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The Cognitive Agronomic Asymmetry in Upland Ecological Literacy: A Psychometric and Socio-Demographic Assessment in the Upper Jeneberang Basin, Indonesia

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Abstract: Upland agricultural intensification can increase pressure on tropical watersheds, particularly where horticultural production takes place on steep slopes. This study examines the measurement properties and empirical distribution of ecological literacy among smallholder farmers in the Upper *Jeneberang Basin*, South Sulawesi, Indonesia. A descriptive-exploratory survey involving 250 farmers from seven villages/urban villages in Tinggimoncong District was conducted using multistage proportional random sampling. The ecological literacy construct was assessed through six five-point Likert items representing three reflective dimensions: biophysical understanding, agronomic capacity, and carrying-capacity awareness. Analyses comprised descriptive statistics, the Friedman test, group comparisons using one-way ANOVA and Kruskal–Wallis tests, effect-size estimation, and evaluation of the reflective measurement model using PLS-SEM. The construct showed acceptable internal consistency and convergent validity (Cronbach's $\alpha = 0.818$; composite reliability = 0.855; AVE = 0.663). The three dimensions displayed markedly different mean scores: carrying-capacity awareness was highest (3.85 ± 0.88), followed by biophysical understanding (2.45 ± 0.92), while agronomic capacity was lowest (2.10 ± 1.05). The Friedman test indicated significant differences across the three dimensions ($\chi^2 = 361.95$, $p < 0.001$). Formal education was associated with the largest between-group difference in the composite ecological literacy score ($\eta^2 = 0.468$; $p < 0.001$), whereas differences among the seven study locations were not statistically significant ($p = 0.730$). The findings indicate that an aggregate ecological literacy score can conceal substantial differences among its constituent dimensions. Extension and watershed education initiatives may therefore benefit from dimension-specific assessment, particularly in strengthening farmers' understanding of soil processes and environmentally sound agronomic practices.

Keywords: *Ecological Literacy; Biophysical Understanding; Agronomic Capacity; Carrying-Capacity Awareness; Upland Agriculture; Watershed Conservation.*

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I. INTRODUCTION

The degradation of tropical headwater catchments is a major environmental concern because changes in land use and agricultural intensification can increase soil erosion and sediment delivery to downstream water bodies [1], [2]. These processes are particularly important in mountainous agricultural landscapes, where steep slopes, intensive cultivation, and inadequate soil-management practices can increase the vulnerability of land resources. The consequences extend beyond individual farms, potentially affecting water quality, reservoir sedimentation, agricultural productivity, and the long-term sustainability of downstream water systems. In this context, soil and water conservation in upland agricultural areas should be understood not only as a farm-level management issue but also as an important component of wider watershed protection.

In South Sulawesi, the Upper *Jeneberang Basin*, particularly the Tinggimoncong area, forms part of the hydrological landscape connected to the Bili-Bili Reservoir and the wider Makassar region [3]. Horticultural production,

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including potato and cabbage cultivation on sloping land, creates a need for soil- and water-conservation practices that are appropriate to local topography and farming conditions. The extent to which such practices are understood and applied cannot be explained solely by physical characteristics of the land; farmers' knowledge and capacity to interpret ecological processes are also relevant. Practices such as maintaining topsoil quality, applying fertilizers and pesticides responsibly, establishing soil-conservation structures, and protecting riparian buffer zones are therefore relevant to reducing agricultural pressure on the watershed. Previous research has shown that the effectiveness of soil conservation depends not only on biophysical conditions but also on farmers' knowledge, resource availability, and capacity to implement appropriate management practices [4], [5].

Farmers' understanding of ecological processes is particularly important because agricultural decisions can influence environmental conditions beyond individual cultivated plots. Knowledge of topsoil degradation, erosion processes, nutrient movement, and downstream sedimentation can help farmers recognize the connections between farming activities and watershed conditions. However, understanding environmental problems does not necessarily mean that farmers possess the agronomic knowledge required to respond to them. For example, farmers may recognize the importance of protecting sloping land while having limited understanding of appropriate fertilizer application, pesticide management, or other agricultural practices that reduce environmental pressure. Conversely, farmers may be familiar with particular conservation techniques without fully understanding the ecological processes that justify their application. This distinction indicates that ecological understanding and agronomic capacity represent related but analytically distinguishable aspects of farmers' environmental competence.

Ecological literacy provides a conceptual link between understanding environmental systems and making decisions about resource use. However, a single composite score may obscure differences between what farmers know about ecological conditions and what they understand about agronomic practices that can reduce environmental pressure. Previous work has examined ecological literacy and pro-environmental farming behaviour [6], while studies of smallholder farmers have highlighted the importance of environmental knowledge, soil-management ability, and learning processes in supporting sustainable resource management [7], [8]. Misanya et al. [7], for example, identified environmental knowledge, connection with nature, and ecological behaviour as interconnected dimensions of socio-ecological stewardship among smallholder farmers in a watershed context. Similarly, Occelli et al. [8] demonstrated that different sources of farming knowledge, including household learning and social learning, are associated with farmers' soil-management ability. These studies reinforce the importance of understanding farmers' ecological knowledge in relation to the agricultural and environmental contexts in which they make decisions.

Despite these contributions, an important analytical issue remains: the use of a single composite ecological literacy score may conceal differences among the underlying dimensions of farmers' knowledge and capabilities. A relatively high overall score, for example, may not necessarily indicate that farmers have an equally strong understanding of ecological processes and the agronomic practices required to manage environmental risks. Likewise, awareness of conservation requirements may coexist with limited knowledge of how to implement environmentally responsible farming practices. Research on conservation agriculture has also identified inadequate technical knowledge, limited training, and difficulties adapting conservation practices to local farming conditions as important constraints among smallholder farmers [9]. Consequently, examining ecological literacy through its constituent dimensions may provide a more informative assessment than relying exclusively on an aggregate score.

The term cognitive–agronomic asymmetry is used here to describe the observed imbalance between these dimensions, rather than to imply a causal relationship. Using survey data from the doctoral research of Ansar (2026), this article evaluates the reflective measurement model, compares the mean scores of the three dimensions, and examines variations in ecological literacy across selected socio-demographic and spatial groups.

