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Lapopu river, Sumba; photo by Krist Setyawan

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Introduction is about 600 words, covering the aims of the research and provide an adequate background, avoiding a detailed literature survey or a summary of the results. **Materials and Methods** should emphasize on the procedures and data analysis. **Results and Discussion** should be written as a series of connecting sentences, however, for a manuscript with long discussion should be divided into subtitles. Thorough discussion represents the causal effect mainly explains why and how the results of the research were taken place, and do not only re-express the mentioned results in the form of sentences. **Concluding** sentence should be given at the end of the discussion. **Acknowledgements** are expressed in a brief; all sources of institutional, private and corporate financial support for the work must be fully acknowledged, and any potential conflicts of interest are noted.

Figures and Tables of a maximum of three pages should be clearly presented. The title of a picture is written down below the picture, while the title of a table is written above the table. Colored figures can only be accepted if the information in the manuscript can lose without those images; the chart is preferred to use black and white images. The author could consign any picture or photo for the front cover, although it does not print in the manuscript. All images property of others should be mentioned the source. Author is suggested referring to Wikipedia for international boundaries and Google Earth for satellite imagery. If not specifically mentioned, it is assumed to refer to these sources. **There is no appendix**, all data or data analysis is incorporated into Results and Discussions. For broad data, it can be displayed on the website as a supplement.

References Preferably 80% of it comes from scientific journals published in the last 10 years. In the text, give the author names followed by the year of publication and arrange from oldest to newest and from A to Z; in citing an article written by two authors, both of them should be mentioned; however, for three and more authors only the first author is mentioned followed by et al. For example, Saharjo and Nurhayati (2006) or (Boonkerd 2003a, b, c; Sugiyarto 2004; El-Bana and Nijs 2005; Balagadde et al. 2008; Webb et al. 2008). Extent citation should be avoided, as shown with the word "cit." Reference to unpublished data and personal communication should not appear in the list but should be cited in the text only (e.g., Rifai MA 2007, pers. com. (personal communication); Setyawan AD 2007, unpublished data). In the reference list, the references should be listed in alphabetical order. Names of journals should be abbreviated. Always use the standard abbreviation of a journal's name according to the **ISSN List of Title Word Abbreviations** (www.issn.org/2-22661-LTWA-online.php). Please include DOI links for journal papers. The following examples are for guidance.

Journal:

Saharjo BH, Nurhayati AD. 2006. Domination and composition structure change at hemic peat natural regeneration following burning; a case study in Pelalawan, Riau Province. Biodiversitas 7: 154-158. DOI: 10.13057/biodiv/d070213.

The usage of "et al." in long author lists will also be accepted:

Smith J, Jones M Jr, Houghton L et al. 1999. Future of health insurance. N Engl J Med 965: 325-329. DOI: 10.10007/s002149800025.

Book:

Rai MK, Carpinella C. 2006. Naturally Occurring Bioactive Compounds. Elsevier, Amsterdam.

Chapter in the book:

Webb CO, Cannon CH, Davies SJ. 2008. Ecological organization, biogeography, and the phylogenetic structure of rainforest tree communities. In: Carson W, Schnitzer S (eds.). Tropical Forest Community Ecology. Wiley-Blackwell, New York.

Abstract:

Assaeed AM. 2007. Seed production and dispersal of *Rhazya stricta*. 50th annual symposium of the International Association for Vegetation Science, Swansea, UK, 23-27 July 2007.

Proceeding:

Alikodra HS. 2000. Biodiversity for development of local autonomous government. In: Setyawan AD, Sutarno (eds.). Toward Mount Lawu National Park; Proceeding of National Seminary and Workshop on Biodiversity Conservation to Protect and Save Germplasm in Java Island. Universitas Sebelas Maret, Surakarta, 17-20 July 2000. [Indonesian]

Thesis, Dissertation:

Sugiyarto. 2004. Soil Macro-invertebrates Diversity and Inter-Cropping Plants Productivity in Agroforestry System based on Sengon. [Dissertation]. Universitas Brawijaya, Malang. [Indonesian]

Information from the internet:

Balagadde FK, Song H, Ozaki J, Collins CH, Barnet M, Arnold FH, Quake SR, You L. 2008. A synthetic *Escherichia coli* predator-prey ecosystem. Mol Syst Biol 4: 187. DOI: 10.1038/msb.2008.24. www.molecularsystembiology.com.

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Biophysical land evaluation for Cavendish banana (*Musa* spp.) intensification in Pulivendula Tehsil, Kadapa District, Andhra Pradesh, India

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Manuscript received: 15 November 2023. Revision accepted: 5 February 2024.

Abstract. *Bhaskar BP, Kumar SCR, Ramanappa RV. 2024. Biophysical land evaluation for Cavendish banana (*Musa spp.*) intensification in Pulivendula Tehsil, Kadapa District, Andhra Pradesh, India. Intl J Trop Drylands 8: 1-13.* The study is being conducted in Pulivendula, a drought-stricken area in the Kadapa District, Andhra Pradesh, India, to protect the agroecosystems from unpredictable seasonal rainfall and soil degradation. The study includes agro-climatic data, geopedological information, and a delineation of drip irrigation zones for bananas. Rainfall data from the past 21 years shows that the region receives an average rainfall of 650 mm per year, with seasonal droughts from June to September. The productivity statistics for bananas in the region show a compound growth rate of 3.8% per year, but it is considered a marginal zone due to the mean annual rainfall of 672.15±111.55 mm. The soil map was generated with 43 soil mapping units from twenty-five soil series classified under the subgroups of Entisols (4.1% of total area), Inceptisols (35.5%), Alfisols (4.8%), and Vertisols (23.3%). Overall, the mildly to strongly alkaline soils are grouped into five depths and eight textural groups, having high to very high cation exchange capacity, low organic carbon, and mean clay of 39.64±14.25%. The study found that 35% of the area had a high risk of soil erosion due to poor soil quality. Twenty soil mapping units in the interhill basin are evaluated as suitable for bananas, whereas they are moderately suitable for soils in colluvio-alluvial plains. Thirty-five thousand hectares of land are suitable for banana production under drip irrigation with biophysical limitations of rooting depth, topography, coarse fragments, alkalinity, and organic matter.

Keywords: Agroecology, geoenvironment, land evaluation, Pulivendula, semi-arid ecosystem

Abbreviations: AAFRD: Alberta Agriculture, Food and Rural Development, AAR: Average annual rainfall, AAT: average annual temperature, AEA: Agro Ecosystem Analysis, CEC: cation exchange capacity, Ci: Capability index, CV: Coefficient of variation, DTPA: Diethylene triamine penta acetic acid, ESP: Exchangeable sodium per cent, FAO: Food and Agriculture Organization of United Nations, FYM: Farm yard manure, GIS: Geographic information system, I_{dm}: Aridity index (De Martonne), IRS: Indian Remote sensing Satellite, K: Potassium, KML: Key hole markup language, LISS: Linear imaging self scanning sensor, OC: Organic carbon, SMU: Soil mapping unit, t/ha: tonnes per hectare

INTRODUCTION

The increasing population demands environmentally friendly land use to support food security. However, soil degradation can hinder food supply, especially in small-scale agricultural systems (Nziguheba et al. 2022). To address this, improved soil resource management and assessment of soil agricultural potential are necessary (Amara et al. 2021). Factors such as soil quality and climate are crucial in determining land suitability for agricultural use. Most land capability and soil suitability assessments fail to consider soil geographical variation and essential characteristics, despite this information being essential for resolving site or location-specific land use concerns. A comprehensive investigation of soil distribution provides precise classifications of land capacity and soil suitability (De Feudis et al. 2021). As an outcome, gaining comprehensive site-specific information on land and soil resources may assist in identifying the limitations and potentials of these scarce resources for sustainable banana production at Makuleke Farm (Swafo and Dlamini 2023). The significance of land qualities in land evaluation is underscored by their close association with topography, soil, and climate, which are crucial for meeting the specific requirements of banana cultivation (Ritung et al. 2007). When evaluating land, it is essential to consider land characteristics, including drainage, texture, soil depth, nutrient retention (such as pH and cation exchange capacity), alkalinity, erosion hazard, and flood/inundation. These factors are pivotal in determining banana growth and productivity potential (Zuazo 2008). To ensure optimal conditions for banana cultivation, the effective soil depth should exceed 125 cm and a suitable banana climate should have a mean temperature of 26.67°C and an average annual rainfall of 120 to 150 cm. It is crucial to avoid any dry months that could hinder the successful cultivation of bananas. When comparing different methods, it is imperative to establish a quantitative correlation with physical parameters that yield similar outcomes (Mueller et al. 2009).

Furthermore, it is advisable to consider locally proven and tested approaches and their respective indicator sets and thresholds (Kumar et al. 2017). These methods offer valuable insights and guidance for evaluating land quality and making informed choices about banana cultivation. Geographic Information Systems (GIS) can help identify the most suitable spatial arrangement for banana cultivation, considering specific requirements and preferences. GIS is highly appropriate for this purpose, as it provides attribute values for each location and offers a range of arithmetic and logical operators to combine these attributes. According to Samanta et al. (2011) and Nuarsa et al. (2018), GIS is vital in facilitating the multi-criteria evaluation function of suitability assessment.

Pulivendula Tehsil in Kadapa District of Andhra Pradesh is highly vulnerable to agricultural drought due to its rocky topography, high number of marginal farmers, and semi-agricultural nature (Bhaskar et al. 2019). Understanding the geo-environmental and agroecosystem relationships in different areas is crucial for promoting uniform soil-crop zones and integrating geo-environmental assessment. Gathering accurate site-specific information about land and soil resources is vital for identifying the limitations and potentials of these finite resources. The objectives of this study were twofold: firstly, to survey, classify, and characterize soils at Pulivendula division to derive and map land capability classes, and secondly, to quantify the physical and chemical properties of the soils to derive and map soil suitability classes for bananas.

MATERIALS AND METHODS

Description of the study site

The Pulivendula Tehsil in the Kadapa District, Andhra Pradesh, India has a total area of 1462.35 km^2 (146,235 ha). There are six Mandals within this tehsil's boundaries: Pulivendula, Vemula, Vempalli, Tondur, Simhadripuram, and Lingala (Figure 1). The research site is in a semi-arid region with 43 wet days and 564 mm of average annual rainfall. The Length of Growing Periods (LGP) for Pulivendula and Vemula, Lingala and Tondur, and Simhadripuram and Vempalli Mandals are from 90 to 105 days, 105 to 120 days, and 120 to 135 days, individually. Peanut production is only marginally feasible in this region under a hot, dry eco-subregion of the Rayalseema plateau's deep loamy and clayey red and black soils (Mandal et al. 1999). The research region comprises rocks from the Papaghni and Chitravati groups of the Cuddapah Super Group. The rock types found in the Papaghni group include conglomerates, quartzite, and arkose. The Chitravathi Group comprises intrusive rocks, dolomites, chert, mudstone, quartzite, and basic flows. Basu et al. (2009) state that the Tadipatri formations are made of quartzite and dolomite/quartzite.

Procedures

Agroecosystem analysis. The Agro Ecosystem Analysis (AEA) process was divided into three stages: I. agroclimatic analysis (rainfall and temperature), II. geo-pedological data sets, and III. suitability of soil units for bananas under drip irrigation. The data aggregation for the agroecosystem research is described as given below.

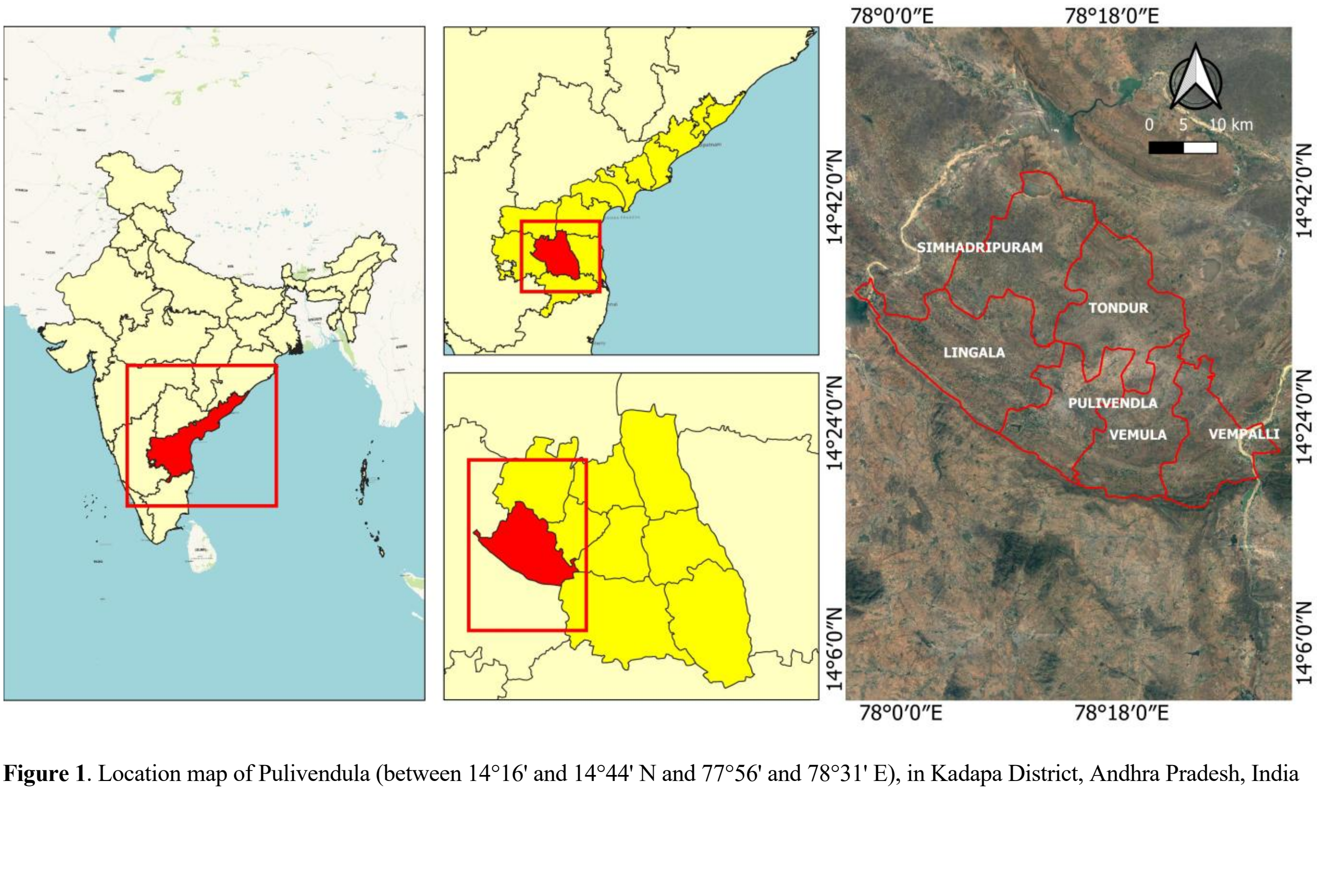

Figure 1. Location map of Pulivendula (between 14°16' and 14°44' N and 77°56' and 78°31' E), in Kadapa District, Andhra Pradesh, India

Agroclimatic analysis

The aridity index of De Martonne (1926) was calculated using data from the Indian Water Portal.org. from 1901 to 2002.

De Martonne's aridity index

The aridity index of De Martonne (Im) is defined as the ratio of the annual rainfall amount P in mm and the annual mean temperature in °C + 10.

I_{dm} = Aridity Index (De Martonne) = *AAR* /*AAT*+10

Where:
AAR: Annual Average Rainfall (mm)
AAT: Average Annual Temperature (°C)

The following equation determines the De Martonne Aridity Index's monthly value: I_{dm} = 12p'/t' + 10, where p' and t are the monthly mean values of precipitation and air temperature for the driest month (taken as January, February, March, April, and May for Kadapa District). Irrigating the land in this month is necessary when I_{dm} is less than 20 (Zambakas 1992). According to I_{dm} values, the climate is classified as follows: 0-10: Arid, 10-20: Semi-arid, 20-24: Mediterranean, 24-28: Semi-humid, 28-35: Humid, 35-55: Very humid, and >55: Extremely humid.

Geopedological data sets

The semi-detailed soil survey was completed following established standards. The base was created using topographical and geological maps of Pulivendula Tehsil in the Kadapa District at 1:50,000 and IRS-P6-LISS-IV at 1:25,000 scales. A geomorphological map was used to guide the selection of transects and random inspections (Soil Science Division Staff 2017; Shalaby et al. 2017). The soil data, including field and laboratory observations, represent the main soil series in the area (Dent and Young 1981; Grunwald 2009). A total of 330 profiles were studied in 66 transects, and each of them was examined (cut across as 3 to 4 landform units) in 128,609 ha of cultivated area, excluding the mining area of 17,626 ha in the region. The morphological characteristics of 25 soil series have been outlined by Schoeneberger et al. (2012). The samples were air-dried and set through a 2 mm sieve to estimate the fine earth component. The fine Earth fraction's physical (particle size distribution) and chemical characteristics were determined following established methods (Dewis and Freitas 1970).

Soil site suitability

The FAO framework for land evaluation and rainfed farming norms (FAO 1983) were used to evaluate the soil suitability at Pulivendula Tehsil, Kadapa District, Andhra Pradesh, India. The requirements indicated for banana suitability with degrees of limits were used and logically classified for highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and, currently (N1), based on soil site attributes as given in Table 1 (Djaenudin et al. 2003; Naidu et al. 2006; Mujiyo et al. 2021). Soils classified as S1 have no significant barriers to be used over time for a specific use. Soils in the S2 category have moderate to substantial constraints for long-term application of a particular use. In contrast, soils in the S3 category have serious constraints for sustained application of a specific use. The parametric technique was used to evaluate soil unit suitability for drip irrigation (Sys et al. 1991) by multiplying the soil series rating with its fraction of area (AAFRD 2004). The irrigation capacity index (Ci) for evaluating the capability of irrigation was determined using the following formulas:

Ci = A * B/100 C/100 D/100 E/100 F/100.

Where:
Ci: Irrigation capacity index
A: Soil texture rating
B: Soil depth rating
C: CaCO3 concentration rating
D: Salinity/alkalinity rating,
E: Drainage rating
F: Slope rating.

The five capability groups for Ci were categorized as follows: Excellent (CI >80 with symbol, S1), Suitable (S2-CI ranging from 80-60), Slightly suitable (S3-CI ranging from 45-60), Almost unsuitable (N1-CI ranging from 30-45), and Unsuitable (N2-CI less than 30).

Data analysis

GIS analysis

The maps of soil units (also known as soil series association) and soil suitability were generated with IRS-P6 plus 1:25000 scale topo base and Arc GIS 10.8.1 software. Therefore, to begin, the coordinates of the 23 soil series were used to mark the site of each profile pit. Each placemark was designated with the name of the soil series association in the land unit. After inserting and labeling all 43 soil mapping unit placemarks, the "add path" option was used. The mapping units were established utilizing the soil attributes derived from the profile pits. The "add polygon" tool made a polygon from land, forming placemarks. The polygon was then digitized to generate the shape of each soil form. The polygon was given a name based on the soil type and saved as a KML layer. Second, in Arc Map, a conversion tool called "From KML" (Keyhole markup language, file format used for displaying geographic data) was used to convert the KML layers of the polygons stored as a shape file. After generating all of the soil-landform shape files, a spatial distribution map was generated by "checking" all of the shape files on the same reference frame. The Pulivendula Tehsil base map was added using the "add data" function. Soil suitability maps have been renamed based on suitability class. They were subsequently mapped using the same process to map the soil forms.

Table 1. Soil site suitability rating for banana

Land–climate suitability	Suitable class banana (Mujiyo et al. 2021)			
	S1	S2	S3	N1
Climatic parameters				
Altitude(meters)	<1,200	1,200-1,500	1,500-2,000	>2,000
Rainfall(mm/year)	1,500-2,500	1,250-1,500	1,000-1,250	<1,000
Temperature (^{0}C)	22-33	34-36/24-25	37-38	>38
Soil physical characteristics				
Soil depth(cm)	>125	125-75	50-75	<50
Soil textural class	L, Cl, SCl, SiL	SiCL, SC, C (<45%)	C (>45%), Sl	LS, S
Period of dry month	0-3	3-4	4-6	>6
Topography				
Slope (%)	<8	8-16	16-40	>40
Drainage class	Good to well-drained	Moderately drained	Poorly drained	Very poorly drained
Soil chemical parameters				
Total N (%)	>0.4	0.1-0.4	0.05-0.1	<0.05
Olsen's P(mg/kg)	>20	15-20	8-15	<8
Exchangeable K (cmol/kg)	>0.8	0.4-0.8	0.1-0.4	<0.1
pH	6.0-7.5	5.5-6.0&7.5-8.0	5.0-5.5&8.0-8.5	<5.0 &>8.5
OC(g/kg)	24 to 15	15 to 8	<8	
Base saturation(%)	50-35	35 to 20	<20	
Depth to mottling (cm)	>110	85-110	60-85	<60
Ground water table (cm)	>150	125-150	100-125	<100
Bulk density (Mgm^3)	<1.31	1.31-1.47	>1.47	
Permeability (cm/h)	>7.9	7.9 - 5.00	<5.0	
Clay CEC	>12.4	8.9-12.4	<8.93	

Profile weighted mean

the depth-weighted approach was utilized To depict the overall pattern of soil properties for each soil profile. This involved integrating the measured value of each soil property for genetic horizons with respect to depth, as per the formulae proposed by Clark and Roush (1984). The formula is as follows:

$$\hat{w} = \frac{\sum_{i-1}^{n}(measured\ soil\ property\ XD)n}{\sum_{i-1}^{n} D}$$

Where:
ŵ: Weighted mean
'n': Number of horizons
'D': Thickness of each horizon,
∑: Total thickness of the soil profile

Soil erosion estimation

The soil erosion for each soil mapping unit was calculated using the USLE (Universal Soil Loss Equation) developed by Wischmeier and Smith (1978). The general USLE equation is as follows:

A = R x K x LS x C x P

Where:
A: Computed spatial average soil loss and temporal average soil loss per unit area (ton ha^{-1} yr^{-1})
R: Rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1})
K: Soil erodibility factor (Mg h MJ^{-1} mm^{-1})
LS: Slope length and steepness factor
C: Cover management factor
P: Conservation practice factor

Based on the calculated values, the mapping units were categorized into 8 classes: Very low: soil loss ≤0.5 t/ha/yr, Low: 0.5-1 t/ha/yr, Low-medium: 1-2 t/ha/yr, Medium: 2-5 t/ha/yr, High-medium: 5-10 t/ha/yr, High: 10-20 t/ha/yr, Very high: 20-50 t/ha/yr, Extremely high: > 50 t/ha/yr (Uddin et al. 2016).

Compound growth rate

To determine the compound growth rate for the area and productivity of bananas over the years, a calculation was performed using time as the independent variable and the area and productivity of bananas as the dependent variable. The exponential growth function used for this calculation is as follows:

$Y = a.b^x$

Where:
Y: Dependent variable for which the growth rate is estimated
a: Intercept or constant
b: Regression/trend coefficient
x: Period in years
b = (1+r) and r = is the compound growth rate.

RESULTS AND DISCUSSION

Climate and soils

Monthly rainfall and temperature (1901 to 2002)

The average annual precipitation was 672.17±111.55 mm, and the Coefficient of Variation (CV) was 16.59. Monthly precipitation data shows that September and October receives over 100 mm of precipitation with a CV of less than 55 percent. The percent coefficient of variation was greater than 100 for January, February, March, April, and December. The skewness coefficients are positive, indicating that light precipitation is regular while heavy precipitation is very common. A skewness coefficient close to zero for August, September, and October suggests that the data follow a normal distribution. The average air temperature is 26.23±0.38°C, and the CV is 1.43%. While the average monthly air temperature in April and May was above 30.0°C, the average air temperature in other months was 22.01±0.61°C in December and 28.40±0.70°C in June. The skewness coefficient of air temperature for May (-0.09), June and August (-0.02), December (-.024) and January (-0.4) was negative, showing that the data are normal. This result showed that rainfall is unpredictable and erratic, with large seasonal variations (Table 2).

Aridity analysis

The De Martonne Aridity Index (I'_{dm}) of less than 15 is given for monthly decadal data sets from January to August to designate climate as semi-arid, and I'_{dm} less than 20 indicates that the land in this month requires irrigation (Zambakas 1992). Similar observations have been recorded, warranting the identification of substitute remunerative crops in Alfisols (Kumari et al. 2016). This crop requires an annual rainfall of 1,200 mm to 2,690 mm (Carr 2009). However, the banana production area in the Kadapa basin falls in marginal zones, receiving mean annual rainfall of 672.17±111.55 mm. The percent coefficient of variation (CV) was 16.59 (Table 2), where bananas experience seasonal droughts (Aridity index less than 15 from June to August, Table 3), resulting in considerable yield losses (Bhaskar et al. 2023). The results from Pulivendula are in agreement with the findings of Van Asten et al. (2011), who reported that in areas with rainfall less than 1,100 mm per year, yield losses in banana can range from 20 to 65% and 8 to 10% loss of bunch weight for every 100 mm decline in rainfall. The mean monthly aridity (De Martonne Aridity Index) from 1901 to 2002 is shown as 18.43, signifying semi-arid conditions, with a mean annual rainfall of 679.59±237.52 mm, of which Kharif rainfall contributes 340.69 mm (50.28% of total rainfall) and a mean air temperature ranging from 30.70°C to 36.90°C.

Area and productivity of bananas concerning rainfall

Table 4 presents fourteen years of data on the banana area and productivity in the Kadapa District from 2007-2008 to 2020-2021. The banana area expanded steadily from 4,282 ha (2007-2008) to 42,533 ha (2020-2021), with a mean productivity of 51,508.8±11,420.6 kg ha^{-1} and moderate variation (CV of 22.17%). The average annual rainfall in the region is 733.9±259.7 mm/year, with moderate variability (CV of 35.38%). The Dwarf Cavendish banana, a semi-perennial crop with a long cycle (approximately 12 to 14 months), is grown in the Kadapa District from June to July. The area statistics under banana show a substantial increase from 4,282 ha (2007-2008) to 42,533 ha with a compound annual growth rate of 25.82%. The productivity statistics of bananas show a gradual increase from 35 t ha^{-1} (2007-2008) to 59.9 t/ha (2020-2021) with a 12.2% compound annual growth rate (Table 4). The area under banana relation to rainfall can be explained with a regression equation:

Area (ha) = 71.9749 + 0.1442 (Rainfall, mm) with a correlation coefficient of 0.39, indicating a weak direct relationship and p-value of 0.167 and F value of 2.16. For every increase of 1 mm rainfall, the increase in area is 0.1442 ha.

Productivity(t ha^{-1}) = 50.4893 + 0.001389 (rainfall, mm) with R^2 of 0.001 and F value of 0.0119, p= 0.91

The linear regression studies concerning rainfall and yield data have Inherent uncertainty to match yield data and need refinement in mapping cropland areas, specifically banana-growing regions in Kadapa. The annual rainfall is below 1,500 mm (Calberto et al. 2015), which is inadequate for a good harvest, and 6 to 7 dry months receiving below 60 mm rainfall (From December to June). The poor correlation between annual precipitation and banana production is positive but insignificant, which means that production increases with rainfall. This observation confirms with the findings of Sabiiti et al. (2016).

