in their death. However, during the dry season, in the afternoon, swamp buffaloes are not kept in *kalang* but in simple pens in dry locations (not submerged), which is given a barrier made of wood. In hot weather, swamp buffalo will prefer to wallow and soak in rivers or lakes because they are less resistant to hot weather due to sunburn. Under these circumstances, swamp buffalo usually gather near water sources or rivers under trees.

Farming swamp buffalo as a part-time business often results in paying attention to the quality and quantity of feed, especially during the rainy season when getting enough forage is challenging due to the high-water levels. When it comes to herding patterns, inbreeding is common and male swamp buffaloes with good performance are often sold for their economic value. Unfortunately, these practices lead to a decrease in the genetic quality of the seeds and ultimately result in decreased productivity.

3.3 Sustainability analysis

Based on the results of the multidimensional analysis, swamp buffalo farming in HSU and HSS is moderately sustainable, with sustainability indices of 51.70 and 53.13%, respectively. However, it is less sustainable in HST, with a sustainability index of 48.87% (Figure 4). On average, the sustainability index of swamp buffalo farming in South Kalimantan is 51.23%. Likewise, a study conducted on Moa Island in Maluku province demonstrates that buffalo farming in that area is moderately sustainable, as indicated by the sustainability index of 52.72% [19]. Another study [20] showed that traditional buffalo farming in Muaro Jambi district, Jambi province, is less sustainable, similar to that in HST. Deb et al. [53] suggested that it is important to take a holistic approach and address all the factors that affect the sustainability of buffalo farming.

Although swamp buffalo farming is considered multidimensionally sustainable, it does not necessarily mean that every dimension is sustainable. Swamp buffalo farming in HSU is considered moderately sustainable. However, out of the six dimensions, there are two less sustainable

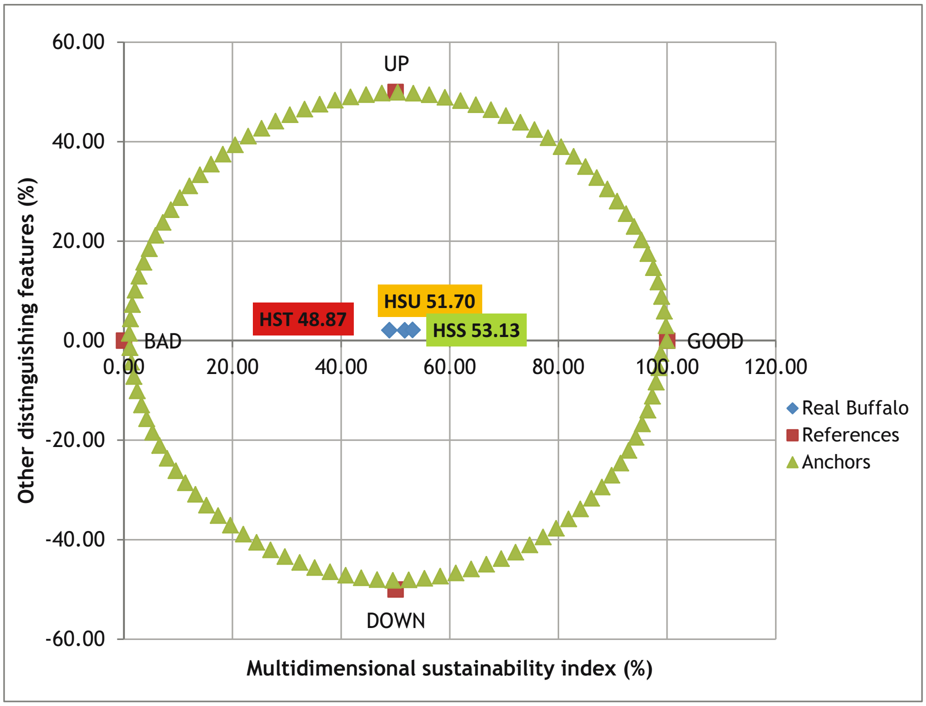

Figure 4: RAPs ordination of swamp buffalo farming in the three study locations in South Kalimantan, 2022.

dimensions: technological and welfare dimensions. The same case happens in HSS. It also has a moderately sustainable status but has one less sustainable dimension, namely, the technological dimension. Swamp buffalo farming in HST has the lowest sustainability status among the three studied districts, i.e., it is less sustainable. Out of the six dimensions, only the economic aspect shows moderate sustainability. However, the remaining five dimensions exhibit less sustainability, as seen in Table 3. The results show that all the districts have a less sustainable technological dimension, emphasising the importance of enhancing the technological aspect to improve the sustainability of swamp buffalo farming in these three districts.

On the ecological dimension, the analysis results show that swamp buffalo farming in HSU and HSS is moderately sustainable, as demonstrated by the index values of 57.71 and 56.71%, respectively. In contrast, it is less sustainable in HST, with an index value of 48.99% (Table 3). The average ecological sustainability index for all districts is 54.47%. As explained previously, HST has the smallest swampland area, mainly shallow to medium depth. This condition made the local government and farmers prioritise developing food crops, horticulture, and livestock that can utilise agricultural waste. As a result, the availability of swampland for developing swamp buffalo is increasingly limited. Hence, food production from buffalo faces several challenges, such as environmental emissions, climate change, and land conversion. These challenges have led to competition between food, fuel, and feed. Moreover, there is also competition for utilising fertile land for food crops [54].

Previous studies show that most buffalo farming is less sustainable regarding ecological factors, except for the Toraya buffalo. Tatipikalawan et al. [19] reported that Moa buffalo farming is less ecologically sustainable, as shown by the sustainability index of 41.15%. Moa buffalo is the swamp buffalo that lives on Moa Island, Maluku Barat Daya district, Maluku province. The same case is reported on swamp buffalo farming in Jambi, with a sustainability index of 42.81% [20]. Different results were found in the Toraya (Bolang) buffalo farming in Tana Toraja district, South Sulawesi province, which has a relatively high ecological sustainability index [55]. Toraja buffalo also belongs to swamp buffalo. The buffalo has a specific characteristic of skin colour, ranging from striped to albino. The unfavourable ecological condition needs to be followed up by stakeholders, especially the availability of pastures that do not compete with other commodities [11,51].

