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Connections between household environmental knowledge and land-use allocation among rural communities in South Africa

Muhammad Mubbin · Lobina G. Palamuleni · Elhadi Adam · Fehmida Qaddus Rabbani · Tabukeli Ruhiiga · Sadaf Javed

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Abstract Land-use allocation is a management framework for sharing land resources among different uses for diverse purposes. This study investigated household local environmental knowledge and land-use allocation using two local municipalities in South Africa. The study aimed to understand the interactions among household knowledge systems and environmental parameters and how these influence land use allocation decisions. A quantitative research design was employed, and a questionnaire was used to cover household environmental knowledge. The field observations and questionnaire data were coded and analyzed using Microsoft Excel to yield valuable statistics. Spearman's correlation (two-tailed), multiple regression, and two-way ANOVA analyses were applied in hypothesis testing. The findings inferred a strong linkage between land-use allocation and environmental knowledge. The community's land allocation for different purposes depends on their education level, occupational status, resource access, and residence time. Local ecological knowledge about rainfall, the onset of seasons, temperature range, and soil type influences cropping and land utilization. The local environmental knowledge acquired from formal or informal sources significantly influences land use, planning, and management of land resources. Therefore, incorporating indigenous knowledge during land-use allocation is essential for the resilience of rural economies and livelihoods. This paper pays attention to the central contribution of local environmental knowledge to the information on sustainable land-use planning and rural development policy guidance.

Keywords Livelihood · Land-use allocation · Local knowledge · Environmental knowledge · Sustainability

M. Mubbin (✉) · E. Adam · F. Q. Rabbani
School of Geography, Archaelogy and Environmental Studies, University of the Witwatersrand, Private Bag 3 Wits 2050, Johannesburg, South Africa
e-mail: mubbin@hotmail.com

M. Mubbin · L. G. Palamuleni
School of Geo and Spatial Sciences, North-West University, Private Bag X2046, Mmabatho, South Africa

T. Ruhiiga
Department of Humanities Education, Faculty of Education, Kabale University, P.O. Box 317, Kabale, Uganda

S. Javed
Earth and Atmospheric Remote Sensing Lab (EARL), Department of Meteorology, COMSATS University Islamabad, Islamabad 45550, Pakistan

Introduction

Livelihood is a cumulative outcome of a complex system that depends on environmental, economic, and institutional arrangements. It depicts the relationships between individuals and their environment

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(Lan et al., 2021). A robust livelihood mechanism maintains balance despite socio-economic and ecological changes (Mubbin et al., 2022). It empowers humans to cope with shocks and stresses without disturbance (Gwiriri et al., 2021). Therefore, it should be flexible when dealing with high-risk combinations. Thus, it depends on various capital/ assets and activities, i.e., livelihood strategies driven by critical decisions such as land-use allocation. Local Environmental Knowledge characteristically influences cardinal decisions that decide livelihoods (Li et al., 2024).

Local environmental knowledge is the cumulative body of knowledge, practices, and beliefs that evolve through adaptive processes (Bernard et al., 2024; Lam et al., 2020). Therefore, it reflects perceptions and practices based on human interactions with the environment (Mosissa et al., 2017; Vortkamp & Hilker, 2023). The formal and/or informal systems for acquiring knowledge, values, skills, and social attitudes define this knowledge framework (Wu et al., 2020). Local Environmental knowledge increases interest, awareness, and proclivity for ecological resilience (Debrah et al., 2021; Durar et al., 2023; Peattie, 2010; Scott & Vigar-Ellis, 2014). At the same time, the community's well-being is dependent on the effectiveness of the land distribution process (Warden et al., 2024). As a result, skilled decision-making using local environmental knowledge is necessary to boost land productivity and human well-being (Mohammadi et al., 2021; Tang et al., 2013).

As a result, empirical knowledge at the grassroots level is critical. They infer perceptions and orientations towards local environmental knowledge. Cook et al. (2014) define local environmental knowledge as people's living experiences representing dialectical interactions with the natural environment (Kupika et al., 2019). Environmental knowledge contributes to the resilience of the natural and human environments, which is necessary for social, economic, and environmental stability (Dewulf et al., 2020; Shi et al., 2023). It is critical in developing and growing patterns that are dynamic and interconnected. Thus, local environmental knowledge is critical for ensuring integrated ecosystem management and community-based adaptation strategies (Kupika et al., 2019). The United Nations Convention to Combat Desertification (UNCCD) recognizes the significance of local environmental knowledge for ensuring sustainable development (Edsand & Broich, 2020). It offers crucial inputs for public and private decision-making.

South African land use is shaped by the interaction between environmental knowledge and ecological knowledge that shape environmentally sustainable peri-urban and rural resource management (Bird et al., 2024). Local ecological knowledge influences the agriculture, water harvesting, and wildfire avoidance of the local and indigenous population, promoting the resilience of the ecosystem (Bird et al., 2024). Environmental awareness, including biodiversity conservation and climate change adaptation, contributes more authority to land-use choice, particularly soil erosion and drought (Ziervogel et al., 2024). Industrialization, agriculture, urbanization, and the absence of policy integration are, however, endangering long-term sustainability of such knowledge systems (Shackleton et al., 2024). Gender and age differences affect knowledge exchange, and critical comment by women and older people is known to be excluded from planning (Agarwal, 2024). Joining local environmental knowledge with scientific land-use models improves growth and environmental concord (Reyers et al., 2025). Pastoral grazing has recovered lost land in the Eastern Cape. Land security of tenure and policy mainstreaming of local environmental knowledge are significant increasing sustainability (Ostrom et al., 2025), assisting in resilience and culture conservation in South Africa.

Contrary to that, the decision-makers do not acknowledge local environmental knowledge and its usefulness. Thus, it entails a better understanding of the decision-making processes regarding environmental and land resources (Christensen & Eetvelde, 2024; Dewulf et al., 2020). Land allocation is a tricky process that weighs the options for equitable distribution of limited land resources for alternative usages. Shuqair and Abdel-Aziz (2015) observed that the mechanism provides a blueprint for ensuring economic development, ecological sustainability, and social equity.

Realizing these objectives is obligatory for the resilience of natural and social systems. It is also required to harmonies the societal demands for integrated local, regional, and national development (Chakir & Le Gallo, 2013). Therefore, the present study focused on two objectives: (i) to examine the relationship between land use allocation decisions and knowledge systems and (ii) to compare variations in household environmental knowledge. For this purpose, the data was retrieved from two rural local municipalities in South Africa.

Materials and methods

To illustrate the methodical order of steps in the study, Fig. 1 presents the research design as a flow chart. Maluti-a-Phofung and Thulamela are two local municipalities in South Africa where the study was carried out. To evaluate their knowledge and awareness of the environment, data was gathered at the household level.