Table 2. Month-wise descriptive statistics for rainfall and air temperature (1901 to 2002)

Month	Rainfall (mm)			Air Temperature (°C)		
	Mean ±SD	CV (%)	Skewness coefficient	Mean ±SD	CV (%)	Skewness coefficient
January	0.72±1.0	139.0	1.42	22.57±0.67	2.98	-0.04
February	3.06±6.09	198.5	1.48	24.69±0.76	3.11	0.07
March	6.67±10.28	154.1	1.56	27.70±0.77	2.78	0.22
April	21.97±23.71	107.9	0.99	30.24±0.62	2.07	0.35
May	58.1±44.31	76.3	0.85	30.63±0.81	2.66	-0.09
June	50.1±28.27	56.3	0.48	28.40±0.70	2.46	-0.02
July	70.9±32.73	46.1	0.57	26.99±0.54	2.00	0.14
August	92.2±50.08	54.2	0.053	26.55±0.46	1.76	-0.002
September	154.4±69.82	45.2	0.20	26.30±0.57	2.17	0.30
October	123.9±66.35	53.5	0.31	25.38±0.46	1.84	0.08
November	72.37±53.76	74.2	0.68	23.33±0.66	2.82	0.06
December	17.25±18.97	109.9	1.19	22.01±0.61	2.79	-0.24
Total	672.2±58.66	16.59		26.23±0.38	1.43	

Table 3. Monthly decadal data on the aridity index

Climatic variables	January	February	March	April	May	June	July	August	September	October	November	December
De Martonne Aridity Index												
1901-1910	10.06±0.04	10.07±0.18	10.13±0.25	10.52±0.71	11.22±1.11	11.29±0.58	12.03±0.93	13.37±1.99	15.79±2.75	13.49±1.68	12.34±2.66	10.75±0.79
1911-1920	10.03±0.03	10.05±0.09	10.25±0.46	10.29±0.43	11.54±0.66	11.09±0.51	12.13±1.39	12.56±1.42	15.52±1.62	13.88±2.47	13.45±2.09	10.46±0.54
1921-1930	10.04±0.02	10.11±0.18	10.19±0.27	10.75±0.75	11.58±2.01	11.35±0.53	12.08±1.07	12.10±0.99	15.05±2.25	14.03±2.26	12.97±2.28	10.54±0.86
1931-1940	10.02±0.03	10.18±0.30	10.17±0.18	10.81±0.85	11.20±0.85	11.47±0.67	11.98±0.63	12.66±2.09	14.57±2.47	13.66±1.57	12.75±1.61	10.44±0.61
1941-1950	10.02±0.03	10.09±0.13	10.15±0.34	10.48±0.37	11.65±1.25	11.41±0.63	12.15±1.17	13.13±1.14	15.46±1.62	13.40±2.10	12.62±1.95	10.68±0.87
1951-1960	10.01±0.02	10.03±0.07	10.17±0.22	10.82±0.75	12.06±1.61	11.55±1.14	12.60±1.06	12.71±1.70	14.68±3.55	14.47±2.60	11.78±1.92	10.67±0.89
1961-1970	10.03±0.05	10.06±0.10	10.16±0.29	10.72±0.90	11.58±1.17	11.67±0.62	12.52±0.97	13.52±1.81	15.29±2.43	13.98±2.30	12.06±1.87	10.91±0.66
1971-1980	10.02±0.03	10.12±0.19	10.09±0.16	10.57±0.85	11.94±1.49	11.40±0.48	12.27±1.00	12.85±1.51	14.44±2.35	15.08±3.00	12.91±1.60	10.51±0.67
1981-1990	10.02±0.05	10.14±0.26	10.37±0.29	10.56±0.45	11.40±1.34	11.39±0.60	12.54±1.21	12.76±1.87	16.02±2.75	13.82±1.30	12.03±0.83	10.67±0.42
1991-2002	10.02±0.04	10.07±0.13	10.11±0.16	10.64±0.47	11.67±0.69	11.90±0.92	12.05±0.68	13.84±1.32	13.96±1.32	15.46±1.41	12.07±1.24	10.60±0.71

Table 4. Area, the productivity of bananas concerning rainfall

Year	Area (ha)	Productivity (kg ha^{-1})	Rainfall (mm)
2007-2008	4,282	35,000.00	910.80
2008-2009	5,329	34,343.22	648.70
2009-2010	14,752	35,000.00	591.60
2010-2011	13,129	35,000.76	899.70
2011-2012	16,504	52,200.01	664.30
2012-2013	15,914	54,900.03	548.20
2013-2014	15,665	56,700.03	689.20
2014-2015	15,888	60,000.00	432.60
2015-2016	12,800	65,000.00	1,012.80
2016-2017	16,371	53,000.00	590.70
2017-2018	26,212	59,980.12	854.20
2018-2019	23,685	60,000.00	376.70
2019-2020	25,887	60,000.00	678.20
2020-2021	42,533	59,999.72	1,378.10
Mean±SD	17,782.2±9,577.1	51,508.8±11,420.6	733.9±259.7
CV(%)	53.85	22.17	35.38

Table 5. Physical and chemical characteristics of soil series in Pulivendula Tehsil, Kadapa District, Andhra Pradesh, India

Soil series	Particle size distribution (%)			pH	EC (dS m^{-1})	Organic carbon	$CaCO_3$	CEC cmol kg^{-1}	PBS	ESP
	Sand	silt	clay			g kg^{-1}				
1. Kanampalli (Kpl)	72.1	4.3	23.6	8.3	0.14	16.3	10	12.9	71	0.16
2. Ganganapalle (Ggp)	32.1	20.5	47.4	7.1	0.23	17.7	30	30.5	100	0.39
3. Lingala (Lgl)	44.4	23.8	31.8	8.1	0.22	11.9	20	26.6	100	0.15
4. Rachanakuntapalle (Rkp)	57.3	18.3	24.4	7.2	0.16	8.4	-	25.7	46	0.16
5. Mupendranapalle (Mpl)	29.5	29.0	41.5	8.4	0.38	10.7	40	29.1	100	0.76
6. Tallapalle (TlP)	40.9	19.6	39.5	7.9	0.19	9.7	70	28.3	100	1.13
7. Santhakovur (Skv)	48.8	18.7	32.5	7.9	0.29	9.2	150	21.7	100	2.76
8. Tatireddipalle (Trp)	14.9	27.8	57.3	7.7	0.22	11.2	40	54.5	100	0.26
9. Cherlapalle (Cpl)	32.5	21.2	46.3	8.1	0.34	6.2	110	33.2	100	23.64
10. Kottalu (Ktl)	74.9	10.3	14.8	7.9	0.16	3.6	20	7.6	100	1.97
11. Murarichintala (Mct)	71.1	14.2	14.7	8.0	0.25	4.7	10	7.2	100	0.14
12. Vemula (Vml)	32.8	24.9	42.3	8.0	0.20	7.0	160	30.1	100	1.79
13. Sunkesula (Skl)	50.1	15.4	34.5	8.0	0.30	11.1	40	28.0	100	1.61
14. Simhadripuram (Spm)	23.2	21.5	55.3	8.0	0.25	8.4	140	42.7	100	6.46
15. Velpula (Vpl)	60.7	13.5	25.8	7.9	0.14	3.3	50	13.0	100	2.31
16. Agraharam (Ahm)	23.6	18.2	58.2	8.3	0.21	9.3	110	44.2	100	2.22
17. Balapanur (Bpr)	23.0	24.0	53.0	8.0	0.41	5.7	100	37.4	100	11.04
18. Parnapalle (Prp)	78.4	8.9	12.7	7.8	0.31	5.0	20	10.3	100	4.95
19. Gondipalle (Gpl)	29.5	19.4	51.1	7.9	0.21	14.7	150	35.8	100	0.87
20. Goturu (Gtr)	42.0	13.9	40.0	8.2	0.47	8.4	90	36.9	100	15.77
21. Pulivendula (Pvd)	38.6	1.2	60.2	8.5	1.47	2.6	110	24.2	100	67.89
22. Pernapadu (Ppd)	33.4	19.3	47.3	8.0	0.19	6.3	130	45.0	100	0.33
23. Agadur (Agd)	32.6	19.8	47.6	7.8	0.19	5.4	100	42.6	100	0.45
24. Tondur (Tdr)	29.8	22.3	47.9	8.1	0.25	5.8	100	41.9	100	4.6
25. Bhadrampalle (Bpl)	45.0	5.9	49.1	7.9	0.33	4.1	100	27.3	100	8.78

Textural characteristics of soil series

Table 5 shows each soil series's profile weighted mean of sand, silt, and clay. Among the 25 soil series analyzed, the sand content shows significant variation. In Paranapalle (P18), the weighted mean for sand content is 78.4%, while it ranges from 74.9% in Kottalu (P10) to 72.1% in Kanampall (P1) and 71.1% in Murrarichintala (P11). The lowest recorded weighted mean for sand content is 14.9% in Tatireddipalle (P8), but it varies from 23% in P1 to 60.7% in P15. For the silt content, the profile weighted mean is 1.2% in P1, but it varies from 27.8% in P8 to 5.9% in P25. As for clay, soils with a weighted mean of more than 60% in P21 are classified as very fine at the family level, while soils with clay content ranging from 30% to 60% are considered fine. In specific soil series, P18 (12.7%), P10 (14.8%), and P11 (14.7%) are classified as coarse loamy due to their weighted mean clay content. On the other hand, Rachanakuntapalle (P4) and Velpula (P15) have loamy soils with a weighted mean clay content of 24.4% and 25.8%, respectively. The Kanampalli (P1) and Ganganapalli (P5) have lithic contact within 50cm but differ in particle size class, with P1 being loamy skeletal (clay of 23.6%) and Ganganapalli (P2) being clayey (clay of 47.4%). The weighted mean clay percentage of the Rachanakuntapalle series (P4) is 24.4%, whereas Mupendranapalle (P5) and Tallapalle (P6) are 41.5% and 39.5%, respectively. Particle size is considered fine for 13 soil series (P6, P8, P9, P12, P14, P16, P17, P19, P20, P22, P23, P24 and P25) where clay content exceeds 35% in the control section (25 to 100cm, (Soil Survey Staff 2014). The weighted mean for clay is 12.7% for P18 and 14.8% for P10/P11 when the sand content exceeds 70%.

Chemical characteristics of soil series

The mean pH value of the soils in Pulivendula (P21) is 7.68±0.68 with a coefficient of variation of 7.99% in soils on quartzite (P1 to P5) and 8.01±0.2 with a coefficient of variation of 2.47 % in other soils over shale. These soils are mild to moderately alkaline with a pH of up to 8.0, which aids in nitrogen fixation (Varaprasad et al. 2000). These soils had exceptionally low organic carbon (2.6 g kg^{-1}) in Pulivendula soil (P21) but more than 10 g kg^{-1} in P8, P13, and P19 in shale soils with a mean of 7.26±3.13 g kg^{-1} (Table 5). The mean organic carbon in soils over quartzite is 13.58±4.24 g kg^{-1} to be classified as medium to high status (Hazelton and Murphy 2007), which promotes good structural condition and stability. Only 28% of soils have more than 10 g kg^{-1} organic carbon and may be used for sustainable banana production. The remaining soils have low to extremely low organic carbon status, limiting the capacity to improve banana yields and necessitating organic carbon build-up. The Cation Exchange Capacity (CEC) of Pulivendula Tehsil soils varies from 7.2 cmol (+) kg^{-1} in P11 to 54.5 cmol (+) kg^{-1} in P8. Soils on quartzite have a mean CEC of 23.93±7.64 cmol (+) kg^{-1}, whereas soils on shales have a mean CEC of 30.52±13.12 cmol (+) kg^{-1}. It was shown that 72% of soils have high (24%) to very high (48%) CEC, while the remaining 28% had low (12%) to moderate (16%) CEC. Notably, low CEC might be attributable to soils' high sand and low organic matter content. The calcium carbonate ($CaCO_3$) level varies from 10g/kg in P1 to 160 g kg^{-1} in P12 for classification as Calcic Haplustalfs. Soils on shale contain higher $CaCO_3$ with a mean of 87.62 46.57g/kg than soils on quartzite with a mean of 20±10 g kg^{-1}. During soil studies in the region, it was observed that greater $CaCO_3$ levels in the interhill basin and colluvial alluvial complex soils are caused by limited drainage, as evidenced by the emergence of calcic layers in P12. This conclusion is consistent with the findings of Bhaskar et al. (2015) in the Seoni area of Madhya Pradesh. Except for P9, P20, and P21, these soils have a percent base saturation of more than 100 and an ESP (exchangeable sodium percent) of less than 15%. The mean ESP of shale soils is 7.61±15.03 (Sd), although less than one in other soil series.

Soil map

Twenty-five soil series were identified, and a soil map with 43 mapping units was developed (Figure 2). Soils on quartzitic hills and ridges include eight mapping units, typically interconnected with rock outcrops, are extremely shallow, somewhat excessively drained, moderately alkaline, sandy loam to clay loam textured, and cover 54,812 hectare (37.48% of total area). Shale landforms cover 73,797 ha (50.46% of total area). The interhill basin soil mapping units consist of seven mapping units with six soil consociations and one soil association (4.79% of the total area). These soils are shallow and well-drained, with highly alkaline gravelly clay subsoil layers of loam to gravely clay. The gently sloping lands cover 39,092 hectares (30.4% of the total area) and have been separated into 12 soil mapping units.

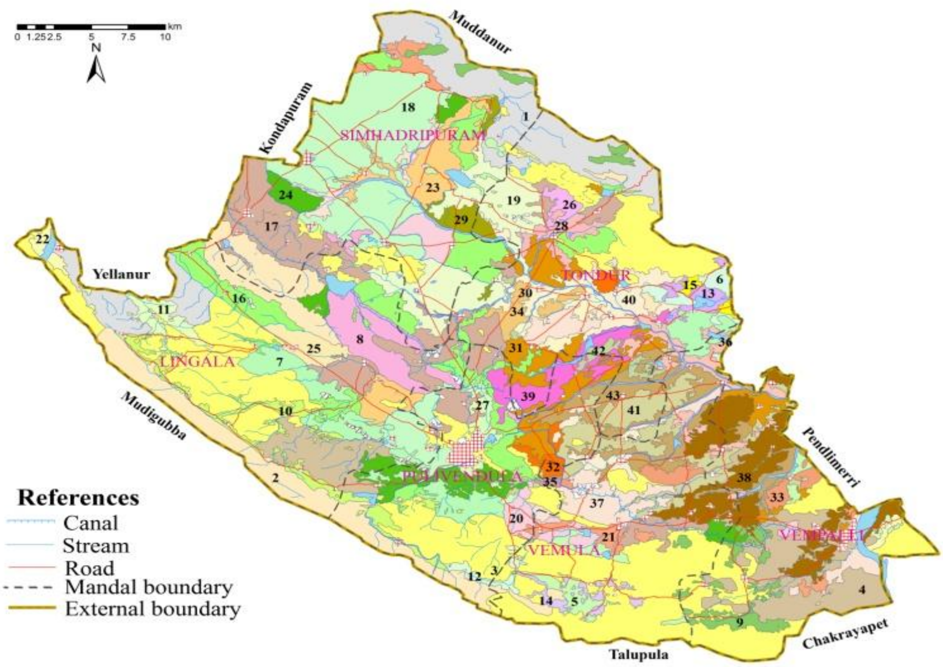

Figure 2. Soil map of Pulivendula Tehsil, Kadapa District, Andhra Pradesh, India

Vemula soils (20-1,667 ha, 1.2%) are shallow, well-drained calcareous red soils with strongly alkaline clay surface soils and argillic horizon. The 11 SMUs are linked with very deep, moderately well-drained calcareous, strongly to moderately alkaline black soils with shrink-swell potential. Colluvic and alluvial plains soils cover 28,542 ha (22.19% of total land area) with Tondur-Pernapadu series (30), Pernapadu-Gondipalle association (33), Goturu-Gondipalle association (36), and Agadur-Pernapadu association (41). Furthermore, 25 soil series were classified in four orders viz., Alfisols (6 367 ha, 4.8%), Entisols (5 477 ha, 4.1%) Inceptisols (47,342 ha, 35.5%) and Vertisols (31,118 ha, 23.3%), five suborders (Ustalfs, Orthents, Aquepts, Ustepts, and Usterts), seven Great groups (Paleustalfs, Rhodustalfs, Haplustalfs, Ustorthents, Halaquepts, Haplustepts and Haplusterts. Six soil series, Murarichintala, Kottalu, Vemula, Rachakuntapalle, Lingala, and Velupula, are classed as Alfisols because they have distinct wet and dry seasons (ustic moisture regime), and the clay ratio in B layers is 1.2 times higher than in eluvial A horizons. The particle size of these soils differs from fine loamy (P10, P11), clayey skeletal (Vemula, P12, Lingala, P3), loamy skeletal (P4), and fine (Velupula, P15). These series are classed at the great group level as Paleustalfs, Rhodustalfs, and Haplustalfs, with lithic contact within 50 cm (P3/P4), calcic (P12), and Typic in others. The seven series of Vertisols in colluvio-alluvial sectors have high sodium-loaded slickensided horizons and are classified as Sodic Haplusterts. At the broadest level, nine soil series are categorized as Haplustepts. However, they are subdivided into three subgroups: Lithic, Typic, and Vertic. In addition, three soil series on hills/ridges are grouped into two subgroups: Lithic/Typic Ustorthents.

Suitability for banana under drip irrigation

Sys et al. (1993) parameters were used to assess the suitability of 43 soil mapping units for bananas. As shown in Table 6, SMU 1 to 8 in hills and ridges (54,812 ha, 37.48% of total area) are unsuitable for banana growing due to their proximity to rock outcrops. This unit comprises shallow, gravelly soils (Kanampalle, Ganganapalle, Rachanakuntapalle, Mupendranapalle, and Lingala series) with low water holding capacity, low organic carbon, root limiting layers below 50 cm, and low readily available K/Zn. These units are potentially unsuitable but respond well to input use and conservation strategies to upgrade to S3. The interhill basin has 20 SMUs and encompasses 45,255 hectares (30.94% of the total area). The soil depth of over 100 cm is excellent for banana production, although feeder roots are limited to 45 cm (Shanmugavelu et al. 1992). In addition, 15 soil mapping units (SMU 29 to 43) in colluvio-alluvial plains (28,542 ha, 19.52%) contain very deep, fairly well-drained, calcareous, strongly to moderately alkaline black soils with significant shrink-swell potentials. Only five SMUs (32, 38, 40, 41, and 43) are moderately suitable for bananas due to the coarse texture, coarse fragments, calcium carbonate, exchangeable Na/K, and drainage constraints (Table 6). The data indicates that an estimated 56,091 hectares, comprising 38.353 percent of the land, are considered suitable for growing bananas. These suitable areas are geographically dispersed along the canal network, extending from the northwest to the southeast.

The optimal soil conditions for bananas is 30 to 50% clay, pH of 5.5 to 7, 0.5% organic carbon, 50 cm, and a slope of 0-3% (FAO 2018). The land evaluations for bananas using 43 soil mapping units were made and delineated 8 soil mapping units (12, 21, 23, 24, 25, 26) covering 8,337 ha (5.70% of total area) in interhill basins with medium soil erosion risk and needs organic carbon management for enhancing productivity (50 t/ha of FYM). The seven marginally suitable SMUs (22,688 ha,15.51% of area), viz., 11, 13, 14, 17, 19, 20 and 27) have soil constraints of high calcium carbonate, low organic carbon, strong alkalinity, coarse fragments, and low available K and DTPA-Zn. The strongly alkaline shrink-swell soils in colluvial-alluvial sectors are evaluated as marginally suitable for bananas (Figure 3).

These soils have more than 45% clay with high soil water holding capacity, and experiencing seasonal drought in the region led to poor crop growth and subsequent yield loss. Shrink-swell soils and off clay-rich Alfisols subsoils acquire significant structures in the B horizon (Pedocutanic B). Root development and water transport are frequently hampered by the hard, compact, and thick B horizons (Fey 2010). Banana growth on these soils will be limited to a tiny volume of soil that cannot supply appropriate anchoring, water, and nutrients (Fullen and Catt 2014). The bananas on shallow Lithocutanic and Pedocutanic B horizons have root-limiting soil depth, causing waterlogging during periods of heavy rain, and are susceptible to falling below the permanent wilting percentage during drought events (Jackson 2008). Waterlogging promotes Panama disease in bananas by increasing the solubility and bioavailability of redox-sensitive micronutrients, including iron and manganese, and inhibiting nitrification (Orr and Nelson 2018). Under reduced conditions, the banana plants will exhibit reduced water intake and stomatal conductance, delayed development, withering, and lower yields (Maestre-Velero and Martínez-Alvarez 2010).

The suitability of 43 soil mapping units for bananas is evaluated using the criteria of Sys et al. (1993). The SMUs from 1 to 8 in hills and ridges (54,812 ha, 37.48% of total area) are unsuitable for banana cultivation but respond well to inputs and conservation measures. Furthermore, the interhill basin comprises twenty soil mapping units, which collectively span an area of 45,255 hectares, accounting for 30.94% of the total area. Out of these twenty units, only eight (namely, 12, 18, 21, 23, 24, 25, 26, and 28) are moderately suitable, requiring careful organic carbon management. These eight units cover 12.42% of the interhill basin, equivalent to 18,174 hectares. Conversely, seven soil mapping units (covering 22,688 hectares, or 15.51% of the area) are marginally suitable. These units, namely 11, 13, 14, 17, 19, 20, and 27, face limitations such as calcium carbonate enrichment, low organic carbon content, strong alkalinity, coarse fragments, and low availability of potassium and DTPA-Zinc. Fifteen soil mapping units (SMU 29 to 43) on colluvial-alluvial plains (28,542 ha, 22.19%) have very deep, moderately well-drained, calcareous, and strongly to moderately alkaline black soils with high shrink-swell potentials. Only 5 SMUs (32, 38, 40, 41, and 43) are marginally suitable for bananas (Table 6). The results from land evaluation for drip irrigation show that 13 units were evaluated as marginally suitable for bananas. In addition, 9 SMUs are highly suitable (34,502 ha) since 8 SMUs (13,882 ha) are moderately suitable (Figure 4).

Table 6. An assessment of soil mapping units for suitability of bananas using drip irrigation and their erosion status

Land Form	Soil Mapping Unit	Area		Banana		Drip		Soil Loss (t/ha/year)
		ha	Percent (%)	Rating	Suitability Class	Rating	Suitability Class	Soil Erosion Risk
Hills and ridges	1. Rockoutcrops®-Kanampalli (Kpl)	7,953	6.18	3.34	N2	17.96	N2	25.11/high
	2. Rockoutcrops®-Ganganapalle (Ggp)	7,464	5.80	9.65	N2	21.60	N2	57.94/high
	3. Rockoutcrops®-Rachanakuntapalle(Rkp)	24,939	19.4	3.72	N2	24.30	N2	9.91/high-medium
	4. Rockoutcrops®-Lingala (Lgl)	6,410	4.98	4.26	N2	25.52	N2	102.8/extremely high
	5. Rachanakuntapalle (Rkp)-rockoutcrops®	1,333	1.04	4.12	N2	53.20	N2	8.93/high-medium
	6. Ganganapalle (Ggp)-Rockoutcrops®	677	0.53	16.40	N2	33.25	N2	57.94/extremely high
	7. Rockoutcrops®-Mupendranpalle (Mpl)	3,572	2.78	15.60	N2	29.93	N2	8.6/high-medium
	8. Mupendranpalle (Mpl)-Rockoutcrops®	2,464	1.92	11.32	N2	76.95	S1	8.56/high medium
Interhill basin	9. Tallalapalle (Tlp)	1,829	1.42	14.21	N2	90.25	S1	8.97/high- medium
	10. Murarichintla (Mct)	1,934	1.50	15.83	N2	85.50	S1	8.90/high -medium
	11. Tatireddipalle (Trp)	788	0.61	49.42	S3	95.00	S2	1.33/low-medium
	12. Kottalu (Ktl)	372	0.29	69.04	S2	68.40	S1	3.46/medium
	13. Santhakovur (Skv)	548	0.43	41.42	S3	72.20	S1	11.84/high
	14. Murarichintala (Mct)-Tallapalle (TlP)	508	0.39	43.73	S3	95.00	S3	8.92/high -medium
	15. Cherlapalle (Cpl)	184	0.14	19.81	N1	85.50	S1	5.27/high- medium
	16. Balapanur (Bpr)	6,559	5.10	41.18	S3	95.00	S1	24.23/very high
	17. Simhadripuram (Spm)	7,583	5.90	43.73	S3	90.25	S1	1.82/low -medium
	18. Simhadripuram (Spm)-Agraharam (Ahm)	9,125	7.10	61.29	S3	67.50	S1	2.68/medium
	19. Balapanur (Bpr)-Sunkesula (Skl)	4,294	3.34	52.89	S3	56.53	S1	3.65/medium
	20. Vemula (Vml)	1,667	1.30	40.00	S3	85.50	S2	7.65/high-medium
	21. Velpula (Vpl)	1,326	1.03	68.64	S2	85.74	S1	4.12/medium
	22. Parnapalle (Prp)	446	0.35	30.78	N1	90.25	S2	1.36/low-medium
	23. Agraharam (Ahm)	2,690	2.09	76.71	S2	90.25	S1	3.59/medium
	24. Sunkesula (Skl)	2,778	2.16	64.60	S2	90.25	S2	2.97/medium
	25. Agraharam (Ahm)-Sunkesula (Skl)	802	0.62	71.87	S2	80.75	S2	3.61/medium
	26. Agraharam (Ahm)-Simhadripuram(Spm)	369	0.29	66.82	S2	17.96	s1	2.78/medium
	27. Sunkesula(Skl)-Simhadripuram (Spm)	741	0.58	58.34	S3	21.60	S2	2.65/medium
	28. Velpula (Vpl)-. Vemula (Vml)	712	0.55	61.16	S2	24.30	S2	5.36/high-medium
Colluvial-alluvial pediplains	29. Bhadrampalle (Bpl)-Agadur (Agd)	788	0.61	29.84	N1	25.52	S2	19.34/high
	30. Tondut (Tdr)-Pernapadu (Ppd)	1,351	1.05	31.12	N1	53.20	S1	85.36/extremely high
	31. Tondur (Tdr)	3,568	2.77	29.07	N1	33.25	S1	102.80/extremely high
	32. Agadur (Agd)	633	0.49	48.45	S3	29.93	S1	1.86/low-medium
	33. Pernapadu (Ppd)-Gondipalle (Gpl)	853	0.66	29.17	N1	76.95	S2	5.68/high-medium
	34. Tondur (Tdr) – Agadur (Agd)	709	0.55	34.88	N1	90.25	S1	90.56/extremely high
	35. Pulivendula (Pvd)-Pernapadu (Ppd)	101	0.08	23.27	N2	85.50	S1	15.32/high
	36. Goturu (Gtr)-Gondipalle (Gpl)	1,501	1.17	33.80	N1	95.00	S1	2.75/low-medium
	37. Pernapadu (Ppd)	3,689	2.87	34.20	N1	68.40	S1	17.31/high
	38. Pernapadu (Ppd)-Tondur (Tdr)	4,358	3.39	32.15	N1	72.20	S1	85.36/extremely high
	39. Gondipalle (Gpl)	1,683	1.31	22.72	N1	95.00	S3	3.10/medium
	40. Goturu (Gtr)	1,707	1.33	41.18	S3	85.50	S1	1.33/low-medium
	41. Agadur (Agd) – Pernapadu (Ppd)	3,613	2.81	42.75	S3	95.00	S1	15.36/high
	42. Bhadrampalle (Bpl)	448	0.35	17.44	N2	90.25	S1	24.23/very high
	43. Pulivendula (Pvd)	3,540	2.75	15.99	N2	67.50	S1	17.31/high
	Total	128,609	100			56.53		

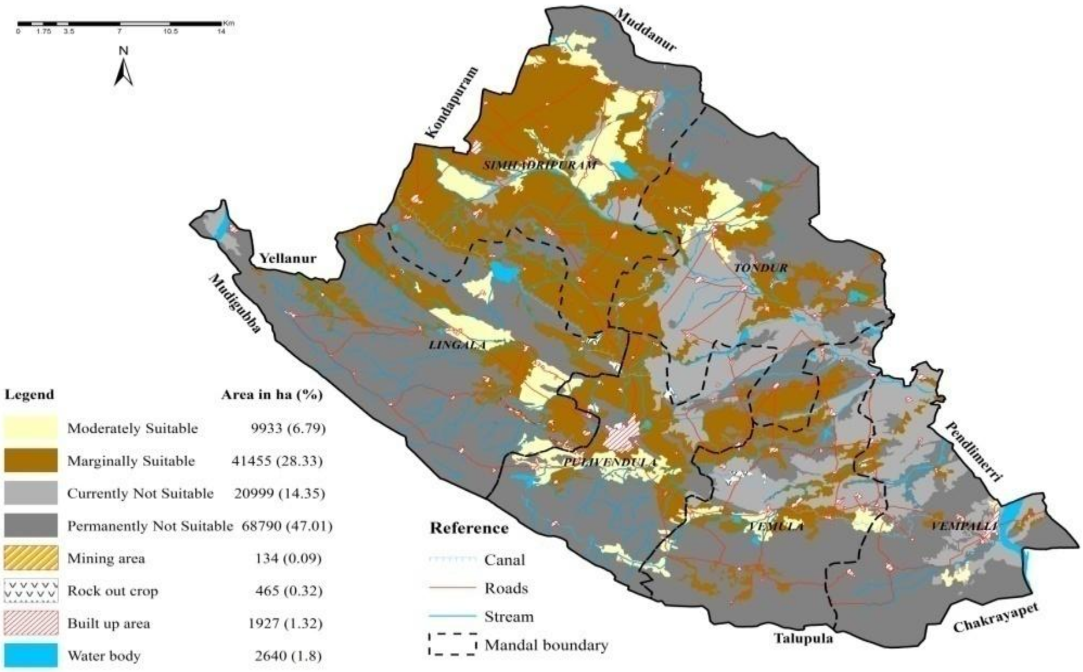

Figure 3. Soil–site suitability map for banana in Pulivendula Tehsil, Kadapa District, Andhra Pradesh, India

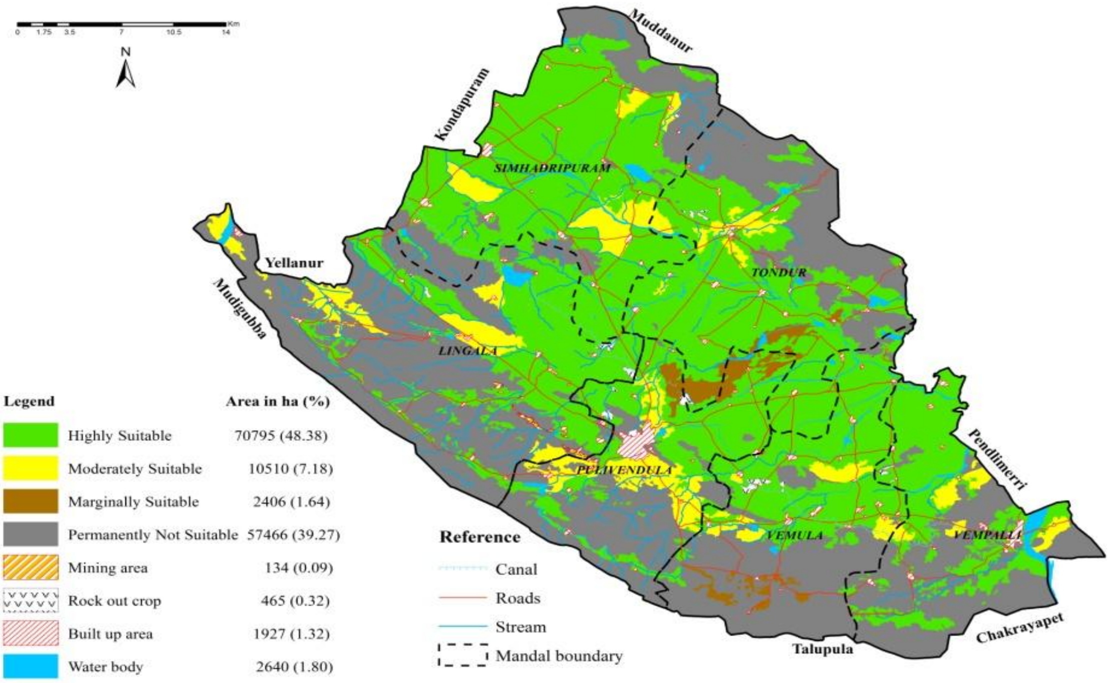

Figure 4. Suitability map for drip irrigation in Pulivendula Tehsil, Kadapa District, Andhra Pradesh, India

The interhill basin includes 20 soil mapping units covering 30.95% of the total area (45,255 ha), with a mean soil loss of 5.76±5.25 t/ha/yr. The mean soil loss with high medium erosion risk. Seven suitable SMUs for bananas (SMU12, 21,23,24,25,26 and 28) are classified as medium erosion risk zones, with mean soil loss of 3.25±0.55 t/ha/yr except in SMU 28 with high-medium risk (5.36t/ha/year, Table 6). This landscape unit is generally employed in the region for banana-based cropping systems, where crop management and soil erodibility determine adoption strategies for climate variability, input management, and moisture conservation. The 15 colluvial-alluvial pediplain SMUs encompass 28,542 ha (19.52%), with a mean of 32.51±37.39 t/ha/yr. The five SMUs with high erosion risk encompass 11,731 ha (8.02%), with a mean of 16.92±1.66 t/ha/yr. The four SMUs in colluvial-alluvial pediplains are designated as extremely eroded zones and include 9,986 ha (6.82%) with mean soil loss of 91.02±8.23 t/ha/yr. Pernapadu-Gondipalle (33) unit has an area of 853 ha (0.58%) under the low-medium erosion class and 1.46% (2,134 ha) under the high-medium erosion class (Table 6). The focus is on soil conservation practices in highly degraded regions. Sustainable land management options must be prioritized in light of terrain characteristics, land use cover status, and local community interests. Agroforestry, terracing, and a cut-and-carry technique can mitigate erosion in the steep slopes of the Palakonda range.