From the economic dimension, swamp buffalo farming in the three locations is moderately sustainable (Table 3). The sustainability index value for each district is 60.00% (HSU), 54.44% (HSS), and 52.66% (HST), with an average value of 55%. This result is similar to Moa buffalo farming in Maluku province, where the economic dimension of buffalo farming is within the sustainable criteria (56.73%) [19].

Table 3: Sustainability index of swamp buffalo farming in the three study areas by dimension

No.	Description	Ecological	Economic	Social	Technological	Institutional	Welfare
1.	**MDS**						
	HSU	57.71	54.20	51.37	46.69	51.41	49.89
	HST	48.99	52.66	49.46	43.28	48.14	48.14
	HSS	56.71	54.44	53.00	45.49	52.82	52.82
2.	**Monte Carlo**						
	HSU	57.96	54.72	51.24	46.48	51.61	50.13
	HST	48.89	52.66	49.20	43.00	42.46	48.40
	HSS	57.27	53.97	52.72	44.00	56.93	52.72
3.	**Difference**						
	HSU	0.25	0.52	0.13	0.21	0.20	0.24
	HST	0.10	0.00	0.26	0.28	5.68	0.26
	HSS	0.56	0.47	0.28	1.49	4.11	0.10
4.	**Status**						
	HSU	Moderately sustainable	Moderately sustainable	Moderately sustainable	Less sustainable	Moderately sustainable	Less sustainable
	HST	Less sustainable	Moderately sustainable	Less sustainable	Less sustainable	Less sustainable	Less sustainable
	HSS	Moderately sustainable	Moderately sustainable	Moderately sustainable	Less sustainable	Moderately sustainable	Moderately sustainable

However, different results were revealed by Syarifuddin et al. [20] that swamp buffalo farming in Muaro Jambi is in the less economic sustainability criteria (46.67%). These findings show that each region has variations in the sustainability status of buffalo farming according to regional potential, human resources, and other support.

Profitability analysis results show that, with a selling price of IDR 16,000,000 per head, 30 buffalo-scale farmers who sell 5–10 buffaloes can get a net income of IDR 19,675,000 million per year, with a revenue-cost ratio (RCR) of 1.33. These results show that swamp buffalo farming is profitable and feasible. Swamp buffalo farming is profitable because the farming costs are relatively low, the feed is readily available in nature, and it requires fewer work hours. In addition, marketing swamp buffaloes is relatively easy because of marketing institutions supported by the community tradition of consuming buffalo meat, such as wedding parties, religious events, and other celebrations, so the demand for swamp buffalo is high and can ultimately benefit farmers [8]. These results align with the previous studies, which reported that swamp buffalo farming is profitable and feasible [56], with a benefit–cost ratio of 1.05 [52]. Swamp buffalo farming needs to be supported by business scale, capital, and adequate credit facilities to provide benefits and as a source of income for farmers, and hence, be sustainable from an economic standpoint.

Based on the social aspect, the analysis indicates that swamp buffalo farming in HSU and HSS is moderately sustainable, as shown by the sustainability indices of 51.37 and 53.00%, respectively. However, in HST, it falls into the less sustainable category (49.46%) (Table 3). On average, the social sustainability index for the three districts is 51.28%. The lack of social sustainability of swamp buffalo farming in HST is because the community in that location is more concerned with food crops and horticulture. Viewed from the same dimension, swamp buffalo farming in Muaro Jambi is less sustainable (42.56%) [20], while Moa buffalo farming is sustainable (60.28%) [19].

Viewed from the technological aspect, swamp buffalo farming in the three research locations is less sustainable (HSU: 46.69%; HST: 43.28%; and HSS: 45.49%; Table 2), with an average technological sustainability index of 45.15%. This condition means that from a technological field, it is less sustainable. Therefore, the technology applied in swamp buffalo farming in all districts still needs to be improved. Swamp buffalo farming in South Kalimantan is carried out extensively, and feed availability depends on nature. The use of technology is still low, whether it is related to feed, housing, reproduction, breeding, rearing management, or product processing. More optimal efforts are needed to apply modern technology in swamp buffalo farming to increase productivity.

These facts align with a previous study [16], which found that technology adoption in swamp buffalo farming could be higher regarding breeds, feed, housing, disease, and marketing. Research with a genomic science approach could improve swamp buffalo genetics to increase productivity, adapt to climate change, and be more profitable for farmers [6]. Currently, buffalo productivity is low [18,57]. Several vital factors are suggested to improve productivity, such as genetic improvement, effective technology implementation, infrastructure development to strengthen the value chain, and assisting farmers in overcoming technical and non-technical challenges [10].

In this study, genetics is not included as a separate attribute but instead became part of the attribute of breeding technology. Swamp buffalo breeds are long-standing derivatives, breeding using natural mating. Male swamp buffalo are generally sold at 2–3 years old, leaving 1–2 heads for bulls. Typically, farmers have more adult female buffaloes to get more offspring for breeding. Due to the limited number of males, the adult female will mate with a male buffalo from her group, so inbreeding is very likely to occur. Research on the genetics of swamp buffalo at the research location has not been carried out because buffalo is not a national priority program, making it difficult to obtain research funding.

According to Table 3, swamp buffalo farming in HSU and HSS is moderately sustainable in terms of institutional dimension, with sustainability index values of 51.41 and 52.82%, respectively, while in HST, it is less sustainable (48.14%). The average institutional sustainability index for all districts is 50.79%. These relatively low values are due to the low institutional capacity of swamp buffalo farming in South Kalimantan [16]. The institutional performance of swamp buffalo farming is not optimal and lacks the group leader's direction [17]. Therefore, strengthening farmer organisations is the best strategy to overcome common obstacles in feed supply, land availability, housing technology, and marketing [49].

The welfare dimension shows that swamp buffalo farming in HSS is moderately sustainable (52.82%), while in the other two districts, it is less sustainable (HSU: 49.89%; HST: 48.14%), as shown in Table 3. Although the average sustainability index value falls under the moderately sustainable category (50.28%), it is relatively low, nearing the threshold for less sustainable criteria. This low value is likely due to the lack of program support from the central and regional governments for developing swamp buffalo. The concept of welfare encompasses the well-being of livestock and humans, including farmers, the role of swamp buffaloes for the community, food sources, regional and central program activities, and community health. According to Borghese et al. [12], the well-being of buffaloes and the quality of their products are closely connected to the sustainability of buffalo production systems. Current observations reveal that swamp buffalo farmers are relatively prosperous.

