

Research Article

Fish Farmers' Knowledge, Attitudes and Practices in Assessing Suitability of Earthen Pond Sites for Nile Tilapia in Kisumu County, Kenya

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Abstract

Earthen pond aquaculture remains the dominant production system for Nile tilapia (*Oreochromis niloticus*) in resource-constrained regions, yet inappropriate pond siting continues to undermine productivity and sustainability. This study assessed fish farmers' knowledge, attitudes, and practices (KAP) regarding pond site suitability prior to GIS-based suitability modelling in Kisumu County, Kenya. A cross-sectional survey of 309 earthen-pond fish farmers was conducted, and KAP responses were analysed using descriptive statistics, multiple linear regression, and multivariate techniques (Principal Component Analysis and Factor Analysis). Results revealed marked imbalances in farmers' KAP. Knowledge was relatively high for water availability indicators, particularly proximity to rivers and groundwater access, but consistently low for critical water quality parameters (dissolved oxygen, salinity, and pH) and soil quality attributes (organic matter, nitrogen, clay content, and cation exchange capacity). Attitudes strongly favoured water security, flood avoidance, and market proximity, while water chemistry and soil fertility received weak endorsement. Practices mirrored these patterns, with limited water and soil quality testing but high consideration of socio-economic and visually observable land characteristics. Multiple linear regression showed that farmer age, household income, prior aquaculture training, and extension visits were significant predictors of KAP, jointly explaining 81% of the observed variation. PCA and Factor Analysis further identified four latent dimensions structuring site-selection decision-making: water availability and quality, land and soil characteristics, socio-economic feasibility, and training and extension support. The findings demonstrate that pond site selection among smallholder farmers is driven primarily by experiential and economic considerations, with insufficient integration of technical biophysical criteria. Strengthening targeted training, extension services, and access to affordable water and soil testing tools is therefore essential to improve site-selection decisions and enhance the sustainability of Nile tilapia pond aquaculture.

Keywords

Nile Tilapia, Earthen Pond Site Suitability, Fish Farmers' Knowledge, Attitudes, Practices (KAP), Aquaculture Training, Kisumu, Kenya

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1. Introduction

Earthen pond culture entails the use of natural or man-made depressions in terrestrial landscapes to rear fish under semi-controlled conditions. This production system represents one of the oldest and most widely adopted forms of aquaculture globally, with documented origins in ancient China more than a millennium ago and subsequent diffusion across Asia, Europe, and Africa [1, 2]. Despite the emergence of intensive and recirculating systems, earthen ponds remain dominant in low- and middle-income regions due to their technical simplicity and cost efficiency. The continued popularity of earthen ponds is largely attributed to their low construction and maintenance costs, adaptability to diverse climatic conditions, flexibility in size and layout depending on local site characteristics, and suitability for culturing a wide range of freshwater fish species [3-5].

Globally, inland freshwater aquaculture accounts for over 60% of total aquaculture production, with an even higher contribution in Africa where inland systems dominate national aquaculture outputs [6]. Within these systems, Nile tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*) constitute the principal cultured species in earthen ponds across Sub-Saharan Africa, owing to their fast growth, environmental tolerance, and market acceptability [7-9].

Pond site selection is a critical determinant of aquaculture productivity, environmental performance, and economic viability. Appropriate site assessment enables optimization of water quality, pond hydrology, construction costs, and long-term sustainability [10, 11]. Site suitability for earthen ponds is commonly conceptualized as the interaction of four key domains: water availability and quality, soil characteristics, landscape features, and socio-economic conditions [7, 12, 49]. Water supply must be both reliable and suitable, as it directly governs fish survival, growth, and pond ecosystem functioning. For Nile tilapia, optimal production is generally achieved at water temperatures of 28–32°C, pH values between 6.5 and 8.5, and dissolved oxygen concentrations of at least 5 mg L⁻¹, with low salinity preferred under freshwater pond conditions [7, 13, 14].

Soil properties are equally important in determining pond performance, particularly with respect to water retention, nutrient cycling, and pond fertility. Clay or clay-loam soils containing at least 20% clay are recommended to minimize seepage and enhance pond stability, while adequate organic matter and nutrient content support natural food production [12, 49]. Landscape features such as gentle slopes (approximately 1–2%) facilitate drainage and reduce erosion risks, whereas sites prone to flooding or excessive elevation variability may compromise pond integrity [15]. In addition, land-use planning is essential to avoid conflicts with agriculture, settlements, and environmentally sensitive areas [12]. Socio-economic factors including proximity to roads, availability of labour, access to markets, and availability of organic manure strongly influence operational costs, profitability, and management feasibility of

pond-based aquaculture [9, 16].

The knowledge, attitudes and practices (KAP) of fish farmers regarding pond site suitability play a central role in determining whether these ecological and technical requirements are adequately considered in practice. Within aquaculture research, KAP has increasingly been applied as a diagnostic framework to assess farmer awareness, perceptions, and decision-making behaviour in relation to recommended management practices, particularly in small-scale systems [17, 18]. Previous studies in Kenya and the wider region have documented substantial knowledge gaps among fish farmers regarding critical water-quality parameters such as dissolved oxygen, temperature, and pH, as well as key soil properties influencing pond productivity [19-23]. However, comparatively limited attention has been paid to farmers' KAP concerning water availability, landscape characteristics, and socio-economic considerations that directly shape pond site-selection decisions.

Construction of earthen ponds in sub-Saharan Africa has been guided by biophysical recommendations for many years, yet poor site selection has contributed to low productivity and high failure rates. Thus, the literature has largely emphasized technical standards including water quality, soil characteristics, and topography, but with limited empirical evidence on how farmers perceive and prioritize these standards in actual site-selection decisions [24, 25]. Specifically, relatively few studies combine farmers' KAP with multivariate analytical techniques to quantify site-suitability awareness as influenced by socio-demographic and institutional factors. Additionally, the connection between farmer decision processes and GIS-based site-suitability modelling remains under-examined. The current research addresses these gaps by evaluating farmers' KAP on Nile tilapia (*O. niloticus*) pond location suitability in Kisumu County, Kenya, and by identifying key determinants of KAP using regression and multivariate analyses to strengthen the evidence base for farmer diagnostics in designing and extending sustainable aquaculture plans.