In conclusion, the climatic study of Pulivendula Tehsil is critically analyzed for banana production at a suitable scale for regional planning. The findings of a banana suitability analysis under drip irrigation reveal that 56,091 ha of land in winter hill basins and colluvial-alluvial deposits are appropriate (S2 and S3) for banana agriculture, compared to the present area of 22,000 ha. Furthermore, the analysis showed that 34,502 ha of feasible banana land is considered highly suitable for drip irrigation systems, with an extremely high erosion risk area of 16,364 ha. This study provides a baseline for agricultural land appraisal; it will assist farmers and decision-makers in various agroecological zones in determining how to undertake land evaluations to boost agricultural production and prevent unsuitable agricultural practices that may contribute to land degradation.

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Short Communication: Avifauna survey in Bama coastal area of Baluran National Park, East Java, Indonesia

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[1]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Jember. Jl. Kalimantan 37, Tegalboto, Jember 68121, East Java, Indonesia. Tel.: +62-331-334293, ♥email: arifsiddiq.fmipa@unej.ac.id

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Manuscript received: 19 November 2023. Revision accepted: 3 February 2024.

Abstract. *Siddiq AM, Sulistiyowati H, Setiawan R, Wimbaningrum R, Wahono ND. 2024. Short Communication: Avifauna survey in Bama coastal area of Baluran National Park, East Java, Indonesia. Intl J Trop Drylands 8: 14-20.* Baluran National Park is an essential habitat for avifauna in the East Java region, Indonesia. We surveyed the avifauna in the Bama coastal area using the line transect method at three stations, including Kalitopo, Bekol-Bama, and Manting. During a three-day survey, we recorded 53 bird species belonging to 47 genera and 32 families. According to the IUCN Red List, there are three conservation statuses (least concern: 49 species, near threatened: one species, endangered: three species); then, based on the CITES status, there are two categories (non-appendix: 47 species, Appendix II: six species), and finally, based on national status, there are two categories (non-protected categories: 41 species, protected categories: 12 species). Based on the frequencies, 32 common and 21 rare bird species are reported in the Bama coastal area. Three of the common species are Sunda Pied Fantail (*Rhipidura javanica*), Cave Swiftlet (*Collocalia linchi*), and Oriental Pied Hornbill (*Anthracoceros albirostris*), which was found in all observation tracks. Furthermore, these surveys provide recommendations for further research related to ecological topics for several threatened bird species, such as *Padda oryzivora*, *Pavo muticus*, *Acridotheres melanopterus*, *Gracula religiosa*, *A. albirostris*, and *Nisaetus cirrhatus*.

Keywords: Avifauna, Baluran National Park, Bama coastal

INTRODUCTION

Baluran National Park (BNP) is one of the prominent conservation areas with high bird diversity in East Java, Indonesia. Approximately 225 bird species inhabit the natural ecosystems in this area, such as tropical rainforest, monsoon forest, savanna, mangrove forest, and coastal forest (Winnasis et al. 2011). This ecosystem variety also provides several habitats used by bird communities (avifauna). Its conditions provide the resources birds need as food sources, mating sites, nesting sites, and protection sites (Sumaila et al. 2020; Tu et al. 2020), especially for birds with a limited distribution range and are threatened with extinction. Several endemic bird species are also found in BNP, including eight endemic birds for Java-Bali (*Loriculus pusillus, Glaucidium castanopterum, Halcyon cyanoventris, Psilopogon javensis, Hydrornis guajanus, Stachyris melanothorax, Orthotomus sepium, Padda oryzivora*) and three birds species endemic for Java (*Nisaetus bartelsi, Centropus nigrorufus, Macronous flavicollis*) (Winnasis et al. 2011). Furthermore, according to The International Union for Conservation of Nature's (IUCN) Red List of Threatened Species (IUCN 2023), there are 17 bird species in the threatened category, including 7 near threatened species (*Esacus neglectus, L. pusillus, P. javensis, Turdinus macrodactylus, Ploceus hypoxanthus, Ciconia episcopus, Ducula aenea*), 6 vulnerable species (*Buceros rhinoceros, Fregata andrewsi, Egretta eulophotes, Leptoptilos javanicus, C. nigrorufus, Mulleripicus pulverulentus*), and 4 endangered species (*N. bartelsi, Pavo muticus, Acridotheres melanopterus, P. oryzivora*). These birds are distributed in several potential BNP habitats, including the Bama coastal forest.

Bama Coastal is one of the diversity hotspot areas for avifauna in BNP. According to Winnasis et al. (2011), which is the latest report from BNP, there are several endemic and protected birds inhabiting this area, such as *P. muticus*, *B. rhinoceros*, *M. pulverulentus*, *A. melanopterus*, *C. episcopus* and *L. javanicus*. Geographically, this area is located on the eastern side of BNP, and it includes Bama Resort management. This area has two types of forest ecosystems: mangrove and coastal. Hariyanto et al. (2019) reported that there are 6 mangrove species in Bama, including *Rhizophora stylosa, Rhizophora mucronata, Rhizophora apiculata, Bruguiera gymnorhiza, Ceriops tagal,* and *Nypa fruticans*.

Meanwhile, the vegetation composition and structure of the coastal forest at Bama are still lacking. The forest's existence at Bama is essential in supporting bird diversity in this area. The forest provides several resources that avifauna need, like food, shelter, nesting sites, and socialization areas. According to Graells et al. (2022), the coastal area is a significant bird habitat, affecting the high diversity of bird species. Furthermore, revegetation in

BNPcoastal areas enhances bird diversity, as in Socorejo, Tuban, East Java (Lestari et al. 2017). Therefore, the vegetation in coastal forests influences the existence of avifauna in those areas, including Bama.

Periodic studies of avifauna in Bama are still very limited, at least the last report in 2009 (Widodo 2009) and 2011 (Winnasis et al. 2011). Data updating is needed to determine the existence of birds in their natural habitat, including in this natural park. These data are significant information for bird monitoring in Baluran National Park, particularly those with threatened conservation statuses. On the other hand, birds also have sensitivity to the environment, including human activities (Alexandrino et al. 2016). Hence, the richness and abundance of avifauna in an area have the potential to change every period.

Furthermore, the Bama coastal area is being developed as a tourist destination. Therefore, tourists periodically come to this area (Nuzula et al. 2017), potentially threatening the birds on the Bama coast. Periodic monitoring or avifauna surveys can be set up in several potential areas in Bama. These results can be considered for managing conservation areas, especially in utilization zones such as tourism. Further, the potential hotspots of bird diversity in the Bama area can be developed into birdwatching area options for researchers, observers, or tourists.

MATERIALS AND METHODS

Study area

The study was conducted from 5 to 7 May 2023 in the Bama coastal area of BNP, Indonesia (Figure 1). Data collection was done using line transect (Bibby et al. 2000; Thunhikorn et al. 2016) in three stations (St) including St. Manting (7°50'41.21"S; 114°27'34.96"), St. Kalitopo (7°50'24.69"S; 114°27'45.99"), and St. Bekol-Bama (7°50'42.33"S; 114°27'18.32"). Furthermore, 2-3 observers walk from the starting point (coordinates) through the existing line transect for 500-700 m. These surveys were conducted in the morning (05.30-09.00 AM) and were considered peak ecological bird activities (Thunhikorn et al. 2016; Siddiq et al. 2023).

Bird observations were based on morphological sightings and vocalizations. The equipment was also used for this observation, such as a DSLR camera (Canon EOS 60D), a telephoto lens (300 mm), a binocular (Nikon Aculon), a voice recorder by the BirdNET application (https://birdnet.cornell.edu/), and a stationary note. Ecological data were collected, including bird species, abundance, and frequencies. We used a guidebook for species identification of birds in Greater Sundas (MacKinnon et al. 2010; Taufiqurrahman et al. 2022) and the XenoCanto website (https://xeno-canto.org/) for recording verification. Furthermore, frequencies were determined using Common (recorded in two to three observation tracks with minimal two-day encounters) and Rare (recorded in one observation track with a one-day encounter). Furthermore, the conservation status of each species was collected through three statuses, i.e., The International Union for Conservation of Nature's (IUCN) Red List of Threatened Species (https://www.iucnredlist.org/), Convention on International Trade in Endangered Species (CITES) of Wild Fauna and Flora (https://cites.org/eng), and National Regulation (*Peraturan Menteri Lingkungan Hidup dan Kehutanan* Number P.106/MENLHK/SETJEN/KUM.1/12/2018).

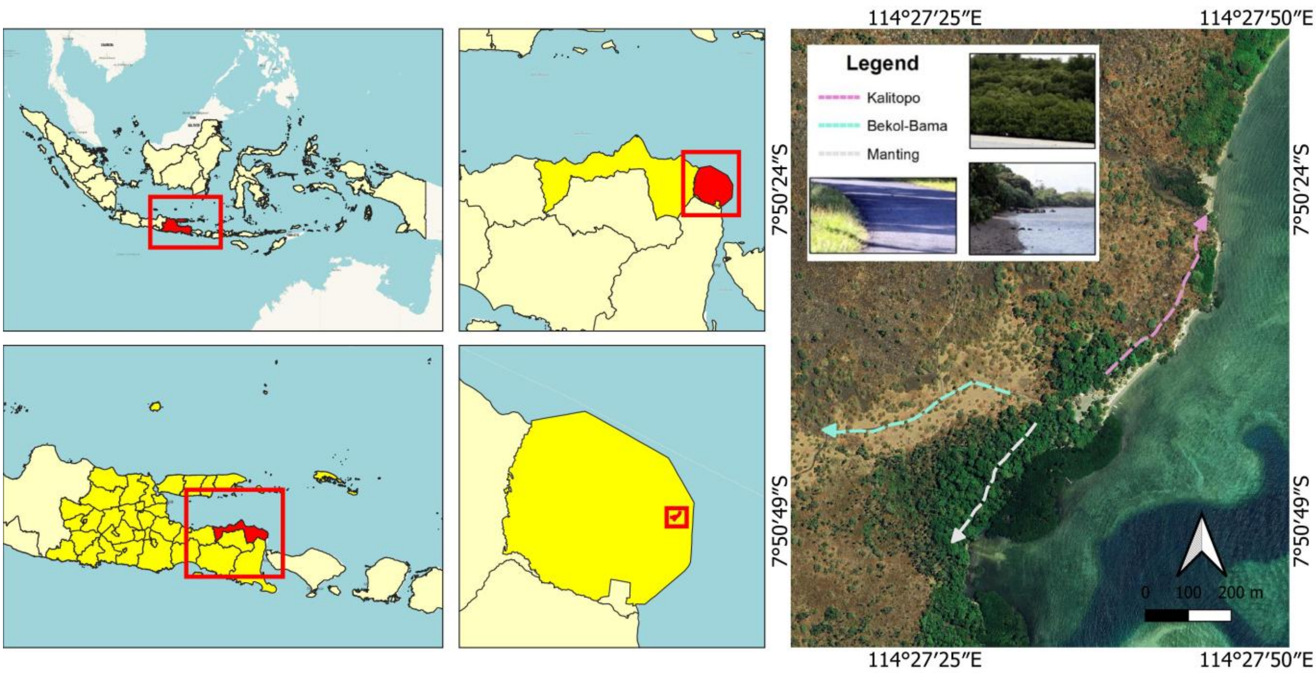

Figure 1. Study sites for avifauna survey at Bama coastal area, Baluran National Park, East Java, Indonesia

RESULTS AND DISCUSSION

The surveys recorded 53 bird species belonging to 47 genera and 32 families in the Bama coastal area of BNP (Table 1). There are 50 species also reported by Winnasis et al. (2011) in BNP; however, three species (*Orthotomus ruficeps, Dicaeum trigonostigma, Gracula religiosa*) have been confirmed by this survey. A late report by Winnasis et al. (2011) revealed that these species were unconfirmed in Baluran National Park. Common Hill Myna (*G. religiosa*) was one of the important findings in this survey, as this species has been protected under the Ministry of Forestry and Environment of Republic Indonesia Regulation No. P.106/MENLHK/SETJEN/KUM.1/12/2018. A single individual was recorded perching on the top canopy of *Corypha utan* with calling activity (Figure 2). Taufiqurrahman et al. (2022) revealed that this species is solitary, in pairs, or in small groups (<10 individuals) and perches on open twigs at the top of tall trees or foraging at fruiting trees.

This survey also reported two species of migratory birds, i.e., Arctic Warbler (*Phylloscopus borealis*) (Figure 2) and tern (*Sterna* sp.). Species *P. borealis* were also reported in BNP during the September-January migratory season (Winnasis et al. 2011). This species breeds across the northern Palaearctic and northwesternmost Nearctic, then migrates to Southeast Asia, the Philippines, and Indonesia (Alstrom et al. 2011). This species was observed solitary with forage activity in the low-medium stratification of the Bama coastal forest. Taufiqurrahman et al. (2022) stated that this species is a common migratory bird in the Greater Sunda, with stopover sites in hilly forests, forest edges, plantations, and parks. Meanwhile, *Sterna* sp. was seen flying in groups (12-16 individuals) in the intertidal-subtidal zone area at Bama, and unclear characteristics were observed for the species. Previous reports stated that there are six tern species, such as Lesser Crested Tern (*Thalasseus bengalensis*), Greater Crested Tern (*Thalasseus bergii*), Little Tern (*Sternula albifrons*), Black-naped Tern (*Sterna sumatrana*), Gull-billed Tern (*Gelochelidon nilotica*), and Whiskered Tern (*Chlidonias hybrida*) in BNP. However, those found on the Bama coast are black-napped and greater crested terns (Winnasis et al. 2011).

Based on the frequencies, 32 common and 21 rare bird species are reported in the Bama coastal area. One common species is the Sunda Pied Fantail (*R. javanica*), found in all observation tracks (Figure 2). This species is found solitary or in pairs with social activities and moving from several trees such as *Syzygium polyanthum, Thespesia populnea*, and *Rhizopora apiculata*. This species is a common bird in coastal areas, mangroves, and plantations of up to 1,500 masl (Taufiqurrahman et al. 2022). In the north of Badung, Bali (Indonesia), this species is common in plantations, forest edges, and riparian areas (Yuni et al. 2022a).

Furthermore, Cave Swiftlet (*C. linchi*) is a common species in this area; this species is indeed very common in Java and Bali, with a wide distribution from lowland to highland forest habitats (Taufiqurrahman et al. 2022). Siddiq et al. (2023) also reported that this species is common in the highlands of Erek-erek Geoforest, Mount Ijen. In the Bama coastal area, *C. linchi* was found in flight activities, with an abundance ranging from 12-25 individuals in each encounter.

The Oriental Pied Hornbill (*A. albirostris*) was also a common species in the Bama coastal area (Figure 2). This species was observed in groups of 3-8 individuals and occupied the coastal forest, particularly in *Ficus variegata* and *C. utan* vegetation. We also recorded this species foraging on fruits at both tree species. A previous report also revealed that *A. albirostris* used *F. variegata* and *C. utan* for foraging behavior in the Bama coastal area (Nurdiansyah et al. 2023). As a member of the Bucerotidae, this species was also reported to be a frugivore bird, especially feeding on some fruits of *Ficus*. However, it has also been reported to experience adaptive predation, preying on farmed edible bird nests of Swiftlet (*Aerodramus* spp.) in Kalabakan, Sabah, Malaysia (Chong et al. 2022).

On the other hand, the Great-Billed Heron (*Ardea sumatrana*) is a waterbird species that is a common category in the Bama coastal area. This species was found as a single individual in the intertidal zone during low tide periods (Figure 2). Sometimes, *A. sumatrana* observed foraging activity and caught several small fish. Taufiqurrahman et al. (2022) revealed that this species inhabits coastal areas, rubbles, and mangrove forests. This species is usually solitary for forage coral fish in the intertidal zone.

Several birds with important conservation status also occupy the Bama coastal area. There 12 bird species are nationally protected (*Gerygone sulphurea, Spilornis cheela, N. cirrhatus, A. sumatrana, A. albirostris, Crypsirina temia, P. oryzivora, Microhierax fringillarius, P. muticus, R. javanica, A. melanopterus,* and *G. religiosa*) found in this area. Furthermore, according to IUCN Red List status, one near-threatened species (*D. aenea*) and three endangered species (*P. oryzivora, P. muticus,* and *A. melanopterus*) were also recorded. Meanwhile, based on CITES status, six species are in the Appendix II category (*S. cheela, N. cirrhatus, A. albirostris, P. oryzivora, P. muticus,* and *M. fringillarius*) in the Bama coastal area. Therefore, considering these results, this area is an essential habitat for threatened birds in Baluran National Park.

The Green Peafowl (*P. muticus*) is a member of the Phasianidae that has an endangered category and protected status in Indonesia. The species is threatened by hunting, trade, and habitat destruction (Birdlife International 2018). In the Bama area, *P. muticus* was recorded to commonly occupy the forest floor of coastal forests, especially those bordering the Bekolsavannah. A previous study revealed that the habitat characteristics of Javan green peafowl in Baluran and Alas Purwo National Park were composed of open areas such as savannah or feeding grounds (Hernowo et al. 2018). Furthermore, black-winged myna (*A. melanopterus*) is globally endangered. This species is a member of the Sturnidae that has a limited distribution in Java-Bali. In this survey, five individuals of *A. melanopterus* were observed flying across the border of the Bama coastal forest and Savannah area (Figure 2). Currently, this species has remaining habitats in conservation areas. Subspecies *A. melanopterus* tricolor is endemic to East Java, and it is only distributed in the tropical savanna landscape of conservation areas in East Java (Sadanandan et al. 2020; Taufiqurrahman et al. 2022).

Table 1. Species composition of avifauna in the Bama coastal area, BNP, Indonesia

Family	Species	Common Name	FS	Status		
				IUCN	CITES	NS
Acanthizidae	*Gerygone sulphurea* (Wallace, 1864)	Golden-bellied Gerygone	R	LC	NA	PR
Accipitridae	*Spilornis cheela* (Latham, 1790)	Crested Serpent-eagle	C	LC	A.II	PR
	Nisaetus cirrhatus (Gmelin, 1788)	Changeable Hawk-Eagle	R	LC	A.II	PR
Aegithinidae	*Aegithina tiphia* (Linnaeus, 1758)	Common lora	C	LC	NA	NP
Alcedinidae	*Halcyon cyanoventris* (Vieillot, 1818)**	Javan Kingfisher	C	LC	NA	NP
	Alcedo coerulescens Vieillot, 1818 *	Cerulean Kingfisher	R	LC	NA	NP
	Ceyx erithaca (Linnaeus, 1758)	Oriental Dwarf-kingfisher	R	LC	NA	NP
	Todiramphus chloris (Boddaert, 1783)	Collared Kingfisher	C	LC	NA	NP
Apodidae	*Collocalia linchi* (Horsfield & F.Moore, 1854)	Cave Swiftlet	C	LC	NA	NP
Ardeidae	*Ardea sumatrana* (Raffles, 1822)	Great-billed Heron	C	LC	NA	PR
Bucerotidae	*Anthracoceros albirostris* (Shaw, 1808)	Oriental Pied Hornbill	C	LC	A.II	PR
Campephagidae	*Lalage nigra* (J.R.Forster, 1781)	Pied Triller	C	LC	NA	NP
	Pericrocotus cinnamomeus (Linnaeus, 1766)	Small Minivet	C	LC	NA	NP
Caprimulgidae	*Caprimulgus affinis* (Horsfield, 1821)	Savanna Nightjar	C	LC	NA	NP
Cisticolidae	*Orthotomus ruficeps* (Lesson, 1830)	Ashy Tailorbird	R	LC	NA	NP
	Orthotomus sutorius (Pennant, 1769)	Common Tailorbird	C	LC	NA	NP
Columbidae	*Streptopelia bitorquata* (Temminck, 1809)	Sunda Collared-dove	C	LC	NA	NP
	Ducula aenea (Linnaeus, 1766)	Green Imperial-pigeon	C	NT	NA	NP
	Treron griseicauda Bonaparte, 1855 *	Grey-cheeked Green-pigeon	C	LC	NA	NP
	Geopelia striata (Linnaeus, 1766)	Zebra Dove	C	LC	NA	NP
	Spilopelia chinensis (Scopoli, 1786)	Eastern Spotted Dove	C	LC	NA	NP
Corvidae	*Crypsirina temia* (Daudin, 1800)	Racket-tailed Treepie	R	LC	NA	PR
Cuculidae	*Cacomantis merulinus* (Scopoli, 1786)	Plaintive Cuckoo	C	LC	NA	NP
Dicaeidea	*Dicaeum trigonostigma* (Scopoli, 1786)	Orange-bellied Flowerpecker	R	LC	NA	NP
	Dicaeum trochileum (Sparrman, 1789) *	Scarlet-headed Flowerpecker	C	LC	NA	NP
Dicruridae	*Dicrurus macrocercus* Vieillot, 1817	Black Drongo	R	LC	NA	NP
	Dicrurus paradiseus (Linnaeus, 1766)	Greater Racquet-tailed Drongo	R	LC	NA	NP
Estrildidae	*Padda oryzivora* (Linnaeus, 1758) *	Java Sparrow	C	EN	A.II	PR
	Lonchura leucogastroides (Moore, 1858) *	Javan Munia	C	LC	NA	NP
	Lonchura punctulata (Linnaeus, 1758)	Scaly-breasted Munia	C	LC	NA	NP
Falconidae	*Microhierax fringillarius* (Drapiez, 1824)	Black-thighed Falconet	R	LC	A.II	PR
Hirundinidae	*Hirundo javanica* (Sparrman, 1789)	Pacific Swallow	C	LC	NA	NP
Laniidae	*Lanius schach* (Linnaeus, 1758)	Long-tailed Shrike	R	LC	NA	NP
Laridae	*Sterna* sp.	Tern	R	LC	NA	NP
Megalaimidae	*Psilopogon haemacephalus* (P.L.S.Müller, 1776)	Coppersmith Barbet	C	LC	NA	NP
Nectariniidae	*Chalcoparia singalensis* (Gmelin, 1789)	Ruby-cheeked Sunbird	R	LC	NA	NP
	Anthreptes malacensis (Scopoli, 1786)	Brown-throated Sunbird	C	LC	NA	NP
	Cinnyris jugularis (Linnaeus, 1766)	Olive-backed Sunbird	C	LC	NA	NP
Pellorneidae	*Malacocincla sepiaria* (Horsfield, 1821)	Horsfield's Babbler	C	LC	NA	NP
Phasianidae	*Pavo muticus* (Linnaeus, 1766)	Green Peafowl	C	EN	A.II	PR
	Gallus varius (Shaw, 1798) *	Green Junglefowl	C	LC	NA	NP
Phylloscopidae	*Phylloscopus borealis* (J.H.Blasius, 1858)	Arctic Warbler	R	LC	NA	NP
Picidae	*Dinopium javanense* (Ljungh, 1797)	Common Flameback	R	LC	NA	NP
	Dendrocopos analis (Bonaparte, 1850)	Freckle-breasted Woodpecker	C	LC	NA	NP
Pycnonotidae	*Pycnonotus plumosus* (Bonaparte, 1850)	Olive-winged Bulbul	R	LC	NA	NP
	Pycnonotus aurigaster (Vieillot, 1818)	Sooty-headed Bulbul	C	LC	NA	NP
	Pycnonotus goiavier (Scopoli, 1786)	Yellow-vented Bulbul	C	LC	NA	NP
Rhipiduridae	*Rhipidura javanica* (Sparrman, 1788)	Sunda Pied Fantail	C	LC	NA	PR
Scolopacidae	*Actitis hypoleucos* (Linnaeus, 1758)	Common Sandpiper	C	LC	NA	NP
Sturnidae	*Acridotheres melanopterus* (Daudin, 1800) **	Black-winged Myna	R	EN	NA	PR
	Gracula religiosa (Linnaeus, 1758)	Common Hill Myna	R	LC	NA	PR
Timaliidae	*Mixornis flavicollis* (Bonaparte, 1850) ***	Grey-cheeked Tit Babbler	R	LC	NA	NP
Vangidae	*Hemipus hirundinaceus* (Temminck, 1822)	Black-winged Flycatcher-shrike	C	LC	NA	NP

Note: FS: Frequency Status, LC: Least Concern, NT: Near Threatened, EN: Endangered, NA: Not Appendix, A.II: Appendix II, NR: National Status, PR: Protected, NP: Not Protected. *: Endemic to Indonesia, **: Endemic to Java-Bali, ***: Endemic to Java, Indonesia (Taufiqurrahman et al. 2022)

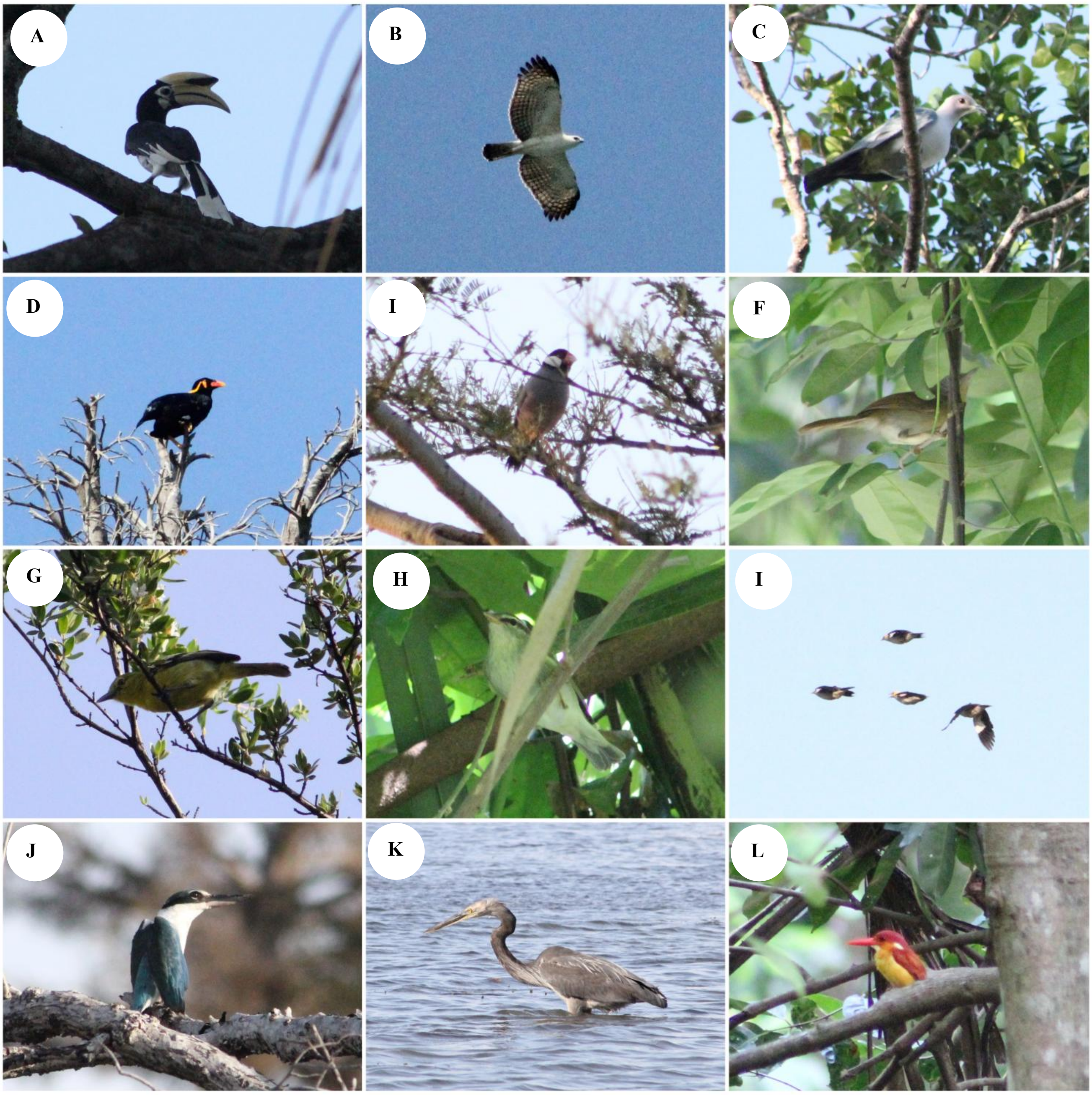

Figure 2. Bird documentation from the Bama coastal area of BNP, Indonesia. A. Oriental Pied Hornbill, B. Changeable Hawk-Eagle, C. Green Imperial-pigeon, D. Common Hill Myna, E. Java Sparrow, F. Grey-cheeked Tit-Babbler, G. Common Lora, H. Arctic Warbler, I. Black-winged Myna, J. Collared Kingfisher, K. Great-billed Heron, L. Oriental Dwarf-kingfisher

A further threatened species in Bama is the Javan sparrow (*P. oryzivora*) (Figure 2). This species was observed with a small group (8-12 individuals) and was only found in Bekol-Bama tracks. The flocks were observed on the top canopy and flew to the ground. This species is a rare category in the surveys. Winnasis et al. (2011) reported that this species was distributed in the monsoon forest at Labuhan Merak Block, around Bilik-Sijile Beach, Balanan, Talpat, Keramat, Bekol, and even along the Batangan-Bekol road of Baluran National Park. Populations in Baluran tend to be stable; however, globally, their population is significantly declining (Birdlife International 2021) due to the illegal capture of pets (Yuda 2015; Chng and Eaton 2016). Thus, conservation areas like Baluran National Park are one of the most appropriate habitats for this species. In addition, this endangered species also inhabits a transition area of monsoon forest and savannah at Bali Barat National Park (Yuni et al. 2022b).