Table 4: Stress and *R*-squared values of swamp buffalo farming in South Kalimantan

No.	Dimension	*S*	R^2
1.	Ecological	0.17	0.94
2.	Economic	0.18	0.93
3.	Social	0.18	0.93
4.	Technological	0.19	0.93
5.	Institutional	0.19	0.93
6.	Welfare	0.20	0.92
7.	Multidimensional	0.14	0.95

According to the data presented in Table 4, no significant difference was observed between the MDS and Monte Carlo sustainability indices. This result means that the sustainability criteria remain consistent for every dimension and district. Most of the difference in sustainability index values is <5, meaning that the model is adequate and valid [30,58], except for the institutional dimension in HST, which has a sustainability index difference of 5.68. A Monte Carlo analysis in the Rap-SwampBuffalo method was performed to estimate the random error rate in the model resulting from the MDS analysis for all dimensions at 95% confidence level. The smaller the value difference between the MDS and the Monte Carlo analysis results, the better the model produced by the Rap-SwampBuffalo technique.

A normalisation test was carried out with reference to the value of stress (S) and the coefficient of determination (R^2) to analyse the feasibility of the model. Table 4 shows that the S values are <0.25, and the R^2 values are <1 for all dimensions, which means that the model used is feasible and reasonable. The smaller the value of S, the better the model is, and vice versa. The R^2 values of all dimensions are above 0.90, meaning that the sustainability estimation model is excellent and adequate [44,46].

3.4 Leverage analysis

The results of the leverage analysis show that, of a total of 52 attributes, 12 strongly influence the sustainability of swamp buffalo farming in South Kalimantan province, two of each dimension (Table 5).

3.4.1 Ecological dimension

In the ecological dimension (Figure 5), two sensitive attributes that strongly affect the sustainability of swamp

Table 5: Recapitulation of the most sensitive attributes to the sustainability of swamp buffalo farming in South Kalimantan, two for each dimension

No.	Dimension	No.	Attribute	RMS change (%)
1.	Ecological	1.	Climate change/condition	1.48
		2.	Land suitability	1.10
2.	Economic	3.	Marketing	1.17
		4.	Income from buffalo farming	0.88
3.	Social	5.	Mutual assistance (*gotong royong*)	2.64
		6.	Education	2.08
4.	Technological	7.	Processing technology	2.46
		8.	Reproduction technology	1.40
5.	Institutional	9.	The role of local government	1.47
		10.	Capital institutional	1.39
6.	Welfare	11.	Programs from the central government	1.37
		12.	Farmers' welfare	1.06

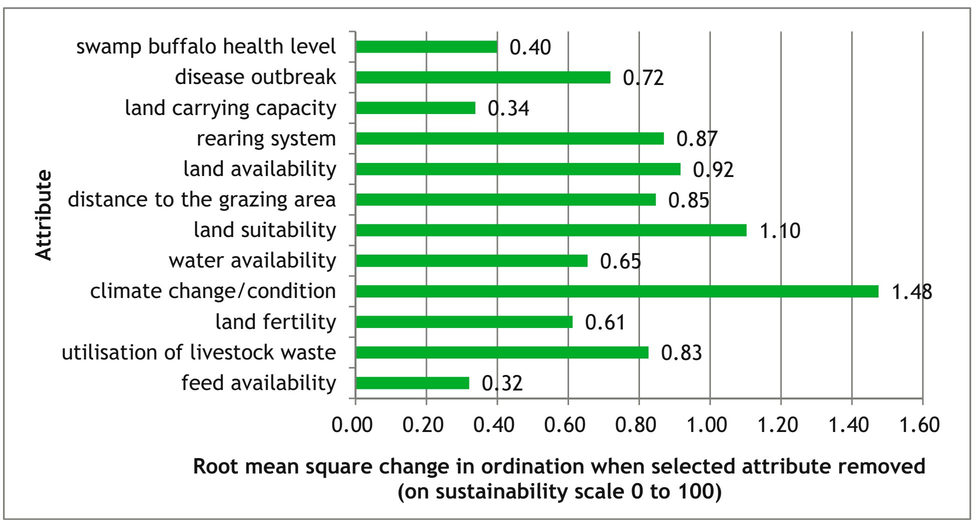

Figure 5: Leverage of ecological attributes in the sustainability analysis of swamp buffalo farming in South Kalimantan.

buffalo farming are climatic conditions (climate change) and land suitability. According to the IPCC's report [59], climate change has spread quickly and become more severe, significantly impacting agriculture. Due to varying climate conditions, swampland landscape patterns are susceptible to change from extreme floods and droughts. Excessive high and low water levels can negatively impact plant growth [60], including forage for swamp buffalo. Therefore, climate change can significantly harm swamp buffalo. Farmers need to employ suitable risk management strategies to minimise potential risks [61]. Adopting agricultural innovations can enhance farmers' capabilities and promote sustainable farming practices [62]. Several solutions and technologies that can be considered to address the problem of feed scarcity are the development of local forage cultivation technologies that are adaptive to grazing land, development of non-local grass and legume cultivation, rotation of grazing land usage, utilisation of agricultural waste, and the application of feed processing technology such as silage and ammoniation. Additionally, weed eradication can help revitalise grazing land.

Farmers must adjust to climate change to address its adverse impacts. Improved farming practices and nutritional management are increasingly crucial for small-scale farmers to cope more efficiently with the growing climate variability and potential environmental degradation [63]. Buffaloes are well-suited to living in tropical environments, but they need to be physiologically equipped to handle extremely high temperatures with access to water. As climate variability increases and temperatures rise, buffalo may experience heat stress. Several strategies can be put in place to address climate change, such as diversifying businesses, reducing livestock scale, increasing access to drinking water, planting more trees for shade, and combining crops and livestock [64]. Moreover, forage plantations are being promoted as a solution to manage feed shortages and fatten large ruminants before they are sold, which can increase the value of the animals [63].