2. Research Methodology

2.1. Research Design

The study adopted a descriptive cross-sectional research design to assess fish farmers' knowledge, attitudes, and practices (KAP) regarding criteria used to evaluate the suitability of sites for earthen pond culture of *Oreochromis niloticus*. Descriptive cross-sectional designs are appropriate for systematically describing characteristics of a population and examining existing conditions without manipulating variables, thereby enabling an objective assessment of perceptions and practices within a defined context [26, 27].

2.2. Study Area

The study was conducted in Kisumu County, located in western Kenya within the Lake Victoria Basin. The county lies between latitudes 0°20' South and 0°50' South and longitudes 33°20' East and 35°20' East (Figure 1). Kisumu County is bordered by Nandi County to the north-east, Vihiga County to the north-west, Kericho County to the east, Homa Bay County to the south, and Siaya County to the west. The county covers a total area of 2,676.5 km², representing approximately 0.46% of Kenya's total land area, of which about 567 km² is occupied by Lake Victoria. The remaining 2,109.5 km² constitutes terrestrial land suitable for agriculture and aquaculture activities [28].

Administratively, Kisumu County comprises seven sub-counties: Kisumu East, Kisumu West, Kisumu Central, Muhoroni, Nyando, Seme, and Nyakach, with a total of 35 wards. According to the 2019 Kenya Population and Housing Census, Kisumu County has a population of 1,155,574 persons, comprising 556,942 males (49.0%), 594,609 females

(51.0%), and 23 intersex persons, with an average population density of approximately 550 persons km⁻² [29].

Kisumu County experiences a modified subtropical climate characterized by long rains from March to May and short rains from September to November. Mean annual temperatures range between 23°C and 33°C, conditions that fall within the optimal thermal requirements for *O. niloticus* pond culture. Annual rainfall varies from approximately 1,000–1,800 mm during the long rainy season and 450–600 mm during the short rains. Altitude ranges from about 1,144 m above sea level in the low-lying plains to 1,525 m above sea level in Maseno and upper Nyakach areas. These conditions collectively make Kisumu County a suitable region for earthen pond aquaculture in Kenya.

The study area comprises a mix of urban and peri-urban sub-counties (Kisumu Central, Kisumu East and Kisumu West) and predominantly rural sub-counties (Muhoroni, Nyando, Nyakach and Seme), reflecting differing land-use pressures and aquaculture intensification patterns across the county

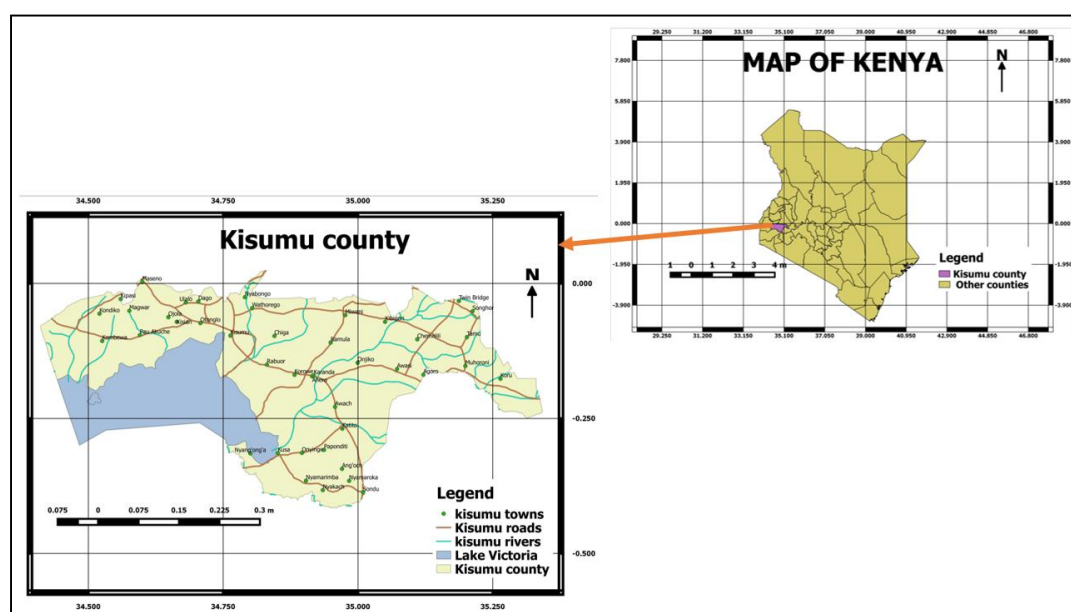


Figure 1. A Map of Kisumu County (the study area) and the map of Kenya.

2.3. Target Population and Sample Size

The target population comprised households engaged in fish farming within Kisumu County. A county-wide survey of fish ponds was conducted between January and April 2022, covering all 35 wards. During this survey, a total of 1,350 households with earthen ponds were identified, geo-referenced using GPS, and recorded on a digitized platform.

The required sample size was determined using Yamane's formula for estimating sample size from a finite population [30]:

$$n = \frac{N}{1 + Ne^2}$$

Where:

n = required sample size

N = total population size (Fish farmers at the household level)

e = level of precision (sampling error), set at 0.05

Thus the sample size was calculated as:

$$n = \frac{1350}{1 + 1350 \times 0.05^2} = \frac{1350}{1 + 3.375} = \frac{180}{4.375} \approx 308.57$$

Therefore, the sample size was 309 households.

2.4. Sampling Design

A proportionate stratified random sampling design was used to select respondents. The total population of 1,350 pond-owning households was first stratified by sub-county, with the

seven sub-counties treated as strata to ensure adequate representation of spatial variability in aquaculture practices and ecological conditions across Kisumu County [31, 32]. Respondents were allocated proportionally to each sub-county based on its share of pond-owning households. Within each stratum, households were selected using simple random sampling, ensuring equal probability of inclusion.

Proportionate stratification minimized sampling bias and improved precision of estimates compared to simple random sampling alone [32, 33]. The distribution of sampled households is presented in Table 1.

Table 1. Population distribution and sample size of pond-owning households by sub-county ($n = 309$).