The surveys also recorded three diurnal raptor species, i.e., Black-thighed Falconet (*M. fringillarius*), Crested Serpent-eagle (*S. cheela*), and Changeable Hawk-Eagle (*N. cirrhatus*). All raptor species are protected under the Ministry of Forestry and Environment of the Republic of

Indonesia Regulation Number P.106/MENLHK/SETJEN/ KUM.1/12/2018. Species *N. cirrhatus* has the least concern status, but its population is experiencing a downward trend (Birdlife International 2020). This species was observed solitary and flying through the mangrove forest at Bama. Based on the documentation results (Figure 2), the species was observed in the light phase. Taufiqurrahman et al. (2022) revealed that this raptor has two color phases: light and dark. The presence of this raptor species indicates the availability of prey in Baluran National Park. In Mudumalai Tiger Reserve in Tamil Nadu, India, *N. cirrhatus* was recorded preying on an Indian grey mongoose (*Herpestes edwardsi*) (Samson et al. 2020). In Gunung Halimun-Salak National Park, West Java, this species was identified as prey, including reptiles (snakes and agamid lizards), birds (white-breasted waterhen or *Amourornis phoenicurus*) and mammals (squirrel) (Gunawan et al. 2017).

Several endemic bird species were also found in this survey. There are six endemic birds to Indonesia (*Alcedo coerulescens*, *Treron griseicauda, Dicaeum trochileum, P. oryzivora, Lonchura leucogastroides, Gallus varius*), two endemic birds to Java-Bali (*H. cyanoventris*, *A. melanopterus*), and one endemic bird to Java (*M. flavicollis*) (Table 1). Species *M. flavicollis* is only distributed in Java, from the west to the east (Collar et al. 2022). Taufiqurrahman et al. (2022) revealed that *M. flavicollis* is a member of the Timaliidae family, commonly found in various types of open forests and forest edges, including coastal forests. This species favors dense understory and creeping vegetation and has been recorded feeding on black beetles and small insects (MacKinnon et al. 2010). In the Bama coastal area, this species was observed as a single individual with moving activity in creepers. The *M. flavicollis* is categorized as rare in this area, found only on the Manting track. It was found in the dry coastal forests with semi-dense vegetation cover.

The existence of several endemic birds or those with important conservation values in BNP is essential information for staff or managers. The availability of complete and up-to-date data is crucial in determining conservation area management policies. This conservation area is one of several protected areas in East Java that serves as a natural habitat for several endemic and protected birds. The protected areas contribute measurably to conserving avifauna in several of the world's most diverse and threatened terrestrial landscapes (Cazalis et al. 2020). Citizen science also contributes significantly to monitoring or checking birds in some areas using applications. Using the Burungnesia application by citizen science can provide important information such as bird encounters (especially common categories), their population, and habitats (Winnasis et al. 2018).

Monitoring avifauna in Baluran National Park needs to be done periodically and continuously. It is intended to monitor the existence of birds, especially those with important and protected conservation status. These monitors can be based on scientific expeditions by staff, researchers, or citizen science with simple data collection. More importantly, the results are analyzed and published scientifically to be used as a reference for further research or future studies. According to these survey results, further research can be conducted on several threatened bird species, such as *P. oryzivora, P. muticus, A. melanopterus, G. religiosa, A. albirostris,* and *N. cirrhatus* related to several ecology topics, including population, reproduction, behavior, habitat, distribution, and ecological threats. Thus, the research complements the lacking data and becomes a reference in the sustainable management of threatened birds in Baluran National Park.

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Traditional knowledge in land management and utilization of natural resources in Wonogiri District, Central Java, Indonesia

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Abstract. *Afriawan MDAA, Al-Akromi MAI, Andira MHP, Sutrisno MT, Nurwulandari M, Sugiyarto, Nazar IA, Md. Naim D, Setyawan AD. 2024. Traditional knowledge in land management and utilization of natural resources in Wonogiri District, Central Java, Indonesia. Intl J Trop Drylands 8: 21-26.* Traditional knowledge helps farmers cultivate land to be more effective and efficient. It also contributes to maintaining environmental sustainability and reducing the adverse impacts of land management activities due to hereditary teachings about protecting nature. Wonogiri District has great potential for further development, especially in the agricultural and plantation sectors. This potential provides opportunities for economic drivers and the development of a more holistic agricultural sector in the district. Therefore, this study aimed to look at how land management knowledge and the utilization of natural resources in Wonogiri District, Central Java, Indonesia. Moreover, 65 informants were selected to be interviewed to obtain information on land use and land management procedures. This research used descriptive analysis with socioeconomic percentage parameters. The results show that the people of Wonogiri benefit from natural resources in terms of socio-cultural, ecological, economic, medicinal, energy, and construction advantages. The community utilizes agricultural and plantation products to fulfill their daily lives, resulting in a complex relationship between humans and nature that creates a unique agricultural landscape. Agriculture and plantations have become part of the activities of the Wonogiri community. The application of local wisdom that the community has applied can support the management and utilization of natural resources in a sustainable manner.

Keywords: Agriculture, culture, land, local wisdom

INTRODUCTION

Indonesia is known as a mega-biodiversity country because it possesses abundant biodiversity (Dewi et al. 2020). This high diversity has provided benefits to the community throughout their livelihoods. Traditional knowledge is used from generation to generation to support environmental challenges and assist in the management of natural resources (Das et al. 2021). Traditional knowledge and community support for natural resource management plans will shape their future fate in sustainable forestry and resource management (Hoagland 2017).

Wonogiri District is one of the districts in Central Java Province, Indonesia that has promising potential in the agro-industrial sector, strengthened by agricultural land that can serve as the primary foundation for various food commodities. The main focus in Wonogiri is producing food crops such as cassava, corn, and rice, which are considered priority sectors for development This potential provides opportunities to drive the economy and develop the agricultural sector in Wonogiri District more holistically. Based on Badan Pusat Statistik Kabupaten Wonogiri (2023), in 2022 in Wonogiri District, 20 species of vegetables will be planted, of which shallots, cayenne peppers, cabbage, mustard greens, eggplants, tomatoes, carrots, cucumbers, melons and watermelons are the main products with respective yields more than 1000 ton. There are around 24 species of medicinal plants, with the main products being ginger, turmeric and galangal with yields of more than 1000 ton each. There are 22 species of fruit plants, with the main products being avocado, durian, guava, pomelo, mango, jackfruit, papaya, banana, snakefruit, sapodilla, soursop, breadfruit, jengkol, gnetum, and petai with a yield of more than 1000 ton each. Apart from that, the main ornamental plant product is potted orchids, around 50,000 pots.

The people of Wonogiri utilize their agricultural land by applying traditional knowledge in the arrangement and utilization of land. This plays a crucial role in the advancement of the agricultural sector. However, traditional knowledge also faces limitations when dealing with challenges from globalization, increasing population pressure, and the growing demands of the community. As a result, local knowledge is vulnerable to the increasing economic impact, the rapid development of modern technology, and rapid population growth (Hidayat et al.

2010). Traditional knowledge has inherent characteristics of dynamism, sustainability, and acceptability by its community (Sinapoy 2018). In local communities, traditional wisdom emerges as a set of rules, knowledge, skills, norms, and ethics that govern the community's social structure. This system continues to live and develop from generation to generation (Toansiba et al. 2021).

In addition to the challenges mentioned above, traditional knowledge also faces the challenge of adapting to society's increasingly complex needs. This is driven by lifestyle changes that demand more diverse and high-quality agricultural products. Traditional knowledge needs adaption to meet society's increasingly complex needs. Traditional knowledge helps farmers to manage. It assists farmers in managing land effectively and efficiently. Moreover, traditional knowledge contributes to environmental sustainability and mitigates the negative impacts of land management activities (Prameswari et al. 2019). The traditional knowledge system develops and shapes the community's habits in caring for natural resources. Traditional knowledge in agricultural land management covers various aspects, such as land selection, planting, maintenance, harvesting, and post-harvest. In managing and developing resources, the role of local communities, especially *adat*, is crucial due to their high dependence on natural resources. Therefore, to preserve sustainability, it is important to maintain the balance between humans and nature by paying attention to tradition, culture, and local wisdom. Community empowerment can also be emphasized to optimize communities' potential. Through empowerment, communities can acquire the knowledge and skills to manage natural resources sustainably (Lakoy et al. 2021). Unsustainable land management activities can cause environmental damage that affects local communities, both economically, socially, and environmentally. This study aims to observe land management knowledge and the utilization of natural resources in Wonogiri District. The results of this study are expected to provide useful information for the local government, the community, and researchers to preserve traditional knowledge in the management of agricultural land in Wonogiri District.

MATERIALS AND METHODS

Study area

This research was conducted in Bubakan Village, Semagar Village, and Girimarto Village, Wonogiri, Central Java Province, Indonesia (Figure 1). The research was conducted for one month in October 2023. The districts of Karanganyar and Sukoharjo border Wonogiri District in the north; Indonesian Ocean, namely the South Coastal Coast, is in the south; Gunungkidul District is in the west, and the east is by East Java Province, namely the districts of Ponorogo, Magetan, and Pacitan (Figure 1) (Rachmawatie et al. 2022).

Data collection

The method used involved interviews and direct observation of the research object, and data were collected using a questionnaire sampling method (Khoridah et al. 2019) and distributed to 65 informants from the community of Wonogiri District. The informants involved were local people and traditional leaders who manage agricultural land and utilize natural resources in the local area. Furthermore, interviews were conducted with informants by asking for socioeconomic data, such as gender, age, occupation, and latest education. This research collected community knowledge about managing agricultural land and utilizing natural resources.

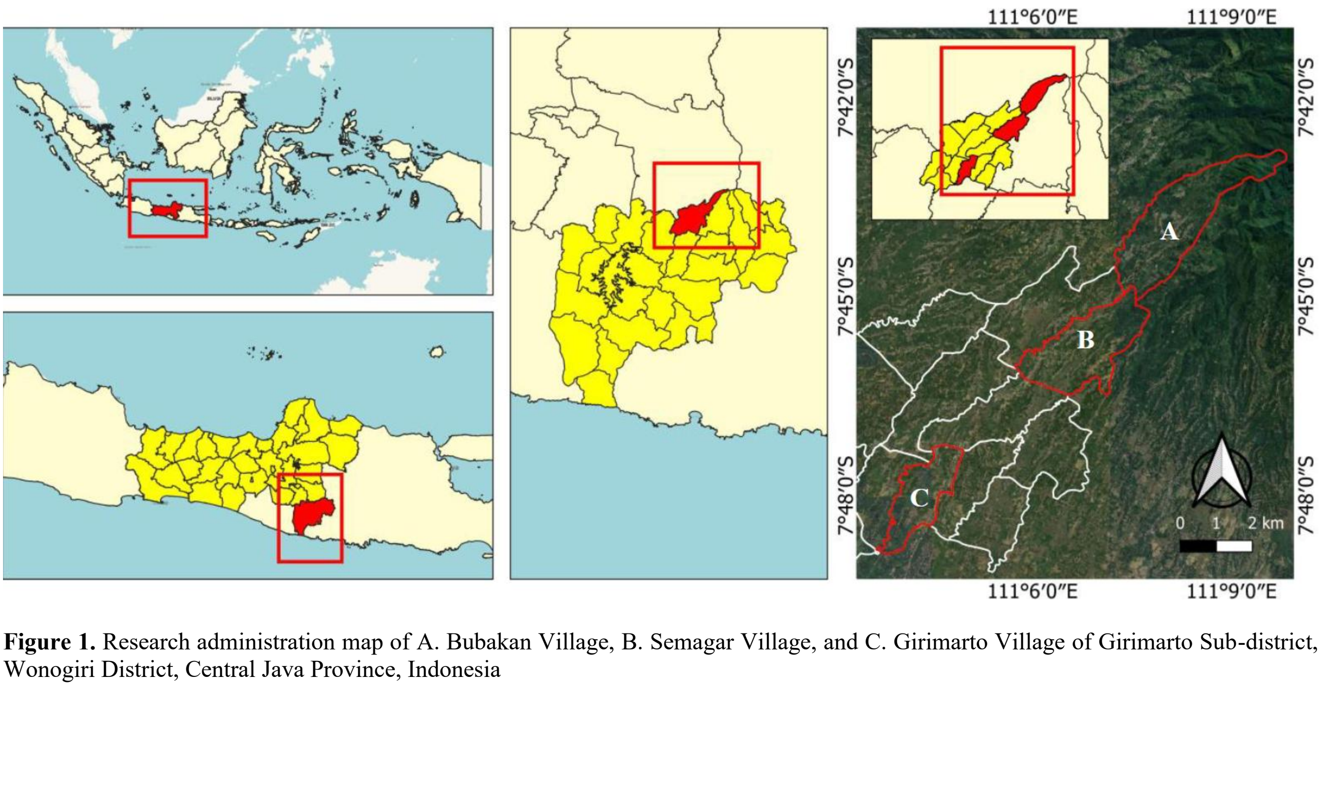

Figure 1. Research administration map of A. Bubakan Village, B. Semagar Village, and C. Girimarto Village of Girimarto Sub-district, Wonogiri District, Central Java Province, Indonesia

Data analysis

The research was conducted using the method of filling in data or information prepared on a tally sheet in the form of a list of questions. Then, the data were analyzed using descriptive analysis, displaying the percentage (%) of socioeconomic parameters describing the number of categories, divided by the total number of informants, as follows (Wasilah 2012):

$$Pi = \frac{ni}{N} \times 100\%$$

Where:

Pi: The proportion of socio-demographic characteristics (gender, education, occupation, and age) in percentage

ni : The number of socio-demographic characteristics (gender, education, occupation, and age),

N : The number of informants

RESULTS AND DISCUSSION

Socio-demographic characteristics

This study interviewed 65 respondents. Table 1 comprises 39 female informants (60%) and 26 male informants (40%). Based on the level of education of the respondents, 8 informants had no education (12.3%), 27 by elementary school (41.5%), 16 by junior high school (24.6%), 9 by senior high school (13.8%), and 6 above high school (9.2%). Additionally, the type of work shows 2 informants are students (3.1%), 23 farmers (35.4%), 13 housewives (20%), 11 laborers (16.9%), and 16 ordinary laborers (24.6%). In the age group that has been interviewed, there are 8 elderly informants (60 years) constituting 12.3%, or around 8 people, and 2 informants under the age of 20, constituting around 3.1%. The most dominant age range is 21-60 years, with 55 informants, or around 84.6%.

Table 1 shows that the respondents are predominantly farmers with elementary school as their highest education, and ages range from 21 to 60. The age range of 21-60 years is considered productive for farmers as they exhibit high enthusiasm and have high expectations for farming activities in Wonogiri District (Satriawan et al. 2021). Additionally, there is a high level of innovation among farmers who have been farming for an extended period. A lack of self-awareness influences farmers with elementary school education to pursue further education, and the challenging economic conditions of their families (Khairunnisa et al. 2021). The problem with our agricultural labor force is the changing demographic structure that is unfavorable to the agricultural sector and leads to farmers' aging. In contrast, Indonesia needs productive farmers to maximize food production (Arvianti et al. 2019).

Socio-cultural characteristics

The people of Wonogiri mostly utilize land in the agricultural sector, namely agriculture and plantations. Therefore, an agrarian society has social characteristics, including crop involvement, close family ties, high awareness of mutual cooperation, and creativity in channeling irrigation (Lakoy et al. 2021). In addition, Wonogiri District is a tourist destination for locals and visitors. This tourism potential is at Muncar Temple, an area referred to as a dam located on the slopes of the South Lawu Mountains.

In addition to tourism potential, there are also customs with indigenous knowledge in Wonogiri District still believed by the local community, and tourists should be be aware of them. Customs that are still strong in local traditional communities can be considered a guideline for the dependence of traditional communities on meeting their needs and preserving the surrounding environment. Table 2 shows local wisdom in Wonogiri District, including *rumah tiban, ruwahan, bersih desa, syukuran, kodanan, tumpengan, kirim kali,* and *ilmu titen* when farming. In addition to the existence of customs and local wisdom, Wonogiri District has the potential to be an agro-tourism site, an irrigated plantation, and an adventure site.

The highlands in Wonogiri District use agricultural technology with modern irrigation, including drip and sprinkler irrigation. This technology can increase irrigation efficiency and water use efficiency compared to surface irrigation methods (Kumar et al. 2007). Drip irrigation involves the use of flowing water directly to the roots of plants through pipes or hoses with regular drip outlets. On the other hand, sprinkler irrigation is the application of irrigation that involves spraying water over agricultural land using sprinkler technology, resembling artificial rain with a windmill-like method (Jha et al. 2019). This irrigation also impacts the community, especially the agricultural and plantation sectors, as it can improve the community's economy.

Table 1. Socio-demographic characteristics of informants

Socio-Demographic Characteristics	Number of Informants	Percentage of the Total
Gender		
Female	39	60%
Male	26	40%
Education		
No Education	8	12.3
Elementary School	27	41.5
Junior High School	16	24.6
Senior High School	9	13.8
Above High School	6	9.2
Occupation		
Student	2	3.1
Farmer	23	35.4
Housewife	13	20
Laborer	11	16.9
Employee	16	24.6
Age Group (year)		
<20	2	3.1
21-60	55	84.6
>60	8	12.3
Total	65	100

Table 2. Socio-cultural characteristics

Tradition	Description
Rumah Tiban	House that originated from Raden Mas Said's shrine when he fought against the Yogyakarta Palace, which was allied with the Dutch troops
Ruwahan	The ritual ceremony is mentioned when you want to send prayers to the spirits of ancestors who have passed away
Bersih Desa	An annual tradition that is routinely held once a year and tradition is carried out in the month of *Muharram* or what the Javanese people commonly call the month of *Suro*
Syukuran	A ritual that is often mentioned when a prayer request has been granted and carried out
Kodanan	The community custom in the area around Muncar Temple to accommodate rainwater
Tumpengan	Yellow cone-shaped rice serving with the intention of requesting the realization of wishes and gratitude
Kirim kali	Traditional habit by the local community is used in sending prayers to ancestors
Ilmu titen	Knowledge used in planting, which functions to read natural symptoms and impending disasters

Natural resources and their benefits to local communities

The people of Wonogiri can benefit from sharing natural resources for their socio-cultural activities, such as traditional ceremonies, often called *ruwahan*. The *ruwahan* traditional event is a village cleaning event that is usually held once a year. The local community uses crops such as rice, vegetables, and other dishes in the ceremony. The culture is intended to maintain intimacy and socialization between communities in the area. However, fewer people uphold the traditional culture, especially the younger generation, because many young people, especially those in rural areas, prefer to live outside their villages.

Local communities in Wonogiri District utilize their resources to support their economy, especially agricultural and plantation products, using them as their main source of income. The dominant agricultural and plantation products are corn, rice, vegetables, and coffee. These crops are traded directly in the market or to collectors, usually frequent buyers.

Table 3 shows the utilization of natural resources for treatment by 72% of informants, most of whom were parents. Since ancient times, traditional medicinal plants have played an important role in maintaining health, stamina, and treating diseases (Parawansah et al. 2020). The low dependence of young people on traditional medicinal plants occurs because there are many modern health facilities in the community, such as clinics (*puskesmas*). These facilities are very helpful for the community because they are easy to access and reachable. Medicinal plants that are still used in traditional medicine are easy to grow and obtain in the surrounding environment, such as ginger (*Zingiber officinale*), *kunir* (*Curcuma longa*), betel (*Piper betle*), and *laos* (*Alpinia galanga*). These plants are used only for minor illnesses such as fever, colds, flu, and certain diseases. People prefer to go to existing health services because traditional medicinal plants are not the main treatment to cure diseases but rather companion medicinal.

Despite using natural resources as an energy advantage, the community of Wonogiri District still uses firewood as a companion to LPG (liquefied petroleum gas) (Figure 2). Firewood is the oldest traditional energy source used by humans, especially in rural areas, since ancient times (Syaufina et al. 2020) and is used for cooking and other needs. Furthermore, using firewood is considered much more efficient than natural gas when cooking in large quantitites. The surrounding community still uses the wood for making tile roof foundations and house ornaments such as doors, windows, and other items such as livestock cages for construction excellence. The firewood and wood supply for construction are obtained from their gardens and the surrounding forest because it is easy to obtain. Most people in Wonogiri still use wood to support their buildings, although not a few houses are built using concrete.

Table 3. Natural resources and traditional plant usage of informants' knowledge

Age	Number of Informants	The number of Traditional Plant Users	Percentage
<20	1	0	0
20-40	23	13	28
>40	41	34	72
Total	65	47	100

Figure 2. Transportation of firewood

Traditional agricultural practices as primary natural resource management

By incorporating different types of crops, managing natural resources, facing challenges, applying different farming methods, and utilizing local wisdom, these traditional farming practices reflect the complex relationship between humans and nature from farmlands and plantations. This realization is evident through different crops grown, such as rice, coffee, cassava, corn, and bananas (Figure 3.A). The diverse choice of crops not only reflects adaptation to local conditions but also creates variations in farming methods based on possible weather conditions and the preferences of local people. There are criteria for agricultural landscape features and rural panoramas based on the type of agricultural products grown, resulting in a unique and distinctive landscape panorama. Some locations also have panoramas of irrigation systems and waters influenced by geographical factors (Dahlan et al. 2020).

Most natural resources in Wonogiri District as agricultural land, are managed privately, but some obstacles, such as limited planting media, less than optimal management, and the use of traditional tools, persist. In addition to being used for agriculture, some land in Wonogiri is utilized for plantations, settlements, and Muncar Temple as a tourist attraction, which showcasing efforts to diversify land use (Figure 3.B). Many challenges in managing agricultural land are pests, landslide risks, organic and inorganic fertilizers scarcity, and seasonal changes. However, the community still maintains traditional farming practices using hereditary teachings called *ilmu titen*, which involves planting with a certain consideration derived from ancestors and intercropping systems (Figure 3.C; planting several types of plants on the same land and time to use nutrients more effectively and reduce the risk of crop failure) (Utami et al. 2023). Land management is also adjusted to the season and land altitude, such as vegetable cultivation as the main crop because it does not depend on a particular season; planting cassava, corn, bananas, rice, and yams as intercrops because it adjusts to the existing season. Tobacco and coffee cultivation also require planting them in the highlands in the middle of the dry and rainy seasons. The farming method of the Wonogiri community can be categorized as mixed farming, reflecting a strong cultural heritage. The conventional agriculture application is considered the correct alternative and solves the world population's food and nutritional shortages and food security (Indahyani and Maga 2023).

Figure 3. A. Agricultural land use, B. Muncar Temple in Wonogiri District, C. Intercropping system, D. Traditional selling place of crops

Therefore, the community of Wonogiri District applies various organic and inorganic fertilizers to increase agricultural yields. In particular, most respondents use chemical fertilizers, rely on chemical pesticides, and practice crop rotation, a sustainable farming technique. Only a small percentage of the farmers use organic fertilizers, citing low labor intensity and longer harvests (Arifin et al. 2023). Furthermore, agricultural produce is mostly sold directly to traditional markets (Figure 3.D), and fewer are left for personal use. The central government also created a protected forest area in the form of pine trees around Muncar Temple to drive local people to be aware of the importance of protecting the ecosystem. This awareness follows the existence of protected forests in some areas, but some people do not realize the policies for protecting these forests.

Moreover, the above analysis results show that the people of Wonogiri benefit from natural resources in terms of socio-cultural, ecological, economic, medicinal, energy, and construction advantages. The community utilizes agricultural and plantation products to fulfill their daily lives, resulting in a complex relationship between humans and nature that creates a unique agricultural landscape. Agriculture and plantations have become part of the activities of the Wonogiri community. Local wisdom practices, such as *bersih desa, ruwahan*, and *kirim kali*, are still practiced by the people of Wonogiri today, reflecting the deep connection between the community and the surrounding environment. The potential of Muncar Temple is not only as a tourism area but also as a benefit to the economy through irrigation and market facilities; some communities propose restructuring to maximize this potential, affirming their involvement in sustainable development. Thus, traditional farming practices become a tangible representation of human efforts to manage natural resources sustainably while balancing local values and ecosystems. The application of local wisdom that the Wonogiri community has applied can support the management and utilization of natural resources in a sustainable manner.

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Butterflies (Lepidoptera: Papilionoidea) diversity in Kedung Klurak Tourism Area, Mojokerto District, East Java, Indonesia

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Abstract. *Umami S, Amaliyah NS, Fahlefi AR, Zumar MR, Romzalis AA, Wibisana OR, Susanto MAD. 2024. Butterflies (Lepidoptera: Papilionoidea) diversity in Kedung Klurak Tourist Area, Mojokerto District, East Java, Indonesia. Intl J Trop Drylands 8: 27-34.* Kedung Klurak is a natural tourism area with very good environmental conditions and is naturally maintained. This study aims to identify and analyze the diversity of butterflies (Lepidoptera: Papilionoidea) in the Kedung Klurak Tourism Area, Mojokerto District, East Java, Indonesia. The sampling method used in this study was the sweeping net and cruising or transect method. The research location was divided into three locations: the riverbank, pine forest, and bamboo area. The results of this study found 37 species, with a total of 593 individuals belonging to 5 families. The index value of species diversity in the Kedung Klurak Tourism Area is H = 3.313 in the high category. The highest diversity index is at the riverbank location with H = 3.313, followed by pine forest with H = 3.060, and the lowest diversity index is at the bamboo area location with H = 2.811. Several factors affecting differences in butterfly species diversity (Lepidoptera) are their location because they have different environmental conditions and are influenced by the availability of biotic and abiotic factors, food, and host plants. Abiotic factors include light intensity, temperature, and air humidity.

Keywords: Butterfly, environment, species diversity

INTRODUCTION

The lives on earth for plants, animals, fungi, microorganisms, and various genetic materials that exist on the earth from all habitats, both on land, in the air, and in the sea, are called biodiversity (Subahar and Yuliana 2010). Indonesia is a mega biodiversity country with diverse flora and fauna (Budiansyah et al. 2015), including butterfly species. Butterflies are one part of biodiversity that must be preserved from extinction and decreased species diversity (Pertiwi et al. 2020), with more than 2,000 species spread throughout the archipelago (Murwitaningsih et al. 2019). Butterflies belong to the order Lepidoptera or "scaly-winged insects" and are known as diurnal animals (Nuraini et al. 2020). Butterflies have a morphological structure divided into the head, thorax, and abdomen (Parmadi et al. 2016). The butterfly cycle consists of egg, larva (caterpillar), pupa (cocoon), and imago (adult) phases; hence, it is called a holometabola insect because it undergoes a perfect metamorphosis (Schulze 2013).