II. LITERATURE REVIEW AND RESEARCH GAP

Ecological literacy concerns the ability to understand ecological relationships and apply that understanding when making decisions that affect the environment [10]. In agricultural settings, this perspective is relevant because farmers' decisions about soil management, chemical inputs, cropping practices, and land use can influence the condition of surrounding ecosystems. Research on sustainable agricultural practices has highlighted the roles of information, extension services, economic incentives, and farmers' characteristics in shaping adoption [11], [12], [13]. Studies have also considered ecological literacy and pro-environmental behaviour in farming contexts [6], [14]. These strands of literature provide a basis for examining ecological literacy as a multidimensional construct rather than relying exclusively on an overall score. In this study, the construct is operationalised through biophysical understanding, agronomic capacity, and carrying-capacity awareness. The research gap addressed is empirical and measurement-oriented: whether these dimensions show different levels of performance among upland farmers, and whether the composite score varies across socio-demographic and village groups. The study does not assume that the dimensions have causal effects on conservation behaviour; instead, it provides a descriptive and psychometric assessment of their profiles.

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Table 1 Summary of Previous Research and the Position of the Present Study

Author(s) and year	Focus and setting	Method	Main finding	Research gap
Fatmawati et al. (2018)[15]	Farmers' ecological behaviour in Gowa	Quantitative survey	Education influenced adoption of environmentally friendly inputs	Did not examine the measurement loadings of the three ecological literacy dimensions
Keesstra et al. (2018) [16]	Land degradation and the SDGs	Conceptual synthesis	Restoration requires integration of soil and water systems	Macro-level focus; no site-level psychometric validation
Amadu et al. (2020) [11]	Climate-smart agriculture adoption in Malawi	Bivariate probit (n = 808)	Extension services accelerated agroforestry adoption	Focused on physical adoption rather than cognitive disparities
Piñeiro et al. (2020) [12]	Incentives for sustainable agriculture	Global scoping review	Economic incentives and advisory support encouraged conservation	Did not test the role of ecological literacy
Leonhardt et al. (2021) [13]	Land tenure and soil conservation in Austria	Survey and modelling	Owner-farmers showed stronger commitment to soil stewardship	Different context; did not address small, fragmented upland holdings
This study (Ansar, 2026)	Upper *Jeneberang Basin* (n = 250)	PLS-SEM, descriptive statistics, ANOVA and Kruskal–Wallis	Dimension-level disparity, particularly low agronomic-capacity score	Examines dimension-level measurement and socio-demographic variation

The comparison of previous studies presented in Table 1 highlights the distinct contribution of the present research. While earlier studies have primarily examined the adoption of sustainable agricultural practices, the influence of institutional and economic support, or broader approaches to land degradation, limited attention has been given to the measurement of ecological literacy at the dimension level among upland farmers. This study addresses that gap by integrating a psychometric assessment with descriptive and comparative analyses of three ecological literacy dimensions: biophysical understanding, agronomic capacity, and carrying-capacity awareness. Its contribution lies in identifying differences in the performance of these dimensions and examining variations in composite ecological literacy across socio-demographic and village groups. In particular, the analysis provides empirical evidence on whether farmers' understanding of ecological conditions is accompanied by comparable levels of agronomic capacity and awareness of land-carrying capacity. Thus, the study extends previous research by offering a more differentiated account of ecological literacy in an upland agricultural context and providing an evidence base for designing context-specific environmental education and sustainable land-management initiatives.

- *Literature Review and Research Gap*

This study used a descriptive-exploratory cross-sectional survey, supplemented by qualitative contextual information, in seven villages/urban villages in *Tinggimoncong* District, South Sulawesi, at elevations of approximately 950–1,650 metres above sea level. The sample comprised 250 farmers drawn from a reported population of 4,025 farmers across 161 farmer groups. Multistage proportional random sampling was used to allocate respondents across the seven locations: *Malino* (n = 42), *Pattapang* (n = 46), *Bulutana* (n = 37), *Gantarang* (n = 26), Parigi (n = 39), *Garassi* (n = 29), and *Bonto Lerung* (n = 31).

Ecological literacy was measured using six five-point Likert items (B7–B12), grouped into three reflective dimensions: biophysical understanding (B7–B8), agronomic capacity (B9–B10), and carrying-capacity awareness (B11–B12). The items had undergone expert content validation, with Aiken's V values ranging from 0.917 to 0.958 [17]. The measurement model was evaluated using PLS-SEM in SmartPLS 4.0, considering outer loadings, Cronbach's alpha, composite reliability, average variance extracted (AVE), and variance inflation factors. Descriptive statistics were used to summarise item- and dimension-level scores. Differences among the three dimensions were assessed using the Friedman test. Differences in composite ecological literacy scores across socio-demographic and village groups were examined using one-way ANOVA and Kruskal–Wallis tests, with eta-squared (η^2) reported as an effect-size measure where available. Because the study is cross-sectional and observational, the group comparisons are interpreted as associations or differences, not causal effects.

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Table 2 Spatial Distribution, Elevation, Population, and Proportional Sample Allocation

Village/urban village	Elevation (m a.s.l.)	Population (N)	Farmer groups	Sample (n)
Malino	1,050–1,500	676	27 groups	42 (16.8%)
Pattapang	1,250–1,650	741	30 groups	46 (18.4%)
Bulutana	1,100–1,480	596	24 groups	37 (14.8%)
Gantarang	1,000–1,380	419	17 groups	26 (10.4%)
Parigi	950–1,340	628	25 groups	39 (15.6%)
Garassi	980–1,400	467	19 groups	29 (11.6%)
Bonto Lerung	1,020–1,420	498	19 groups	31 (12.4%)
Upper Jeneberang total	950–1,650	4,025	161 groups (65 clusters)	250 (100%)

The distribution presented in Table 2 demonstrates that the study covered seven villages/urban villages across the upper-elevation landscape of the Jeneberang watershed, with elevations ranging from approximately 950 to 1,650 metres above sea level. The proportional allocation ensured that each location was represented in accordance with its share of the reported farmer population, while maintaining a total sample of 250 respondents. Pattapang contributed the largest number of respondents (n = 46; 18.4%), followed by Malino (n = 42; 16.8%), whereas Gantarang had the smallest allocation (n = 26; 10.4%). This spatial distribution provided a basis for examining variations in ecological literacy across different village contexts within the upper watershed. By covering locations with varying elevations and agricultural settings, the sampling design also enabled the study to capture contextual differences relevant to farmers' understanding of biophysical conditions, agronomic practices, and watershed carrying capacity.