The availability of suitable land is essential for supporting the sustainability of swamp buffalo farming. It is crucial to have enough land available for the swamp buffalo to graze and roam. Therefore, extensive swampland is a valuable resource necessary for swamp buffalo development. Swampland filled with grass is the primary requirement for adequate caring of swamp buffalo [51]. Furthermore, maintaining ecological sustainability in a development area depends highly on the land suitability attribute, making it the most significant sub-criteria [65]. This attribute is crucial for swamp buffalo activity and as a feed source. Developing swamp buffalo farming requires the establishment of swampland agroecological zones for swamp buffalo farming and preserving swampland, which can be achieved with government policy support. This support needs to be accompanied by clear and detailed implementation guidelines in the agricultural land protection law so that it is sustainable [66].

3.4.2 Economic dimension

According to the leverage analysis results, marketing is the most sensitive attribute for the economic sustainability of swamp buffalo farming (1.17; Figure 6), followed by livestock income (0.88). This finding means that enhancing the marketing of swamp buffalo products can substantially affect the sustainability of swamp buffalo farming in the studied areas. The availability of a market is essential for the sustainability of any commodity business because, without a market, the product cannot be traded for commercial purposes. Swamp buffalo farmers will gain considerable profits with good marketing; therefore, they can sustain and expand their farms. This finding aligns with the previous study stating that marketing is critical to small, medium, and micro enterprises' (SMMEs) growth and sustainability. Moreover, farmers must earn sufficient income to reinvest in their businesses to maintain sustainability [67].

Swamp buffalo farmers generally sell male and culled buffaloes. This practice is also done by cow farmers [68]. Swamp buffalo marketing channels in HSU follow four patterns: (1) direct marketing funnel patterns, (2) one-level marketing funnel patterns, (3) two-tier marketing funnel patterns, and (4) three-tier marketing funnel patterns. Even though the first pattern is the most efficient, most farmers (40%) prefer to follow the two-tier marketing channel pattern due to the higher price they get [8]. However, according to a different study, farmers who engage in direct marketing tend to earn higher incomes, whereas those who choose indirect marketing channels may benefit from better efficiency [69]. Swamp buffalo farmers face a disadvantageous bargaining position due to their limited knowledge of pricing and marketing information. Additionally, their urgent financial needs often compel them to sell their livestock at lower, less reasonable prices. Improving processing and marketing is crucial in enabling small-scale swamp buffalo farmers to participate in the

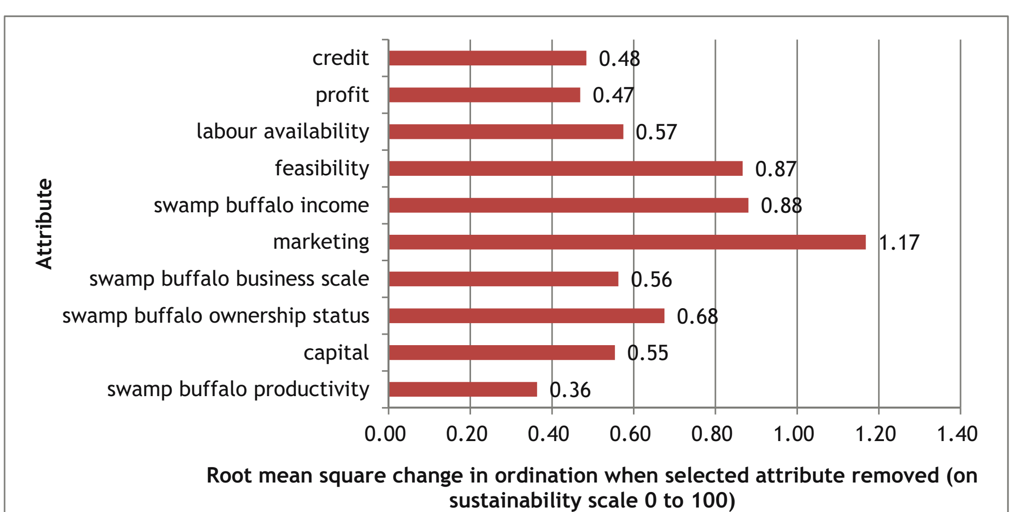

Figure 6: Leverage of economic attributes in the sustainability analysis of swamp buffalo farming in South Kalimantan.

growing beef market and expand their agricultural business, improving their rural livelihoods. This could alleviate rural poverty while bolstering food security [63].

A marketing strategy is required to improve swamp buffalo marketing. The concept of marketing strategy is crucial to marketing and serves as the core of strategic marketing [70]. In addition, maintaining strong relationships with key partners and customers is essential to successful marketing [71]. Ensuring customers are satisfied with their benefits is key to building strong relationships and cultivating loyalty. Developing economic partnerships is a priority among the various strategies for maintaining positive relationships with important partners and clients [72], including forming farmer cooperatives [69]. Farmers can also enhance their swamp buffalo marketing efforts by utilising digital marketing strategies and engaging on social media platforms to access price development information and promote their products [8].

3.4.3 Social dimension

In the social dimension, mutual assistance (*gotong royong*) activities and education are the two most influential factors for sustainable swamp buffalo farming (Figure 7). Swamp buffalo farmers participate in *gotong royong* activities such as repairing or building roosters, contributing to pay for labourers' salaries, assisting with medical and vaccination tasks from the livestock Services, providing transportation for livestock health medical officers, and helping each other search for missing buffaloes. *Gotong royong*, a cultural practice in Indonesia, functions as a form of social capital in a business and contributes to reducing societal inequality [73]. This practice also supports poverty alleviation and sustainable development [74].

The education level of farmers directly impacts their ability to access and utilise modern technology for sustainable agriculture [75,76]. Farmers require convenient access to technology that supports their operations to make their livestock business profitable and sustainable. This is because technology is essential for profitable and easy-to-implement livestock production, enabling businesses to develop sustainably [77]. Farmers can increase their capacity in terms of technology through extension workers so that the adoption rate increases, which in turn can increase income and welfare [62,78].