Many factors, including vegetation diversity and the abundance of host plant species, influence the diversity and structure of butterfly communities; the host plants are very important for butterfly larvae (Najah 2023). The presence and abundance of vegetation in a place can support the diversity of butterflies in a habitat (Kurniawan et al. 2020). In addition to vegetation factors, light intensity at a location also plays an important role in the structure of the butterfly community (Apriana et al. 2022). Butterflies are found in various regional landscapes, such as mountains, plantations, and agriculture (Sahputra et al. 2022), and the species' existence in an area is inseparable from the distribution and adaptation capabilities of the species itself (Dewi et al. 2016). Butterflies have important values: ecology, conservation, endemism, aesthetics, education, economy, and culture. Butterflies are a biotic component easily recognized in the ecosystem because this type of insect looks attractive in shape and various colors (Alfida et al. 2016).

The presence of butterflies can indicate pollution of the surrounding environment (Noor and Zen 2015), including the decline in environmental quality and the decline in butterfly diversity in an area, which is land conversion that causes loss of vegetation (Ardianto et al. 2023). The habitat conversion changes in an area are the main factors causing the reduction of butterfly species. Likewise, the problem of decreasing the quality of the surrounding environment can cause changes in the environmental components that make up the habitat, drastically reducing butterfly breeding (Rahayu and Basukriadi 2012).

The environment and climate in Java gradually changed from west to east, from wet and humid dense rainforests in western Java to dry savanna environments in eastern Java, according to the climate and rainfall of the region. Kedung Klurak Tourism Area is located in East Java, Indonesia, in the production forest area of BKPH Pacet and RPH Claket of the Indonesian Forest Enterprise (Perhutani). The tourism area is about 5 ha, the water discharge is not too large, and shady pine forests surround it. This area has a pine forest, campground, and waterfall; the cool natural nuances and beautiful aroma are the main attractions. This study aims to determine the diversity of butterflies (Lepidoptera: Papilionoidea) in the Kedung Klurak Tourism Area, East Java, Indonesia.

MATERIALS AND METHODS

Time and location of research

This research was conducted in Kedung Klurak Tourism Area, Kembangbelor Village, Pacet Sub-district, Mojokerto District, East Java, Indonesia. This study was conducted in September 2023 during the butterfly's active hours, 08.00-11.00 AM, where, in the previous month, a survey and research had been carried out at the location. This research was not conducted in the afternoon because butterflies are only active in the morning. This is supported by the opinion of Zulaikha and Susanto (2022) which state that the active hours of butterflies are from 08.00 AM to 1.00 PM and during sunny weather.

The riverbank location is on the banks of the river. The riverbank has some vegetation found at this location, such as trees, shrubs, and shrubs with open canopies. The dominant vegetation type in this location is lush shrubs with an open canopy and sunlight supply. The pine forest has a closed canopy type with a pine tree vegetation type, and with this canopy and vegetation type, this station lacks sunlight. The bamboo area is filled with bamboo plants. The dominant vegetation type at this station is pole plants, mostly bamboo plants. The bamboo area has an open canopy; sunlight maximally enters the location (Figure 1).

Data collection method

This study used the exploring method and a visual encounter survey, which is one of the ecological observation methods that involves seeing, capturing, and recording the species encountered during the observation. This research is also determined by vegetation in the observed locations. Sampling was determined using the transect method along the location. The transect method collects data through density, density, and frequency variables at an observation location (Hidayat et al. 2018). Butterfly species found during observations were documented with digital or cellphone cameras for further identification and data analysis processes.

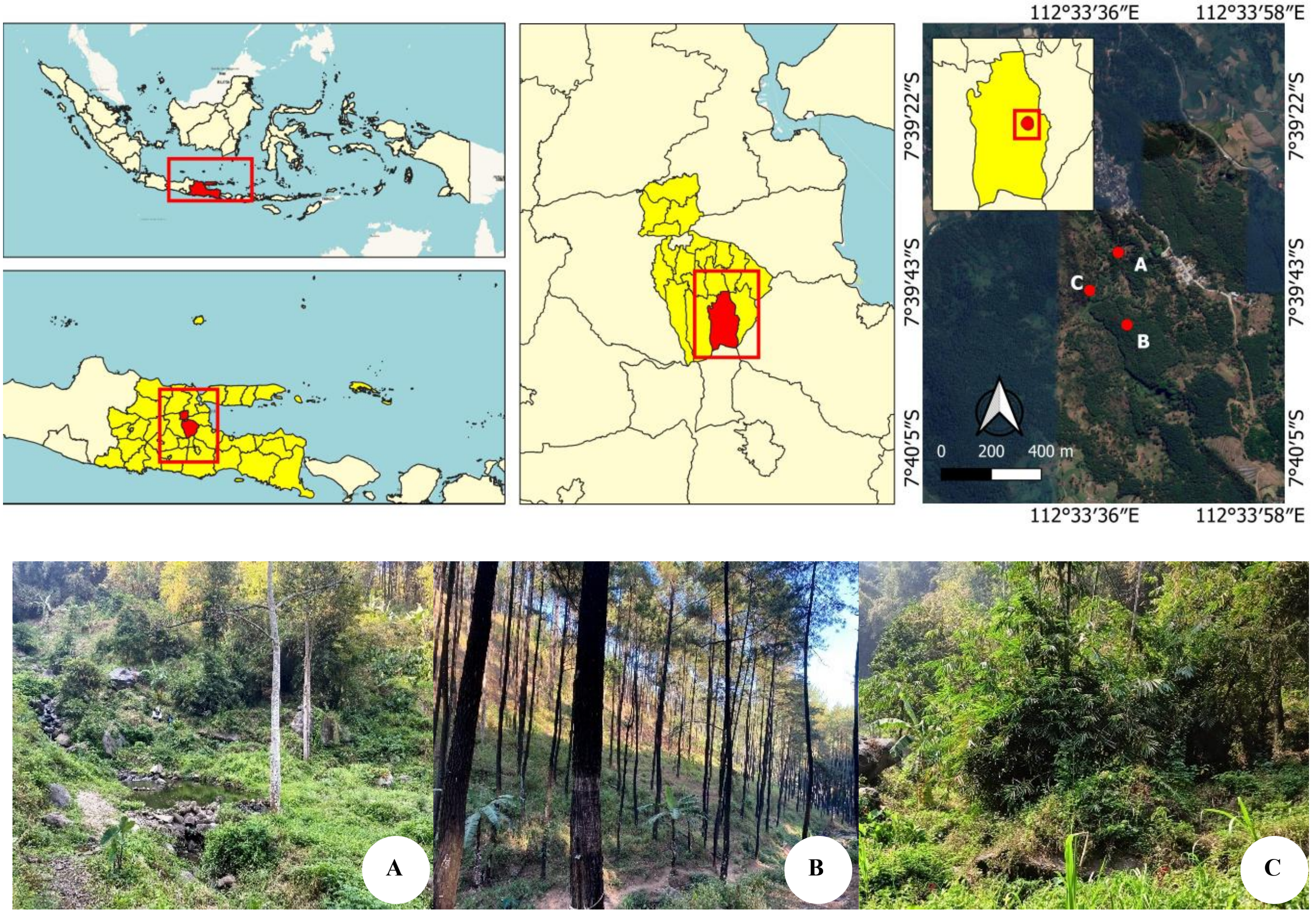

Figure 1. Research location in Kedung Klurak Tourism Area, Kembangbelor Village, Pacet Sub-district, Mojokerto District, East Java, Indonesia. A. Riverbank, B. Pine forest, C. Bamboo area

Butterfly species identification is based on morphological keys, including wing color, pattern, and shape, and this is conducted using an identification book by Baskoro et al. (2018). The study also measured supporting factors, namely biotic and abiotic factors. Abiotic factor measurements include temperature, humidity, light intensity, and wind speed. Temperature and humidity were measured using a thermohygrometer, while light intensity and wind speed were measured using a lux meter and anemometer. Biotic factor measurements include host plants and food, which greatly influence the presence of butterflies in a habitat. This is supported by Ruslan and Yenisbar (2023) state that the presence of host plants and food for butterflies is an important factor related to the presence of butterflies in a habitat. At the same time, vegetation data was collected at the research location, which will be analyzed as additional supporting data.

Data analysis

The total individuals obtained were then calculated using the relative abundance formula to determine the percentage of species:

$$RA = \frac{ni}{N} \times 100\%$$

Where:
RA : Relative abundance
Ni : Number of individuals of a species
N : Number of individuals of all species

Butterfly data obtained during the study were analyzed using the Shannon-Wiener diversity index (H'), dominance index (D), and evenness index (E).

Shannon-Wiener Diversity Index

$$H' = -\sum pi \, Ln \, pi$$

Where:
Pi : total ni/N
H' : Diversity index
ni : Number of individuals of the i-th species
N : Total number of species
ln : Natural logarithm

The Shannon-Wiener Index (H') ranges from 1.5 to 3.5 and rarely exceeds 4. The higher the H' value, the higher the diversity value (Rozak et al. 2020).

Dominance Index

$$D = \sum (ni/N)^2$$

Where:
D : Dominance Index
Ni: Number of individuals per species
N : Number of individuals of all species

Index of Evenness

$$E = \frac{H'}{Ln \, S}$$

Where:
E : Evenness index
H : Shannon-Wiener diversity index
S : Number of species
ln : Natural logarithm

RESULTS AND DISCUSSION

Based on observations made in the Kedung Klurak Tourism Area, 37 species were found, with a total of 593 individuals, from 5 families, namely Hesperiidae, Lycaenidae, Nymphalidae, Papilionidae, and Pieridae (Table 1). The family with the most species and individuals found in the Nymphalidae family totals 17 species with 315 individuals. The Nymphalidae family is the largest and most widespread butterfly, with around 6,000 species (Khyade and Jagtap 2017). The Nymphalidae family likes open areas, such as the Kedung Klurak Tourism Area, which has forests and other open areas. This is because the distribution of the Nymphalidae family is spread across various regions of the world and can survive in various habitat types (Santosa and Purnamasari 2017). Kedung Klurak Tourism Area is one of the right places for the butterfly habitat of the Nymphalidae family because environmental conditions are favorable for their survival. The family with the fewest species and individuals found is the Hesperiidae family, totaling three species with 71 individuals. Most of the Hesperiidae family has a lush habitat and hides behind the leaves, making it difficult to see directly or difficult to see with the unaided eye (Ilhamdi et al. 2023). In this study, butterflies were observed from morning (08.00 AM) to afternoon (11.00 AM). Therefore, this observation found the Hesperiidae family with fewer species.

The species with the highest relative abundance in Kedung Klurak Tourism Area is *Junonia iphita* (Figure 2.H) with RA= 9.95%. This is supported by Indrayani (2022), who reported that the species with the highest number of individuals *is J. iphita,* found in parks with flowering plant vegetation, a butterflies food source. The *J. iphita* is one species with a specific habitat and in this study, mostly found in forest habitats. The *J. iphita* is also a seasonal species supported by Islam et al. (2015), who reported that *J. iphita* only appears in summer.

The species with the least relative abundance in the Kedung Klurak Tourism Area is *Troides helena* (common birdwing) (Figure 2.P) with RA= 0.34%. This type of butterfly, *T. helena*, was one of the rare species found at Suranadi Natural Park (Ilhamdi 2018). The *T. helena* is a protected species in Indonesia, and its trade is regulated by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (APPENDIX II CITES). It is very easy to distinguish between males and females of this *T. helena* species by observing the dark markings on the hind wings (Kurniati et al. 2018).

The value of the butterfly diversity index in the Kedung Klurak Tourism Area is H= 3.351, so it can be seen that the butterfly diversity in the Kedung Klurak Tourism Area is classified as high. According to Subedi et al. (2021), the Shannon-Wiener diversity index provides a statement about the composition of the species community; the higher the number, the higher the species diversity (H' ≥ 3.00). This shows that the Kedung Klurak Tourism Area is diverse and characterized by the discovery of diverse butterfly species with abundant numbers due to biotic factors such as vegetation for the survival of butterflies in the Kedung Klurak Tourism Area.

Figure 2. Butterfly species found in Kedung Klurak Tourism Area, Mojokerto District, East Java, Indonesia. A. *Potanthus ganda*, B. *Pseudocoladenia dan*, C. *Nacaduba kurava*, D. *Taraka hamada*, E. *Chersonesia rahria*, F. *Doleschallia polibete*, G. *Junonia erigone*, H. *Junonia iphita*, I. *Neptis hylas*, J. *Orsotriaena medus*, K. *Tirumala hamata*, L. *Tanaecia trigerta*, M. *Ypthima pandocus*, N. *Graphium sarpedon*, O. *Papilio polytes*, P. *Troides helena*

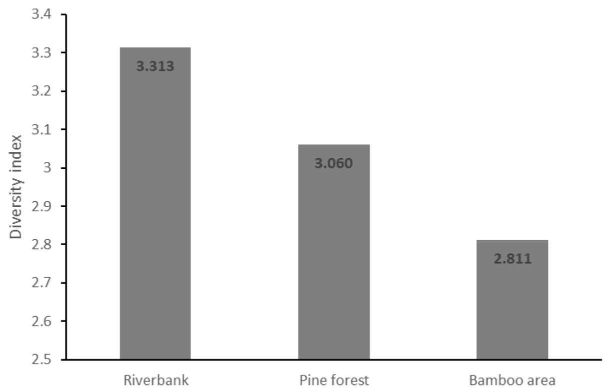

Figure 3. Results of butterfly species diversity at Kedung Klurak Tourism Area, Mojokerto District, East Java, Indonesia

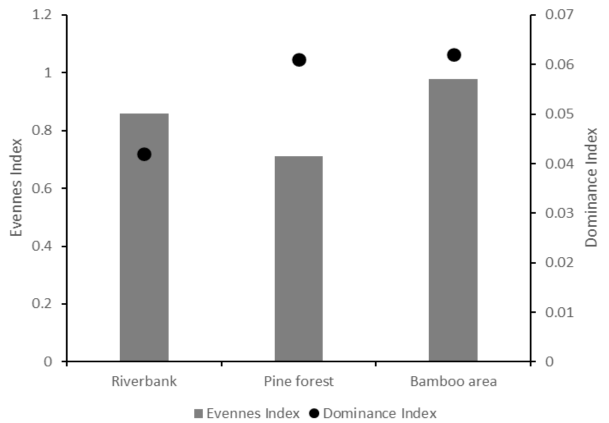

Figure 4. Results of evenness and dominance of butterfly species at Kedung Klurak Tourism Area, Mojokerto District, East Java, Indonesia

Table 1. List of butterfly species in Kedung Klurak Tourism Area, Mojokerto District, East Java, Indonesia

Family	Species	Relative abundance (%)			
		Riverbank	Pine Forest	Bamboo Area	Total
Hesperiidae	*Pelopidas mathias* (Fabricius, 1798)	5.42	3.66	0.00	3.88
	Potanthus ganda (Fruhstorfer, 1911)	2.08	7.33	0.00	4.22
	Pseudocoladenia dan (Fabricius, 1787)	1.25	7.33	0.00	3.88
Lycaenidae	*Heliophorus epicles* (Godart, 1823)	6.25	3.66	0.00	4.22
	Nacaduba kurava (Moore, 1858)	3.33	5.13	0.00	3.71
	Taraka hamada (Druce, 1875)	0.00	1.10	0.00	0.51
	Udara dilectus (Moore, 1879)	2.08	1.10	0.00	1.35
	Zizula hylax (Fabricius, 1775)	5.00	1.47	0.00	2.70
Nymphalidae	*Chersonesia rahria* (Westwood, 1857)	5.83	0.00	12.50	4.05
	Doleschallia polibete (Cramer, 1782)	5.83	3.66	0.00	4.05
	Euploea mulciber (Cramer, 1777)	1.25	1.10	6.25	1.85
	Junonia atlites (Linnaeus, 1763)	5.42	0.00	0.00	2.19
	Junonia erigone (Cramer, 1775)	0.83	2.20	5.00	2.02
	Junonia hedonia (Linnaeus, 1764)	6.25	2.56	3.75	4.22
	Junonia iphita (Cramer, 1782)	6.25	13.55	8.75	9.95
	Lethe confusa (Aurivillius, 1897)	0.83	2.20	0.00	1.35
	Neptis hylas (Linnaeus, 1758)	6.25	5.13	0.00	4.89
	Neptis vikasi (Horsfield, 1829)	1.67	0.73	8.75	2.19
	Orsotriaena medus (Fabricius, 1775)	0.42	1.10	6.25	1.52
	Parantica aspasia (Fabricius, 1787)	3.33	0.00	3.75	1.85
	Tanaecia trigerta (Moore, 1857)	3.75	1.83	0.00	2.36
	Tirumala hamata (MacLeay, 1826)	2.92	0.00	5.00	1.85
	Ypthima iarba (Nicéville, 1895)	1.25	1.83	7.50	2.36
	Ypthima pandocus (Moore, 1857)	2.50	6.96	6.25	5.06
	Mycalesis horsfieldi (Moore, 1892)	0.00	1.83	3.75	1.35
Papilionidae	*Graphium agamemnon* (Linnaeus, 1758)	0.00	1.47	0.00	0.67
	Graphium sarpedon (Linnaeus, 1758)	1.67	0.00	0.00	0.67
	Pachliopta adamas (Zincken, 1831)	0.00	1.83	0.00	0.84
	Papilio memnon (Linnaeus, 1758)	2.08	0.73	0.00	1.18
	Papilio polytes (Linnaeus, 1758)	0.83	0.37	0.00	0.51
	Troides helena (Linnaeus, 1758)	0.83	0.00	0.00	0.34
Pieridae	*Appias lyncida* (Cramer, 1779)	0.00	9.16	0.00	4.22
	Delias belisama (Cramer, 1779)	2.50	0.73	0.00	1.35
	Eurema blanda (Boisduval, 1836)	1.67	0.00	2.50	1.01
	Eurema hecabe (Linnaeus, 1758)	1.25	0.73	5.00	1.52
	Hebomoia glaucippe (Linnaeus, 1758)	2.50	0.37	2.50	1.51
	Leptosia nina (Fabricius, 1793)	6.67	9.16	12.50	8.60

Table 2. Abiotic factors in the Kedung Klurak Tourism Area, Mojokerto District, East Java, Indonesia

Location	Temperature (°C)	Humidity (%)	Light intensity (lux)	Wind speed (m/s)
Riverbank	32.6	60	22,700	0.3
Pine Forest	34.5	62	20,300	0.2
Bamboo Area	33.2	60	17,100	0.1

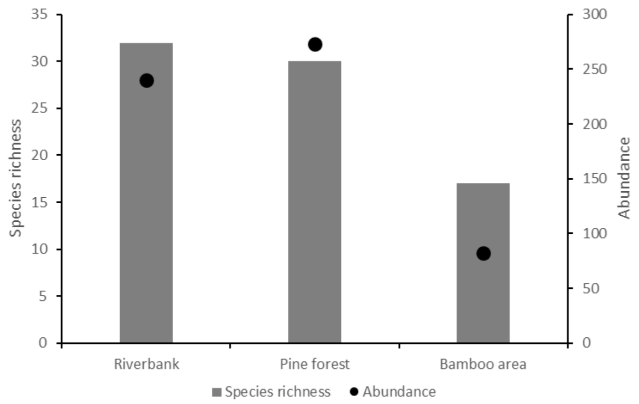

Figure 5. Number of butterfly species and individuals at Kedung Klurak Tourism Area, Mojokerto District, East Java, Indonesia

The value of butterfly species diversity at the riverbank location is H = 3.313, pine forest H = 3.060, and bamboo area H = 2.811. This H value proves that the butterfly species diversity on the riverbank is higher than in pine forests and bamboo areas (Figure 3). The value of butterfly diversity varies because each location has different environmental conditions. Butterfly species diversity is also influenced by plant food availability and is closely related to physical environmental factors such as temperature, humidity, and light intensity. Other influencing factors are biological factors that include vegetation and animals that are in the vicinity (Koneri et al. 2020). Temperature and humidity affect all levels of biological organization, especially butterfly insects (Abram et al. 2017). This is supported by the opinion of Xiong et al. (2017), which state that temperature and humidity play an important role in the diversity of animals around them. Light intensity is an abiotic factor that can affect insects' activity, including butterflies, because it can affect butterflies in carrying out their activities (Perks and Goodenough 2020). The butterflies will use it at optimal light intensity for sunbathing and foraging; if it is low or too high, they use it to rest and shelter (Lestari et al. 2018).

Based on the data obtained, it shows that the average temperature and light intensity in the Kedung Klurak Tourism Area are in the pine forest (34.5°C), riverbank (32.6°C), and bamboo area (33.2°C) (Table 2). This shows that the temperature in the Pine Forest is higher than in the riverbank and bamboo area. While the light intensity on the riverbank is higher (22,700 Lux) compared to the bamboo area (17,100 Lux), The humidity in the pine forest is greater (62%) than on the riverbank and bamboo area (60%). While the wind speed on the riverbank is higher (0.3 m/s) than the bamboo area (0.1 m/s), The thinner canopy on the riverbank makes the light intensity higher. It will affect the temperature, air, and humidity at the location. Meanwhile, the slightly dense environmental conditions and the large number of trees in the Pine Forest inhibit the rate of temperature, air, and sunlight intensity. Hence, the humidity value at this location is higher.

The evenness index value of butterfly species in Kedung Klurak Tourism Area is E = 0.928, so it can be seen that the evenness of butterfly species in Kedung Klurak Tourism Area is high. According to Ashari et al. (2024) the evenness index value of $0 \leq 0.4$ is in the low category, $0.4 \leq 0.6$ is in the medium category, and $0.6 \geq$ is in the high category. The butterfly evenness index value at the riverside location is E = 0.859, pine forest E = 0.711, and bamboo area E = 0.978. This proves that the evenness value of butterfly species in the bamboo area is higher than that of butterfly species in the riverbank and pine forest (Figure 4). The butterfly dominance index value in the Kedung Klurak Tourism Area is D = 0.043, which is classified as low. This is stated by Diba et al. (2021), where the dominance index is categorized into three criteria, namely $0 \leq 0.50$ including the low category, $0.50 \leq 0.75$ including the medium category and $0.75 \leq 1.00$ including the high category. The dominance index value of butterfly species in the riverside location is D = 0.041, pine forest D = 0.061, and bamboo area D = 0.062. This indicates that no butterfly species dominate the bamboo area habitat type. Meanwhile, the smallest species evenness value was found in the pine forest, where several butterfly species dominated in the number of individuals of each species.

The Evenness index is the composition of each individual of a species present in a community. The evenness index (E) is a good predictor of determining dominance in an area. The dominance index (D) is one way to determine how much a group dominates other groups. The greater the dominance index (D) value, the greater the tendency for certain species to dominate (Yuliana et al. 2020). The presence of an insect species in a habitat is influenced by abiotic factors such as temperature, air, humidity, light intensity, vegetation, and food availability. Light intensity is an environmental factor that affects the increase in air temperature, ability to see, flight activity, foraging, mating, egg laying, and the species' metabolic processes (Taradipha 2019).

On the riverbank, 32 species were found, and there were a total of 240 individuals (Figure 5). The species found on the riverbank had the highest number compared to the pine forest and bamboo area, which is one of the uniqueness of the riverside location. The riverbank has an open habitat and higher butterfly diversity than pine forests and bamboo areas. In riverside locations, vegetation commonly grows grasses, herbs, shrubs, and shrubs. Therefore, it can be concluded that canopy and vegetation strongly influence the presence of butterflies (Ruslan et al. 2022).

Pine forest is an open area growing around *Pinus* sp., and we often encounter many butterflies. The species found only in this pine forest are *Appias lyncida, Graphium agamemnon, Taraka hamada*, and *Pachliopta adamas*. Pine forest habitat is an area of pine trees overgrown with shrub vegetation, grasses and slightly closed canopy cover conditions so that several species can be found in this habitat.

The bamboo area around Kedung Klurak Tourism Area is one in which *Bambusa* sp. and herbaceous plants become butterfly perches. The bamboo area has a closed habitat and environmental conditions, riparian vegetation, a high canopy density, and is located close to the river flow. The canopy cover that dominates this location causes light to be unable to enter the environment, so the temperature decreases and humidity becomes high (Zulaikha and Bahri 2021). In the bamboo area, the species and abundance were the least compared to the riverbank and pine forest. This is because the bamboo area has a closed habitat, so it has the least butterfly diversity compared to the riverbank and pine forest, which are open habitats. In the bamboo area, the presence of a canopy greatly affects the low intensity of incoming sunlight; therefore, it affects the low heterogeneity of butterfly host plants, resulting in minimal butterfly presence (Ruslan et al. 2022).

The impact of climate change on butterfly diversity in the Kedung Klurak Tourism Area in the future may experience an increase in average temperature and changes in rainfall patterns due to erratic climate change. This may affect the availability of food resources for butterflies and their life cycle. While, the impact of changes in environmental factors may include disturbance from human activities in the Kedung Klurak Tourism Area, such as development and conversion of green open spaces. In Kedung Klurak Tourism Area, there are developments such as swimming pools, eating places, rivers and waterfalls with surrounding vegetation. The area is often used as a campsite or for other activities. Environmental changes at the location reflect anthropogenic intervention, which can change the dynamics of the ecosystem and be a threat to butterflies. One of the threat factors for butterflies in tourist areas is conversion. The conversion of green open space functions as a threat to butterflies because it can eliminate the presence of plants that host butterflies in tourist areas (Murti et al. 2017).

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Modeling climate change impacts under future CCM3 scenario on sorghum (*Sorghum bicolor*) as an drought resilient crop in tropical arid Lombok Island, Indonesia

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Abstract. *Wibowo AA, Meylani V. 2024. Modeling climate change impacts under future CCM3 scenario on sorghum (*Sorghum bicolor*) as an drought resilient crop in tropical arid Lombok Island, Indonesia. Intl J Trop Drylands 8: 35-43.* The arid ecosystems and drought conditions exacerbated by climate change and rising CO_2 levels necessitate the identification of alternative drought-tolerant crops. *Sorghum bicolor* L. has emerged as a promising option due to its resilience to drought. However, there is dearth of information regarding its future potential distribution, particularly in arid regions like Lombok Island, Indonesia, where sorghum is being considered as a viable alternative to ensure food security. This study employs Maximum Entropy (MaxEnt) modeling, incorporating environmental and bioclimatic variables, along with the National Center for Atmospheric Research (NCAR) Community Climate Model (CCM3) scenario reflecting doubled CO_2 levels, to model the future potential distribution of *S. bicolor*. The model projects a total suitable habitat area of 1,875 km^2, constituting 39.56% of Lombok Island's land area. Notably, very high-suitability areas of 175 km^2, and high-suitability areas of 200 km^2 encompass 3.69% and 4.22% of the island's territory, respectively, predominantly concentrated in the southern region of the island and characterized by low precipitation and high temperatures, particularly at altitudes ranging from 0 to 1,000 meters. The model's performance, evaluated using the Area Under the Curve (AUC), yields a score of 0.725, indicating a good level of accuracy. Key factors influencing sorghum distribution include annual precipitation (68.69%), isothermality (9.56%), temperature seasonality (9.56%), precipitation seasonality (8.69%), and annual mean temperature (3.47%). The CCM3 model forecasts an expansion of sorghum distribution toward the north, occupying approximately 6.25% of Lombok's total area. These findings highlight sorghum's adaptability and resilience to future climate changes, positioning it as a valuable resource for sustainable agriculture in arid environments.

Keywords: Arid, CCM3, El Nino, food security, MaxEnt

Abbreviations: MaxEnt: Maximum Entropy, NCAR: National Center for Atmospheric Research

INTRODUCTION

Lombok Island, situated in eastern Indonesia as part of the Lesser Sunda Island archipelago, is characterized by arid habitats and climates, predominantly consisting of shrublands and grasslands. The island's arid environment, exacerbated by the climate phenomena known like El Nino, has led to extensive dry seasons, threatening crop supplies, particularly rice. Approximately 8,400 hectares of rice fields on Lombok Island have been impacted by El Nino, highlighting the vulnerability of rice cultivation in such dry conditions (Yasin et al. 2004). Over the period from 1980 to 2020, Lombok Island experienced 13 extremely dry seasons (Yanti et al. 2022), accounting for 25.46% of all natural disasters and climate-extreme events. These dry spells lasting for four months on an average, have resulted in a significant decline in annual precipitation (1,900 mm from 2,702 mm), leading to famine situations (Akbar et al. 2021). In response to these challenges, *Sorghum bicolor* L., known for its drought-resilient properties, has emerged as a potential solution. Despite the low precipitation of 300 mm, sorghum requires only 350-400 mm of water annually Ruiz-Giralt et al. (2023), making it well suited for cultivation in arid environments (Zbigniew 2014). Sorghum also offer nutritional benefits, being rich in fiber and protein (McCann et al. 2015). However, it's worth noting that drought stress may impact sorghum's nitrogen uptake in the soil Sarshad et al. (2021).