The study area

The study area is located in South Africa, focusing on two local municipalities (LM) chosen from two municipalities in the Free State and Limpopo Provinces of South Africa (Fig. 2). These are Maluti-a-Phofung LM in Thabo Mofutsanyana

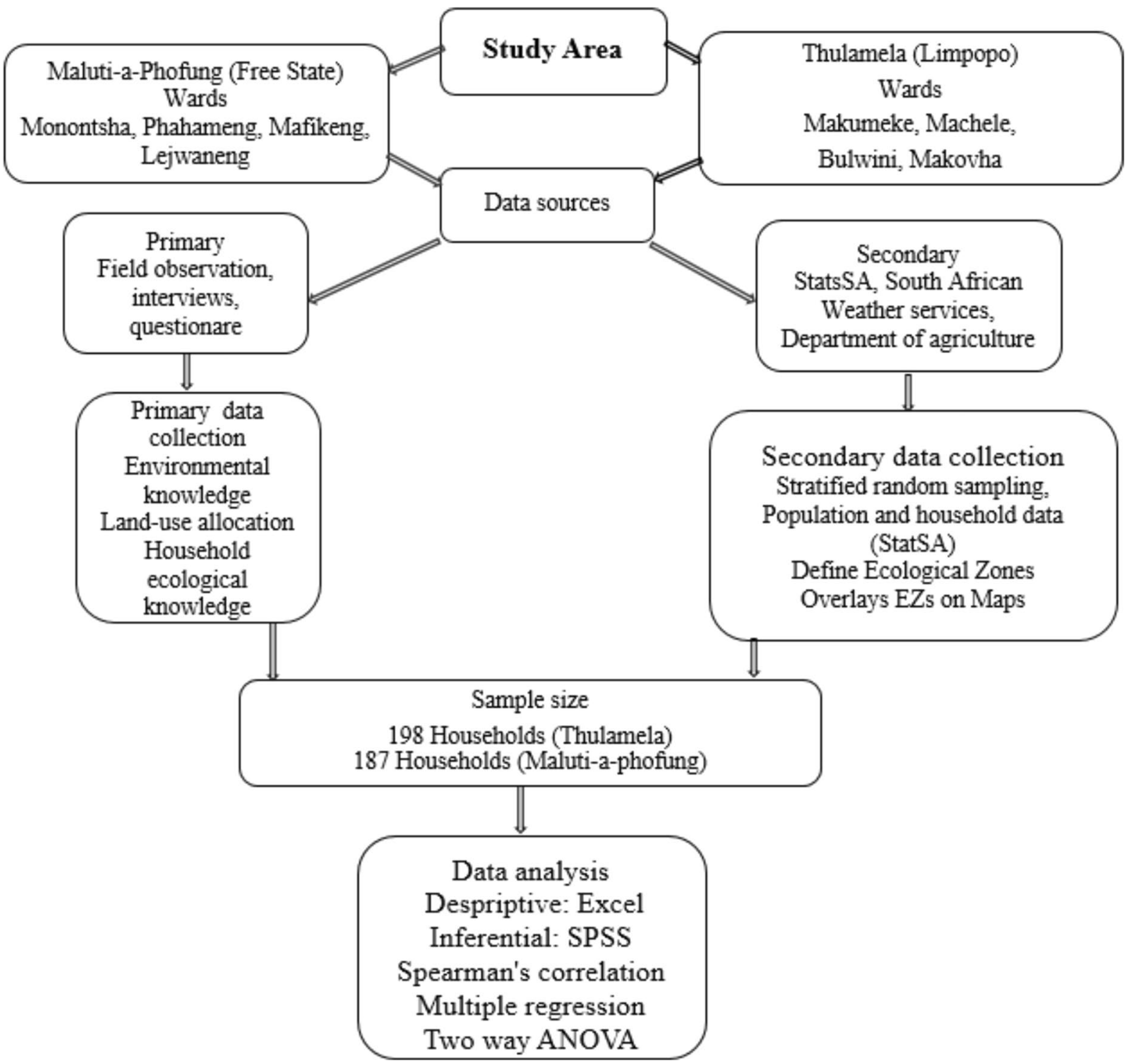

Fig. 1 Research and methods flow chart

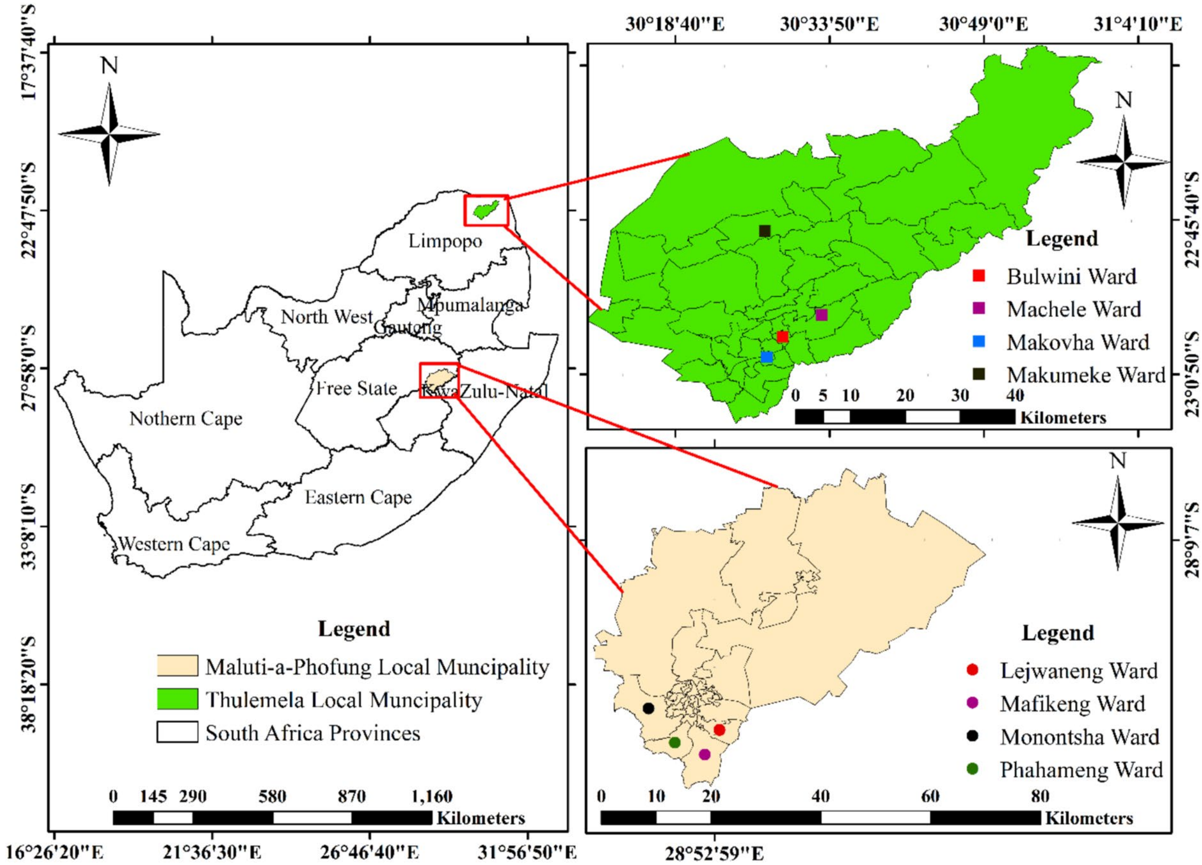

Fig. 2 South African provinces and the two study sites

District Municipality (Free State province) on Latitude 28°33′04’S and Longitude 29°4′48’E. Maluti-a-Phofung LM is a Category B municipality established in 2001. Almost 27% of the population lives in traditional residences. In Maluti-a-Phofung LM, four wards were selected for the research: Monontsha, Phahameng, Mafikeng, and Lejwaneng.