3.4.4 Technological dimension

On the technological dimension, Figure 8 shows that post-harvest/processing technology is the most sensitive attribute that significantly affects the sustainability of swamp buffalo farming in South Kalimantan province. In this province, buffalo slaughter is more frequent than beef cattle, specifically in HSU. However, buffalo product processing technology has not developed well. Swamp buffalo meat at the study site is generally sold as fresh meat. However, some people process the meat using very simple technology on a household business scale with simple equipment usually available at the household. Moreover, after the government imported buffalo meat in the last few years, people started to use it as a mixture for making meatballs due to its slightly lower price than beef [48]. So far, the processing of buffalo skin is still done simply by washing away the dirt and blood from skin and then

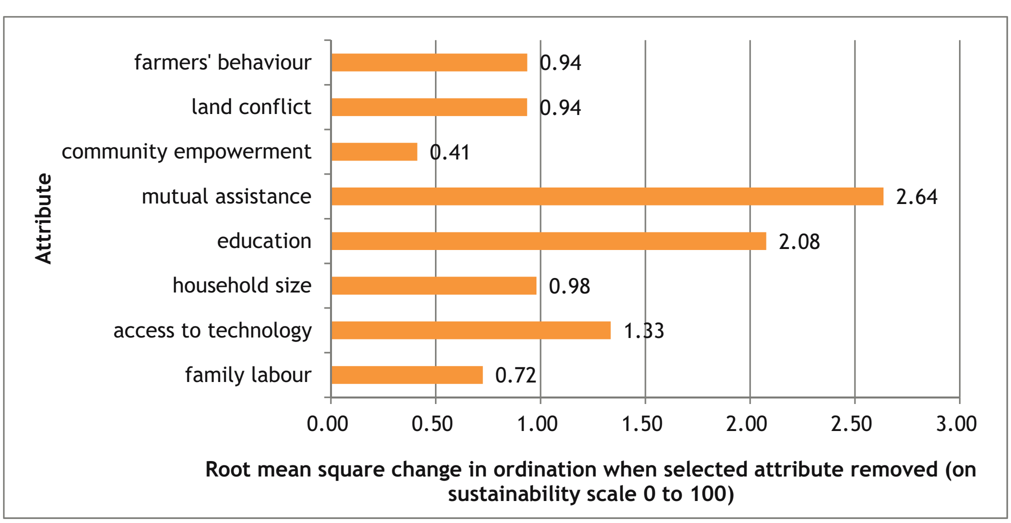

Figure 7: Leverage of social attributes in the sustainability analysis of swamp buffalo farming in South Kalimantan.

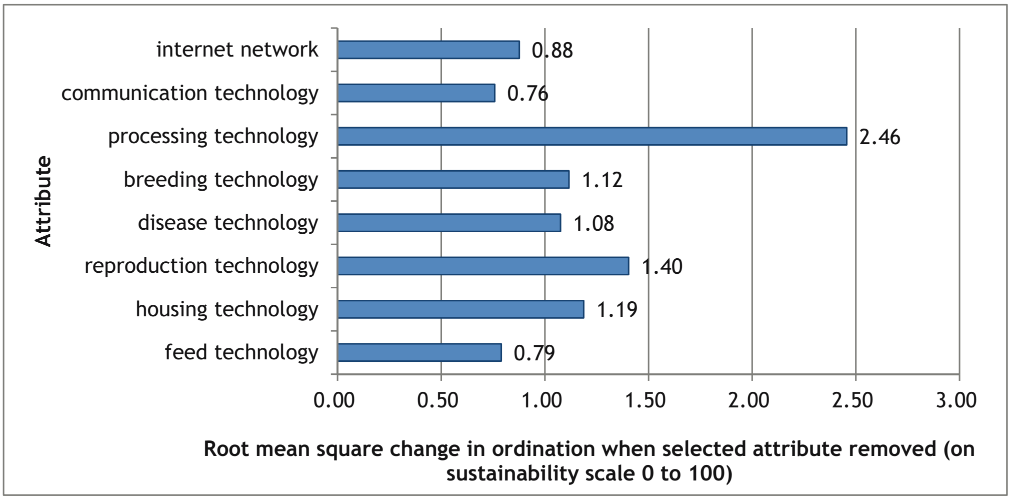

Figure 8: Leverage of technological attributes in the sustainability analysis of swamp buffalo farming in South Kalimantan.

drying it in the sun to dry. Buffalo skins are sold to collectors to be sent to the leather industry in Java.

Improvements in processing technology for swamp buffalo meat and related products can enhance their overall quality and competitiveness while generating added value. These improvements are necessary to overcome the subpar quality and competitiveness of other available meat products [79]. On the other hand, the development and diversification of swamp buffalo products are expected to increase consumption levels.

Another technological attribute that becomes a strong leverage factor for maintaining swamp buffalo farming in South Kalimantan is reproduction technology. The decrease in the population of swamp buffalo can be attributed to low female productivity [18]. The problems often found in female swamp buffalo are delayed puberty, late ovum maturity, prolonged post-partum oestrus, and low conception rates in artificial insemination (AI) systems. Improved nutrition in additive feeding, especially minerals needed to support reproduction, can improve the reproduction rate of swamp buffaloes [80,81]. AI is a reproductive technology to improve the quality of livestock products [68]. However, the implementation of AI in buffalo has not been widely adopted in Indonesia and is considered not optimal.

Poor livestock management results in inbreeding due to the continuous use of an extensive rearing pattern. The limited number of bulls causes inbreeding because farmers usually sell male swamp buffalo when they are 2–3 years old. The current condition at the study site is that there are not enough males so that a bull can mate with an adult female swamp buffalo and its offspring as well (inbreeding). Ciptadi et al. [82] in East Java province also reported a shortage of bulls in swamp buffalo farming.

Inbreeding causes low birth rates and possibly a decrease in the swamp buffalo population and genetic quality in South Kalimantan. Inbreeding is common in animal husbandry, which has a negative effect on livestock performance [83], i.e., it reduces the profitability of individual animals, decreases the productive age, decreases all the characteristics of the individual, and prolongs the calving interval [84]. Inbreeding reduces the quality of genotypes and phenotypes [85]. The decline in genetic quality due to inbreeding causes mortality at birth. Praharani and Sianturi [86] showed that high inbreeding pressure affects the susceptibility of livestock to disease, which causes a high mortality rate of embryos and neo-natal due to livestock recessive genes, causing low birth rates. Inbreeding reduces production, lengthens the reproductive process, and limits lifetime traits [87]. Another study [88] showed that increasing levels of inbreeding in Turkish buffalo led to inbreeding depression, which was indicated by low production and reproduction. In addition, the effect of inbreeding on birth weight was very significant ($P < 0.01$). Birth weight decreased by 0.121 kg for every 1% increase in the inbreeding coefficient.