Sub-county	Pond-owning households (N)	Proportion (%)	Sample size (n)
Kisumu East	122	9.0	28
Kisumu Central	75	5.6	17
Kisumu West	102	7.6	23
Muhoroni	425	31.5	97
Nyakach	202	15.0	46
Nyando	265	19.6	61
Seme	159	11.8	37
Total	1,350	100	309

2.5. Research Instruments, Validity and Reliability

Data were collected using a structured researcher-administered questionnaire (interview schedule) designed to capture farmers' KAP regarding six key criteria influencing earthen pond site suitability. Items were developed based on established aquaculture site-selection guidelines and KAP survey literature. Content validity was established through expert review by researchers with expertise in aquaculture systems, fisheries extension, and survey methodology. Feedback guided refinement of wording and structure prior to final administration [27, 34].

Instrument reliability was assessed using Cronbach's alpha coefficient, based on a pilot test conducted among households not included in the final analytical sample. A Cronbach's alpha value of ≥ 0.60 was considered acceptable for exploratory KAP research [35, 36].

2.6. Methods of Data Collection

A cross-sectional household survey was conducted using a structured interview schedule administered by trained enumerators. This approach enhanced completeness of responses,

minimized item non-response, and ensured clarity of questions during administration, particularly where technical pond site suitability concepts were involved [26].

2.7. Ethical Considerations

The study adhered to principles of responsible research conduct, including informed consent, confidentiality, voluntary participation, objectivity, and respect for respondents' rights [37]. Ethical approval and authorization to conduct the study were obtained from the National Commission for Science, Technology and Innovation (NACOSTI) prior to data collection.

2.8. Data Analysis and Scoring of the Instrument

Attitude statements were measured using a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). Mean scores were interpreted as negative (1.00–2.49), neutral (2.50–3.49), or positive (3.50–5.00) attitudes [38, 39]. Quantitative data were coded, cleaned, and analyzed using SPSS version 26 and Microsoft Excel. Descriptive statistics (frequencies, percentages, means, and standard deviations) were used to summarize demographic characteristics and KAP

responses.

Composite indices were constructed for each KAP component as follows: knowledge scores were computed by assigning 1 to correct responses and 0 to incorrect/“don’t know” responses and standardized to percentages; attitude scores were derived from Likert-scale items with reverse-coding for negatively worded statements; practice scores were computed by assigning 1 to appropriate practices and 0 to inappropriate practices and aggregated into a composite index.

Multiple linear regression was used to examine relationships between socio-demographic characteristics and composite KAP scores. Separate models were fitted for knowledge, attitude, and practice scores as dependent variables, while age, education level, aquaculture training, years of fish-farming experience, and sub-county were included as predictors. Regression coefficients (β), standard errors, and significance levels were used to assess magnitude and direction of associations. Model fit was evaluated using R^2 and model significance assessed using F-tests. Assumptions of linearity, normality, multicollinearity, and homoscedasticity were evaluated before analysis [40].

Exploratory factor analysis was considered; however, given the a priori conceptual grouping of KAP items and the diagnostic nature of the study, composite indices were constructed directly.

3. Results

3.1. Socio-Demographic Background

The socio-demographic characteristics of the surveyed fish-farming households are summarized in Table 2. Overall, fish farming in Kisumu County was largely dominated by older adults, within the age 51–65-years category, followed by those above 65 years. There was low youth involvement in earthen pond aquaculture (18–35 years). Males constituted approximately two-thirds of respondents, indicating a male-dominated sector.

Most respondents reported primary or secondary education, implying basic literacy. Household sizes ranged from small to medium (typically below five members), with implications for family labour availability. Incomes were generally low, with most households reporting less than USD 100 per month, highlighting the resource constraints faced by small-scale fish farmers. Occupations were diverse, but a notable proportion reported technical engagement, which likely relates to pond construction, maintenance, or aquaculture-related skilled work.

Table 2. Socio-demographic characteristics of earthen-pond fish farmers in Kisumu County, Kenya ($n = 309$).

Variable	Response category	Frequency (n)	%
Age (years)	18–35	16	5.2
	36–50	58	18.9
	51–65	171	55.2
	Above 65	64	20.8
Gender	Male	203	65.6
	Female	106	34.4
Level of education	None	13	4.2
	Primary	117	37.7
	Secondary	163	52.9
	Tertiary	16	5.2
Household size	<3	106	34.4
	3–5	117	37.7
	6–10	48	15.6
	11–20	38	12.3
Household income (US\$ / month)	<50	149	48.1
	50–100	91	29.2
	101–200	59	18.9
	201–500	10	3.3

Variable	Response category	Frequency (n)	%
Occupation	None	59	18.9
	Salaried employment	38	12.3
	Casual labour	42	13.7
	Self-employed	26	8.5
	Technical expert	128	41.5
	Business	16	5.2

Source: Field survey, 2022

3.2. Farmers' Knowledge, Attitudes and Practices (KAP) on Suitability of Pond Siting

3.2.1. Farmers' Knowledge of Pond Site Suitability Factors (n = 309)

Farmers' knowledge of site suitability factors was assessed across five criteria domains: water availability, water quality, soil quality, land characteristics, and socio-economic factors (Table 3). Knowledge was highest for water availability factors, particularly the importance of proximity to rivers and

groundwater availability, while the role of distance to lakes showed greater uncertainty. Knowledge of water quality parameters was uneven: temperature was relatively well recognized, whereas dissolved oxygen, salinity, and pH were poorly understood by most farmers. Knowledge of soil quality indicators (organic matter, total nitrogen, clay content, and cation exchange capacity) was consistently low, with the majority indicating uncertainty. For land characteristics, farmers showed moderate awareness of slope and land use, but weaker recognition of elevation and flood risk. Awareness of socio-economic considerations was mixed, with market access more recognized than roads, labour, or manure-related considerations.

Table 3. Fish farmers' knowledge of site suitability factors for Nile tilapia earthen ponds in Kisumu County, Kenya (n = 309).