Meanwhile, Thulamela LM in Vhembe District municipality (Limpopo province) is situated at Latitude 22°57’ S and Latitude 30° 29’ E. Thulamela Local Municipality is a Category B municipality established in 1998. More than 85% of the people in this municipality live in tribal areas. Four wards were selected for the research in Thulamela LM: Makumeke, Machele, Bulwini, and Makovha.

Maluti-a-Phofung LM reflects a diversified land use pattern. Its land use classes range from agriculture, forestry, mining, open spaces, protected buffer zones, residential, transport, and wetlands to wildlife and tourism attractions. Thulamela LM’s land use classes include agricultural land, forest cover, and mining areas. Besides, open spaces, protected buffer zones, residential transport, and wetlands for wildlife tourism attractions are also prominent classes.

Research design

This study assesses the respondents’ local environmental knowledge and evaluates land allocation mechanisms based on selected environmental and climatic parameters, i.e., rainfall and temperature. Besides this, the linked ecological variables, such as soil, were also focused on. The yield relies on the soil’s physical, chemical, and biological characteristics. However, indigenous knowledge about the soil productively contributes to soil resilience and agroecosystem management (Huynh et al., 2020). Thus, local knowledge about soil characteristics is obligatory for informed decision-making concerning environmental stability. This study utilized a quantitative research design based on observations, measurement, and management of household interviews. The primary data was captured on the ratio and interval scales for the objective statistical analysis.

Data sources and collection

The study relies on primary data and secondary data sources. The population and household characteristics were retrieved from Statistic South Africa (StatsSA, 2021). The data about the climate was obtained from the South African Weather Services (SAWS). The Department of Agriculture and Land Affairs sieved the land use data. These data sources empowered the critical analysis of the research problem according to the study's objectives. In addition, the secondary data was used to verify and supplement the information collected from the interviews.

The main focus of this investigation was to collect present data on the status and role of the knowledge system of households in local municipalities. It was not obtainable from the above-mentioned secondary data sources. Therefore, the primary data were collected through field observations followed by face-to-face interviews using questionnaires from the study areas, i.e., Thulamela LM and Maluti-a-Phofung LM. Three types of data were collected from primary sources: (i) perception about environmental parameters; (ii) the orientation towards land use was noticed through field observations; (iii) household data regarding environmental knowledge was collected through a structured interview. A household questionnaire was designed for this purpose. A set of observable socio-economic indicators were incorporated into the tool for data collection. Questionnaires were administered to 187 inhabitants from Maluti-a-Phofung LM and 198 residents from Thulamela LM to collect data on household environmental knowledge. The process was conducted during January and February 2021.

Sampling procedures

Using a stratified random sampling technique, the number of households per ward as of the end of 2020 was obtained from the records of Statistics South Africa (StatSA, 2020) and the Municipal Demarcation Board. Stratified random sampling involves dividing a population into smaller groups called strata and randomly selecting samples from each stratum. Potential respondents were identified based on specific selection criteria.

The selection procedure followed four interrelated phases:

Phase 1: Population estimates for December 2020 were sourced from StatSA, according to each local municipality (LM).

Phase 2: Household numbers for each LM and its respective wards were established from StatSA (2020).

Phase 3: Ecological zones (EZs) were defined using climatic, soil, vegetation, landform, and drainage data.

Phase 4: EZ boundaries were overlaid on ward maps to produce an ecological zone map for the two study areas.

The study used a sample size of 385 households. Proportional percentages (32% of Thulamela and 24% of Maluti-a-Phofung) were used to determine the household representation in each ward. This approach ensured representative, precise, and well-balanced data gathering from the municipalities' different socio-economic and geographic locations (Table 1).

Data processing and analysis

The data was used to compare household environmental knowledge between the two selected study sites. Socio-economic characteristics and environmental knowledge data were analyzed using Microsoft Excel (TM) by calculating descriptive statistics and transferred into Statistical Package for Social Scientists (SPSS) software version 25.0 for further analysis. Cross-tabulations helped to determine the association between socio-economic variables (education, length of residence, and occupational status) and environmental knowledge. Therefore, inferential statistics techniques like two-tailed Spearman's correlation coefficient, multiple regression, and two-way analysis of variance were consulted.

Results

The elements of weather and climate (rainfall and temperature) suggestively influence the composition

Table 1 The sample size distribution was selected for this work

Research site (1)	Wards (2)	Households (3)	Stratum I population* (4)	% of households** (5)	Stratum II households*** (6)	Sample size (7)
Thulamela LM		130,320	497,237			
Makumeke	15	172	664	32%	55	49
Machele	16	128	557	32%	41	38
Bulwini	17	207	931	32%	66	57
Makovha	18	195	787	32%	62	54
						Total = 198
Maluti-a-Phofung		110,725	353,452			
Monontsha	11	325	1164	24%	78	65
Phahameng	15	340	1113	24%	82	68
Lejwaneng	20	90	302	24%	22	21
Mafikeng	21	150	505	24%	36	33
						Total = 187

Source: Census 2020; * = stratum I population; ** = % of households engaged in selected land-based activities; *** = stratum II population expressed as a percentage based on field enumeration

and structure of ecological infrastructure. The meteorological record of 25 years (1994–2018) formulates that Bloemfontein lies in a moist (466 mm) environmental zone (Mubbin et al., 2022). At the same time, Thulamela municipality is in the subtropical climatic zone. The mean annual rainfall ranges from 300 to 1000 mm in this area. Temperature is a critical element of weather and climate. It has significant bearings on the other cardinal aspects of weather and atmosphere, such as precipitation, air pressure, and winds. The findings formulate an average monthly maximum temperature of 23.5 °C in the study area. However, the mean monthly minimum temperature observed in winter was 2.5 °C; in summer, it was 26.4 °C in Maluti-a-Phofung LM. In Thulamela LM, observations formulate a summer maximum of 29.2 °C and a minimum winter temperature of 9.7 °C. An escarpment, highlands, and mountainous types of land surfaces characterize the physiography of Maluti-a-Phofung LM. In comparison, Thulamela LM is composed of floodplains and mountain areas.

The study areas' topography, climate, and geology govern the drainage systems. Meanwhile, Maluti-a-Phofung combines seasonal streams, permanent streams, and water reservoirs. In contrast, the drainage system in Thulamela LM is characterized by a floodplain associated with the prevalence of seasonal streams and water reservoirs.