Sianturi et al. [89] reported that buffaloes in rural areas have experienced inbreeding due to the scarcity of superior males, making it challenging to arrange mating for buffaloes in rural areas. The occurrence of inbreeding can be seen from the increased population of albino buffalo and buffalo with hanging horns. In line with this study, Windusari et al. [85] found that swamp buffalo in the Pampangan district, South Sumatra province had low genetic variation, and the closest kinship to the average heterozygosity (h) was 0.1286, which means the buffalo kinship is very close.

Initially, buffalo mating took place randomly/well by maintaining diversity in the population so that the level of inbreeding was minimal. However, in the end, when bulls have been used across generations with the number of 1–2 bulls per group, then the inbreeding within the family increases, which is marked by a decrease in diversity in the population and the level of inbreeding increases from generation to generation to form inbred buffalo groups. Inbred buffaloes have been seen in buffalo herds in Indonesia, with inbreeding rates of 10–30% [90].

Genetic improvement needs to be followed by the application of improved feed and reproduction in accordance with the level of genetic improvement that has been achieved. The spread of superior buffalo breeds will be able to reduce the degree of inbreeding and support the increased productivity and population of buffalo in Indonesia [90]. Outbreeding with AI and oestrous synchronisation can be done to reduce the rate of inbreeding and, therefore, improve swamp buffalo genetic quality [86]. Another way to address the limited availability of high-quality bulls for sperm donation is to use a combination of natural mating intensification systems (INKA) and AI technology. INKA is applied by entering superior males into a parent group with no close blood relations (kinship). The use of males as bulls must be limited within a certain period to prevent inbreeding. Superior males can also be rotated among existing farmer groups. Replacing the bulls can also be done by bringing high-quality swamp buffalo bulls from outside South Kalimantan province.

Although it is essential for genetic improvement and controlling the buffalo breeding period [91], AI has not been widely done by buffalo farmers [92]. AI application in buffalo is more challenging than in cattle due to varying oestrous cycles, reduced oestrous behaviour, and reproductive seasonality [91,93]. Moreover, the semi-extensive and extensive management of swamp buffalo complicates the application of AI in swamp buffalo breeding. Despite the difficulties, using AI in buffalo farming is worthwhile. In India, buffalo farming has experienced a notable boost in productivity by implementing AI-powered controlled breeding techniques [92].

3.4.5 Institutional dimension

Institutions play a crucial role in promoting sustainable development by fostering cooperation and avoiding conflicts of interest [94]. The two most sensitive institutional attributes are the role of local government and capital institutions. These two institutional attributes, therefore, significantly influence the sustainability of swamp buffalo farming in the three districts of South Kalimantan (Figure 9). Supporting sustainable agricultural development relies heavily on agricultural institutions as a crucial factor. Buffalo farming needs support from the central, regional, and other related institutions and agricultural institutions to achieve a sustainable business [95]. The role of local government is crucial so that farmers can manage their businesses optimally. In addition, farmers can develop their business capabilities and receive locally specific, appropriate technology. Support and guidance are needed so that farmer human resources can learn and try technology according to the potential of the surrounding environment [96].

The local government can start building and strengthening effective farming institutions by approaching village

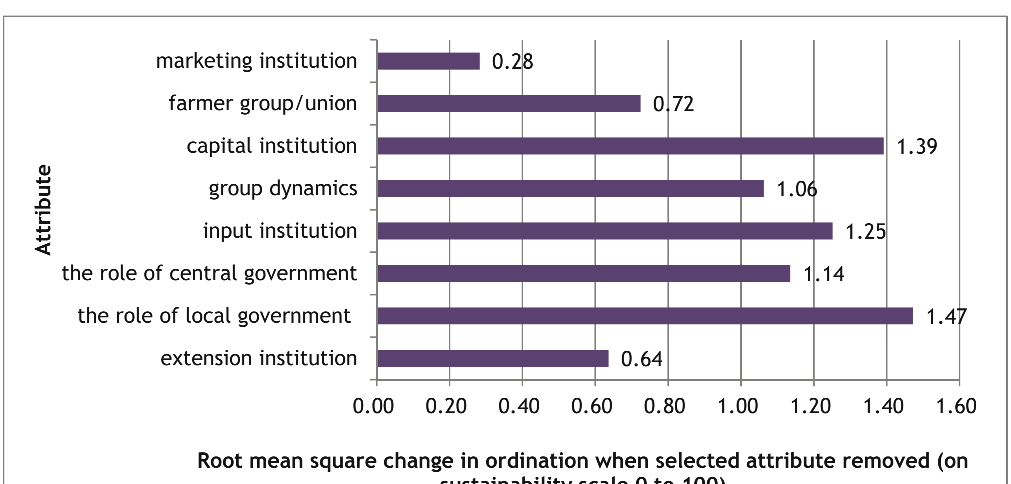

Figure 9: Leverage of institutional attributes in the sustainability analysis of swamp buffalo farming in South Kalimantan.

officials and encouraging the formation of village-based farmer groups [97]. Streamlining less efficient swamp buffalo farming management and improving the marketing system to enhance farm productivity is also essential. These actions will enable to achieve cross-institutional synergy.

Nainggolan et al. [98] suggested that the government facilitates technical and non-technical assistance to increase income, provide access to capital, and secure stable output prices for agricultural products. Since farmers often have difficulties funding their farming activities, it is crucial to facilitate farmers' access to agricultural loans. Improving access to agricultural loans and expanding lending institutions can significantly improve agricultural production by effectively meeting input requirements [99].