Criteria	Factor	Yes n (%)	No n (%)	Not sure n (%)
Water availability	Precipitation	163 (52.8)	34 (10.8)	112 (36.3)
	Groundwater availability	179 (58.0)	31 (9.9)	99 (32.1)
	Distance to lake	109 (35.4)	16 (5.2)	184 (59.4)
	Distance to rivers	239 (77.4)	33 (10.8)	37 (11.8)
Water quality	Temperature	162 (52.4)	49 (16.0)	98 (31.6)
	Salinity	29 (9.4)	18 (5.7)	262 (84.9)
	Water pH	130 (42.0)	48 (15.6)	131 (42.5)
	Dissolved oxygen (DO)	13 (4.2)	25 (8.0)	271 (87.7)
Soil quality	Organic matter	19 (6.1)	31 (9.9)	259 (84.0)
	Total nitrogen	18 (5.7)	23 (7.5)	268 (86.8)
	Clay content	12 (3.8)	25 (8.0)	272 (88.2)
	CEC	18 (5.7)	38 (12.3)	253 (82.1)
Land characteristics	Elevation	49 (16.0)	45 (14.6)	215 (69.3)
	Slope	159 (51.4)	18 (5.7)	132 (42.9)
	Land use	165 (53.3)	16 (5.2)	128 (41.5)
	Flooding risk	48 (15.6)	28 (9.0)	233 (75.5)

Criteria	Factor	Yes n (%)	No n (%)	Not sure n (%)
Socio-economic factors	Distance to roads	22 (7.1)	19 (6.1)	268 (86.8)
	Availability of labour	31 (9.9)	19 (6.1)	259 (84.0)
	Availability of manure	57 (18.4)	61 (19.8)	191 (61.8)
	Access to market	163 (52.8)	34 (10.8)	112 (36.3)

Source: Field survey, 2022

3.2.2 Farmers' Attitudes Towards Site Suitability Factors (n = 309)

Attitudinal responses (Table 4) showed that respondents strongly valued stable water supply, particularly accessible groundwater and reliable rainfall. There was moderate agreement that proximity to rivers and lakes supports pond water supply. In contrast, attitudes towards routine water quality monitoring were weaker: while respondents generally agreed that temperature supports tilapia growth, perceptions were neutral-to-weak regarding monitoring salinity, pH, and dissolved oxygen, indicating limited emphasis on water quality

testing at pond establishment and during operation.

Soil-related attitudes suggested greater appreciation for physical suitability (clayey soils for water retention) than for chemical fertility indicators (organic matter, nitrogen, and CEC). Land attributes received strong support for avoiding floods and preferring gentle slopes, while elevation and land-use planning were less strongly endorsed. Among socio-economic factors, market proximity was the strongest driver, whereas labour, manure access, and roads were rated more modestly, implying that profitability signals are clearer to farmers than enabling infrastructure and input constraints.

Table 4. Fish farmers' attitudes towards site suitability factors for Nile tilapia earthen ponds in Kisumu County, Kenya (n = 309), Responses: SD = Strongly Disagree; D = Disagree; N = Neutral; A = Agree; SA = Strongly Agree.

Factor	Statement	SDn	Dn	Nn	An	SA n	Mean	SD
Water availability	Rainfall is critical for ensuring consistent pond water supply	9	15	33	79	173	4.27	0.90
	Groundwater should be readily accessible for fish pond siting	10	12	19	71	197	4.40	0.89
	Proximity to lakes improves pond water supply	17	28	35	188	41	3.67	0.75
	Proximity to rivers is an essential factor for site selection	7	22	35	178	67	3.89	0.90
Water quality	Optimal water temperature enhances tilapia growth	17	17	35	172	73	3.84	0.94
	Salinity negatively affects fish health and should be considered	70	31	45	143	20	3.04	1.08
	Water pH should be tested before pond establishment	79	48	79	53	50	2.83	0.95
	Dissolved oxygen levels affect fish survival and should be monitored	66	39	89	106	9	2.85	1.13
Soil quality	Organic matter content improves pond soil fertility	55	66	66	111	11	2.86	1.06
	Total nitrogen levels should be known before pond construction	66	64	48	123	8	2.82	1.21
	Clayey soils are ideal for pond construction due to water retention	13	22	48	157	69	3.80	0.94
	CEC is an important soil property for ponds	108	74	83	33	11	2.24	1.28
Land characteristics	Elevation affects water drainage and fish growth	51	121	45	82	10	2.61	0.97
	Gentle slopes are preferred for pond stability	9	47	33	184	36	3.62	0.83
	Land use planning is important before pond establishment	22	57	69	149	13	3.24	0.72

Factor	Statement	SDn	Dn	Nn	An	SAn	Mean	SD
Socio-economic factors	Flood-prone areas should be avoided when siting ponds	13	18	18	125	135	4.14	0.84
	Closeness to roads enhances market access and reduces transport cost	53	61	93	90	12	2.83	0.76
	Availability of labour influences pond management effectiveness	106	85	49	60	9	2.29	0.87
	Availability of manure enhances pond fertilization and productivity	73	58	32	130	16	2.86	0.89
	Nearness to market improves profitability of fish farming	16	18	39	61	175	4.17	0.66

Response scale: SD = strongly disagree; D = disagree; N = neutral; A = agree; SA = strongly agree.

Source: Field survey, 2022

3.2.3. Farmers' Practices on Pond Site Suitability Criteria (n = 309)

Farmers' reported practices (Table 5) indicated moderate consideration of water availability indicators, but consistently low implementation of water quality monitoring, particularly pH and salinity testing. Soil testing practices remained uncommon across all chemical and physical indicators. Land

features were more frequently incorporated into decision-making, especially slope and land use, suggesting stronger farmer attention to visible physical attributes. Socio-economic considerations were the most frequently applied, especially manure and labour availability and market survey activities, indicating that logistical and cost-related realities strongly shape farmer practice even when technical knowledge is limited.

Table 5. Farmers' practices regarding pond site suitability criteria for Nile tilapia earthen pond farming in Kisumu County, Kenya (n = 309).

Criteria	Practice	Yes n (%)
Water availability	Recorded rainfall amount	147 (47.6)
	Assessed groundwater availability	143 (46.2)
	Considered distance to lake	152 (49.1)
	Considered distance to rivers	111 (35.8)
Water quality	Measured water temperature	99 (32.1)
	Measured water salinity	49 (16.0)
	Measured water pH	48 (15.6)
	Measured dissolved oxygen (DO)	114 (36.8)
Soil quality	Assessed organic matter	80 (25.9)
	Assessed total nitrogen	36 (11.8)
	Assessed clay content	39 (12.7)
	Assessed CEC	33 (10.8)
Land characteristics	Measured/considered elevation	154 (50.0)
	Measured/considered slope	195 (63.2)
	Considered land use	207 (67.0)
	Considered flooding risk	159 (51.4)
Socio-economic factors	Considered distance to roads	149 (48.1)
	Considered availability of labour	244 (78.8)

Criteria	Practice	Yes n (%)
	Considered availability of manure	260 (84.0)
	Conducted market survey	226 (73.1)

Source: Field survey, 2022

3.3. Relationships Between Farmers' Individual Factors and KAP Level

3.3.1. Regression Assumption Diagnostics

Before estimating the multiple linear regression model, the key assumptions of linear regression were evaluated to ensure that the parameter estimates and inferential tests were valid. Diagnostic checks covered multicollinearity, normality of residuals, homoscedasticity, linearity, and independence of errors.