To modeling the potential impacts of climate change, particularly increased CO_2 levels, the fourth iteration of the National Center for Atmospheric Research (NCAR's) Community Climate Model (CCM), namely CCM3, has been utilized. This model simulates a twofold increment of CO_2 concentration in the atmosphere, providing insights into future climate scenarios (Chen et al. 2003). For modeling species distribution and habitat suitability, various approaches exist, including statistical liner models like Generalized Additive Model (GAM) and the Generalized Linear Model (GLM), geographical analysis-based models such as domain and biomapper, and more recent Maximum Entropy (MaxEnt), in particular, offers several advantages in terms of capacity, data requirements, accuracy, and the ability to discriminate environmental variables (Marcer et al. 2013; Stephenson et al. 2022).

In Indonesia, sorghum has been considered a substitute rice (Paesal et al. 2021), and the Government of Indonesia has planned allocation of 115,000 ha of land for sorghum farming in 2023 and an additional 154,000 ha in 2024. However, there is still limited information on the potential distribution of sorghum under the CCM3 climate change model, especially on Lombok Island. Hence, this study aims to identify potential sorghum farming areas on Lombok Island using MaxEnt modeling. The results of this study are expected to contribute to food security in arid environment of Lombok Island.

MATERIALS AND METHODS

Study area

This study was conducted on Lombok Island (115.816605°-116.609078° E and 8.085101°-8.972345° S), located in West Nusa Tenggara Province, Indonesia (Figure 1). This island is part of the Lesser Sunda Islands, separated from Bali to the west by the Lombok Strait and from Sumbawa to the east by Alas Strait. Lombok Island comprises of four districts, namely West Lombok, Central Lombok, East Lombok, North Lombok, along with Mataram City. This island has a total area of 5,435 km^2. Positioned amidst the seas, Lombok Island is bordered by the Bali Sea to the north and the Timor Sea to the south. .

Mount Rinjani, a stratovolcano and the second-highest volcano in Indonesia at 3,726 meters (12,224 ft), is situated at the island's center, rendering Lombok the 8^{th}-highest island in the country. The ecosystems of Lombok Island exhibit dominance by patchy and fragmented savanna and grassland ecosystems, alongside lowland tropical rain forests, upland tropical forests, and sub-alpine vegetation, owing to the dry temperature and arid ecosystems. Additionally, the island features numerous meadows and shrublands (Sapta et al. 2015).

Areas of southern Lombok Island are designated as arid ecosystems and are vulnerable to water shortages due to inadequate rainfall and a scarcity of water sources. In October, the maximum air temperature ranges from 33.4°C to 35.8°C, while the lowest air temperature ranges from 20.6°C to 21.7°C. Humidity in West Nusa Tenggara Province fluctuates between 68% and 88%, with average wind speeds ranging from 2.30 to 5.30 knots and maximum wind speeds reaching 5 knots. During dry seasons, annual rainfall rates may drop as low as 1,900 mm.

Procedures

Sorghum occurrence surveys

The study methodology followed the methods developed by Semu et al. (2021), including species occurrence, environmental variables, and model evaluation. To document the presence of sorghum in real time, field surveys and explorations were carried out across Lombok Island from September to October 2023. In September, surveys were conducted in North Lombok, Timur and Tengah, while in October, West Lombok and Mataram City were surveyed. Information retrieved from The Herbarium Bogoriense, Indonesia, a database developed from literature reviews, and the Agency for Agriculture and Forestry of the Ministry for Agriculture and Forestry, Indonesia, were used to identify sorghum during field surveys. The Global Positioning System (GPS) of the Garmin Etrex 30 was used to capture the geographic coordinates of *S. bicolor* presences in the field. Subsequently, the data were transformed into Microsoft Excel and exported in CSV format for utilization in MaxEnt habitat suitability modeling.

Environmental variables

A variety of environmental parameters were included in this study (Table 1), including the most important bioclimatic variables identified by Dong et al. (2023) and Arshad et al. (2022). These variables consist of the yearly mean temperature (°C), yearly precipitation (mm), isothermality (%), temperature seasonality, and precipitation seasonality. Bioclimatic variables from the WorldClim global climate database (www.worldclim.org, version 2.1) have been extensively used in habitat suitability modeling in the Asian region (Pradhan and Setyawan 2021). Additionally, geophysical information in the form of altitude and topography was obtained through the Shuttle Radar Topography Mission (SRTM), with a spatial resolution of 30 meters.

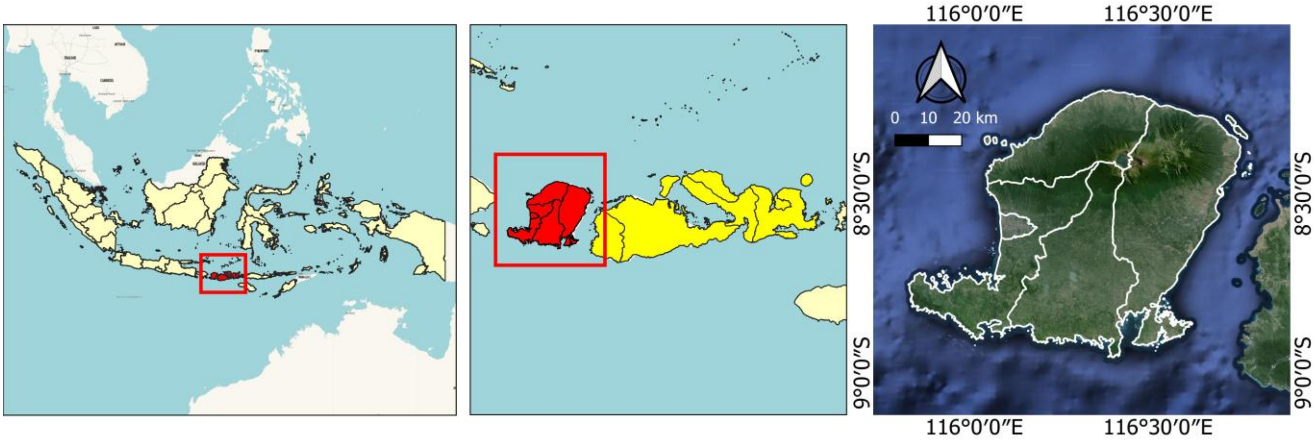

Figure 1. Location map of the study area in Lombok Island, West Nusa Tenggara Province, Lesser Sunda Island archipelago, Indonesia

Table 1. Environmental variables used in this study

Variables	Sources	Format	Unit
Annual mean temperature	www.worldclim.org	Image data in Raster	°C
Isothermality	www.worldclim.org	Image data in Raster	%
Annual precipitation	www.worldclim.org	Image data in Raster	mm
Temperature seasonality	www.worldclim.org	Image data in Raster	dimensionless
Precipitation seasonality	www.worldclim.org	Image data in Raster	dimensionless
Topography and altitude	30 m SRTM	Image data in Raster	m
Current climate	www.worldclim.org	Image data in Raster	°C
Future climate CCM3 $2\times CO_2$	www.worldclim.org	Image data in Raster	°C

To produce an accurate and informative habitat suitability model, these environmental variables were selected based on their significant influence. The contribution of each environmental variable to the final model of sorghum distribution was assessed using Jackknife analysis. Two crucial elements for comprehending and quantifying the environmental variable's contribution and significance to the MaxEnt model were the contribution percentage and permutation. Some environmental variables were not employed in the model creation due to their negligible contribution. These variables exhibited an average contribution percentage of less than 6%, or a modest permutation relevance of less than 6%.

Suitability analysis

MaxEnt analysis was utilized to generate projected suitability maps of *S. bicolor* throughout Lombok Island. Suitability analysis was carried out utilizing the MaxEnt tool incorporated in dismo package within R platform version 3.6.3 (Mao et al. 2022), along with relevant R packages required for mapping viz. maptools, rgdal, raster, and sp (Lemenkova 2020), and the BioClim module inside the DIVA-GIS platform (Xie et al. 2020). The input environmental variables for MaxEnt included mean annual temperature, annual precipitation, isothermality, seasonality of temperature and precipitation.

The contribution and influence of each environmental variable on the *S. bicolor* habitat suitability model were ascertained within the model through a Jackknife test. The receiving operating curve (AUC) area was utilized to evaluate performance of the model. AUC serves a versatile independent threshold statistic, capable of assessing how effectively a model can differentiate between the presence and absence of a species to determine its potential distribution. According to Zhu et al. (2017), the range of AUC values spans from 0, considered least suitable, to 1. A value nearing 1 indicates that the final model is very effective, informative and more accurate, while a value below 0.5 suggests that that the real-world species occurrence is uncommon and the model provides no more utility than random and unrevealing data. Wei et al. (2018) delineate five different habitat appropriateness levels on the MaxEnt model suitablity map: 0 for inappropriate, 1 for suitability at a moderate level, 2 for suitability at a medium level, 3 for suitability at a high level, and 4 for suitability at a very high level. The analytical outcomes from the MaxEnt models predicting the suitability ranges for *S. bicolor* were subsequently imported into GIS for further examination and visualization.

Model evaluation

The model evaluation in this study follows the approach outlined by Reddy et al. (2015) and Song et al. (2023). Area Under the Curve (AUC) analysis was employed to evaluate the model, with the MaxEnt model used to determine the percentage contribution of each variable to the species distribution. Each variable's contribution to the species' distribution is represented by the percentage contribution. The Area Under the Curve (AUC), combined with the Receiver Operating Characteristic (ROC) curve, was used to evaluate the accuracy of the model's predictions. The variables for the MaxEnt model were selected following Zhao et al. (2018). Jackknife was used to methodically eliminate every variable and assess the most important topography and bioclimatic environmental variables. Jackknife test enable the identification of the most influential variables to ascertain the potential species distribution. The response curve generated by the model indicates the relationship between topographic and bioclimatic variables and the potential habitat for the species. The proportional percentage contributions of each environmental variable to the MaxEnt model were computed accordingly.

CCM3 model

This study employed two models. The first utilized the MaxEnt model with the dismo package in R to predict the current potential distribution of sorghum. The second model employed CCM3 model with the BioClim module of DIVA-GIS to project both the current and future potential sorghum under doubled CO_2 conditions. The variables used to develop the current and future potential distribution of sorghum under BioClim model (Table 1) included current climate data with 10 minute resolution and future climate data under the CCM3 $2\times CO_2$ scenario, also with a 10-minute resolution (Govindasamy et al. 2003).

RESULTS AND DISCUSSION

Sorghum occurrences

According to the collected occurrence data and survey from September to October 2023, *S. bicolor* was predominantly observed (Figure 2) within the 116°-116.5° E and 7.5°-8° S in the northern coasts of island and between 116°-116.5° E and 8.5°-9° S in the southern coasts of island (Table 2). A total of nine instances of sorghum sightings were recorded. Across Lombok Island, sorghums were predominantly found in low-lying areas with altitudes ranging from 0-500 m. Notably, sorghum occurrence were not found in high-altitude regions exceeding 500 m, primarily within the hilly terrain in the northern part of the island. Furthermore, during our ground field surveys, no evidence of sorghum presence was found in the western part or in West Lombok Districts.

Model evaluation and validation

The reliability of modeling outcomes was evaluated and validated, with the area under the Receiver Operating Characteristic (ROC) curve (AUC), serving as a key metric. In this study, the AUC value for the MaxEnt model was 0.725 under the current conditions (Figure 3). This indicates that the MaxEnt model exhibited good predictive performance regarding the potential distribution of sorghum on Lombok Island.

Environmental variable distributions

Spatial distributions of environmental variables across Lombok Island, consisting of mean annual temperature, annual precipitation, isothermality, seasonality of temperature, and precipitation are depicted in Figure 4. Analysis reveals that the annual mean temperature tends to be lower in the northern regions, particularly at high altitudes. While, lower altitudes in the southern areas exhibit higher annual mean temperature alongside reduced precipitation. In contrast, the northern regions, characterized by lower temperatures, experience higher annual precipitation rates and greater precipitation seasonality. Additionally, a peak in isothermality was observed in the northern parts of the island.

Environmental variable contributions

Table 3 presents the results of Jackknife testing on the % contribution and permutational importance of predictor variables. Notably, the most influential variables, ranked from highest to the lowest contribution, include annual precipitation (68.69%), isothermality (9.56%), temperature seasonality (9.56%), precipitation seasonality (8.69%), and annual mean temperature (3.47%) These finding affirmed that annual precipitation, followed by either isothermality or temperature seasonality, were the most relevant variables for predicting potential habitat suitability for sorghum in the study area.

Table 2. The coordinates of occurrence points of sorghum collected from ground field surveys

Occurrence Points	Longitude	Latitude	Districts	Sources of Occurrence Points from Ground Surveys
1	116.258343°	-8.735645°	Lombok Tengah	September 2023
2	116.077362°	-8.569429°	Mataram City	October 2023
3	116.282666°	-8.739216°	Lombok Tengah	September 2023
4	116.198577°	-8.313063°	North Lombok	September 2023
5	116.439969°	-8.291627°	North Lombok	September 2023
6	116.272605°	-8.288367°	North Lombok	September 2023
7	116.651439°	-8.515896°	East Lombok	September 2023
8	116.486992°	-8.756678°	East Lombok	September 2023
9	116.477366°	-8.882698°	East Lombok	September 2023

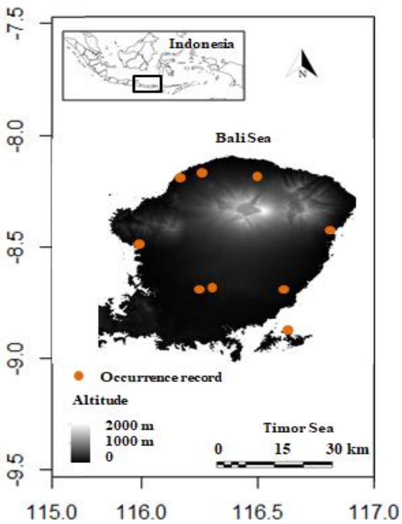

Figure 2. Current occurrences of *Sorghum bicolor* across Lombok Island in various altitudes based on ground field surveys

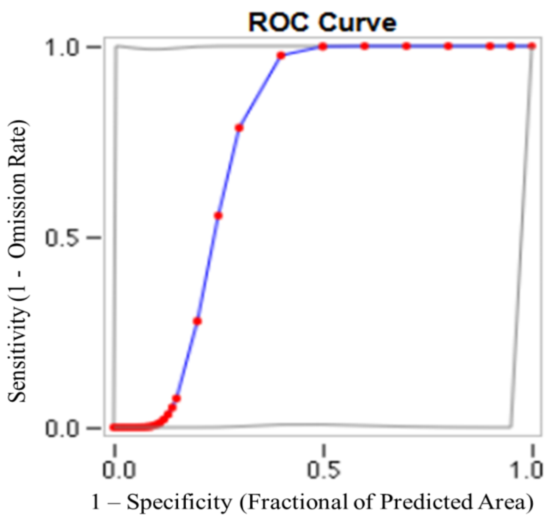

Figure 3. The Receiver Operating Characteristic (ROC) curve result of the MaxEnt modelling

Table 3. Relative contributions of the environmental variables to the MaxEnt.

Environmental Variables	Relative Contribution (%)
Annual mean temperature	3.47
Isothermality	9.56
Annual precipitation	68.69
Temperature seasonality	9.56
Precipitation seasonality	8.69

Response curves of environmental variables

The response curves depicted in Figure 5 illustrate the relationships between the probability of occurrence and the habitat suitability level of sorghum with each environmental variable. Notably, the species response curve delineates a negative relationship with several environmental variables, including annual precipitation, isothermality, temperature seasonality, and precipitation seasonality. While, the annual mean temperature was the only variable showing positive relationships. These response curves underline the considerable influence of these environmental variables on the distribution of sorghum across Lombok Island. Specifically, the suitability level for growth increases with rising temperature, ideally ranging between 24 to 25°C or higher. Similarly, the suitability level for growth increases as precipitation and isothermality decrease, ideally aligning with areas with annual precipitation of less than 1,000 mm. This relationship shows the preference for and adaptation of sorghum to the arid ecosystems characterized by drought conditions.

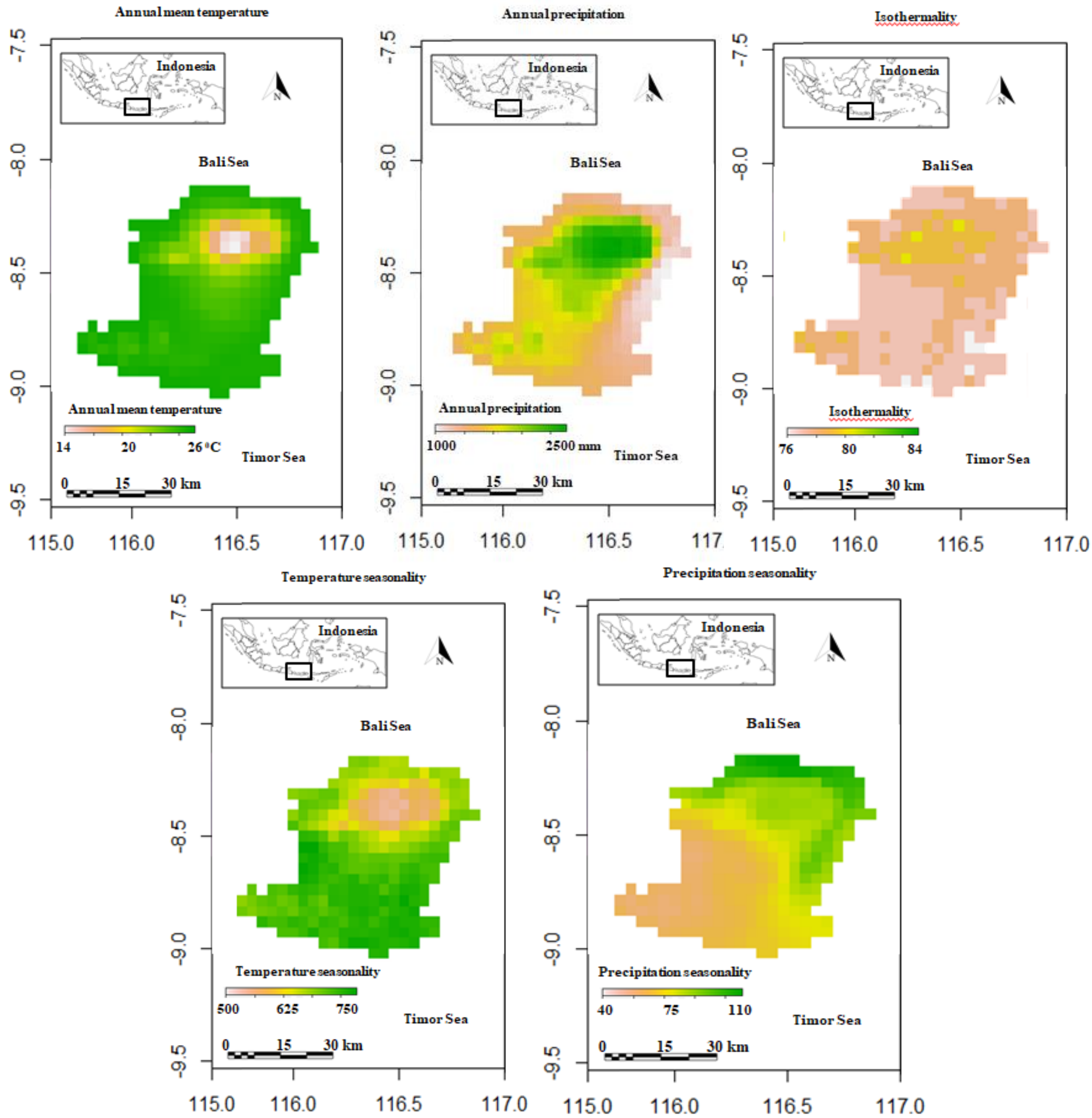

Figure 4. Distributions of environmental variables including annual mean temperature (°C), annual precipitation (mm), isothermality (%),temperature seasonality (dimensionless), and precipitation seasonality (dimensionless) in Lombok Island, Indonesia

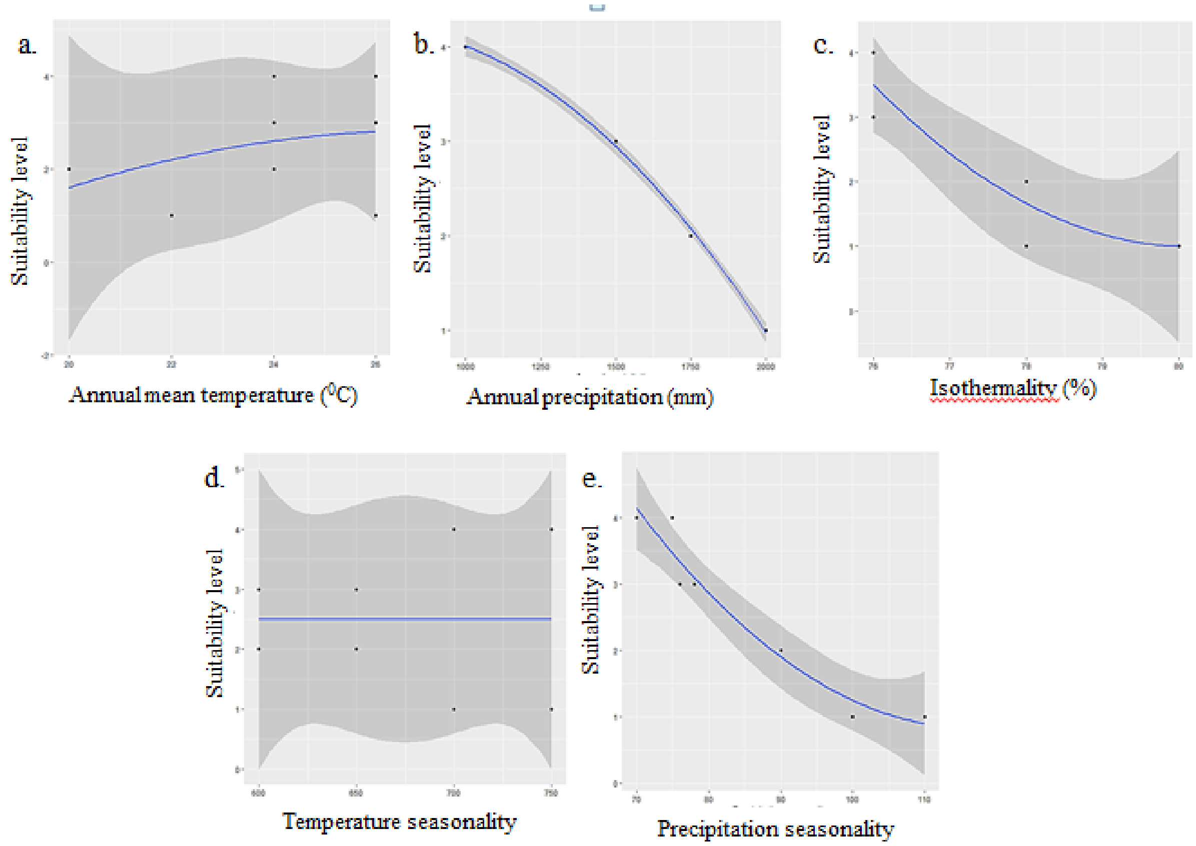

Figure 5. The response curves with 95% CI (shaded area)for the contributing variables for sorghum habitat suitability levels including (a) annual mean temperature (°C), (b) annual precipitation (mm), (c) isothermality (%),(d) temperature seasonality (dimensionless), and (e) precipitation seasonality (dimensionless) in Lombok Island, Indonesia

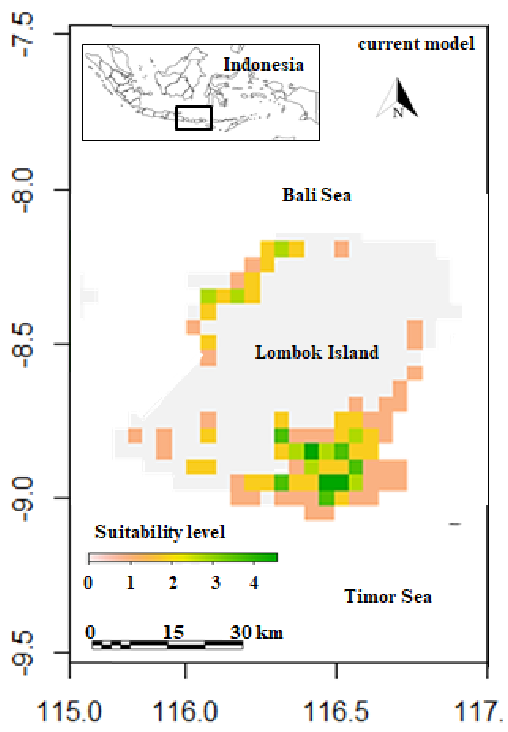

Figure 6. Distribution of current potential suitable areas for sorghum on the Lombok Island, Indonesia based on MaxEnt (Suitability level 0: unsuitable,1: low suitability, 2: medium suitability, 3: high suitability, 4: very high suitability)

Current suitability model

The current suitability model for sorghum, using MaxEnt model based on R dismo package, was classified, mapped, and evaluated to calculate the land area for each identified suitable habitat (Figure 6). Suitable habitats for sorghum on Lombok Island were predominantly located in the northern and southern regions, primarily in the low-lying areas with altitudes ranging of 0-1,000 m. Conversely, the northern parts, characterized by elevations exceeding 1,000 m and predominantly highlands, lacked suitable areas for sorghum cultivation. The total potential suitable habitat for sorghum, as projected by the MaxEnt modeling, was estimated at around 1,875 km^2 or equivalent to 39.56% of Lombok Island's total area (Table 4). This estimation includes around 175 km^2 of land classified as very highly suitable (3.69%), 200 km^2 as highly suitable (4.22%), 625 km^2 as moderately suitable (13.18%), and 875 km^2 as least suitable (18.46%) on Lombok Island.

Table 4. Predicted suitable area in km^2 for *Sorghum bicolor* habitat suitability in Lombok Island, Indonesia based on MaxEnt

Suitability Levels	Area in km^2	% of Lombok Island's Total Area
Low suitability	875	18.46
Medium suitability	625	13.18
High suitability	200	4.22
Very high suitability	175	3.69
Total	1,875	39.56

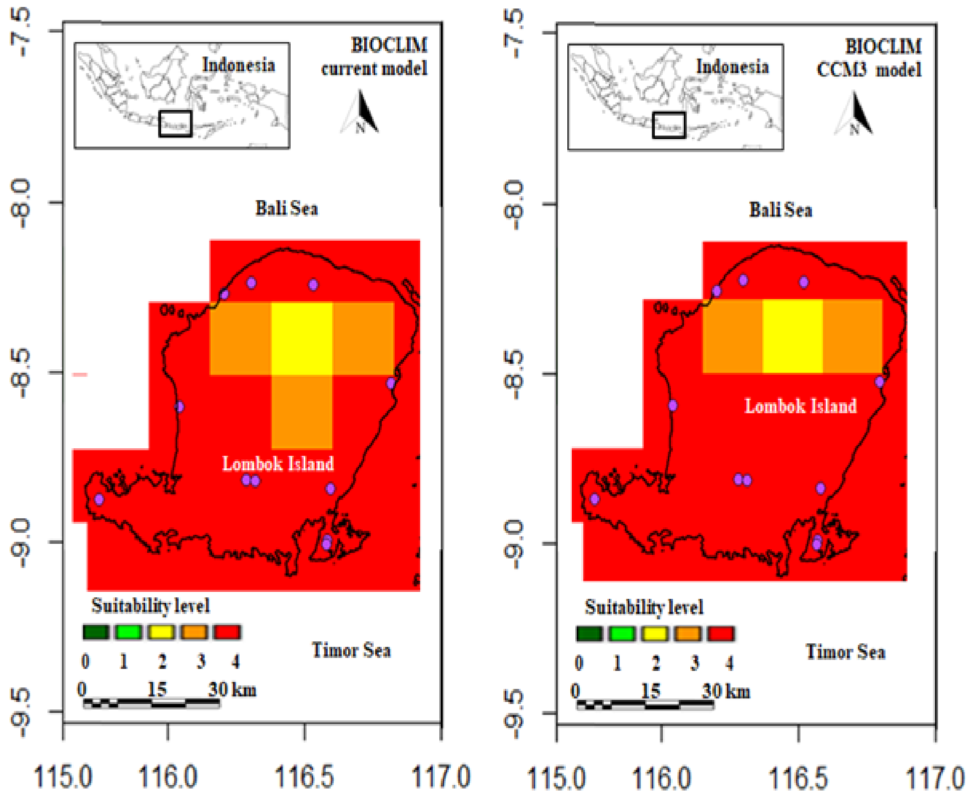

Figure 7. Distribution of current (left) and future (right) potential suitable areas for sorghum on the Lombok Island, Indonesia under CCM3 scenario based on BioClim (Suitability level 0: unsuitable,1: low suitability, 2: medium suitability, 3: high suitability, 4: very high suitability)

Future CCM3 suitability model

The impact of climate change on suitable areas for sorghum was modeled using CCM3 based on DIVA-GIS BioClim module, assuming a near doubling of CO_2 levels (Figure 7). The model reveals a northward expansions of sorghum habitats in response to elevated CO_2 concentrations and temperature. Approximately 6.25% of Lombok's total land area, previously unsuitable for sorghum cultivation in the northern regions, are now deemed suitable. This indicates that climate change may promote the presence and distribution of sorghum on the island.