3.4.6 Welfare dimension

The two most sensitive welfare attributes are swamp buffalo programs from the central government and farmers' welfare (Figure 10). To advance farmers, government support for strengthening smallholder swamp buffalo farming is essential so that farmers can be independent and prosperous. The government has implemented several programs to increase the population and production of livestock, including buffaloes. These programs include the Beef Self-Sufficiency Program in 2005–2014, efforts to boost the birth rate through the Breeding and AI Program in 2015–2016, Special Efforts for Obligatory Breeding Cows and Buffaloes (Upsus Siwab) in 2017–2019, and the Country Mainstay Buffalo Livestock Program (Sikomandan), from 2020 until now. Until 2015, government programs in the development of cattle and buffalo focused on establishing policies related to self-sufficiency in meat production. However, since 2016, the government has focused on policies related to implementing management and farming techniques with a more pro-innovation approach (improving the genetic quality of livestock breeds, livestock productivity, forage production, disease prevention and control, and credit facilitation) [100,101].

Although the government program has not achieved maximum results, farmers are beginning to experience a positive impact. For example, the Sikomandan program implemented in Aceh province notably impacted farmers' welfare [102]. Implementing AI technology improved buffaloes' reproductive performance and increased profits, impacting farmers' income and interest. Farmers who implemented AI in the Siwab program benefited more (RCR of 1.80) compared to farmers who used natural mating (RCR of 1.27) [103].

Policy implementation that focuses on increasing farmers' capacity by considering farmers' needs and livestock technology is one of the factors supporting the success of livestock development [100,101]. Government programs should include intensive coaching and counselling, institutional development, improving breed quality through quality bulls, facilitating prevention and treatment for buffaloes, and providing appropriate technological support regularly. The significant potential enhancement of swamp buffalo can boost farmers' income, leading to increased welfare and prosperity [104].

The input–output market is very influential in increasing farmers' income and serves as a place to provide livestock production facilities and market the products produced. The synergistic cooperation between input and output markets is one of the factors needed for sustainable farming [105]. This attribute must be considered because the

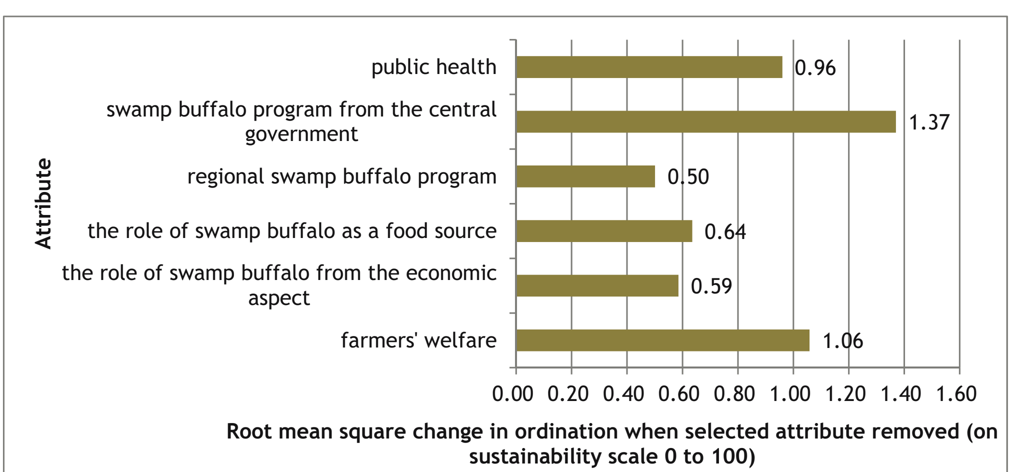

Figure 10: Leverage of welfare attributes in the sustainability analysis of swamp buffalo farming in South Kalimantan.

marketing system is one of the problems smallholder farmers face [106].

4 Conclusion

The research results of the sustainability analysis using MDS show that swamp buffalo farming in HSS and HSU is moderately sustainable, while that in HST is less sustainable. Of the six dimensions analysed, technological aspects appear to be less sustainable in all districts. This indicates that technological improvements in swamp buffalo farming and processing must be prioritised. Welfare is another crucial aspect that needs attention because it has a relatively low sustainability index.

Swamp buffalo farming in HST is only sustainable in the economic aspect, while the other five aspects are less sustainable. This case highlights the policy implication that if buffalo farming solely focuses on the financial aspect while neglecting the other five aspects, it will result in weakened swamp buffalo farming sustainability, as seen in the case of the HST district.

This study results in 12 leverage attributes that should be focused on to improve the sustainability of swamp buffalo farming. These 12 attributes can be grouped into 3. First are those under government control: land suitability, education level, product processing technology, reproduction technology, the role of local governments, capital institutions, and buffalo-related programs from the central governments. Second are those under farmers' control: marketing, farmers' income, mutual assistance (*gotong royong*), and farmers' welfare. Third are those that cannot be controlled, namely, climatic conditions.

Developing swamp buffalo farming requires crucial support from central and regional governments and careful consideration of various key technological and welfare factors to ensure optimal and sustainable production. With the growing demand for national animal protein sources, there is great potential for the future of swamp buffalo farming in Indonesia. The synergy between the government, through its role as regulator and facilitator, and the swamp buffalo farmers, with their social and financial capital, is needed to improve the sustainability of swamp buffalo farming.

5 Strengths and limitations of the study

The main strength of this study is the use of the powerful MDS method in analysing the sustainability of swamp buffalo farming, which is currently still understudied, with three different study locations and using six dimensions. Furthermore, this study also identifies the attributes that influence swamp buffalo sustainability and its policy implications. However, the results of this study cannot be generalised for buffalo farming in other regions of Indonesia because differences in buffalo breeds, regional potential, and rearing systems will result in different conditions and, hence, different policies. Therefore, further research is needed.