Indigenous soil information is essential for long-lasting soil administration and agroecosystems (Huynh et al., 2020). The soil of Maluti-a-Phofung LM is divided into the following distinctive classes: Yellow and red (Ac), none red (Bb), Clay Soil (Ca), Dark blocky and clay (Ea), Shallow and rocky (Fa), much shallow and/or rocky (lb) and mainly rock with little soil (Ic). However, in Maluti-a-Phofung, LM is characterized by red and yellow (Ab), Red soil (Ba), Non-red (Bb), Dark, blocky and clay (Ea), Shallow and/or rocky (Fb), and much shallow and/or rocky (lb) soil types. The most dominant type of soil in the Thulamela LM municipality is rich red loam soil, though it repeatedly experiences excessive overspill. This soil category has a greater and longer water-retaining ability (Musyoki et al., 2016).

Diversified land uses characterize Maluti-a-Phofung LM. The land uses range from agriculture and farming, recreational areas, forestry and timber, construction, mining, open spaces, protected buffer zones, residential, transport, and wetlands to wildlife and tourism attractions. Thulamela LM's land-use classes range from agricultural land, forest cover, and mining areas. Besides, the open spaces, protected buffer zones, residential transport, and wetlands for wildlife and tourism attractions are also prominent classes.

Environmental education acquired through formal education could form the basis of indigenous knowledge, understanding, and standards and determine training outcomes. This study assessed respondents' local knowledge and land-use allocation to analyze household environmental knowledge comprehensively. (Figs. 3, 4, 5) succinctly portray the socio-economic and demographic characteristics of the respondents from Maluti-a-Phofung and Thulamela LMs, the two study sites. The findings (Fig. 3) indicate that most of the respondents (56%) in Maluti-a-Phofung LM and (44%) in Thulamela LM are well-educated. However, a smaller proportion, 1% of the total respondents in the case of Maluti-a-Phofung LM