III. RESULTS

➢ *Socio-Demographic Profile of the Respondents*

The socio-demographic characteristics of farmers provide important contextual information for understanding differences in ecological literacy within upland agricultural communities. Factors such as age, formal education, household size, cultivated land area, and land-tenure status may reflect differences in farming experience, access to information, available resources, and the capacity to implement sustainable agricultural practices. Previous empirical studies have also demonstrated that farmers' socio-economic characteristics, farm resources, land-tenure arrangements, and access to agricultural support are relevant considerations in explaining variations in the adoption of sustainable farming and climate-resilient agricultural practices [18], [19]. These findings reinforce the importance of examining ecological literacy in relation to the socio-economic conditions in which upland farmers make agricultural decisions. Similarly, Leonhardt [13] emphasised the relevance of land-tenure arrangements to farmers' commitment to soil conservation. Therefore, examining the respondents' socio-demographic profiles is necessary to provide a contextual basis for interpreting the ecological literacy patterns identified in this study.

Respondents had a mean age of 47.3 years, and 72.0% were older than 40 years. Formal education was generally limited: 75.2% had completed junior secondary school or less, while only 3.2% had tertiary education. Most respondents cultivated relatively small plots; 85.6% managed no more than 0.50 hectares, with a mean cultivated area of 0.33 hectares. Household size and land-tenure characteristics are also relevant to understanding the socio-economic context of agricultural activities in the study area. The detailed distribution of these characteristics is presented in Table 3.

Table 3 Socio-Demographic Characteristics and Landholding Profile of Respondents (n = 250)

Socio-demographic characteristic	Distribution	Dominant category	Sample summary
Age	≤30 years (22); 31–40 (48); 41–55 (116); >55 (64)	41–55 years: 46.4%	Mean = 47.3 years; 72.0% >40 years
Formal education	No schooling (12); primary (98); junior secondary (78); senior secondary (54); tertiary (8)	≤ junior secondary: 75.2%	Only 3.2% had tertiary education
Household size	1–3 persons (48); 4–6 (154); >6 (48)	4–6 persons: 61.6%	Mean = 4.9 persons/household
Cultivated land area	≤0.25 ha (136); 0.26–0.50 ha (78); >0.50 ha (36)	≤0.25 ha: 54.4%	Mean = 0.33 ha (median 0.25 ha)
Land tenure	Owned (178); sharecropping (46); rented (26)	Owned: 71.2%	Most holdings were inherited and fragmented

The distribution in Table 3 indicates that the respondents were predominantly middle-aged farmers with relatively limited formal education and small cultivated landholdings. The high proportion of respondents with junior secondary education or less suggests that formal educational attainment should be considered when interpreting their ecological literacy profiles, particularly their understanding of biophysical processes and their capacity to translate ecological knowledge into agricultural practices. This observation is consistent with Li et al. [20], who highlighted

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the relevance of farmer characteristics and access to agricultural extension in the adoption of climate-smart agricultural practices. However, the present study does not assume that lower educational attainment directly results in lower ecological literacy; rather, education is examined as one of the socio-demographic characteristics associated with differences in literacy scores.

The predominance of small-scale landholdings also provides an important context for understanding farmers' agricultural decisions. With 85.6% of respondents cultivating no more than 0.50 hectares, land availability and fragmentation may represent practical considerations in implementing soil conservation and sustainable land-management measures. This finding is consistent with Olumba et al. [21], who identified financial limitations, land-related constraints, and inadequate institutional and advisory support as important barriers to the adoption of sustainable land-management practices among smallholder farmers. These findings highlight the importance of designing conservation interventions that are technically feasible, economically accessible, and appropriate to the scale of farmers' landholdings. Furthermore, the high proportion of owner-operated landholdings (71.2%) is noteworthy in relation to Leonhardt [13], who examined the relationship between land-tenure arrangements and farmers' commitment to soil stewardship. Nevertheless, ownership status alone does not necessarily indicate the actual implementation of conservation practices.

Overall, the socio-demographic profile illustrates the structural characteristics of the upland farming community in the Upper Jeneberang Basin. The combination of relatively low formal educational attainment, small and fragmented landholdings, and predominantly owner-operated farms provides an important background for interpreting the differences in ecological literacy dimensions and their variation across respondent groups. These characteristics therefore serve as contextual variables for the subsequent analysis rather than as direct explanations of farmers' ecological literacy or conservation behaviour.

- *Measurement Model and Differences Among Ecological Literacy Dimensions*

The evaluation of the ecological literacy measurement model was conducted to examine the reliability, convergent validity, and measurement quality of the three proposed dimensions. In addition to assessing the statistical properties of the construct, the analysis compared the observed mean scores of each dimension to identify potential differences in respondents' ecological literacy profiles. This distinction is important because a dimension may demonstrate a strong statistical relationship with the latent construct without necessarily representing a high level of respondents' actual knowledge or capacity.

The reflective measurement model showed acceptable reliability and convergent validity for the ecological literacy construct (Cronbach's $\alpha = 0.818$; rho_A = 0.826; composite reliability = 0.855; AVE = 0.663). All three dimensions had outer loadings above 0.70, and the reported VIF values were below 1.90. These results support the adequacy of the three dimensions as measures of the overall construct. However, measurement strength and observed performance should be distinguished: outer loading represents the strength of the relationship between an indicator and the latent construct, whereas the mean score describes respondents' reported level of performance on that dimension.

The mean composite ecological literacy score was 2.78 ± 1.15, equivalent to 56.0% of the maximum possible score. Dimension-level means differed substantially. Carrying-capacity awareness had the highest mean (3.85 ± 0.88), followed by biophysical understanding (2.45 ± 0.92), while agronomic capacity had the lowest mean (2.10 ± 1.05). The Friedman test indicated statistically significant differences among the three dimensions ($\chi^2 = 361.95$, $p < 0.001$). These findings suggest an uneven profile of ecological literacy among the respondents, particularly the contrast between relatively high awareness of land-carrying capacity and considerably lower agronomic capacity.