Multicollinearity was assessed using the Variance Inflation Factor (VIF). As shown in Appendix I, all predictors returned low VIF values (approximately 1.03–1.25), which is well below commonly applied cut-offs (e.g., 5 or 10), indicating that predictor redundancy was minimal and that the model coefficients could be interpreted without concern for unstable variance inflation. Normality of residuals was evaluated using a Q–Q plot of standardized residuals and a Shapiro–Wilk test. The Q–Q plot (Appendix II) showed residual points closely tracking the reference line, consistent with approximately normal residual distribution. The Shapiro–Wilk result was non-significant ($p > 0.05$), supporting the graphical indication that the residuals did not depart meaningfully from normality. Homoscedasticity (constant variance of errors) was examined through a standardized residuals-versus-fitted-values plot. The diagnostic plot (Appendix III) displayed an approximately random scatter around zero without systematic widening or narrowing of variance across fitted values, suggesting that the homoscedasticity assumption was satisfied. Linearity between KAP scores and each predictor was assessed using partial regression plots and residual-based linearity checks. The plots (Appendix IV) did not show obvious curvature or systematic non-linear patterns, indicating that the linear functional form used in the model was appropriate for the observed relationships. Independence of errors was tested using the Durbin–Watson statistic. The Durbin–Watson value (approximately 2.0; Appendix V) fell within the acceptable range for independence, suggesting no evidence of autocorrelation in residuals.

These diagnostics indicate that the main assumptions for multiple linear regression were adequately met, supporting the suitability of the regression model for examining determinants of farmers' KAP levels.

3.3.2. Model Analysis Results for the Influence of Farmers' Characteristics on KAP

A multiple linear regression model was fitted to examine the extent to which farmer and household characteristics predicted overall KAP scores on earthen pond site suitability for Nile tilapia. The model included eight predictors: farmer age, gender, education level, household size, household income, occupation, prior aquaculture training, and extension visits. The regression model was statistically significant (Table 6), explaining a large share of variation in KAP ($R^2 = 0.824$; adjusted $R^2 = 0.810$), indicating strong overall explanatory power in the study context.

Farmer age was positively and significantly associated with KAP ($\beta = 0.29$, $p < 0.001$), implying that KAP scores increased with increasing age. Household income also showed a positive and significant association with KAP ($\beta = 0.26$, $p < 0.001$), suggesting that financially better-resourced households were more likely to exhibit stronger KAP profiles. The variable prior aquaculture training had the strongest positive association with KAP scores ($\beta = 1.99$, $p = 0.001$). This result highlights the crucial role of training in improving farmers' understanding of site suitability. Extension visits were also positively and significantly associated with KAP ($\beta = 1.43$, $p < 0.001$), indicating that households receiving more frequent extension contact tended to report better KAP outcomes. By contrast, gender, education level, household size, and occupation were not statistically significant predictors in this model (Table 6).

Table 6. Multiple Linear Regression Analysis of Factors Influencing Fish Farmers' Knowledge, Attitudes, and Practices (KAP) on Earthen Pond Site Suitability for Nile Tilapia Culture ($n = 309$).

Model Summary			
Multiple R	0.908		
R^2	0.824		
Adjusted R^2	0.810		
Standard Error	0.487		
ANOVA ($F_{(8, 300)}$)	$F = 48.9$	$p < 0.001$	
Unstandardized Coefficients	Standardized Coefficients	t	p-value
Variable	B	Std. Error	Beta

Model Summary

Intercept	9.84	1.15	-
Farmer age	0.29	0.04	0.62
Gender	0.15	0.58	0.03
Education	-0.05	0.08	-0.06
Household size	0.06	0.12	0.05
Income	0.26	0.02	0.71
Occupation	0.04	0.23	0.01
Prior aquaculture training	1.99	0.58	0.29
Extension visits	1.43	0.27	0.42

3.3.3. Principal Component Analysis (PCA) and Factor Analysis

To complement the regression findings and further strengthen inference on how site-suitability considerations cluster conceptually, Principal Component Analysis (PCA) and Factor Analysis were conducted on standardized KAP-related variables. These multivariate techniques were used to identify latent dimensions that summarize how multiple site selection criteria co-vary, thereby revealing the dominant “packs” of knowledge and perceptions shaping farmers’ decision-making.

PCA results supported the retention of four components, based on eigenvalues > 1 and the clear elbow pattern in the scree plot (Figure 2).

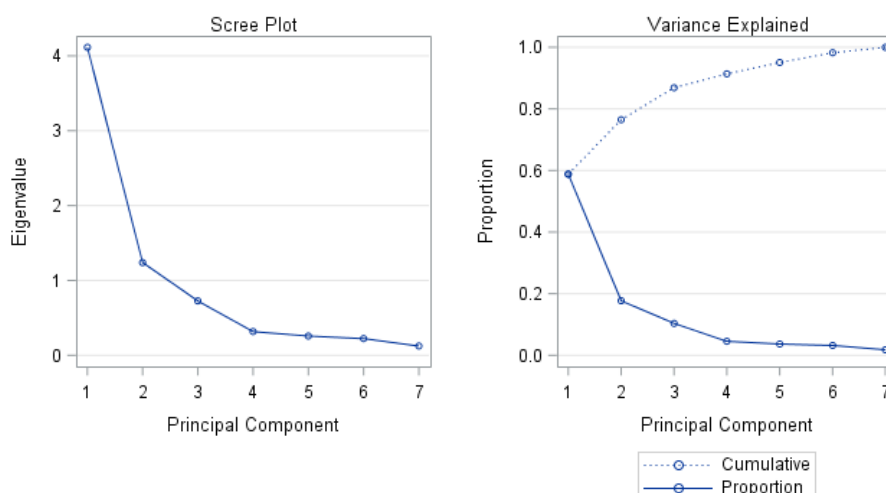


Figure 2. Scree plot showing eigenvalues and component retention for PCA of KAP variables.