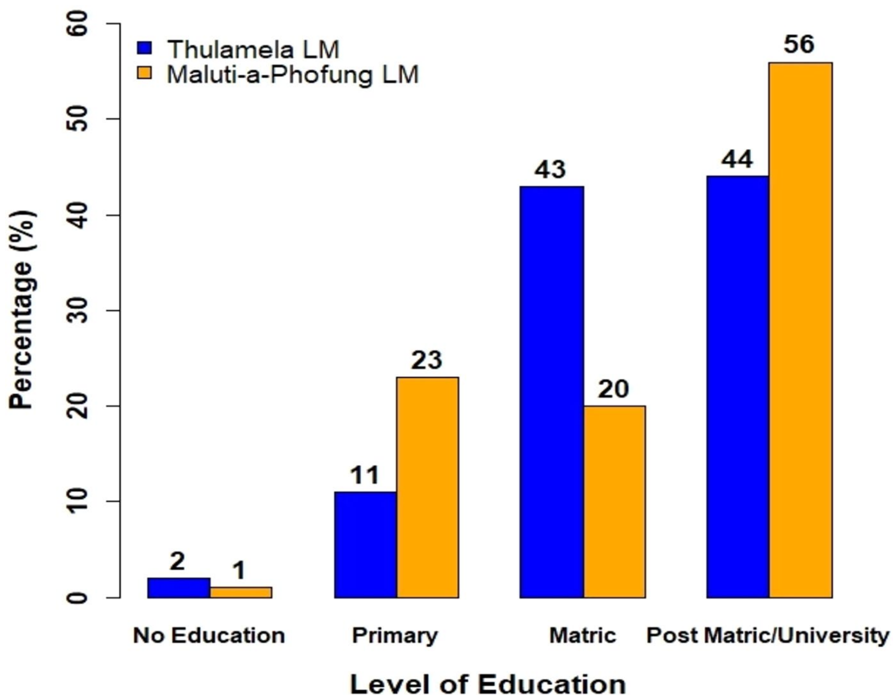

Fig. 3 Distribution of respondents by level of education

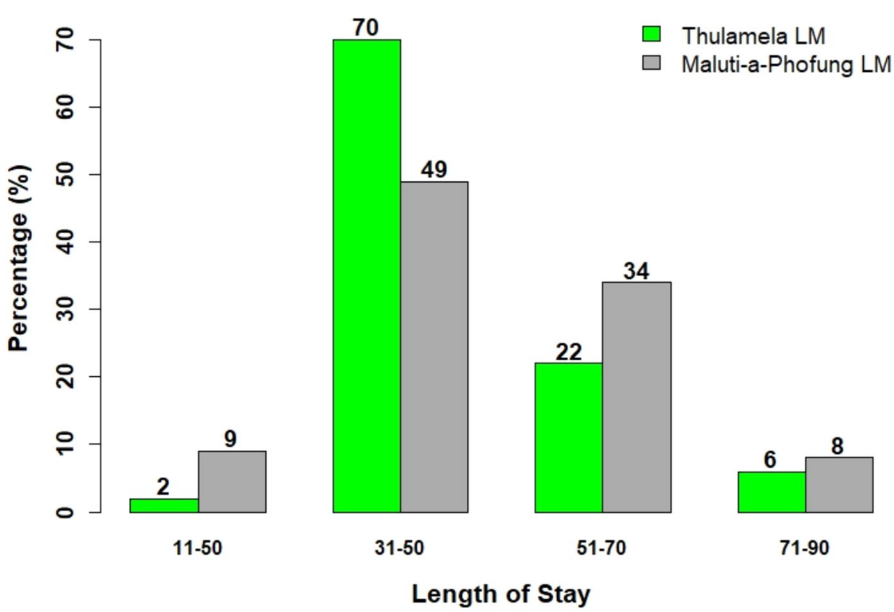

Fig. 4 Distribution of respondents by the length of stay

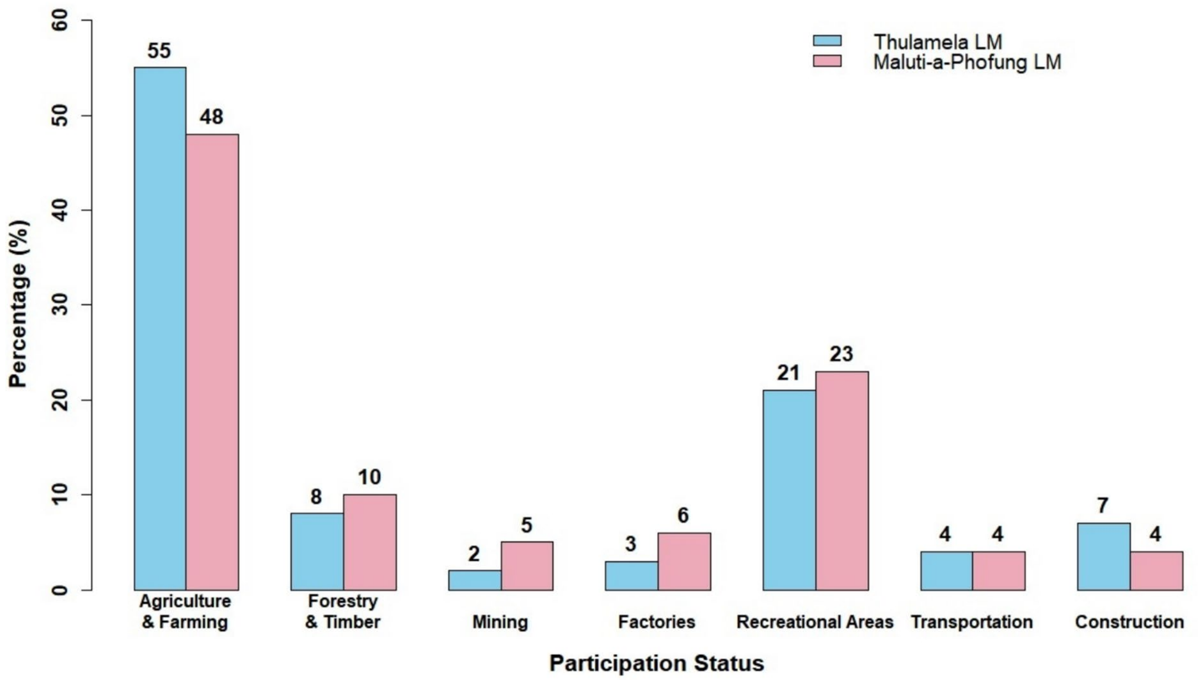

Fig. 5 Distribution of respondents based on participation status

and 2% from Thulamela LM, were uneducated. At the same time, a smaller proportion of the surveyed population (23%) in Maluti-a-Phofung LM and 11% in Thulamela LM also affirmed that they obtained primary education. However, 50% of respondents from Thulamela LM and 25% from Maluti-a-Phofung LM have attained education at the Matric level (Grades 8–12). The study shows that Maluti-a-Phofung LM exhibits higher levels of education, likely due to better access to schools, facilities, and support. At the same time, Thulamela LM may face more educational challenges and fewer resources.

Figure 4 indicates that most respondents (49%) in Maluti-a-Phofung LM and (70%) from Thulamela LM have resided in these areas for 31 and 50 years, respectively. Most respondents in the two study areas stayed within the 31–70 years range. These results further indicate that local people are conversant with their contextual surroundings due to their satisfaction with the environmental setting.

The results (Fig. 5) indicate that most residents directly or indirectly depend on fundamental economic activities of agriculture, forestry, and mining. A significant majority of Maluti-a-Phofung LM interviewees (48%) and 55% of Thulamela LM reported being engaged in farming and agriculture. At the same time, a sizeable share of respondents from Maluti-a-Phofung LM (23%) and Thulamela LM (21%) are involved in the recreational areas. Small proportions account for the mining, manufacturing, and transport industries. About 10% of Maluti-a-Phofung LM and 8% of Thulamela LM respondents are in forestry and wood activities.

Household local knowledge

A study by Adisa et al. (2018) showed that climatic factors such as sunlight, moisture in the air, rainfall, temperature, and humidity frequently decide the global distribution and productivity of crops and livestock within a specific setting. This study estimated respondents' local knowledge and land use distribution based on climate (precipitation and temperature) and environmental variables (soil). Response percentages were used to determine the proportion of respondents with specific local knowledge.

Climatic variables

Climate is defined as the statistical properties of a region's weather. Climate zones are distinguished by unique selections of all climate variables, including rainfall, temperature, humidity, and wind (Mubbin et al., 2022). Inferences and estimates depend on household local knowledge and assessment of climatic variables.

Rainfall

According to Muthoni et al. (2019), suitability for crop diversity and the associated agronomic management is defined by the quantity and distribution of precipitation. The rainfall pattern in the vicinity was presented in its form, and local knowledge information was requested from the respondents. Several indicators were used to deduce the local environmental knowledge concerning rainfall, its temporal distribution, and its reliability. The assessments indicate that the local knowledge of the reliability of rain among the participants from Maluti-a-Phofung Local Municipality and Thulamela Local Municipality is identical; in both municipalities, 14% of the respondents know about reliable rainfall. However, noticeable differences in knowledge about the length of the wettest season and the amount of precipitation were noted. At the same time, the inconsistencies were negligible in the evaluation of other parameters.

Temperature

The variations in local temperature influence humans and the environment through air quality and energy utilization, and impact people's health (Tran et al., 2017). The temperature fluctuation of their area, understanding about the hottest and coldest months, and the average temperature were sought from the respondents. The results revealed differences in responses, as 18% of participants in Maluti-a-Phofung LM and 26% in Thulamela LM know the average summer season temperature. However, the respondents were less divided regarding the coldest month and the average winter temperature.

Household local knowledge and soil quality

Evaluations regarding soil and related aspects were made (Fig. 6). About 50% of the participants in Maluti-a-Phofung LM and 46% in Thulamela LM viewed the soil in their locality as generally fertile. However, rural household farmers have unique Indigenous or local environmental knowledge about farming operations and soil management (Bajgai & Sangchyoswat, 2018). However, the respondents' local knowledge about soil acidity is slightly lower, as only 12% of the respondents in Thulamela LM and 11% in Maluti-a-Phofung LM knew about this concept. The lack of knowledge about the soil characteristics in both municipalities could negatively influence farming operations and soil management.

Figure 7 shows that 14% of the participants in Maluti-a-Phofung LM and 7% in Thulamela LM