Table 4 Measurement-Model Statistics and Descriptive Profile of Ecological Literacy Dimensions

Dimension and items	Outer loading (λ) and VIF	Aiken's V	Mean ± SD (% of maximum)	Observed category
X_{21}: Biophysical understanding (B7 topsoil; B8 erosion)	λ = 0.780*** (VIF 1.628)	0.958	2.45 ± 0.92 (49.0%)	Low (B7 = 2.56; B8 = 2.34)
X_{22}: Agronomic capacity (B9 chemicals; B10 climate)	λ = 0.850*** (VIF 1.892)	0.958	2.10 ± 1.05 (42.0%)	Very low (B9 = 2.04; B10 = 2.16)
X_{23}: Carrying-capacity awareness (B11 terraces; B12 zones)	λ = 0.810*** (VIF 1.745)	0.917	3.85 ± 0.88 (77.0%)	High (B11 = 3.92; B12 = 3.78)
Ecological literacy composite	α = 0.818; rho_C = 0.855; AVE = 0.663	Valid	2.78 ± 1.15 (56.0%)	Moderate (Friedman χ^2 = 361.95***)

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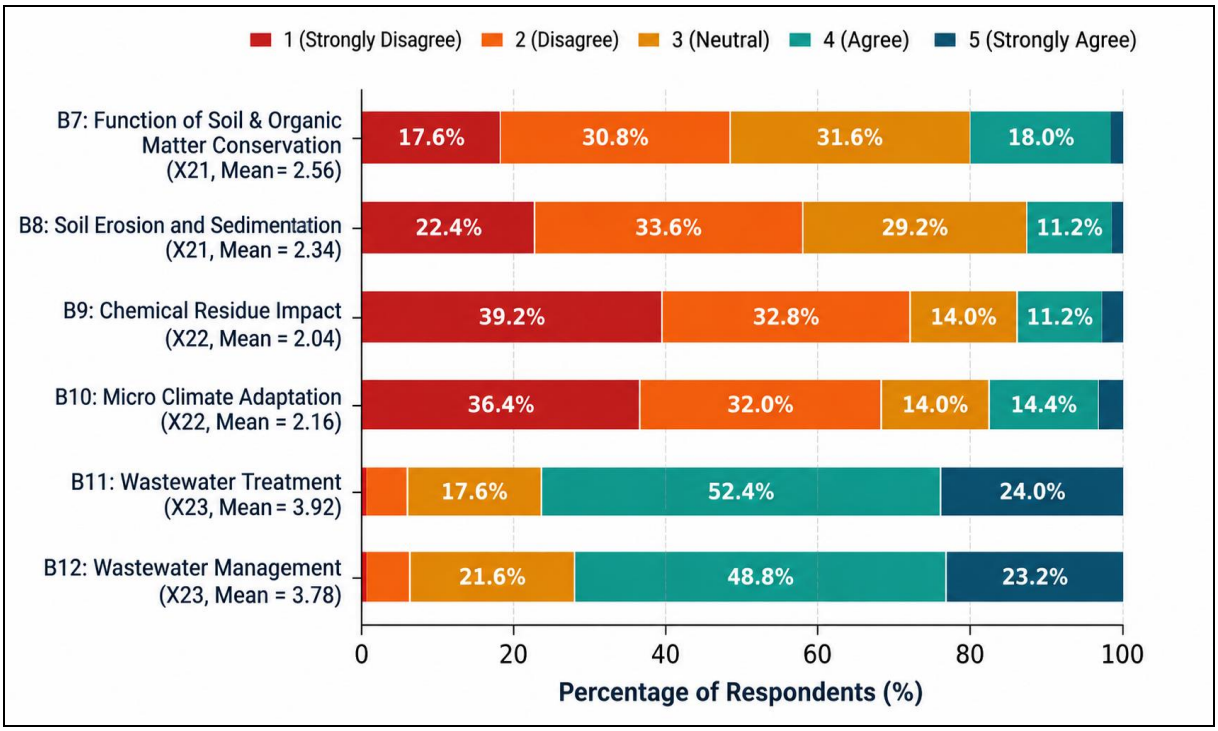


Fig 1 Distribution of Responses to the Six Ecological Literacy Items (B7–B12)

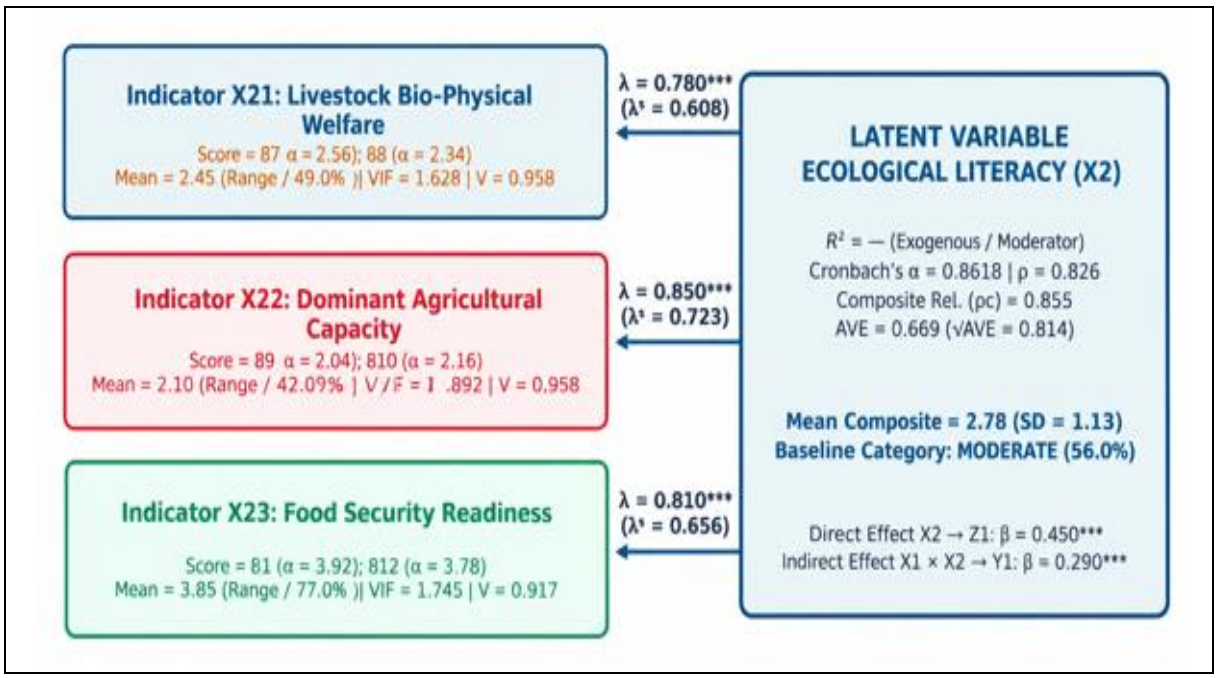


Fig 2 Reflective Measurement Model of Ecological Literacy and Dimension-Level Scores

The distribution of responses in Figure 1 provides further detail on the differences identified in Table 4. Responses to the biophysical understanding items (B7 and B8) were concentrated in the low and moderate categories, indicating that respondents' understanding of topsoil and organic matter conservation, as well as upstream erosion and downstream sedimentation, remained limited. A similar pattern was observed for agronomic capacity (B9 and B10), where a substantial proportion of respondents reported very low or low levels of understanding regarding the environmental impacts of chemical residues and microclimate adaptation. In contrast, the carrying-capacity awareness items (B11 and B12) showed a greater concentration of responses in the high and very high categories. This pattern indicates that respondents expressed relatively stronger awareness of terracing on sloping land and compliance with buffer-zone regulations than their reported capacity in the other two dimensions.