The four retained components jointly explained 72.4% of the total variance in the KAP variable set (Table 7), indicating

substantial dimensional reduction while preserving most of the information in the original variables.

Table 7. Total variance explained by principal components derived from PCA of KAP variables.

Component	Eigenvalue	% of Variance	Cumulative %
PC1 (Water availability and quality)	4.15	29.2	29.2
PC2 (Land and soil characteristics)	3.12	22.3	51.5
PC3 (Socio-economic factors)	2.01	14.4	65.9
PC4 (Extension and training)	1.45	6.5	72.4

The relative contribution of each component to the explained variance is visualized in Figure 3, which shows that the first two components account for the largest share of variance, highlighting the dominance of biophysical and land-

based considerations in the overall structure.

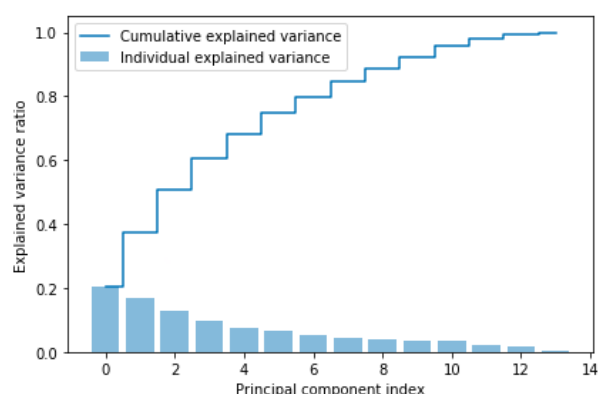


Figure 3. Percentage contribution of principal components to total variance in farmers' KAP.

The rotated solution (Varimax rotation) improved interpretability and revealed coherent groupings of variables (Table 8).

The first component (PC1) captured water availability and water quality considerations, with strong loadings for groundwater availability and water pH, indicating that water-related suitability knowledge and beliefs tend to co-occur. The second component (PC2) represented land and soil characteristics, with high loadings for soil organic matter, clay content, elevation, and slope, reflecting the clustering of physical site attributes relevant to pond construction and water retention. The third component (PC3) reflected socio-economic feasibility, with market access and labor availability loading strongly, consistent with the prominence of practicality and transaction costs in smallholder decision-making. The fourth component (PC4) summarized institutional support, dominated by training and extension variables, highlighting that information access and advisory services form a distinct latent dimension that shapes farmers' capability to apply appropriate criteria.

Table 8. Varimax-rotated component matrix for KAP variables.

Variable	PC1 Water & Quality	PC2 Land & Soil	PC3 Socio-economic	PC4 Training & Extension
Groundwater availability	0.85	0.09	0.12	0.05
Water pH	0.82	0.12	0.20	0.02
Soil organic matter	0.19	0.75	0.14	0.13
Clay content	0.08	0.78	0.23	0.17
Elevation	0.15	0.76	0.12	0.03
Slope	0.25	0.80	0.22	0.14
Market access	0.10	0.13	0.81	0.17
Labor availability	0.13	0.04	0.80	0.07
Prior aquaculture training	0.04	0.17	0.10	0.91
Extension visits	0.16	0.12	0.09	0.93

Loadings ≥ 0.60 indicate strong associations.

The PCA biplot (Figure 4) visually reinforces the rotated component structure by showing how variables align with the principal component axes, clarifying which variables cluster together and which dimensions dominate the variance structure. To further validate the PCA-derived structure, Factor Analysis was performed using principal axis factoring with Varimax rotation, and the extracted factor solution mirrored the PCA pattern, confirming four latent constructs corresponding to water-related suitability, land/soil suitability, socio-economic feasibility, and institutional support.

The conceptual relationships among these four latent factors are summarized visually in the factor-loading schematic (Figure 5). The strongest latent dimensions emphasize (i) water availability/quality, (ii) land and soil attributes, (iii) socio-economic feasibility, and (iv) training and extension support, providing a structured basis for targeting interventions particularly those that strengthen technical training and extension contact while improving farmer understanding of less visible biophysical indicators (e.g., water chemistry and soil fertility properties).

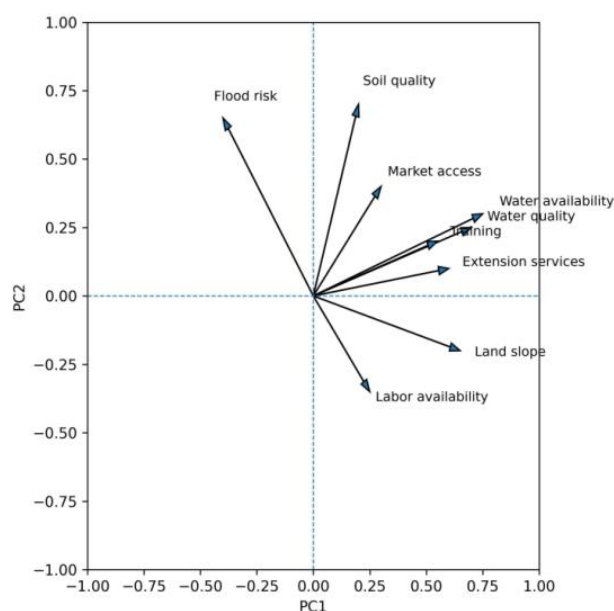


Figure 4. PCA biplot illustrating relationships between KAP variables and principal components.

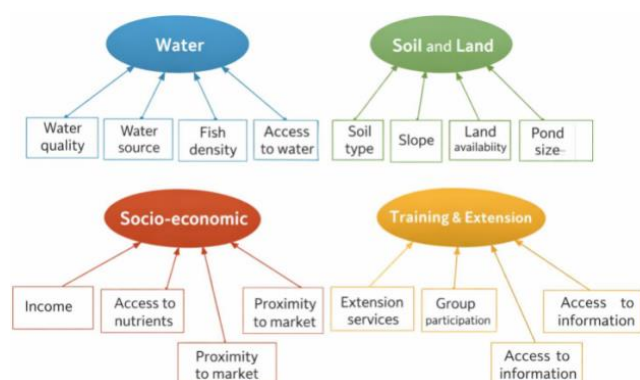


Figure 5. Conceptual factor-loading diagram showing four latent factors influencing pond site suitability decisions.