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Appendix

Dimensions and attributes used in analysing the sustainability of swamp buffalo farming in South Kalimantan, 2022

No.	Dimension	Attribute	Scoring	Good	Bad	Description
1.	Ecological	Feed availability	1, 2, 3, 4, 5	5	1	Feed (forage) availability for swamp buffaloes in sufficient quantity and variety
		The utilisation of livestock waste	1, 2, 3, 4, 5	5	1	The utilisation of buffalo waste for fertiliser and other purposes
		Land fertility	1, 2, 3, 4, 5	5	1	The level of soil fertility, considering the nutrients in the swamp buffalo habitat
		Climate change/condition	1, 2, 3, 4, 5	5	1	The impacts of climate change on swamp buffalo farming, especially temperature and rainfall
		Water availability	1, 2, 3, 4, 5	5	1	Water availability for swamp buffalo farming in terms of quantity and quality
		Land suitability	1, 2, 3, 4, 5	5	1	Land suitability level for swamp buffalo farming
		Distance to the grazing area	1, 2, 3, 4, 5	5	1	The distance from the stall barn (*kalang*) to the grazing area or the location of the feed source
		Land availability	1, 2, 3, 4, 5	5	1	Land availability for swamp buffalo farming
		Rearing system	1, 2, 3, 4, 5	5	1	Swamp buffalo rearing system carried out by the farmers
		Land carrying capacity	1, 2, 3, 4, 5	5	1	The level of land carrying capacity for the development of swamp buffalo farming
		Disease outbreak	1, 2, 3, 4, 5	5	1	Disease incidence rates in swamp buffalo farming
		Swamp buffalo health level	1, 2, 3, 4, 5	5	1	The general health level of the swamp buffaloes
2.	Economic	Swamp buffalo productivity	1, 2, 3, 4, 5	5	1	The production rate of swamp buffaloes (calving, growth)
		Capital	1, 2, 3, 4, 5	5	1	Availability and access to capital for swamp buffalo farming
		Swamp buffalo ownership status	1, 2, 3, 4, 5	5	1	Swamp buffalo ownership status (owned and sharing)
		Swamp buffalo business scale	1, 2, 3, 4, 5	5	1	The scale of the swamp buffalo farms
		Marketing	1, 2, 3, 4, 5	5	1	Access to market and market price
		Income from swamp buffalo farming	1, 2, 3, 4, 5	5	1	Income from swamp buffalo farming and its contribution to total household income
		Feasibility	1, 2, 3, 4, 5	5	1	The feasibility of swamp buffalo farming
		Labour availability	1, 2, 3, 4, 5	5	1	The number of labour available for swamp buffalo farming
		Profit	1, 2, 3, 4, 5	5	1	Profit generated from swamp buffalo farming
		Credit	1, 2, 3, 4, 5	5	1	Access to credit for swamp buffalo farming
3.	Social	Family labour	1, 2, 3, 4, 5	5	1	Household member participation rate in swamp buffalo farming
		Access to technology	1, 2, 3, 4, 5	5	1	The ability of farmers to access introduced technology for swamp buffalo, in terms of cost, time, and distance
		Household size	1, 2, 3, 4, 5	5	1	The number of swamp buffalo farmer household members
		Education	1, 2, 3, 4, 5	5	1	Farmer education level
		Mutual assistance	1, 2, 3, 4, 5	5	1	Mutual assistance (*gotong royong*) among the swamp buffalo farmers
		Community empowerment	1, 2, 3, 4, 5	5	1	The level of community empowerment in the independent management of farmers, the independence of the marketing system, and the independence of the institution
		Land conflict	1, 2, 3, 4, 5	5	1	The potential of land conflicts for swamp buffalo farming
		Farmers' behavior	1, 2, 3, 4, 5	5	1	The level of knowledge, attitudes, and skills of farmers in managing swamp buffalo farming

(Continued)

No.	Dimension	Attribute	Scoring	Good	Bad	Description
4.	Technological	Feed technology	1, 2, 3, 4, 5	5	1	Feed technology applied in swamp buffalo farming
		Housing technology	1, 2, 3, 4, 5	5	1	Housing technology applied in swamp buffalo farming
		Reproduction technology	1, 2, 3, 4, 5	5	1	Reproduction technology applied in swamp buffalo farming
		Disease technology	1, 2, 3, 4, 5	5	1	Disease prevention and treatment technologies applied in swamp buffalo farming
		Breeding technology	1, 2, 3, 4, 5	5	1	Breeding technology applied by farmers in developing their swamp buffaloes
		Processing technology	1, 2, 3, 4, 5	5	1	The processing technology of the main product (meat) and by-products (skin, horn, and bone) into various products after the buffalo has been slaughtered.
		Communication technology	1, 2, 3, 4, 5	5	1	The level of use of communication technology in swamp buffalo farming
5.	Institutional	Extension institution	1, 2, 3, 4, 5	5	1	The role of extension agents in the development of swamp buffalo farming, the ratio of extension agents to the number of farmers, and the frequency of farmer group meetings
		The role of local government	1, 2, 3, 4, 5	5	1	Support by the local government in the development of swamp buffalo farming, both technical and non-technical
		The role of the central government	1, 2, 3, 4, 5	5	1	Support by the central government in the development of swamp buffalo farming, both technical and non-technical
		Input institution	1, 2, 3, 4, 5	5	1	Provision of the necessary inputs to support swamp buffalo farming in the right amount and at the right time as well as the ease of access for farmers to inputs
		Group dynamics	1, 2, 3, 4, 5	5	1	Farmer group activities related to leadership patterns, trust and interaction between members, transparency, and cooperation in supporting swamp buffalo farming
		Capital institution	1, 2, 3, 4, 5	5	1	The availability and role of capital institutions that supports swamp buffalo farming
		Farmer group/union	1, 2, 3, 4, 5	5	1	The availability of farmer organisations that support the development of swamp buffalo farming
		Marketing institution	1, 2, 3, 4, 5	5	1	The availability of marketing institutions at the village and outside village level for swamp buffalo products
6.	Welfare	Farmers' welfare	1, 2, 3, 4, 5	5	1	Improvement in farmers' welfare due to swamp buffalo farming
		The role of swamp buffalo from the economic aspect	1, 2, 3, 4, 5	5	1	The role of swamp buffalo farming for the community from the economic aspect
		The role of swamp buffalo as a food source	1, 2, 3, 4, 5	5	1	The role of swamp buffalo as a food source for the community
		Regional swamp buffalo program	1, 2, 3, 4, 5	5	1	Program support related to the development of swamp buffalo from the local government
		Swamp buffalo program from the central government	1, 2, 3, 4, 5	5	1	Program support related to central swamp buffalo development
		Public health	1, 2, 3, 4, 5	5	1	The impacts of swamp buffalo farming on the health of residents