Discussion

Given sorghum's drought tolerance, it's expected to be particularly sensitive to changes in the climate and precipitation. This study aimed to predict how various climate variables would affect sorghum as a potential crop. This is the first study to explore sorghum range expansions using the MaxEnt species distribution model, particularly in the Southeast Asia. Carefully selected occurrence data for sorghum and relevant environmental variables were validated to ensure model accuracy. The AUC was used to optimize and evaluate model parameters for sorghum, revealing good prediction accuracy. These findings align earlier investigations (Table 5). While, sorghum's potential distribution has been modeled in China, India, and Africa, information remained scarce in the Southeast Asia region.

Sorghum distributions on Lombok Island was found to be influenced primarily by precipitation, exhibiting a negative correlation, while demonstrating resilience to temperature increases. Mugiyo et al. (2022) emphasized the significant impact of rainfall-related parameters, particularly precipitation, on sorghum's potential applicability. Sorghum's characteristic drought tolerance, as highlighted by Niu et al. (2022), emphasizes its ability to withstand varying climatic conditions. The study revealed that environmental variables such as temperature and precipitation collectively contributed 86.2% to the model, indicating sorghum heat resistance and preference for locations with higher temperatures and humidity.

Table 5. Comparisons of sorghum MaxEnt studies in other locations

Locations	AUC	% High Suitable Areas	References
KwaZulu-Natal, South Africa	0.93	13.4	Mugiyo et al. (2022)
China	0.881	na	Niu et al. (2022)
Telangana state, India	na	na	Natarajan et al. (2016)
Kenya, Africa	0.97	na	Kigen et al. (2014)
Lombok island, Indonesia	0.725	3.69-4.22	This study

Temperature seasonality and isothermality were identified as influential factors alongside precipitation variables in this study. This is in line with the findings of Huang et al. (2021), suggesting that plant groups tend to thrive in flat topographies characterized by higher temperature variability, isothermality, and seasonality. Sorghum's potential habitat was estimated to be highly suitable in flat lowlands with elevations below 1,000 m on Lombok Island.

The resilience and adaptation of sorghum to low precipitation are attributed to its physiological and phonological characteristics. During the flowering stage, most plants experience reduced chlorophyll levels, increasing their vulnerability to drought. However, sorghum exhibits an opposite response, producing more chlorophyll to mitigate drought threats (Prasad et al. 2021). The physiological adaptation of sorghum to drought begins at the germination stage, where it delays germination to enhance osmotic potential and reduce water uptake during prolonged dry periods (Abreha et al. 2022). Sorghum is a C4 plant that has evolved to grow at environment above 20°C (Basu et al. 2016), and it has the ability to regulate stomatal closure while sustaining photosynthesis, crucial for minimizing water loss and adapting to arid environments (Rutayisire et al. 2021), which explains the predicted expansion of sorghum to the south of Lombok Island.

Compared to other studies, the percentage of suitable areas identified in this study is relatively low, attributed to Lombok Island's diverse topography and altitudinal variations, which have corresponding effect on the climatic variables, constraining potential spread of sorghum. For instance, the northern parts of Lombok Island, characterized by highlands characterized with high precipitation and low temperatures, are less conducive to sorghum growth.

The study forecasts an expansion of sorghum's suitable habitats to the north of Lombok Island in the future, driven by climate change. However, presence of sorghum still faces threats from non-climatic factors and rising CO_2 levels, including anthropogenic activities (Gafna et al. 2017), livestock grazing (Mahmoudi 2012), and invasive plant species (Čuda et al. 2015; Iqbal et al. 2020). Hence, future modeling efforts should consider these issues to model sorghum's suitable habitats.

The utlilization of maximum entropy model in this study provides insights into sorghum's spatial distribution and habitat suitability on arid Lombok Island. The results and species distribution model serve as valuable resources for devising future strategies to understand the impact of climate variables on sorghum's potential distributions in this region. The study illustrates how farmers and agriculture planners can leverage MaxEnt modeling approaches to identify areas where sorghum cultivation practices yield optimal outcomes. This emphasizes the importance of prioritizing areas to maintain sorghum's natural geographical distribution and ensure food security, primarily on the arid Lombok Island. Key environmental variables affecting sorghum distribution on the arid Lombok Island were identified as annual precipitation, isothermality, temperature seasonality, precipitation seasonality, and annual mean temperature, contributing to 68.69%, 9.56%, 9.56%, 8.69%, and 3.47% of the effects, respectively. The total suitable distribution region of sorghum on arid Lombok Island accounted for 39.56% of the island's total land area, with very high-suitability areas covering 175 km^2 (3.69%) and high-suitability areas covering 200 km^2 (4.22%), primarily concentrated in the southern parts of the island at altitudes of 0-1,000 m and characterized by low precipitation and high temperature.

Furthermore, the CCM3 model, accounting for double CO_2 concentrations, suggests that sorghum-suitable areas would expand northward in the future, with no significant changes observed in the current suitable areas. This resilience to climate change highlights sorghum's adaptability and ability to counter environmental challenges.

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Evaluation of the current situation of sheep production characteristics in Nkasi District, Tanzania

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Abstract. *Kapongo RY, Mbaga SH. 2024. Evaluation of the current situation of sheep production characteristics in Nkasi District, Tanzania. Intl J Trop Drylands 8: 44-57.* This study was conducted in two divisions, Namanyere and Mkwamba of Nkasi District in the Rukwa Region, Tanzania, to assess the sheep production status of smallholder farmers. Eight wards, namely Namanyere, Mtenga, Chala, Swaila, Kipande, Sintali, Kate, and Isale, were surveyed from November 2010 to April 2011. The random sampling technique was adopted to get 20 respondents from each selected ward. Two villages from each ward were chosen randomly, whereby ten respondents were interviewed in each village. A structured questionnaire was used to collect data from smallholder farmers keeping sheep and was complimented by secondary data from the district council offices. The results showed that sheep strains kept mainly by smallholder farmers were variant crosses of local strains and Red Maasai. The strains were deemed tolerant to diseases/parasites, heat, and drought and had better carcasses. Most smallholder farmers adopted an extensive grazing system during both dry and wet seasons. Breeding was uncontrolled; however, rams were selected based on their body sizes, conformation, and performance (e.g., number of lambs per ewe's lifetime, age at first lambing, and lambing intervals). Traits such as disease tolerance, drought, and heat tolerance scored higher for most strains. The average age at first lambing was 6.5 months, the lambing interval was three months, and the average number of lambs per ewe's lifetime was 14. The constraints to sheep production mostly were poor market availability, endemic diseases, and mortality of lambs. On marketing, fewer sheep were sold in the market compared to goats, and the price was 22% lower than that of goats.

Keywords: Farmers, Nkasi, production, Rukwa, sheep

INTRODUCTION

Livestock populations in Tanzania were estimated at 19.2 million cattle, 13.7 million goats, 3.6 million sheep, 1.9 million pigs, and 58 million chickens (MLDF 2010). Sheep and goats are composed of indigenous strains and are widely distributed and adapted to agroecological zones. Smallholder farmers and pastoralists keep them under traditional management systems.

Sheep are more attractive to smallholder farmers because they can multiply and grow faster than cattle at a relatively low cost. They provide a source of income, have two parities per year, are easy to handle, require small grazing areas and little feeds, provide manure, require little initial capital investment, are used in social functions, attain maturity age in a short time, provide meat and have no traditional or religious restrictions compared to pigs (Boutonnet 1999; Mtenga et al. 2003; de Rancourt et al. 2006; Morris 2009). Despite their advantages, sheep production is constrained by the prevalence of diseases, poor nutrition, poor marketing infrastructures, and low genetic potential. In the Rukwa Region, sheep production accounts for 1.6% of the total livestock population. However, in the Nkasi District, sheep production is about 1.9% of the total 296,670 livestock population in the district. The study focused on assessing sheep production status for smallholder farmers because of the socio-economic significance of sheep production in the Nkasi District and Tanzania as a whole.

Sheep are traditionally raised in the Nkasi District, Tanzania, but there are little efforts for improvement despite their socio-economic roles as smallholder farmers. Due to poor sheep husbandry's slow growth, the regular mortality of lambs and adult sheep and low conception rates have been reported (Mtenga et al. 2003). Similarly, delays of ewe on first mating, long lambing intervals, low slaughter weight, and poor mutton marketing are common (Mtenga et al. 2003). Such a situation is caused by many factors, such as poor nutrition, diseases, poor management, low-quality breeds, inbreeding, and inadequate knowledge of sheep production (Mtenga et al. 2003).

In the past, several livestock production improvement programs in the Nkasi District have been implemented by government and development agencies with varying degrees of success. An inadequate knowledge of the need and aspirations of the farmers caused little success in these endeavors. On the other hand, there have been no specific studies on sheep production, and general information on management practices, market availability, production performances, constraints, and their contribution to the livelihoods of smallholder farmers in the district is lacking. Therefore, information is needed to facilitate the design of strategies to improve sheep production in the district. The present study aimed to assess sheep's production status in smallholder production systems of the Nkasi District.

The specific objectives of this study are (i) to describe the desired qualities of sheep kept by smallholder farmers in the Nkasi District; (ii) to determine traditional management practices of sheep kept by smallholder farmers in the Nkasi District; (iii) to assess prices and market availability of sheep inside and outside the district; (iv) to assess production performance and constraints of sheep kept by smallholder farmers.

MATERIALS AND METHODS

Description of the study area

This study was conducted in Nkasi District, Rukwa Region of Tanzania (Figure 1). The district is located to the South-West of Tanzania between latitude 6^{o}58' and 8^{o} 17' South of the equator and between longitude 30^{o}20' and 31^{o}30' East of Greenwich. It borders Mpanda District to the North, Zambia to the South-West, the East, and South-East is boarded by Sumbawanga municipality and the Democratic Republic of Congo to the West. The district has a land area of 13,124 $km^{2,}$ of which 54.4% is arable land, 17% is Katavi game reserve, 28.56% is water bodies, and 4% is others**.** It is a large, sparsely populated district divided into five administrative divisions with 17 wards and 87 registered villages. The study area entails a diversity of farming systems and land use changes. Two divisions, namely Namanyere and Mkwamba, comprising eight wards, were involved in the study from November 2010 to April 2011. Those wards include Mtenga, Chala, Swaila, Kipande, Kate, Sintali, and Isale, dominated by agro-pastoralists and Namanyere, in which agriculture is the dominant economic activity.

According to the 2002 population census, the district has a human population of 207,311, out of which 102,117 were males and 105,194 were females (Nkasi District 2004). The population of Nkasi was estimated to be growing at a growth rate of 4.7% in 2004. 81 % of the population resides in rural areas, and only 19% live in urban areas (URT 2004). About two percent of the population in the district undertook livestock keeping as the main activity, while the majority engaged in crop production. The main types of livestock kept in the district are cattle, goats, sheep, pigs, donkeys, and chickens. Approximately 7.24% of the households have immigrated into the district during the last five years (DALDO 2008). Most of this spectacular growth was due to the immigration of the Sukuma Tribe, who are agro-pastoralists with their cattle, thus reflecting the availability of grazing and agricultural lands. The Nkasi District is largely semi-arid, with bimodal rainfall ranging from 750-1,200 mm and an average altitude of about 1,300 meters above sea level. The short rains are between October and December, whereas the long rains are from February to April. The dominant natural vegetation comprises the plateau woodland occupied by Sukuma agro-pastoralists with a large herd of cattle, goats, and sheep. As a result, soils have natural fertility and are cultivated extensively (DALDO 2008).

Sampling procedure

Purposeful sampling was employed in selecting the study wards based on their accessibility, availability of sheep, prevailing land uses, and socio-economic characteristics. Based on the selected division's sample (n) from each division, it was obtained through the stratification of the population into wards. Five-digit random numbers generated in LIMDEP version 5.1 software matched the name in the ward register that bore the number. The total sample (n=20) was a gross proportionate number of individuals in each stratum from each ward. Four wards were picked in each division, and two villages were selected from every ward.

Smallholder farmers keeping sheep were identified with assistance from extension workers in each ward in the two divisions. For each selected village, ten smallholder farmers keeping sheep were chosen for an interview. At the end of the study, the total number of respondents interviewed in the two divisions was 160 (Table 1).

Data on sheep prices and market availability were collected randomly from sellers and buyers of sheep in the four livestock primary markets using structured questionnaires. Livestock primary markets in the districts are conducted in four wards: Namanyere, Chala, Kipande, and Kate. In each primary livestock market, five buyers and five sheep sellers were interviewed to make up 40 respondents in all primary livestock markets (Table 2).

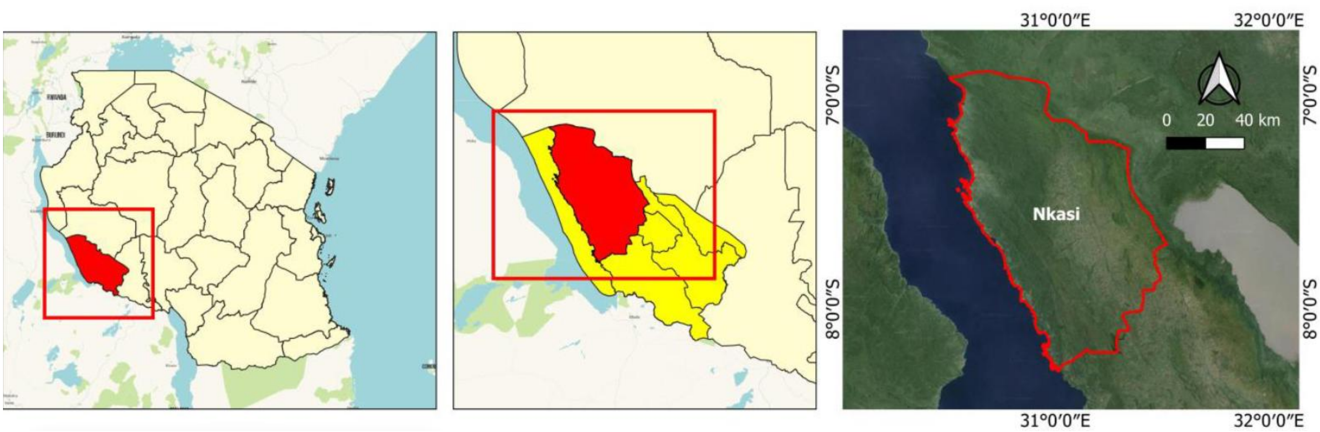

Figure 1. Location of the study area in Nkasi District, Tanzania

Table 1. The sampling frame for smallholder farmers keeping sheep

Division	Ward	Village	Number of respondents
Namanyere	Namanyere	Ipanda, Kakoma	20
	Mtenga	Mashete, Mtenga	20
	Chala	Chala, Kacheche	20
	Isale	Isale, Ntuchi	20
Mkwamba	Swaila	Kasu, Swaila	20
	Kipande	Kantawa, Kipande	20
	Sintali	Nkundi, Sintali	20
	Kate	Ntalamila, Kate	20

Table 2. The sampling frame for the primary livestock market

Division	Primary livestock market (Ward)	Number of respondents
Namanyere	Namanyere	10
	Chala	10
Mkwamba	Kipande	10
	Kate	10

Types and sources of data

Primary data were obtained from rural households in the study area. In addition, a structured questionnaire was administered to a random sample of smallholder farmers in the sample villages. The questionnaire was designed to capture the desired qualities of sheep and information on sheep's traditional management practices, production performances, and constraints faced by smallholder farmers. Furthermore, the study sought information on sheep prices and market availability inside and outside the district. Furthermore, two focus group discussions for each division (8-12 individuals) were used to gather various responses. The conversation taking place during focus group discussions was noted. FGDs were used to identify sheep price and market availability, decision-making on sheep, preferred sheep breeds, and different national policies and programs directed towards the livestock industry in trying to modernize. The interview guide is attached in Appendix 3. In addition, FGD was used to quickly generate more information through interactive learning, knowledge sharing, and assurance of high-level local people's participation in research. That involved relaxed rapport, open dialogue, brainstorming, and mutual sharing of knowledge, skills, and experiences (McCkracken et al. 1988; Chambers 1992). Other techniques used include direct observations. Secondary data were sourced from the district livestock office, unpublished, gray, and published literature from libraries.

Data analysis

Data from questionnaires were coded and analyzed using the Statistical Package for Social Sciences (SPSS 16.0, 2006) computer program. In addition, quantitative data was analyzed, and frequencies, percentages, and means were used to determine the desired qualities of sheep, traditional management practices, prices, market availability, and sheep production performances and constraints. Finally, the recorded information from FGDs was summarised and synthesized according to the checklist used during the discussion.

RESULTS AND DISCUSSION

Overview

The results and discussion of the findings are based on seven sections. The first part of the section provides demographic profiles of the respondents; the second part focuses on sheep strains and preferences kept by smallholder farmers. The third part focused on the traditional management practices of sheep, the fourth part concentrated on sheep's production performances and constraints, and the fifth was based on sheep pricing and market availability. The sixth part explains the preferred animals, prices, and sources in the primary livestock markets. Finally, the last part of the section gives a way forward for improving sheep production.

Demographic profiles of the respondents

The demographic profiles of the respondents examined and presented in this chapter are household profile, source of income, livestock species kept, and household members responsible for sheep activities.

Demographic characteristics of sheep-owning households

Demographic characteristics of sheep-owning households are shown in Table 3. The findings revealed that the leading tribe keeping sheep in the district was the Sukuma (60.6%), while the native comprised Fipa (39.4%). The Sukuma Tribe are agro-pastoralists who emigrated with their herds from different regions of Tanzania to the Nkasi District in search of extensive arable and grazing lands. Also, the study revealed that most of the smallholder families keeping sheep in surveyed wards were male-headed, 81.2%. Under normal situations, in Tanzanian culture, men are the ones who head the family. They are the main speakers considering respondents visited their residential areas during the study.

Furthermore, the results show that 80.6% of the respondents were married, 10.6% single, 6.2% divorced, and 2.5% widowed/widowers. The result showed that 51.9% of the respondents had primary school education, 40% were without school education, and 8.1% attained secondary education. Lack of education was attributed to the long distance to school, and also, in the past, parents were reluctant to send their children to school, and children were considered a source of labor for farm operations. The finding conforms with that reported by Faustine et al. (2002). They observed a low rate of children enrolment in school for the Maasai tribe, partly explained by the fact that pastoralists were less inclined to send their children to school, as they provided an important source of labor in livestock keeping. Education is perceived to be among the factors that influence individuals' perception of innovations before making an adoption decision. It motivates individuals to learn more, attend training, and seek resources or other information regarding livestock production improvement (Fortunate 2009).

It was revealed that the majority (90.6%) of sheep were owned by the household head, followed by the spouse (89.4%), sons (73.1%), and daughters (66.9%) (Table 3). Access to resources such as livestock and land is determined by the patriarchal system in which males dominate women because the inheritance of resources favors men over women. Solomon et al. (2010) reported that in Ethiopia, the access to resources in terms of ownership and decision-making roles varies between husbands, spouses, and children; for example, women and children have property rights over the flocks but are not decision-makers and husbands decide on the income from livestock. In Tanzania, earlier studies by Geoff and Trevor (2009) showed that women and children were usually the managers and not the owners of small ruminants in agro-pastoral communities. The head (father) of the household appropriated all wealth-generated activities, and little to nothing was allocated to women (mother). This type of household power asymmetry constrains women's contribution to poverty alleviation at the household level. However, Pius and Christopher (2010) reported a different finding. They reported that women in the Maasai community in the Simanjiro district in Tanzania owned small ruminants and donkeys while men owned cattle.

Source of income and livestock kept

In terms of respondents' source of income, the results revealed that crops (99.4%) and livestock/livestock products (98.1%) were the primary sources of income for the majority of the households (Table 4). Other sources of income were off-farm business (16.9%), home industries (13.1%), salary/wages (5%), and pension (0.6%). Those indicate that smallholder farmers in the district depend more on crops and livestock than other sources of income. A similar finding was reported by Solomon et al. (2010) in the agro-pastoralist communities in Ethiopia.

The study revealed that most farmers (99.4%) kept goats, sheep (98.8%), and cattle (86.2%) (Table 4). Other livestock species kept were poultry (90.6%), donkey (26.2%), and pigs (12.5%). Cattle were valued for wealth, prestige, dowry, and business, while goats and sheep were kept for household consumption and cash. In addition, sheep were kept for medical purposes, and sheep fat was used in concoctions to treat mothers' medical complications after delivery.

Sheep activities

The study revealed that the activity of purchasing sheep (Table 5) was mainly done by adult males (93.1%) and females (67.5%). Other members of the household who were involved in purchasing sheep were boys (51.2%), girls (26.2%), and hired labor (3.1%). The activity of selling or slaughtering sheep was mainly conducted by adult males (92.5%) and adult females (69.1%). This activity was supported by boys (55.6%), girls (30.6%), and hired labor (5.9%). Finally, herding and feeding sheep was the main activity done by boys (95%) (Figure 2), adult males (68.8%), and girls (68.1%).

That shows that family labor is the primary source of livestock farm labor, and the use of hired labor for flock management is minimal and uncommon. In contrast, Solomon et al. (2010) reported that children and women provide the bulk of labor in sheep and goat management in Ethiopia. This difference in sheep management activities is due to differences in cultural considerations concerning the division of labor. For example, among the Maasai, the young boys *Layoni/Engayoni* not yet circumcised assist their mothers in all female-related works, including grazing sheep, goats, and calves near their *bomas* was shared with girls (Faustine et al. 2002). However, regarding breeding decisions, adult males were responsible (93.1%). Similarly, adult males were responsible for sheep health while other household members assisted.

Table 3. Demographic characteristics of sheep-owning households

Respondents characteristics	Number of respondents (n=160)	Percentage
Tribe name		
Sukuma	97	60.6
Fipa	63	39.4
Total	160	100
Head of household		
Male	130	81.2
Female	30	18.8
Total	160	100
Marital status of the household		
Married	129	80.6
Single	17	10.6
Divorced	10	6.3
Widow/widower	4	2.5
Total	160	100
Highest education level		
No school education	64	40.0
Primary education	83	51.9
Secondary education	13	8.1
Total	160	100
*Members of the household who own sheep**		
Head	145	90.6
Spouse	143	89.4
Sons	117	73.1
Daughter	107	66.9

Note: *Data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Figure 2. Children <15 years of Sukuma Tribe responsible for sheep herding

Sheep strains and preferences

Common name, strain type, and trend within sheep herd

Most sheep strains kept by smallholder farmers (Table 6) were variant crosses of local breeds, Red Maasai, Sukuma, and possibly BHP. Figure 3 shows the mixed strains kept by smallholder farmers in the district. The smallholder farmers kept no pure breeds because no breeding program was in place; instead, uncontrolled breeding was commonly used. The trend of sheep numbers shows that the majority (69.4%) of the respondents said it is increasing, while the minority (11.9%) declared that sheep numbers were decreasing.

Herd structure

The herd structure was consisted of an average of two intact adult males (rams) and nine adult females (Table 7). The intact male lambs were about three, and the intact female lambs were approximately six. The lower proportion of males (intact and castrates) could be attributed to farmers' preference to sell males for slaughter. Smallholder farmers did not prefer to castrate either adult sheep or lambs.

Source and preferred traits of the strain of sheep

The sheep strains' sources were studied to determine where smallholder farmers obtained different types (Table 8). Smallholder farmers purchased their animals from their neighbors (92.5%). Others obtained their initial stock through inheritance (26.2%), purchasing from primary livestock markets (25.6%), and also from the bride price and as a gift after taking care of other people's animals (5.6% each). Smallholder farmers keeping sheep in the district preferred sheep strains that were both tolerant to diseases/parasites (76.9%) and heat (73.1%) because the strains of this type had adaptive capacities enabling them to live and produce under low level of management. A similar finding was reported by Baker et al. (2003) and Owen et al. (2005), as cited by Muigai et al. (2009) that among the traits preferred by farmers keeping indigenous sheep in Kenya include adaptability to the harsh environmental conditions and resistance to gastrointestinal nematodes. Other preferences were better carcass (67.5%) and drought tolerance (63.5%). On the other hand, according to FGDs, the most preferred sheep traits were disease tolerance (84.4%) and easy to market (71.9%). Both farmers and FGD members had a high preference for disease tolerance; however, farmers had other high preferences like heat tolerances, contrary to FGDs, who highly preferred the trait of easy to market.

Also, the preferred traits of sheep strains were achieved by purchasing good sheep breeds from neighbor's sheep flocks (42.5%) and selecting the best animals from the existing stock (26.2%). However, some (40%) of the respondents had no opinion on how the preferred criteria of sheep breed could be achieved.

Table 4. Source of income and livestock kept

Respondents characteristics	Number of respondents (n=160)	Percentage
Source of income		
Salary/wages	8	5
Pension	1	0.6
Off-farm business	27	16.9
Livestock and livestock products	157	98.1
Home industries	21	13.1
Crops	159	99.4
Livestock kept		
Cattle	138	86.2
Goats	159	99.4
Sheep	158	98.8
Pigs	20	12.5
Donkey	42	26.2
Poultry	145	90.6

Note: Data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Figure 3. Variant cross group of local sheep strains kept by smallholder farmers in Nkasi District, Tanzania

Table 5. Members of the household responsible for sheep activities

Activity	Percentage of respondents (N=160)				
	Adult		Boys	Girls	Hired
	Males	Females	(<15 yrs)	(<15 yrs)	labor
Purchasing sheep	149(93.1)	108(67.5)	108(67.5)	42(26.2)	5(3.1)
Selling/slaughtering sheep	148(92.5)	109(68.1)	89(55.6)	49(30.6)	9(5.9)
Selling/slaughtering	110(68.8)	30(18.8)	152(95.0)	109(68.1)	16(10.0)
Breeding decisions	149(93.1)	98(61.2)	110(68.8)	59(36.9)	5(3.1)
Animal health	148(92.5)	111(69.4)	125(78.1)	66(41.2)	11(6.9)

Note: The values in parenthesis are percentages while the ones without parentheses are the number of respondents; data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Perception of sheep quality traits by owners

The excellent quality traits of sheep perceived by smallholder farmers (Table 9) mainly were disease tolerance (64.4%) and drought tolerance (60%). Farmers considered these traits good because the sheep graze in communal land with a high risk of disease infection and low water availability. Sheep kept by smallholder farmers depended on their natural body immunity to tolerate diseases such as FMD and worms since most farmers did not treat or provide vaccination to sheep.

Other traits that scored average quality traits were size (71.9%), conformation/shape (62.5%), and color (Black and white or red) (55%). In addition, FAO (1983) reported that the desirable traits in a crossbreeding system include improving breeding efficiency, growth rate, feed efficiency, market desirability, and adaptability of ewes and lambs to environmental conditions.

Purpose of keeping sheep

Sheep were kept mainly for meat (99.4%), income (84.4%), and manure (68.1%), as shown in Table 10. However, farmers also sold sheep to obtain cash for school fees, clothes, or other household expenditures.

Other purposes were cultural (32.5%), dowry (5%), ceremony (4.4%), and skin (1.2%). The observations in the present study are consistent with the findings of (Andrew 2003; Moradi et al. 2010), who reported that agro-pastoralist communities kept sheep for household consumption and as a source of cash income generation. In most cases, some women from the Sukuma Tribe use ewes for sacrifices. Geoff and Trevor (2009) also reported that sheep in Mexico were kept primarily for wool production, manure, and cultural aspects. Generally, small ruminants contribute to landless, rural farming, peri-urban, and increasingly urban household livelihoods.