Figure 2 illustrates the reflective measurement structure and highlights an important distinction between the statistical contribution of each dimension and its observed score. Agronomic capacity (X_{22}) had the highest outer loading (λ = 0.850), suggesting the strongest association with the

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ecological literacy construct among the three dimensions. Nevertheless, it recorded the lowest mean score (2.10). Conversely, carrying-capacity awareness (X_{23}) had a slightly lower outer loading ($\lambda = 0.810$) but the highest mean score (3.85). Therefore, the higher loading of agronomic capacity should not be interpreted as evidence that farmers performed better in this dimension. Instead, it indicates that agronomic capacity was a strong measurement component of ecological literacy, despite its relatively low observed level among respondents.

This uneven pattern provides empirical support for the concept of cognitive–agronomic asymmetry in upland ecological literacy. In this study, the term refers to the disparity between respondents' relatively high awareness of land-carrying capacity and their lower understanding of biophysical processes and agronomic practices. The finding is relevant to McBride [10], who conceptualised ecological literacy as the ability to understand ecological relationships and apply that understanding in environmental decision-making. It also extends the discussion of ecological literacy and pro-environmental behaviour in agricultural contexts presented by Yu et al dan Keshavarz & Karami [6], [14], by demonstrating that ecological literacy should not necessarily be interpreted as a uniform capacity across all dimensions.

Furthermore, the relatively low agronomic-capacity score has implications for the implementation of sustainable agricultural practices. Previous research by Amadu [11] and Piñeiro [12] highlighted the importance of extension services, information, advisory support, and economic incentives in encouraging the adoption of sustainable agricultural practices. The present findings suggest that such support may need to address not only farmers' general environmental awareness but also their practical understanding of environmentally appropriate agricultural decisions, including chemical-input management and adaptation to microclimatic conditions. However, the current study did not directly measure the effectiveness of extension services or specific interventions; therefore, this implication should be understood as a direction for future educational and agricultural programmes.

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Overall, the results demonstrate that ecological literacy among upland farmers in the Upper *Jeneberang Basin* is characterised by a moderate composite score but substantial differences across its constituent dimensions. The combination of relatively high carrying-capacity awareness and low agronomic capacity indicates that environmental awareness does not necessarily correspond to an equally developed understanding of sustainable farming practices. This dimension-level disparity is the central empirical finding of the study and provides a basis for developing more targeted environmental education and agricultural extension strategies that strengthen the connection between ecological understanding and sustainable agronomic decision-making.

To provide a more detailed understanding of the ecological literacy profile, the analysis was extended to the distribution of responses for each of the six measurement items (B7–B12). Examining item-level responses is important because dimension-level averages may conceal differences in respondents' understanding of specific ecological and agricultural issues. The analysis therefore grouped responses into three categories: low/very low (scores 1–2), moderate (score 3), and high/very high (scores 4–5). This classification makes it possible to identify which aspects of ecological literacy were relatively well understood and which remained areas of concern among upland farmers. The response distributions and descriptive statistics are presented in Table 5.

Table 5 Response Distribution and Descriptive Statistics for Items B7–B12 (n = 250)

Item	Low/very low (1–2)	Moderate (3)	High/very high (4–5)	Mean ± SD
B7: Topsoil and organic-matter functions (X_{21})	48.4% (121)	31.6% (79)	20.0% (50)	2.56 ± 1.04
B8: Link between upland erosion and Bili-Bili sedimentation (X_{21})	58.0% (145)	29.2% (73)	12.8% (32)	2.34 ± 0.98
B9: Effects of fertiliser/pesticide leaching (X_{22})	72.0% (180)	14.0% (35)	14.0% (35)	2.04 ± 1.11
B10: Microclimate adaptation and planting practices (X_{22})	68.4% (171)	14.0% (35)	17.6% (44)	2.16 ± 1.14
B11: Slope limits and stone terraces (X_{23})	6.0% (15)	17.6% (44)	76.4% (191)	3.92 ± 0.89
B12: Compliance with riparian buffer zones (X_{23})	6.4% (16)	21.6% (54)	72.0% (180)	3.78 ± 0.93

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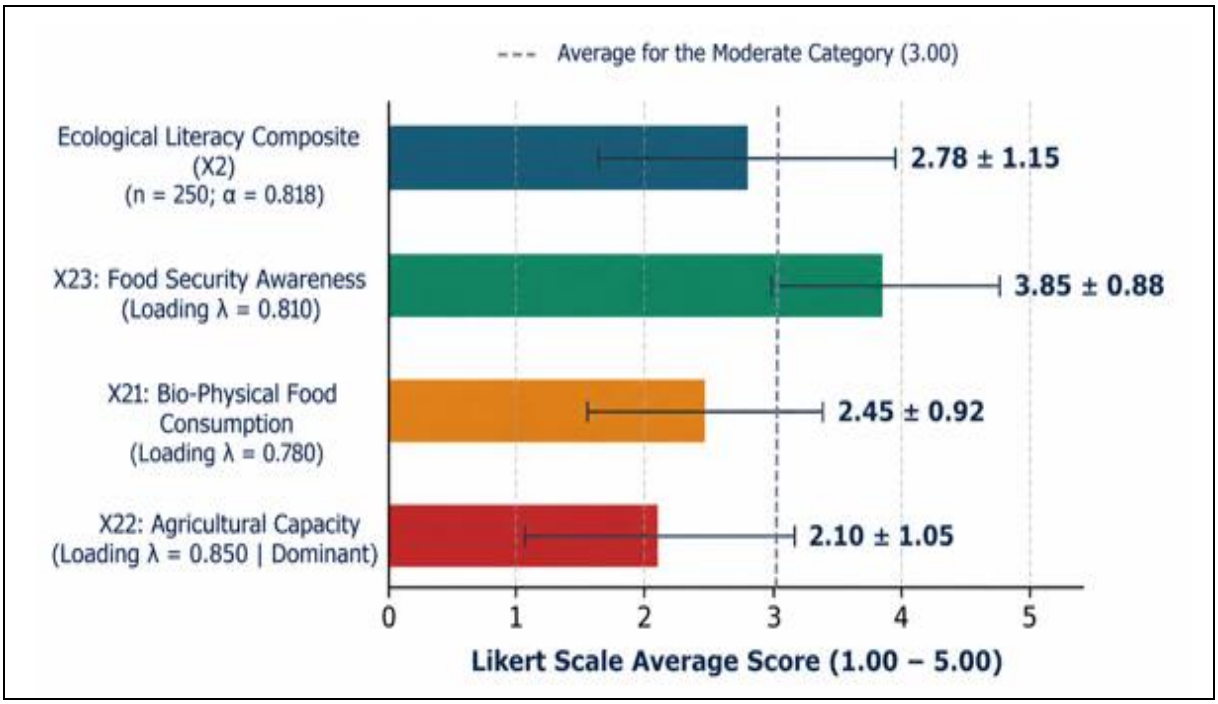