4. Discussion

4.1. Farmers' Knowledge on Pond Site Suitability

This study assessed farmers' knowledge of pond site suitability prior to GIS-based modelling for Nile tilapia (*Oreochromis niloticus*) earthen ponds, revealing substantial variation across site-suitability criteria. Overall, farmers demonstrated relatively strong awareness of water availability and selected land characteristics but showed limited understanding of water and soil quality parameters (Table 3). This uneven knowledge structure indicates that site selection decisions are primarily driven by visible and experience-based factors rather than physicochemical considerations.

High recognition of proximity to rivers (77.4%) and groundwater availability (58.0%) confirms that reliable water

access remains the most salient determinant of pond siting among smallholder farmers. Similar patterns have been reported across Ghana, Nigeria, and East Africa, where proximity to permanent water sources strongly influences aquaculture site selection and investment behaviour [41–43]. In semi-humid and semi-arid systems, predictable water supply reduces production risk and therefore dominates farmers' decision frameworks.

Conversely, knowledge of key water quality parameters particularly dissolved oxygen, salinity, and pH was consistently low, with more than 80% of respondents uncertain about dissolved oxygen and salinity (Table 3). This mirrors findings from Nigeria and Kenya showing that smallholder tilapia farmers often lack basic water chemistry knowledge due to limited technical training and inadequate access to monitoring equipment [44, 45]. Yet these parameters are critical determinants of fish survival, growth performance and feed conversion efficiency [46]. The disconnect between water availability and water quality therefore represents a major vulnerability in pond site-selection practices.

Knowledge gaps were even more pronounced for soil quality indicators. Most farmers were uncertain about the importance of organic matter, nitrogen, clay content and cation exchange capacity (CEC). Similar trends have been documented across African aquaculture systems, where subsurface pond-site characteristics are rarely evaluated because farmers have limited training and weak access to soil testing services [47, 48]. However, soil texture and fertility strongly influence seepage rates, nutrient cycling, and primary productivity in earthen ponds [49]. Limited awareness of these biophysical drivers increases the probability of sub-optimal site selection and long-term pond underperformance or failure.

Moderate awareness of slope and land use reflects farmers' reliance on visual assessment rather than quantitative evaluation, consistent with observations from Uganda and Ethiopia where farmers evaluate topography informally [50]. Socio-economic factors, particularly market access, were more widely recognized, reinforcing the importance of value-chain integration in pond site selection [51]. Overall, the persistent uncertainty regarding technical criteria highlights major knowledge gaps that may constrain pond productivity and sustainability unless addressed through structured extension and targeted farmer training.

4.2. Farmers' Attitudes Towards Pond Site Suitability

Farmers' attitudes further reinforce the centrality of water availability in pond site suitability (Table 4). Strong agreement regarding the importance of groundwater access and rainfall confirms that farmers prioritize water security as a prerequisite for successful aquaculture. Groundwater likely received higher valuation because it provides a more reliable supply compared to increasingly variable rainfall patterns, a trend consistently reported across Sub-Saharan Africa [52]. While

rainfall was recognized as important for replenishing ponds, its unpredictability under climate variability creates substantial production risks [53]. Moderate attitudes toward proximity to rivers and lakes may reflect concerns about seasonal fluctuations, water quality variability and access restrictions associated with surface water bodies [54].

Attitudes toward water quality management were notably weaker. Although optimal temperature was widely recognized likely because its effects on fish growth are directly observable salinity, pH and dissolved oxygen received neutral to weak endorsement. This suggests limited appreciation of less visible chemical stressors, consistent with findings from smallholder aquaculture systems where water testing is perceived as technically demanding or financially inaccessible [55, 56]. Soil-related attitudes followed a similar pattern: clayey soils were valued due to their water-retention attributes, reflecting farmers' emphasis on physical soil traits [54]. In contrast, the low importance assigned to organic matter, nitrogen and CEC deviates from evidence that pond-bottom fertility is a key driver of natural productivity and fish performance [5]. This discrepancy may be explained by increasing reliance on external feed inputs and limited farmer exposure to soil fertility and pond ecology concepts.

Strong attitudes toward flood avoidance and gentle slopes align with best-practice recommendations given the risks of pond damage and fish loss in flood-prone areas [52]. Market proximity emerged as the most strongly endorsed socio-economic determinant, reflecting the importance of profitability and transaction cost minimization in pond investment decisions [57]. Collectively, these attitudes indicate a pragmatic prioritization of operational security and economic returns over long-term biophysical optimization.

4.3. Farmers' Practices on Pond Site Suitability

Reported practices closely mirrored the observed knowledge and attitudes (Table 5). Farmers moderately assessed water availability indicators such as rainfall, ground-water presence and distance to lakes, but systematic water quality monitoring was uncommon. Fewer than 40% of farmers measured temperature, dissolved oxygen, salinity or pH, consistent with studies across Kenya and other African contexts where monitoring is constrained by cost, equipment unavailability, and inadequate extension support [12,58]. Limited water quality monitoring exposes ponds to stress, disease outbreaks and mortality events [24]. Poor dissolved oxygen conditions, inappropriate pH or salinity stress can severely compromise tilapia growth, survival and profitability [18]. Thus, low adoption of water monitoring reflects both technical limitations and a tendency to prioritize visible socio-economic considerations over less observable environmental risks.

Soil-quality assessment practices were even less prevalent. Fewer than 26% of farmers assessed organic matter, and less than 13% evaluated nitrogen, clay content or CEC. Similar findings have been reported in Ethiopia and Tanzania where

farmers rely on visual inspection rather than scientific soil analysis due to limited service access and weak technical training [59]. These practices heighten risks of seepage losses, poor pond fertility and structural failure.

In contrast, land characteristics such as slope, elevation, land use and flood risk were more commonly considered. These indicators are visually observable and directly linked to construction cost and physical vulnerability, making them more accessible without specialized tools [60, 61]. Socio-economic practices showed the highest adoption levels, particularly manure availability, labour access and market surveys, reflecting a pragmatic focus on feasibility and integrated farming systems typical of smallholder aquaculture [8, 24]. However, excessive emphasis on economic feasibility at the expense of environmental suitability may compromise sustainability and long-term productivity.