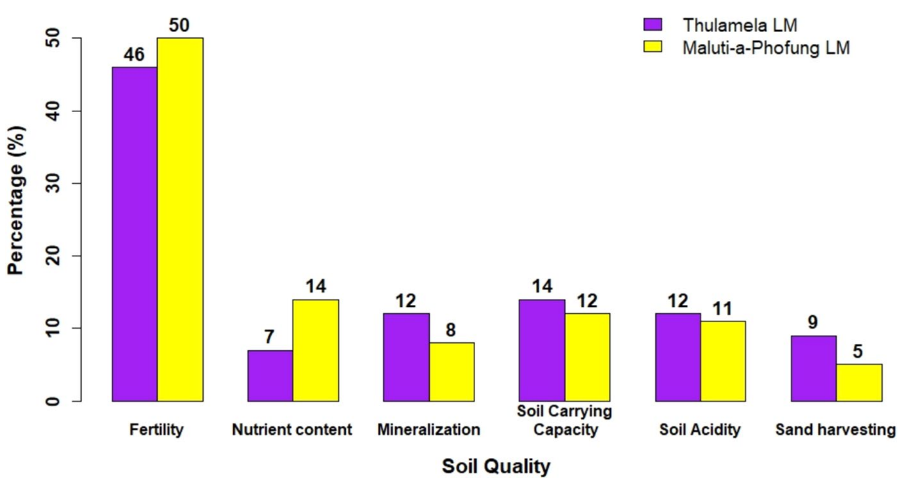

Fig. 6 Distribution of respondents based on knowledge about soil quality

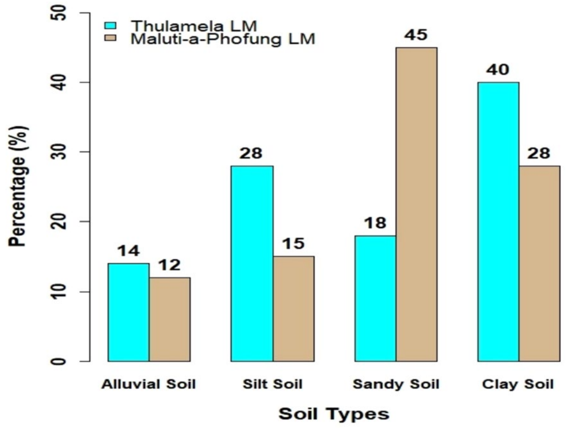

Fig. 7 Distribution of respondents based on knowledge about soil types

affirmed that they know the soil's nutrient composition in their locality. The findings infer that 14% of the participants in Thulamela LM and 12% in Maluti-a-Phofung LM know about soil carrying capacity. Local knowledge about soil richness and carrying capacity is critical because it symptomatically influences soil fertility and management (Bajgai & Sangchyoswat, 2018).

Most of the participants in Maluti-a-Phofung LM have local knowledge about soil fertility and nutrient content, and they perceive that the soils are sandy. Diverse soil types, including sandy, clay, and sandy-loam soils, typify the Thulamela LM. As such, respondents mentioned that the clayey and mud soils are fit for growing cereals like wheat. Clayey soil's water retaining capacity helps grow crops like paddy, which need extra moisture. In contrast, silt soil and alluvial soils are prevalent in Maluti-a-Phofung LM. According to the respondents' knowledge, wind erosion is a powerful element in Thulamela LM.

Drivers of local environmental knowledge

The strength and direction of associations between drivers of local environmental and ecological knowledge were ascertained by deploying a two-tailed Spearman's Correlation coefficient test. The findings (Table 2) reveal that in Maluti-a-Phofung LM, there is a positive association between the level of education and environmental knowledge ($r=0.136$; $P=0.063$). However, a significant negative association was

Table 2 Spearman correlation

			Environmental knowledge
	Correlation Coefficient	1.000	.136
Education		-	.063
		1.000	-.176*
	Sig. (2-tailed)	.000	.013
	Correlation Coefficient	1.000	-.083
Residence		-	.258
		1.000	.003
	Sig. (2-tailed)	.000	.967
Occupation status	Correlation Coefficient	1.000	.134
		-	.067
		1.000	.023
	Sig. (2-tailed)	.000	.750

*Correlation is significant at the 0.05 level (2-tailed)

observed in the case of Thulamela LM regarding education and environmental knowledge ($r=-0.176$; $P=0.013$).

Assessments were also made to determine the relationship between the length of stay and environmental knowledge. Table 2 reveals that Maluti-a-Phofung LM has a negative correlation between the two variables ($r=-0.083$; $P=0.258$), while Thulamela LM has a positive association between residence and environmental knowledge ($r=0.003$; $P=0.967$).

Table 2 reveals that in Maluti-a-Phofung and Thulamela LM, there is a positive association between occupational status and environmental knowledge: $r=0.134$; $P=0.067$ and $r=0.023$; $P=0.750$, respectively.

Furthermore, the multiple regression modelling about Maluti-a-Phofung LM and Thulamela LM was carried out to assess the weights of the selected variables in the case of these settlements. Equation 1 shows results for Maluti-a-Phofung LM.

$$\text{Environmental l Knowledge} = 38.891 + 1.047(\text{Education}) - 0.124(\text{Residence}) + 1.870\,(\text{Occupational status}) \tag{1}$$

Results for the regression model revealed that education ($t=3.04$, $p<0.001$, $\beta=0.242$) and occupational status ($t=2.311$, $p<0.022$, $\beta=0.163$) were statistically significant and residence (t = -1.610, $p > 0.109$, $\beta = 0.113$) was an insignificant negative variable to environmental knowledge. The results agree with Spearman's correlation, whereby negative associations were computed between residence and environmental knowledge in Maluti-a-Phofung. From the model summary, the three predictor variables register an adjusted R-squared value of 0.102, translating to 10.2% of the explained variation in Y (ecological knowledge).

The positive slope for education (1.047), as a predictor of environmental knowledge, indicated that there was about a 1.047% increase in environmental knowledge for each reported improvement in education. In other words, environmental knowledge tends to increase as education increases. The squared semi-partial coefficient (sr^2) that estimated how much variance in environmental knowledge was uniquely predictable from education was (0.244), indicating that education and occupational status uniquely accounted for 24% of the variance in environmental knowledge. Thus, the residual of 76% could be explained by other variables such as environmental knowledge about the environmental factors, i.e., rainfall, temperature, humidity, sunshine, soil vegetation, topography, and drainage.

$$\text{Environmenta l Knowledge Y} = 47.828—0.600\ (\text{Education}) - 0.002\ (\text{Residence}) + 0.19\ (\text{Occupational status}) \quad (2)$$

The positive slope for occupational status (0.19) as a predictor of environmental knowledge indicated a 0.019% increase for each 1-point increase in the occupational group. In other words, environmental knowledge tends to increase with respondents' occupational statuses. The squared semi-partial coefficient (sr^2) estimated how much variance in environmental knowledge was uniquely predictable from occupational status (0.002), indicating that occupational status uniquely accounted for 0.2% of the variance in environmental knowledge. However, education and residence results were reported as insignificant. These results verify the computed Spearman's correlation, whereby there is a weak association between residence and environmental knowledge ($r = 0.003$) and a significant negative relationship between education and environmental learning (−0.176).

Discussion

The context-based knowledge about environmental resources helps to interpret the relationship between human and their surroundings (Durar et al., 2023). Therefore, the present study evaluated the feedback from the grassroots levels. The data for assessing the inclinations about local environmental knowledge was collected from Maluti-a-Phofung LM and Thulamela LM. The study mainly assessed the imprints of socio-economic determinants on the orientations toward LEK. The study's findings confirm that socio-economic factors like education, residence, and occupational status symptomatically influence household environmental knowledge and awareness (Mubbin et al., 2022). Besides, involvement in decision-making and resource access also contributes to knowledge acquisition (Mosissa et al., 2017).

Therefore, households' knowledge regarding the local environment was assessed. It systematically evaluates the linkages between local knowledge and meteorological data. The spatial and temporal climate considerably affects ecological diversity. The scorching, damp summers and chilly winters are the hallmarks of the Maluti-a-Phofung LM climate (Myeni et al., 2019). During the winter weather, the area experiences snowfall, particularly in high mountains (Myeni et al., 2019). Heavy precipitation in this area occurs during summer due to powerful downpours (ARC, 2016). These factors are evident from the respondents' local knowledge of rainfall in Maluti-a-Phofung LM. Based on local climatic knowledge, the eastern parts of the LM are more appropriate for dry land farming production than the wet areas in the western and southern regions of the LM (Moeletsi & Walker, 2013). Dry land-grown crops may include winter wheat, corn, beans, sunflowers, or watermelons. The selection of produce is affected by the timing of main rains in terms of the seasons for instance, winter wheat suits regions with more significant winter rain.