Fig 3 Mean Scores for the Three Ecological Literacy Dimensions and the Composite Score

The results in Table 5 reveal considerable differences in respondents' understanding across the six ecological literacy items. For biophysical understanding (X_{21}), almost half of the respondents (48.4%) demonstrated low or very low scores on B7, while the proportion increased to 58.0% for B8. This indicates that understanding the relationship between upland erosion and sedimentation in the Bili-Bili Reservoir was relatively more limited than knowledge of topsoil and organic-matter functions. The mean score for B8 (2.34 ± 0.98) was also lower than that for B7 (2.56 ± 1.04), suggesting that connecting agricultural activities in upland areas with downstream watershed conditions remains a particular knowledge gap.

The most pronounced limitation was observed in the agronomic capacity dimension (X_{22}). Approximately 72.0% of respondents obtained low or very low scores on B9, concerning the effects of fertiliser and pesticide leaching, while 68.4% showed similar scores on B10, concerning microclimate adaptation and planting practices. The mean scores of these items were also the lowest among all six indicators (2.04 ± 1.11 and 2.16 ± 1.14, respectively). These findings suggest that respondents had relatively limited understanding of how agricultural input management and planting decisions may influence environmental conditions. This pattern is particularly important in upland agricultural systems, where inappropriate fertiliser and pesticide use, together with unsuitable cultivation practices, may contribute to soil and water degradation.

In contrast, carrying-capacity awareness (X_{23}) demonstrated a substantially more favourable response distribution. A total of 76.4% of respondents achieved high or very high scores on B11, while 72.0% did so on B12. Their mean scores were 3.92 ± 0.89 and 3.78 ± 0.93, respectively. These results indicate that respondents were relatively more familiar with slope-related conservation measures, such as stone terracing, and the importance of complying with riparian buffer-zone requirements. Nevertheless, these scores represent reported awareness and understanding rather than direct evidence that all respondents consistently implement the corresponding conservation practices.

The differences in item-level responses are further summarised in Figure 3, which compares the mean scores of the three ecological literacy dimensions with the overall composite score. Figure 3 illustrates a clear disparity among the three dimensions of ecological literacy. Carrying-capacity awareness (X_{23}) recorded the highest mean score (3.85), considerably exceeding the composite mean (2.78). In contrast, biophysical understanding (X_{21}) and agronomic capacity (X_{22}) recorded lower means of 2.45 and 2.10, respectively. The difference between the highest and lowest dimension means was 1.75 points, indicating a substantial imbalance in the respondents' ecological literacy profile. This pattern reinforces the finding that relatively high awareness of land-carrying capacity is not necessarily accompanied by an equivalent understanding of biophysical processes and sustainable agronomic practices.

This finding can be interpreted in relation to the broader concept of ecological literacy proposed by McBride [10], which emphasises not only the understanding of ecological relationships but also the application of such understanding in environmental decision-making. The present results indicate that these components may develop unevenly among farming communities. Although respondents demonstrated relatively high awareness of slope limitations and riparian buffer zones, their understanding of fertiliser and pesticide leaching, microclimate adaptation, and the relationship between upland erosion and downstream sedimentation remained comparatively limited.

The findings also provide a more differentiated perspective on previous studies of sustainable agricultural practices. Amadu et al [11] highlighted the importance of

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agricultural extension services in supporting the adoption of climate-smart agricultural practices, while Piñeiro [12] emphasised the role of economic incentives and advisory support in encouraging conservation-oriented farming. In addition, Yu et al dan Keshvarz & Karami [6], [14] examined ecological literacy and pro-environmental behaviour in agricultural contexts. Building on these perspectives, the present study demonstrates that ecological literacy should be examined at the dimension and item levels because an overall score may obscure specific areas of weakness among farmers.

Taken together, the results provide further empirical evidence of cognitive–agronomic asymmetry among upland farmers in the Upper *Jeneberang Basin*. The relatively high score for carrying-capacity awareness, compared with the lower scores for biophysical understanding and agronomic capacity, suggests that general awareness of land-conservation principles does not automatically correspond to an equally developed understanding of environmentally appropriate farming decisions. This distinction highlights the need for environmental education and agricultural extension initiatives that move beyond general conservation messages and strengthen farmers' understanding of soil processes, agricultural chemical management, microclimate adaptation, and the ecological consequences of upland farming activities.

➢ *Socio-Demographic and Spatial Group Differences*

To further examine the distribution of ecological literacy among respondents, comparative analyses were conducted across selected socio-demographic and spatial characteristics. These analyses focused on formal education, cultivated land area, household size, land-tenure status, and village of residence. The purpose was to identify whether the composite ecological literacy scores varied across different respondent groups and geographical settings. These characteristics were considered relevant because they may reflect differences in access to information, farming experience, available resources, and exposure to agricultural and environmental knowledge. The results of the group comparisons are summarised in Table 6.