Table 6. The common name, type of strain, and trend within sheep herd

Parameter	Number of respondents (N=160)	Percentages
*Common name for the breed/strain**		
Variant cross of BHP and local strains	152	95.0
Variant cross of Red Maasai sheep and local strains	81	50.6
Unknown	23	14.4
Strain type kept		
Pure strain	0	0
Cross-breed/strain	154	96.2
Unknown	6	3.8
Total	160	100
The trend within sheep herd		
Increasing	111	69.4
Decreasing	19	11.9
Stable	29	18.1
Unknown	1	0.6
Total	160	100

Note: *Data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Table 7. Herd structure

Herd structure	Mean
Adult sheep	
Intact male (rams)	2.07±1.7
Castrate	0.01±0.1
Female (ewes)	8.62±7.1
Total	10.41±7.6
Lambs	
Intact male	2.61±1.9
Castrate	0.16±0.9
Female	4.71±4.4
Total	7.02±6.1

Table 8. Source of the breeds/strains, preferred traits of the sheep breeds, and the way the preferred criteria of sheep breeds can be achieved

Parameter	Number of respondents (n=160)	Percentages
Origin/source of the breeds/strains		
Inherited	42	26.2
Market (purchased)	41	25.6
Through paid bride price	9	5.6
Commercial farms	0	0
After taking care of other people's animals	9	5.6
Purchasing from their neighbors	148	92.5
Preferred traits of the sheep breeds(farmers)		
Heat tolerance	117	73.1
Highly fertile	89	55.6
Drought tolerant	102	63.8
Ability to forage	47	29.4
Disease/parasite tolerance	123	76.9
Ability to travel long-distance	95	59.4
Low water requirements	93	58.1
Easy to market	63	39.4
Better carcass	108	67.5
High lamb survival	88	55.0
Preferred criteria of sheep breed achieved?		
Through government by the provision of hybrid sheep to sheep keepers	13	8.1
By purchasing good sheep breeds from neighbors' sheep flocks	68	42.5
By selecting the best animal from the existing sheep flock	42	26.2
No opinion on how the preferred criteria of sheep breed can be achieved	64	40.0
Preferred traits of the sheep breeds (FGDs)		
Disease tolerance	27	84.4
Easy to market	23	71.9
Drought tolerant	21	65.6
Highly fertile	17	53.1

Note: Data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Table 9. Perception of sheep quality traits by owners

Quality traits	Description of the trait (N=160)			
	Poor	Average	Good	No opinion
Size	4(2.5)	115(71.9)	38(23.8)	3(1.9)
Conformation/shape	6(3.8)	100(62.5)	49(30.6)	5(3.1)
Color	4(2.5)	88(55.0)	57(35.6)	11(6.9)
Disease tolerance	6(3.8)	51(31.9)	103(64.4)	0(0)
Drought tolerance	6(3.8)	55(34.4)	96(60.0)	2(1.2)
Heat tolerance	4(2.5)	63(39.4)	90(56.2)	3(1.9)
Meat quality	6(3.8)	62(38.8)	82(51.2)	10(6.2)
Growth rate	2(1.2)	78(48.8)	77(48.1)	3(1.9)
Fertility	4(2.5)	82(51.2)	65(40.6)	9(5.6)

Note: The values in parenthesis are percentages while the ones without parentheses are the number of respondents; data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Table 10. Purpose of keeping sheep

Purpose of keeping sheep	Number of respondents (n=160)	Percentages
Nutrition	159	99.4
Manure	109	68.1
Cultural	52	32.5
Skin	2	1.2
Dowry	8	5.0
Ceremony	7	4.4
Investment	135	84.4

Note: Data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Traditional management practices of sheep

Production, grazing system, feeding, supplementation, and watering

Most (94.4%) smallholder farmers kept sheep under extensive systems through herding continuously during dry and wet seasons (Table 11). That is because a large area in the district is rangeland, where the animals have access to plenty of pasture, although, in some places, they grow crops. On the other hand, few practiced semi-intensive systems (8.1%) and intensive systems (1.2%) by grazing sheep around their homes. Both semi-intensive and intensive systems are mainly practiced in Namanyere town by a few farmers with scarce grazing land. The result aligns with the findings of Mtenga et al. (2003), who reported that sheep-feeding systems practiced in Tanzania are extensive and intensive. However, exercising an intensive system for the large herd is difficult. Most farmers (96.6%) practiced continuous grazing, and only 3.1% rotational grazing. Farmers prefer continuous grazing due to the availability of large grazing land since many farmers live in rural areas.

The most common grazing systems (Table 12) used during the dry season were free grazing (89%) and herded grazing (21.9%). During the wet season, smallholder farmers practiced free grazing (71.2%), herded grazing (23.8%), and tethering (21.9%). Free grazing is preferred because it reduces the costs of feeds. Similarly, Solomon et al. (2010) in Ethiopia reported that extensive grazing in communal lands is practiced, but there were differences depending on agroecologies and geographic regions. For example, farmers in the Nkasi District prefer grazing sheep together with cattle or practicing tethering during the wet season due to the availability of pastures. On the other hand, Sendalo et al. (1993) reported that the Morogoro farmers tethered their sheep to minimize crop damage and avoid using additional labor for herding.

During the dry season, most smallholder farmers relied on crop residues or roughages (49.4%), and most did not supplement their sheep (47.5%). During the dry season, maize straw, sunflower seedcake, maize bran, household food leftovers, sweat, and Irish potatoes were the commonly available supplements. Talle (1995) reported that during the dry season, most smallholder farmers could not supplement animals with concentrates and industrial by-products due to high costs and lack of accessibility. As a result, there were minimal supplementations during the wet season (7.5%). In contrast, Tibbo (2006) reported that the significant supplementary feeds to sheep in Ethiopia were boiled bean, pea, maize, and non-conventional feeds like Atella, Areke, and Borde made with by-products of local beverages. However, FAO (1983) recommended that to improve daily gain and feed efficiency on sheep, the basic concentrate diet containing 16 percent crude protein with a trace element and/or a vitamin mixture (A, D, E) as supplement feed should be used.

Most (97.5%) of the households used communal land for grazing; some had their lands (20.6%), and others had leased lands for grazing (10.6%). Sukuma Tribe, immigrants to the district, often purchase lands from the native Fipa tribe to grow crops or graze their animals after crop harvesting. A similar observation was reported by Solomon et al. (2010) in Ethiopia that the primary feed resources for sheep include grazing on communal natural pasture, crop stubble, fallow grazing, roadside grazing, crop residues, and browses.

In general, smallholder farmers used two methods (Table 13) to provide water to their sheep, *i.e.,* providing water at the household or taking sheep to water sources at a certain distance from their homes. The majority (68.1%) of the smallholder farmers provided water to their sheep during the dry season, while during the wet season, sheep were brought to water sources (75%). A small percentage of the smallholder farmers used both watering methods during the dry and wet seasons. About 73.1% used pond water as a major water source during dry and wet seasons. The distance to the furthest watering point during the dry season was 1-5km (72.5%). Few traveled less than 1km to reach the furthest watering point (22.5%). During the wet season, water was readily available within a radius of 1km. Similarly, Solomon (2010) reported that sheep were taken to watering points at distances ranging from 2-5km during the dry season in Ethiopia.

The frequency of watering in the dry season for most households was twice a day (60%), while water was available at all times in the wet season. On the contrary, Solomon et al. (2010) reported that during the dry season in Ethiopia, sheep were provided with drinking water every three days; however, the watering frequency varied with season and agroecological zones. Similarly, Acharya (1981) reported that the availability of drenching, poor water quality, and animals had to travel long distances in search of water.

The difference in the frequency of watering animals in the Nkasi District and that reported in Ethiopia could be explained by the fact that in the Nkasi District, the water table is high, and ponds or boreholes provide enough water to livestock during dry seasons. Therefore, the quality of sheep drinking water was generally excellent and clear both during the dry season (79.4%) and wet season (97.5%).

Table 11. Production and grazing systems

Parameter	Number of respondents (N=160)	Percentages
Production systems		
Extension system	151	94.4
Semi-intensive system	13	8.1
Intensive system	2	1.2
Grazing management		
Continuous grazing	155	96.6
Rotational grazing	5	3.1
*Grazing land ownership**		
Own	33	20.6
Communal	156	97.5
Lease	17	10.6

Note: Data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Table 12. Grazing system and supplementation

Grazing systems	N=160	
	Dry season	Wet season
Grazing system		
Free grazing	128(80.0)	114(71.2)
Tethering	17(10.6)	35(21.9)
Paddock	2(1.2)	3(1.9)
Stall-fed	1(0.6)	0(0)
Backyard	0(0)	0(0)
Herded grazing	35(21.9)	38(23.8)
Supplementation regime		
Concentrates or bought-in feed	5(3.1)	8(5.0)
Crop residue or roughage	79(49.4)	9(5.6)
Vitamins and minerals (salts)	5(3.1)	12(7.5)
None	76(47.5)	130(81.2)

Note: The values in parenthesis are percentages while the ones without parentheses are the number of respondents; data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Housing and housing materials

The findings revealed that the majority of the smallholder farmers (Table 14) used simple sheds or stalled housing during the dry season (54.4%), while others used yards and houses (20% each). During the wet season, most (60.6%) used a shed or stalled, while some had a house (24.4%). About 7.5% and 8.1% used kraal during dry and wet seasons. Some farmers in the district reported predation by wild animals such as hyenas. The problem was more pronounced in houses constructed using weak local materials, as shown in Figures 4 and 5. In addition, farmers did not clean their sheep houses, thereby increasing the chance of infection.

Lambs were typically housed together with adults, as reported by the majority (55.6%) of farmers (Table 15). Most of the sheep housing materials used were untreated wood (85%), but few used bricks (16.9%), mud houses (12.5%), and iron sheets (1.2%). The results conform to the ones Geoff and Trevor reported (2009), which stated that most smallholder farmers kept their livestock in buildings and pens made from local materials such as wood or sun-dried bricks thatch from local grasses and bush poles. FAO (1983) reported that the cost of sheep housing must be kept low, with buildings providing only the most essential facilities such as feed storage, feeders, waterers, lambing pens, and creeps, while the roof shape should be of the shed type.

Table 13. Watering

Watering	N=160	
	Dry season	Wet season
Provision of drinking water		
1. Water is fetched or provided	109(68.1)	17(10.6)
2. Sheep go to water	50(31.2)	120(75.0)
3. Both	6(3.8)	29(18.1)
Source of water		
1. River	18(11.2)	45(28.1)
2. Spring	23(14.4)	113(70.6)
3. Dam or pond	117(73.1)	124(75.5)
4. Borehole	56(35.0)	64(40.0)
Distance to watering point		
1 At household	0(0)	11(6.9)
2. < 1km	36(22.5)	123(76.9)
3. 1 – 5km	116(72.5)	51(31.9)
4. 6 – 10km	8(5.0)	0(0)
5. > 10km	0(0)	0(0)
Frequency of watering		
1. Freely available	12(7.5)	151(94.4)
2. Once a day	47(29.4)	2(1.2)
3. Twice a day	96(60.0)	8(5.0)
4. Once in two days	3(1.9)	0(0)
5. Once in three days	0(0)	0(0)
Quality of water		
1. Good and clear	127(79.4)	156(97.5)
2. Salty (brackish)	22(13.8)	2(1.2)
3. Muddy	11(6.9)	2(1.2)
4. Smelly	4(2.5)	2(1.2)

Note: The values in parenthesis are percentages while the ones without parentheses are the number of respondents; data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Disease prevalence and health management

The prevalent diseases in sheep flocks kept by most smallholder farmers were (85%) (Table 16). Diseases occurring in sheep flocks include worms (45%), the flue (20%), FMD (15.6%), and mange mites (4.4%).

These results are similar to Solomon et al. (2010), where mange mites, ticks, lice, and fasciolosis were common. Most (61.2%) of farmers in the district did not vaccinate their sheep, while only a few (38.8%) vaccinated them against diseases. The vaccination or preventive treatments were done when the need arose (85.6%), and only 14.4% were vaccinated routinely. According to the farmers, the reasons that caused them not to vaccinate their sheep include inadequate funds to purchase vaccines and poor knowledge of the importance of vaccination.

Most (71.9%) of smallholder farmers (Table 17) treat their sheep themselves, and some (23.8%) have no access to veterinary services. In addition, some villages have no livestock officers or drug shops where the smallholder farmers can access drugs. In this case, they are forced to travel a long distance to other areas in search of services.

Control of ectoparasites

The majority (80%) of smallholder farmers did not routinely control ectoparasites, and only a few (42%) adhered to routines (Table 18). Spraying (56.2%) was the standard method, while about 16.9% used to dip.

Figure 4. Stall/shed for sheep housing

Figure 5. An open kraal for sheep

Table 14. Housing

Housing	N=160	
	Dry season	**Wet season**
Sheep housing		
Yard	(32)20.0	(10)6.2
Kraal	(12)7.5	(13)8.1
Shed or stall	(87)54.4	(97)60.6
House	(32)20.0	(39)24.4

Note: The values in parenthesis are percentages while the ones without parentheses are the number of respondents; data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Table 15. Housing materials

Parameter	N=160	
	Frequency	**Percentage**
Are lambs housed together with adults?		
Yes	89	55.6
No	71	44.4
Total	**160**	**100.0**
*Housing materials used**		
Bricks	27	16.9
Iron sheet	2	1.2
Wire	0	0
Mud	20	12.5
Untreated wood or bush materials	136	85.0

Note: *Data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Table 16. Prevalent sheep diseases

Parameter	N=160	
	Frequency	**Percentage**
Are prevalent diseases occurring on farms?		
Yes	136	85.0
No	24	15.0
Total	**160**	**100.0**
Is treatment given?		
Yes	77	48.1
No	83	51.9
Total	**160**	**100.0**
*Prevalent diseases occur on farms**		
FMD	25	15.6
Mange mites	7	4.4
Flue	32	20.0
Worms	72	45.0
Are vaccination/preventive treatments given		
Yes	62	38.8
No	98	61.2
Total	**160**	**100.0**
Methods		
Done routinely	23	14.4
Done when the need arises	137	85.6
Total	**160**	**100.0**

Note: *Data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Control of internal parasites

Control of internal parasites (Table 19) was mostly done when the need arose during the dry season (28.1%) and wet season (27.5%). Most respondents did not control internal parasites during dry or wet seasons (36.9% each). However, no traditional method was used to control internal parasites in sheep. The low level of internal parasite control could be explained by either the resistant sheep or farmers lacking knowledge of the internal parasite's economic implications.

Overall sheep flock morbidity rate

Morbidity rates were generally high (>70%) both in adults and lambs (Table 20). The high morbidity of lambs was caused by ignorance of disease management, including control of internal parasites, and poor housing. Given the communal grazing system, re-infection was common even for those practicing routine external and internal parasite controls.

Castration

Most (91.9%) smallholder farmers did not castrate their sheep (Table 21). Only (8.1%) practiced castration to control breeding (6.2%) and improve meat quality (5%). Lambs were castrated when they were about three to six months old. According to FAO (1983), castration should be carried out before lambs reach six weeks of age, although it reduces the gain and feed efficiency rate, and the carcass may contain more fat than intact male lambs.

Entries, disposal, and culling

The major sheep entered the flock through lambs born (Table 22). On average, about six lambs were born within the last 12 months. Farmers depend on lambs born to increase the flock size rather than purchasing from their neighbors. Therefore, entries in the form of donations, purchasing, gifts, and exchanges within the last 12 months were generally low.

Most sheep exits were in the form of death, whereas on average, about one lamb died within the last 12 months (Table 23). Also, sheep exited through slaughtering, exchange, and donations. Death to lambs is caused by improper management soon after lambing, whereby most farmers house the lambs born together with their adults. During land preparation, some farmers usually slaughter an animal as a friendly gesture to individuals who assist in these activities.

Most farmers did not cull their sheep, but few practiced culling (Table 24). The main reasons for culling sheep were small size, poor health, poor performance, and poor conformation (1.9% each). However, culling was rarely practiced owing to the small flock size.

Table 17. Health management

Access to veterinary services	Number of respondents (n=160)	Percentage
Government vet	1	0.6
Private vet	115	71.9
Extension service	31	19.4
Veterinary drug supplier	1	0.6
None	38	23.8

Note: *Data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Table 18. Control of ectoparasites

Control methods	n=160	
	Done routinely	Done when the need arises
None	42(26.2)	128(80.0)
Dip	27 (16.9)	5 (3.1)
Spray	90 (56.2)	27 (16.9)
Hand dressing	1 (0.6)	0 (0)

Note: The values in parenthesis are percentages while the ones without parentheses are the number of respondents; data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Table 20. Overall sheep flock morbidity rate

Sheep classes	Number of respondents (n=160)	Percentage
Suckling lambs	117	73.1
Weaned lambs	115	71.9
Adults	118	73.8

Note: Data on percentages were based on multiple responses

Table 21. Castration

Castration process	N=160	
	Number of respondents	Percentage
Do you castrate?		
Yes	13	8.1
No	147	91.9
Total	160	100
*Reasons for castration**		
Better price	4	2.5
Control breeding	10	6.2
Improving meat quality	8	5.0
*Age of castration**		
< 3 months	1	0.6
3-6 months	4	2.5
6-12 months	3	1.2
> 12 months	2	1.2

Note: *Data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Table 19. Control of internal parasites

Methods	Done routinely		Done when the need arises		If routine, specify how often	
	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
Drench	45(28.1)	44(27.5)	8 (5.0)	8 (5.0)	Every three month	Every four month
Traditional	0 (0)	0 (0)	0 (0)	0 (0)	Every 0 month	Every 0 month

Note: The values in parenthesis are percentages, while the ones without parentheses are the number of respondents, and data on percentages were based on multiple responses

Breeding

The primary reason for keeping rams was for breeding 100%, though some were kept for socio-cultural purposes (21.2%) (Table 25). Farmers selected rams for breeding based on size (88.8%) and conformation (71.9%). For example, Sukumas select animals with large body sizes and long fat tails. Fats from sheep tails are used for medical purposes, such as treating a person bitten by a snake.

The breeding method used by most smallholder farmers in the district was uncontrolled natural mating (98.8%). In this regard, during grazing time, smallholder farmers allowed their ewes to mate randomly with rams from other herds in the same village or nearby villages. The consequence of rams and ewes running together throughout the year in uncontrolled breeding includes lambing even in unfavorable seasons of low pasture quality. Tibbo (2006) also reported uncontrolled breeding; Solomon et al. (2010).

Production performances and constraints of sheep

The results (Table 26) indicate the production performances of sheep kept by smallholder farmers. The number of rams kept per herd was approximately two, and the average productive life for rams within the herd was about seven years, while that of ewes was approximately eight years. The average number of lambs per ewes' lifetime is about 13, while the average age at first lambing and lambing intervals were six and two months, respectively.

The most common production constraints faced by smallholder farmers keeping sheep were poor market availability (88.1%), endemic diseases (82.5%), and mortality of lambs (50.0%) (Table 27). Moreover, fewer buyers purchase sheep in the primary livestock market because most people in the community do not prefer mutton since it contains more fats and little taste than goat's meat. In addition, endemic diseases such as worms, FMD, and flu are major diseases that farmers face in sheep production and usually cause high lamb mortality.

Table 22. Entries within the last 12 months

Entry	Mean
Lambs born	5.78±5.4
Lambs bought	0.06±0.7
Adult male sheep bought	0.01±0.1
Adult female sheep bought	0.05±0.3
Total lambs and adult sheep	0.08±0.3
Lambs donated or given a gift	0.01±0.1
Adult male donated/given a gift	0.01±0.1
Adult female donated/given a gift	0.04±0.2
Total lambs and adults donated	0.05±0.2
Lambs exchanged or lent	0.01±0.1
Adult males exchanged/lent	0.07±0.4
Adult females exchanged/lent	0.09±0.6
Adult females exchanged/lent gift	0.18±0.8

Table 23. Exits within the last 12 months

Exits	Mean
Lambs died	1.07±1.4
Lambs sold	0.02±0.2
Adult male sheep are sold	0.09±0.4
Adult female sheep are sold	0.11±0.6
Total lambs and adults sold	0.17±0.7
Lambs slaughtered	0.04±0.4
Adult male slaughtered	0.92±1.3
Adult female slaughtered	0.41±0.9
Total lambs and adults slaughtered	1.13±1.5
Lambs donated/given as a gift	0.01±0.2
Adult male donated/given as a gift	0.02±0.2
Adult female donated/given as a gift	0.03±0.2
Total lambs and adults donated/given as a gift	0.04±0.3
Lambs exchanged/lent	0.02±0.2
Adult males exchanged/lent	0.09±0.5
Adult females exchanged/lent	0.12±0.6
Total lambs & adults exchanged/lent	0.19±1.0
Lambs stolen	0.02±0.2
Adult male stolen	0.02±0.2
Adult female stolen	0.06±0.3
Total lambs and adults stolen	0.09±0.3

Table 24. Reasons for culling

Reasons for culling	N=160	
	Males	Females
Small size	(3)1.9	(1)0.6
Health	(3)1.9	(2)1.2
Performance	(3) 1.9	(1)0.6
Temperament	(1)0.6	(0)0
Body condition	(2) 1.2	(0)0
Old age	(1)0.6	(0) 0
Scarcity	(0) 0	(0)0
Overpopulation	(0) 0	(0)0
Drought	(0) 0	(1)0.6
Prevention of inbreeding	(2)1.2	(1)0.6
Conformation	(3)1.9	(2)1.2

Note: The values in parenthesis are percentages, while the ones without parentheses are the number of respondents and data on percentages were based on multiple responses

Table 25. Breeding, choice criteria, and mating system

Parameters	N=160	
	Frequency	Percentage
Primary reason for keeping ram(s)		
Breeding	160	100.0
Socio-cultural	34	21.2
Criteria for choice of ram(s) for breeding		
Conformation	115	71.9
Performance	74	46.2
Size	142	88.8
Mating system		
Controlled natural mating	3	1.9
Uncontrolled natural mating	158	98.8
Group natural mating	6	3.8

Note: *Data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Other constraints were conflicted with crop growers (34.4%), water shortages (16.9%), feed shortages (9.4%), shortage of grazing land (6.2%), theft, and poor mothering ability (3.8% each). Problems related to service giving include the absence of preventive veterinary services such as vaccination and accessible and adequate veterinary clinics, resulting in unethical and inappropriate use of drugs from illegal sources.

The sheep market was mostly available through buying/selling from neighbors, and there were few customers outside the district. The constraints reported by Solomon et al. (2010) in Ethiopia include a lack of adequate supply of appropriate and good-quality animals, poor marketing infrastructure, livestock diseases, lack of adequate sanitary and phytosanitary services to support exports and long market channels (usually three to five stages between producer and the abattoirs).

In Kenya, Kosgey et al. (2008), as cited by Muigai et al. (2009), reported that indigenous sheep face many challenges, including persistent droughts, diseases, conflicts, and poor nutrition. In addition, the low productivity of sheep was caused by inadequate grazing resources, tropical heat, disease problems, and a serious lack of organized effort for genetic improvement (Solomon et al. 2010).

Sheep pricing and market availability

Most (sheep 65% and goats 37%) of customers involved in purchasing/selling sheep came from within the district (Table 28). Many sheep were sold and purchased by farmers without taking them to primary livestock markets. There were more goat sellers (52.5%) than sheep sellers (30%) in the primary livestock markets. There were opinions that over the years, the number of sheep sold decreased (22.5%) while that of goats was constant (22.5%). Moreover, nearly (70%) had no opinion on the trend for the two species.

On average, the number of sheep sold or bought on each primary livestock market was approximately two, while the number of goats sold or bought was about five per day (Table 29), indicating a higher demand for goats than sheep. The mean selling price of rams (mean) was Tshs 39,200 while that of the buck was Tshs 50,800, and ewes were sold at a mean price of Tshs 36,500 while that of does Tshs 47,400.

Preferred animals, prices, and sources in the primary livestock markets

The most sold species in the primary livestock market (Table 30) was cattle (95%), followed by goats (85%) and sheep (65%). The breed/strain of sheep mostly preferred by customers in the market was variant crosses of BHP and local strains (77.5%) and variant crosses of Red Maasai sheep and local strains (67.5%). The determinant of sheep price in the primary livestock market mostly depended on age (92.5%), sex (85%), and season (80%). The source of sheep to the primary livestock market was within the district (100%). The constraints in sheep marketing in the district were low sheep prices on the primary livestock market (62.5%), few customers (57.5%), and little interest in mutton (52.5%).

Way forward for improving sheep production

Smallholder farmers' plans to improve sheep production in the district were to improve the management of the existing sheep flock (63.8%), while 36.2% had no opinion (Table 31). Farmers argued that the government (DC, MLDF) has to provide vaccines for treating diseases (33.8%) and improve sheep market availability (15%).

Table 26. Production performances

Production performance	N	Mean
Number of rams per herd	160	1.91±1.2
Average productive life for rams (years)	160	7.06±2.3
Average productive life for ewes (years)	160	7.79±2.2
Average number of lambs per ewe's lifetime	160	13.97±4.8
Average age at first lambing (months)	160	6.46±1.8
Lambing interval (months)	160	2.82±1.3

Note: N = Total number of respondents interviewed

Table 27. Production constraints of sheep

Constraints	Number of respondents (N=160)	Percentages
Theft	6	3.8
Feed shortages	15	9.4
Endemic diseases	132	82.5
Water shortages	27	16.9
Shortage of grazing land	10	6.2
Conflict with crops growers	55	34.4
Low fertility	0	0
Poor mothering ability	6	3.8
Mortality of lambs	80	50.0
Poor market availability	141	88.1
Cause overgrazing	3	1.9

N = Total number of respondents interviewed

Table 28. Market availability of sheep and goats

Parameters	Percentages	
	Sheep	Goats
*Where do you come from**		
Within the district	65.0	37.0
Outside the district	17.5	25.0
Are you sellers?		
Yes	30.0	52.5
No	70.0	47.5
Total	**100**	**100**
Trend of animals sold as compared to last year		
Increasing	0	7.5
Decreasing	22.5	0
Constant	10.0	22.5
No opinion	67.5	70.0
Total	**100**	**100**
Demand to the market		
High	0	47.5
Medium	25.0	15.0
Low	42.5	0
No demand at all	10.0	5.0
No opinion	22.5	32.5
Total	**100**	**100**

Note: *Data on percentages were based on multiple responses

Table 29. Number and prices of sheep livestock market and goats sold/bought in the primary

Parameter	N	Mean
Number of sheep/goats sold/bought		
Number of sheep sold	12	1.92±0.5
Number of sheep bought	15	1.67±0.7
Number of goats sold	11	4.91±1.6
Number of goats bought	14	4.86±1.7
Price of sheep/goats sold/bought in Tshs		
Price of ram sold	13	39200±2794.2
Price of ram bought	18	41400±3110.2
Price of ewe sold	13	36500±3526.5
Price of ewe bought	18	38500±4003.7
Price of lamb sold	13	13400±1850.2
Price of lamb bought	18	13100±1567.7
Price of buck sold	12	50800±3713.2
Price of buck bought	13	48500±3281.7
Price of doe sold	12	47400±3604.5
Price of doe bought	13	45100±3451.1
Price of kid sold	12	17100±3800.8
Price of kid bought	13	15800±1589.2

Note: N = Total number of respondents interviewed

Table 30. Preference, price, sources, and constraints in the primary livestock market

Parameters	Number of respondents (N=40)	Percentage
Preferred animals in primary livestock market		
Goats	34	85.0
Cattle	38	95.0
Sheep	26	65.0
Preferred sheep breed/strain in primary livestock market		
Variant crosses of BHP and local strains	31	77.5
Variant crosses of Red Maasai sheep and local strains	27	67.5
Long-fat-tailed sheep (non-descript)	11	27.5
The determinant of sheep price in the primary livestock market		
Season	32	80.0
Age	37	92.5
Sex	34	85.0
Levy	8	20.0
Sources of sheep to the primary livestock market		
Within the district	40	100.0
Outside the district	0	0
Constraints in sheep marketing		
Few customers	23	57.5
Little interest in sheep's meat (mutton)	21	52,5
Low sheep price on livestock primary market	25	62.5

Note: *Data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Table 31. Views for improving sheep productivity

Parameters	(N=160)	
	Number of respondents	Percentages
Plans to improve sheep production in the district		
To improve management in the existing sheep flock, kept	102	63.8
No opinion	58	36.2
Total	**160**	**100.0**
Government (DC, MLDF) contribution to improving sheep production in the district		
Improve sheep market availability	24	15.0
Construction of watering points for drinking animals	13	8.1
Provision of vaccines for treating diseases	54	33.8
Training on proper sheep husbandry	20	12.5
Provision of hybrid sheep	22	13.8
No opinion	27	16.9
Total	**160**	**100.0**
General recommendations on what is required to improve sheep production		
Improving sheep market availability	54	33.8
Construction of watering points for drinking animals	4	2.5
Provision of vaccines for treating diseases	17	10.6
Training on proper sheep husbandry	19	11.9
Provision of hybrid sheep	37	23.1
No opinion	29	18.1
Total	**160**	**100.0**
*Plans to improve sheep market availability**		
Introducing hybrid sheep	2	5.0
No opinion	36	90.0
Other reasons	2	5.0
Advice to the government in improving sheep market availability in the district		
Outsourcing sheep customers from outside the district	24	60.0
Provision of hybrid sheep to sheep keepers	7	17.5
Other reasons	12	30.0
*General recommendations on improving sheep market availability**		
The government has to outsource sheep customers from outside the district	17	42.5
The government has to provide hybrid sheep to sheepkeepers	7	17.5

Note: *Data on percentages were based on multiple responses, and N = Total number of respondents interviewed

Most (60%) advised the government (DC or MLDF) to outsource sheep customers outside the district. In comparison, a few (17.5%) requested to be provided with hybrid sheep breeds for crossbreeding with their local breeds to obtain desired preferred quality traits. Some had no opinion on how the government should improve sheep production in the district (16.9%). In comparison, the majority (33.8%) of them recommended that the government improve the sheep market and provide better breeding stocks (23.1%). Some proposed training on proper sheep husbandry (11.9%). About (18.1%) of the smallholder farmers had no idea about the current situation.

In conclusion, this study found that: (i) Smallholder farmers in the district kept variant crosses of sheep strains of BHP, Red Maasai, and local strains. Most purchased sheep from their neighbors or inherited them from their parents. Farmers prefer sheep that are tolerant to diseases and heat, while the main reason for keeping sheep is for meat and income. (ii) Most farmers kept sheep under an extensive management system. Most farmers kept their sheep in a stall or shed made of untreated bush materials during both dry and wet seasons. (iii) The average herd structure of sheep contained two rams and nine ewes. Ewes had a more productive life span in the herd than rams, and the average first lambing was about 6.5 months. (iv) The most common production constraints faced by farmers were poor market availability, diseases, and mortality of lambs. The sheep market was mainly available within the district rather than outside the district. Also, goats were sold or bought at a higher price than sheep in primary livestock markets, while the price of the animal depended on age, sex, and season. Therefore, there is a need to train smallholder farmers to keep sheep on the proper sheep husbandry to attain high production and improve their socio-economic and national well-being.

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