In comparison, areas with summer wet seasons may be more appropriate for summer-growing crops such as sorghum, sunflower, cotton, etc. (ARC, 2016). Moreover, drought and prolonged waterless periods frequently occur in summer (December to February). Such periods are the main agro-climatological risks influencing agricultural systems and land-use allocation in Maluti-a-Phofung LM (Mbiriri et al., 2018).

The respondents' local knowledge about rainfall was outstanding regarding the dry and wet seasons in Thulamela LM compared to Maluti-a-Phofung. The LM mainly undergoes long, bright days and dry, cool evenings (Tshiala et al., 2011). The LM is characterized by a dry spell from March to September (Musyoki et al., 2016), with the onset of rainfall in October. The mean yearly rain in Thulamela LM is 820 mm. Therefore, flooding is expected from January to February. During winter, from May to August, the weather is hot during the day, with cool, dry air in the evenings (Musyoki et al., 2016). Temperature can plummet rapidly at night. At some point in winter months, Thulamela LM characteristically obtains less than 20 mm of rainfall each month, with almost 8 mm of rain in August (Mpandeli & Maponya, 2013). In Thulamela LM, poor rainfall results in livestock losses, a scarcity of drinking water, reduced crop production, and a shortage of seed (Wilk et al., 2017). In this study, most farmers pointed out that peanuts and peas grow well in dry land areas because these crops need less water than other crops, such as avocados and bananas. Peanuts and cowpeas also retain moisture by spreading over the soil surface. Nonetheless, maize occupies the largest area of all other field crops, followed by sorghum, beans, and groundnuts. Fruits, vegetables, tea, and sugar are also commonly grown. Based on the local knowledge associated with fewer rainfall conditions, farmers opt to grow drought-resistant food crops that can mature fast (Phokele & Sylvester, 2015).

The prevailing temperature conditions of Thulamela Local Municipality and Maluti-a-Phofung Local Municipality were recorded and compared. The respondents' local knowledge portrayed that the contextual surroundings of Thulamela LM have hotter months than Maluti-a-Phofung LM. For Thulamela LM, the typical maximum temperature is 35 and 18 °C in summer and winter, respectively (Musyoki et al., 2016). In Limpopo, during the summer months, hot days are regularly interrupted by brief heavy showers (LDARD, 2019). However, Maluti-a-Phofung LM respondents' knowledge of the coldest month and average summer and winter temperatures was more pronounced than that of Thulamela LM. In the Free State province, temperatures often plunge to below zero in winter. Summers are wet and hot; winters are dry with regular frost. Snowfalls happen at least once a year between July and September, but low-lying areas get infrequent snow events. The area experiences frostiness, which is conducive to the abundance of grassland vegetation and prevents the growth of trees (Rankoana, 2016). Grasslands are significant landscapes and provide the natural resources and ecological infrastructure that assist most of South Africa's vital economic activities and millions of pastoral livelihoods. The conditions in grasslands make them highly apt for human occupancy and land uses upon which food production and other economic activities depend. Therefore, some 40% of South Africans, including the residents of Thulamela LM, tend to sustain their livelihoods from these grasslands (SANBI, 2013).

The statistical findings (Fig. 3) of Thulamela LM indicated the negative associations between the level of education and environmental knowledge. However, Maluti-a-Phofung LM showed a positive association between the level of education and environmental knowledge. However, the findings also show that education and environmental learning groups have noticeable imprints on the residence and occupational status of the respondents. It deduces that the level of education directly (in the case of Malutiu-a-Phofung LM) and indirectly (in the case of Thulamela LM) shapes and tailors the respondents' socio-economic conditions and their inclinations on environmental resources. Thus, the findings of this study substantiate the reported postulations that focus on human capacity building through informed decision-making, which produces dividends for ecological and environmental infrastructure (Li et al., 2024).

In addition, Fig. 4 depicts that most respondents in these two study areas have lived there for decades. It naturally follows that residents are accustomed to their surrounding environments' environmental/ecological states. Most of them depend on primary economic activities, whereby the knowledge about ecological resources significantly determines their social and economic activities. Based on the findings shown here, it is clear that the Maluti-a-Phofung LM sample was defined by the person living in this community for over thirty years.

As far as Thulamela LM (Fig. 5) is concerned, no respondent had lived in the area for less than 11–30 years. In Maluti-a-phong and Thulamela LMs, most dwellers have resided in their locations for 31 to 60 years. There is an assumption that as the duration of stay is prolonged, the residents' knowledge about natural resources is enhanced. However, the findings (Table 2) in this study noted a negative association between residence and ecological knowledge in Maluti-a-Phofung ($r = -0.083$) and a weak association in Thulamela LM ($r = 0.003$). These results suggest that other factors besides residence would determine local environmental knowledge. For example, there is a positive association between occupational status and environmental knowledge in Maluti-a-Phofung LM ($r = 0.134$) and $r = 0.023$ in Thulamela LM. Thus, prudent use of available ecological/environmental resources depends on the residents' awareness and knowledge base. Nonetheless, the study establishes that environmental resources are endangered by possible future unsustainable utilization of the resources, global warming, and climate change (Vicente-Serrano et al., 2020). Lastly, the subsequent degradation of the natural environment could result in human suffering. It is, however, the duty of the people occupying these regions to preserve the natural resources as they derive their sources of livelihood from the same.

Conclusions

For this study, environmental knowledge regarding education, residence, and occupational status was assessed from Maluti-a-Phofung and Thulamela local municipalities. Knowledge of climatic factors and soil was acquired through observation and experience. This acquired knowledge manifests itself in decision-making and guides land use practices. Thus, indigenous knowledge symptomatically influences the orientation of human–environment interactions. Knowledge of the quantity and timings of rainfall, the onset of seasons, temperature ranges, and soil characteristics is acquired through contextual setting experiences. It tailors cropping and land utilization. The findings infer that socio-economic determinants such as education, occupational status, and residence time significantly influence the knowledge and awareness of rural communities about critical decisions such as what crops to grow and where these crops can be grown.

Besides local knowledge, this study recommends public participation in decision-making processes and resource access to motivate communities to acquire formal education and training. The study also stresses the need to adopt innovative measures to tackle challenges such as climate change and resilient socio-economic development. To advance local knowledge, a pragmatic and comprehensive policy response is critical to land-use allocation and environmental sustainability. Therefore, increased public involvement in land-use planning and management is necessary for capacity building and informed land-use allocation decision-making. This study is needed as it explores how socio-economic factors like education, occupation, and residence impact local ecological knowledge and land use decisions. It provides new insights into sustainable land management and emphasizes the importance of public participation, formal education, and innovative solutions to address climate change and socio-economic development challenges.

Declarations

Conflict of interest Regarding this paper, the authors have no competing financial or other interests. All studies adhere to ethical standards.