Formal education showed the largest association with the composite ecological literacy score ($F = 53.86$, $p < 0.001$; $\eta^2 = 0.468$). The reported mean increased from 1.71 ± 0.28 among respondents with no formal schooling to 3.92 ± 0.53 among those with tertiary education. Cultivated land area was also associated with score differences ($F = 12.38$, $p < 0.001$; $\eta^2 = 0.131$), as was household size ($F = 8.51$, $p < 0.001$; $\eta^2 = 0.064$). Differences by land-tenure status were not statistically significant ($p = 0.280$). The seven villages/urban villages also did not differ significantly ($F = 0.60$, $p = 0.730$), indicating that the observed composite scores were broadly similar across the study locations. These patterns are consistent with Zhang et al. [22], who demonstrated that household labour endowment, household population, cultivated land fragmentation, and educational attainment were relevant to farmers' ecological farming decisions. Similarly, Wibisana [23] identified education as an important correlate of farmers' environmental awareness, while land size and household characteristics showed comparatively weaker or less consistent relationships. Taken together, these studies highlight the relevance of socio-demographic and farm-related characteristics when examining differences in farmers' ecological literacy and agricultural sustainability. Nevertheless, the present results represent bivariate group comparisons and should not be interpreted as independent or causal effects.

Table 6 Bivariate Comparisons of Ecological Literacy Scores Across Socio-Demographic and Spatial Groups

Stratification variable	Extreme groups (mean ± SD)	ANOVA F (p-value)	Kruskal–Wallis H	Effect size (η^2)
Formal education	No schooling (1.71±0.28) vs tertiary (3.92±0.53)	F = 53.86 (p < 0.001)	117.79***	0.468 (large)
Cultivated land area	≤0.25 ha (2.98±0.73) vs >1 ha (1.96±0.62)	F = 12.38 (p < 0.001)	29.89***	0.131 (medium)
Household size	1–3 persons (2.43±0.65) vs >6 (2.99±0.68)	F = 8.51 (p < 0.001)	16.58***	0.064 (medium)
Land-tenure status	Owned (2.84) vs rented (2.60)	F = 1.28 (p = 0.280)	2.67 (ns)	0.010 (not significant)
Seven villages/urban villages	Parigi (2.70) to Bonto Lerung (2.94)	F = 0.60 (p = 0.730)	3.92 (ns)	0.015 (spatial differences not significant)

*Note: η^2 represents the reported effect-size estimate. *** $p < 0.001$; ns = not significant. Extreme-group means are presented to illustrate the observed range and do not represent all category means.*

The results in Table 6 indicate that formal education was the socio-demographic characteristic most strongly associated with differences in ecological literacy scores. The substantial difference between respondents with no formal schooling and those with tertiary education, together with the large effect-size estimate ($\eta^2 = 0.468$), suggests that educational background is an important characteristic to consider when examining ecological literacy among upland farmers. This finding is consistent with Belay et al. [24], who reported that educational attainment was significantly associated with farmers' perceptions of climate change and their adaptation decisions, alongside access to climate information, training, and agricultural extension services. Similarly, Akzar et al. [25] found that Indonesian smallholder farmers with lower levels of formal education tended to have lower awareness and adoption of agricultural technologies, highlighting the relevance of educational background and access to information in shaping farmers' knowledge and decision-

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making. Formal education may provide opportunities to access, interpret, and process environmental and agricultural information. Nevertheless, the present bivariate analysis does not establish that formal education independently determines ecological literacy.

Cultivated land area also showed a statistically significant association with ecological literacy scores, with a medium effect size ($\eta^2 = 0.131$). The reported difference between the smallest and largest landholding categories suggests that farmers managing different land areas may have different experiences and information needs in relation to agricultural management. This result should be interpreted cautiously because land area alone does not indicate the quality of land management, farming intensity, or the availability of resources. This interpretation is consistent with Ulukan et al. [26], who demonstrated that differences in household assets and farm characteristics were associated with variations in farming-system sustainability among smallholder households. Their findings highlight the importance of considering farm size alongside other household and resource-related conditions when examining agricultural sustainability. In this context, the relationship between landholding characteristics and ecological literacy may warrant further investigation, particularly in smallholder farming systems where limited land availability may shape farmers' agricultural decisions and management opportunities.

Household size was also significantly associated with ecological literacy scores, although its effect size was smaller than those of education and cultivated land area ($\eta^2 = 0.064$). Respondents from households with more than six members had a higher reported mean score (2.99 ± 0.68) than those from households with one to three members (2.43 ± 0.65). This difference may reflect variations in household resources, labour availability, or opportunities to exchange agricultural information. However, these possible explanations were not directly tested in this study and should therefore be considered contextual interpretations rather than established mechanisms.

In contrast, land-tenure status was not significantly associated with ecological literacy scores ($p = 0.280$). Although respondents who owned their land had a slightly higher mean score than those who rented land, the observed difference was not statistically significant. This finding provides an important qualification to previous research by Asaaga et al. [27], who demonstrated that the relationship between land-tenure security and sustainable land-management investments is not necessarily consistent and may depend on other contextual factors, including access to credit, agricultural inputs, and targeted extension services. The present study further suggests that land ownership should not automatically be regarded as an indicator of higher ecological literacy. Knowledge and awareness may also be shaped by factors beyond ownership status, including education, access to information, and agricultural experience.

Similarly, no statistically significant differences were identified among the seven villages/urban villages ($F = 0.60$, $p = 0.730$). The relatively narrow range of reported village mean scores, from 2.70 in Parigi to 2.94 in Bonto Lerung, indicates that composite ecological literacy was broadly comparable across the study locations. This result suggests that the dimension-level disparities identified earlier were not confined to a single village but appeared within the wider study area. However, the absence of statistically significant village differences does not demonstrate that all local environmental and agricultural conditions were identical. Previous studies have shown that spatial variations in farmers' environmental knowledge and awareness may occur across different village communities and agro-ecological settings. For example, Oliver et al. [28] identified village-level differences in farmers' environmental awareness, knowledge, and training experiences in a catchment in southwest China. Similarly, Maria et al. [29] reported differences in environmental awareness and conservation motivation among farmers across highland, lowland, and coastal agro-ecological zones in Java, Indonesia. These contrasting findings suggest that spatial variation in ecological literacy and environmental awareness may depend on the geographical scale, local agricultural conditions, and characteristics of the farming communities examined. Therefore, the non-significant village-level differences in the present study should be interpreted as evidence of broadly comparable composite scores rather than proof of identical environmental and socio-economic conditions across locations.

Overall, the comparative findings indicate that ecological literacy varied more clearly according to selected socio-demographic characteristics, particularly formal education, cultivated land area, and household size, than according to village location or land-tenure status. These results complement the dimension-level analysis by showing that the observed cognitive–agronomic asymmetry occurred within a farming population that also differed in educational and household characteristics. The findings provide a basis for considering differentiated environmental education and agricultural extension approaches, particularly those that accommodate differences in educational backgrounds and farming conditions. Further multivariable research would be needed to determine whether these characteristics retain independent associations with ecological literacy when examined simultaneously.