APPENDIX

Annexure-1: Environmental and land-use variables.

Parameter	Components	Scale	Units	Scores
Rainfall		LM	mm	
R1	Mean monthly rainfall*	Ratio		
R2	Annual rainfall range*			
R3	Duration in months of the wet season*			
R4	Duration in months of the dry season*			
R5	Mean monthly rainfall#			
R6	Annual rainfall range#			

Parameter	Components	Scale	Units	Scores
R7	Duration in months of wet season#			
R8	Duration in months of dry season#			
Temperature		LM	ºC	
T1	Mean monthly temperature*	Interval		
T2	Winter minimum temperature*			
T3	Summer maximum temperature*			
T4	Annual temperature range*			
T5	Mean monthly temperature#			
T6	Winter minimum temperature#			
T7	Summer maximum temperature#			
T8	Annual temperature range#			
Humidity		LM	Relative %	
H1	Mean monthly humidity*	Ratio		
H2	Winter mean*			
H3	Summer mean*			
H4	Annual humidity range*			
H5	Mean monthly humidity#			
H6	Winter mean#			
H7	Summer means #			
H8	Annual humidity range#			
Solar radiation		LM	Per Hour	
S1	The onset of summer*	Interval		
S2	The onset of winter*			
S3	Onset of spring*			
S4	Onset of autumn*			
S5	Onset of summer#			
S6	Onset of winter#			
S7	Onset of spring#			
S8	The onset of autumn#			

Natural vegetation	Vegetation types	LM	Percentage %
N1	Forest	Ratio	
N2	Savannah woodland		
N3	Savannah Grassland		
N4	Savannah grass & thicket		
N6	Bush land		
N7	Wetland		
N8	Extent of usage		
N9	Extent of degradation		
Landform		LM	Percentage %
L1	Highland	Ratio	
L2	Low-land		
L3	Plateau		
L4	Mountains		
L5	Flood Plain		
L6	Mean altitude of the Ward		
L7	Maximum altitude of Ward		
L8	The lowest altitude of Ward		
L9	Class of dominant slope		
Soil		LM	
S1	Dominant soil type (class)	Interval	
S2	Other soil types by relative area covered in Ward		
S3	Prone to water erosion	Ratio	
Drainage		LM	Count

Natural vegetation	Vegetation types	LM	Percentage %
D1	Number of seasonal streams in Ward	Ratio	
D2	Number of permanent streams in Ward		
D3	Number of reservoirs in Ward		
D4	% of land classified as flood plain		Percentage

Land-use	The relative % size distribution of:	LM	Percentage %
LU1	Agriculture	Ratio	
LU2	Forestry		
LU3	Residential		
LU4	Open space		
LU5	Wetland		
LU6	Protected buffer zone		
LU7	Mining		
LU8	Transport (% of the area covered by roads)		
LU9	Wildlife and Tourist attractions		

Annexure-2: Environmental and land-use variables.

Category	Variables on Households	Measure	Scale
Households	Formal education	Number of years	
	Informal education	Number of years	
	Decision about the environment	Choice from provided options	
	Resource access	Choose from provided options	
	Choice about the environment	Choose from provided options	
	Frequency of reference to environmental controls	Count score on performance sheet provided and capture in % form	

Land-use allocation

Variable	Measures		Data	Scale	Score
Education	1: What is your highest level of education?		Count/ Frequency	Ratio	
E1	Primary	Grade	✓	✓	Score
		0	✓	✓	
		1	✓	✓	
		2	✓	✓	
		3	✓	✓	
		4	✓	✓	
		5	✓	✓	
		6	✓	✓	
		7	✓	✓	
E2	Matric	Grade	✓	✓	Score
		8	✓	✓	
		9	✓	✓	
		10	✓	✓	
		11	✓	✓	
		12	✓	✓	
E3	Post Matric	Grade	✓	✓	Score
		1	✓	✓	
		2	✓	✓	
		3	✓	✓	
E4	University	Grade	✓	✓	Score
		1	✓	✓	
		2	✓	✓	
		3	✓	✓	
Residence	2: For how long have you been a resident of this locality?		Count/ Frequency	Ratio	Score
Residence	Number of Years		✓	✓	
Occupational Status	3: In which land use category is the household active?		Count/ Frequency	Ratio	Score
OS1	Agriculture-Crop farming		✓	✓	
OS2	Agriculture-Livestock rearing		✓	✓	

Variable	Measures	Data	Scale	Score
Education	1: What is your highest level of education?	Count/ Frequency	Ratio	
OS3	Forestry& Craft industry	✓	✓	
OS4	Mining	✓	✓	
OS5	Industrial	✓	✓	
OS6	Open space	✓	✓	
OS7	Transport	✓	✓	
OS8	Construction	✓	✓	
OS9	Non-land based activities	✓	✓	
Determents of land-use allocation	4: What do you consider most when making decisions about land use?	Count/ Frequency	Ratio	Score
DLUI	Climatic conditions	✓	✓	
DLU2	Landform conditions	✓	✓	
DLU3	Soil conditions	✓	✓	
DLU4	Vegetation conditions	✓	✓	
DLU5	Drainage conditions	✓	✓	
DLU6	General environmental conditions	✓	✓	
DLU7	Household circumstances	✓	✓	
DLU8	Land access status	✓	✓	

What is the status of environmental knowledge?

Element	Element	Element
Clay soil	Length of spring	Seasonal vegetation
Sandy soil	Length of autumn	Extent of degradation
Silt soil	Coldest month	Density of trees
Alluvial soil	Hottest month	Dominant plant species
Soil acidity	Average Summer temp	Plain
Fertility	Average Winter temp	Plateau
Nutrient content	Average humidity in Summer	Mountainous
Mineralisation	Average humidity in winter	Floodplain
Water erosion	Driest month	Hills & gentle slopes
Wind erosion	Wettest month	Hills with steep slopes

Element	Element	Element
Sand harvesting	Woodland savannah	Valleys
Soil Carrying capacity	Grassland savannah	Seasonal streams
Rainfall amount	Bush & thicket	Perennial streams
Rainfall reliability	Grass & scrub	Reservoirs
Length of dry season	Arid vegetation	
Length of wet season	Semi-arid	Total =
Length of winter	EverGreen forest	Total as a % =
Length of summer	Deciduous forest	

Who makes decisions about land-use allocation?

Decision about the land-use	Parameter	Count/ frequency	Ratio
DLU1	Internal within household	✓	✓
DLU2	External from outside household	✓	✓
DLU3	Individual by family head	✓	✓
DLU4	Collective by household	✓	✓
DLU5	Collective by immediate community	✓	✓

What is the status of your land ownership?

Resource access	Parameters	Count/ frequency	Ratio
RA1	Private land parcel with title deed	✓	✓
RA2	Communal land parcel on municipal commonage	✓	✓
RA3	Communal land parcel under tribal land	✓	✓
RA4	Private land parcel under lease agreement	✓	✓
RA5	Land parcel held under PTO status	✓	✓

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