IV. DISCUSSION

The principal finding is the marked difference between the three dimensions of ecological literacy. Carrying-capacity awareness had a relatively high mean score (3.85), whereas biophysical understanding (2.45) and agronomic capacity (2.10) were lower. The agronomic-capacity dimension also had the highest outer loading ($\lambda = 0.850$). These statistics describe different properties: the loading indicates how strongly the dimension represents the latent construct, while the mean indicates the respondents' average score. Their coexistence is not a statistical paradox. Rather, it suggests that agronomic capacity is an important component of the ecological literacy construct but is the dimension with the lowest reported level in this sample. The findings support the value of reporting dimension-specific results alongside the composite score, since the overall mean of 2.78 does not

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reveal the pronounced gap between carrying-capacity awareness and agronomic capacity.

One possible interpretation of the higher carrying-capacity awareness score is that farmers may be more familiar with visible or locally established conservation practices, such as terrace boundaries and riparian buffer zones, than with less visible processes such as nutrient leaching, pesticide movement, or the relationship between field-scale erosion and downstream sedimentation. This interpretation is plausible in light of the item content, but the present survey does not directly establish the cultural or behavioural mechanisms underlying the responses. Similarly, the lower biophysical-understanding score suggests a need to strengthen understanding of soil functions and erosion pathways. Future qualitative or observational research could examine whether local knowledge, extension exposure, farm experience, and access to technical information help explain these differences.

The socio-demographic analysis showed that formal education was associated with the largest difference in the composite ecological literacy score, followed by cultivated land area and household size. However, because these comparisons were bivariate, unmeasured factors may contribute to the observed differences. The absence of statistically significant differences among the seven locations suggests that the pattern was not strongly differentiated by village within this sample; it does not establish that all parts of the wider watershed are homogeneous. From an applied perspective, extension programmes could be tailored to the weakest dimensions identified in the assessment. For agronomic capacity, learning activities may address the environmental implications of fertiliser and pesticide use and climate-responsive cultivation. For biophysical understanding, activities may focus on topsoil functions, erosion processes, and downstream sediment connections. Existing awareness of carrying-capacity issues could be used as an entry point for reinforcing conservation practices. The proposed policy directions in Table 7 should be treated as recommendations for consideration, not as interventions evaluated by this study. The study is limited by its cross-sectional design, reliance on self-reported Likert responses, a six-item instrument, and its focus on one district. Further work should validate the instrument in other upland watersheds, incorporate direct observations of farming practices and soil conditions, and use multivariable or longitudinal designs to examine explanatory pathways.

Table 7 Indicative Policy and Extension Responses Based on Dimension-Specific Findings

Dimension and observed gap	**Indicative extension/policy response**	**Possible policy instrument**	**Potential implementing actors**
X_{22} (mean 2.10; λ = 0.85)	Climate-smart agronomy field learning and guidance on responsible fertiliser and pesticide use	Consider conditional incentives linked to verified conservation practices	Agriculture offices; local planning agency
X_{21} (mean 2.45; λ = 0.78)	Ecological literacy sessions on topsoil, erosion, and upstream–downstream sediment connections	Consider integration into relevant environmental assessment and extension activities	Environmental agency; river-basin authority
X_{23} (mean 3.85; λ = 0.81)	Strengthen existing terrace-management practices and awareness of riparian buffer zones	Support village-level conservation rules where locally appropriate	Village government; farmer groups

Table 7 highlights the need for a differentiated approach to strengthening ecological literacy in the Upper Jeneberang Basin. The most immediate priority concerns X_{22}, which recorded the lowest mean score (2.10), despite having the highest outer loading (λ = 0.85). This combination indicates that agronomic capacity is an important component of the ecological literacy construct but remains relatively weak in terms of respondents' reported scores. Accordingly, agricultural extension should prioritise field-based learning on climate-smart agronomy, including appropriate fertiliser and pesticide application. Conditional incentives linked to verified conservation practices may also be considered, provided that implementation criteria are transparent and feasible for smallholder farmers.

For X_{21} (mean = 2.45; λ = 0.78), extension activities should improve farmers' understanding of the connections between topsoil quality, erosion processes, and downstream sedimentation. This could be supported through ecological literacy sessions integrated into existing agricultural extension and environmental assessment activities. Collaboration between environmental agencies and river-basin management authorities would help connect farm-level understanding with wider watershed management concerns.

In contrast, X_{23} recorded the highest mean score (3.85; λ = 0.81), suggesting a relatively stronger level of awareness regarding carrying-capacity constraints, including slope management and riparian buffer zones. Policy responses should therefore focus less on introducing entirely new practices and more on reinforcing existing awareness through locally appropriate terrace-management support and village-level conservation rules. Farmer groups and village governments could play important roles in maintaining these practices through collective agreements and community-based monitoring.

Overall, the proposed responses reflect the cognitive–agronomic asymmetry identified in this study: agronomic capacity and biophysical understanding require greater educational attention, whereas existing awareness of carrying-capacity constraints can serve as a foundation for strengthening conservation initiatives. These recommendations are indicative rather than prescriptive, as their feasibility and effectiveness will depend on local

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institutional capacity, available resources, farmer participation, and coordination among implementing agencies.

V. CONCLUSION

This study identified substantial differences among the three measured dimensions of ecological literacy among 250 farmers in the Upper Jeneberang Basin. Carrying-capacity awareness recorded the highest mean score (3.85 ± 0.88), while biophysical understanding (2.45 ± 0.92) and agronomic capacity (2.10 ± 1.05) were lower. Although agronomic capacity had the highest outer loading (λ = 0.850), this indicates its strong contribution to measurement of the latent construct, not a high level of respondent performance. The significant Friedman test ($\chi^2 = 361.95$, $p < 0.001$) supports the presence of differences among the dimension scores. Formal education was associated with the largest between-group difference in composite ecological literacy ($\eta^2 = 0.468$), while differences across the seven study locations were not statistically significant. These findings show why dimension-specific assessment should accompany composite ecological literacy scores. In practical terms, farmer education and extension activities in upland watersheds should give particular attention to agronomic knowledge and understanding of soil and erosion processes, while building on existing awareness of land-use limits and conservation zones. The results are descriptive and should not be interpreted as evidence of causal effects.

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