4.4. Modelling the Influence of Farmers' Characteristics on KAP

Regression results demonstrate that farmer age, household income, prior aquaculture training, and extension visits are significant predictors of KAP, jointly explaining 81% of the observed variation (Table 7). The positive association between age and KAP suggests that experiential learning improves site-suitability awareness, consistent with studies linking farming experience to better decision-making and technology adoption [62, 3]. Household income emerged as a strong predictor, highlighting how financial capacity enables access to inputs, advisory services and training [63]. Prior aquaculture training showed the strongest effect on KAP, underscoring the importance of structured capacity-building in strengthening technical understanding of site suitability. Extension visits further reinforced KAP outcomes, confirming the role of advisory support in translating knowledge into practice [64, 65].

The non-significance of gender, formal education, household size and occupation suggests that practical exposure and institutional support outweigh demographic attributes in shaping site suitability behaviour. This supports evidence that formal education alone does not guarantee adoption of technically sound practices without targeted training and extension [66].

4.5. Integrating Multivariate Insights into Site Suitability Decision-Making

The PCA and Factor Analysis results (Tables 8-9; Figures 2-5) complement the regression findings by revealing four latent dimensions structuring farmers' KAP: water availability and quality, land and soil characteristics, socio-economic feasibility, and training and extension support. The dominance of water-related and land-based components explains farmers' prioritization of visible and immediately actionable criteria, while water chemistry and soil fertility remain weakly integrated.

The convergence of regression and multivariate analyses strengthens confidence in the robustness of these findings and supports a holistic interpretation of pond site suitability as an interaction between environmental, economic, and institutional factors. Importantly, the identification of training and extension as a distinct latent dimension highlights their leverage potential for improving sustainable aquaculture outcomes

5. Conclusions

The findings indicate that there is a wide range of involvement in various variables such as the availability of water, the quality of water, the quality of soil, the nature of land as well as the socio-economic factors. On the whole, the results suggest that socio-economic and land traits are more emphasized, whereas technical evaluation based on water and soil quality is not that widespread. The imbalance that was observed between socio-economic/land-based factors and technical water and soil quality measures requires holistic extension plans. There are knowledge gaps in water and soil monitoring that should be addressed by training programs and their importance to fish health and the sustainability of ponds should be stressed. The sale of cheap water and soil testing kits and formation of community resource centers may be effective in ensuring that the practice is adopted widely to enhance better selection of pond site by farmers. Additionally, the combination of farmer field schools and participatory practices might make it practical and promote the best practices (FAO, 2018). The infrastructure support of rural areas such as roads and markets continues to be critical to the maintenance of socio-economic benefits and the promotion of technical enhancements.

The results of the current study can give a clear guidance to policy makers and development practitioners who seek to enhance the production of Nile tilapia by ensuring that better pond sites are selected. To begin with, the most important elements to be prioritized in capacity building include specific training and frequent extension assistance because these institutional variables proved to have the most significant associations with KAP. Another consideration should also be tailoring training to need of younger farmers who might be less experienced. Secondly, the economic support systems that can help in uplifting the household income of farmers may indirectly increase KAP and adoption of the appropriate pond site practices. Microfinance or subsidies or cooperative plans may enable farmers to invest in better infrastructures of ponds and inputs. Third, the positive effect of farmer age demonstrates the role of incorporating older farmers into peer learning and mentorship work in order to share practical knowledge among the communities. Lastly, in future studies, the obstacles to adoption of water and soil quality measurements, such as socio-cultural, economic, and institutional, should be investigated to develop more specific interventions.

Abbreviations

CEC	Cation Exchange Capacity
CIDP	County Integrated Development Plan
DO	Dissolved Oxygen
GIS	Geographic Information System
GPS	Global Positioning System
KAP	Knowledge, Attitudes and Practices
KMFRI	Kenya Marine and Fisheries Research Institute
KNBS	Kenya National Bureau of Statistics
NACOSTI	National Commission for Science, Technology and Innovation
<i>O. niloticus</i>	<i>Oreochromis niloticus</i>
PCA	Principal Component Analysis
Q–Q Plot	Quantile–Quantile Plot
SPSS	Statistical Package for the Social Sciences
VIF	Variance Inflation Factor

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Author Contributions

Anne Mokoro: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing.

Geraldine Matolla: Methodology, Investigation, Data curation, Writing – review & editing.

James Njiru: Supervision, Validation, Writing – review & editing.

Johnstone Kimanzi: Validation, Visualization, Writing – review & editing.

Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Appendix

Appendix I: Variance Inflation Factor (VIF) and Multicollinearity Diagnostics

Table A1. Variance Inflation Factor (VIF) values for predictors included in the regression model.

Predictor	VIF
Farmer age	1.21
Gender	1.08
Education level	1.12
Household size	1.03
Household income	1.25
Occupation	1.10
Prior aquaculture training	1.18
Extension visits	1.22

Appendix II: Normality Diagnostics (Q–Q Plot of Standardized Residuals)

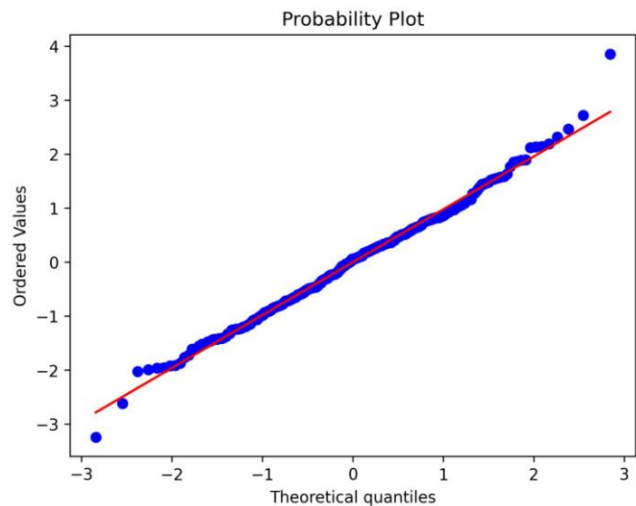


Figure A1. Normal Q–Q plot of standardized residuals. The standardized residuals closely follow the reference line, indicating approximate normal distribution and satisfying the normality assumption of linear regression.

Appendix III: Homoscedasticity (Residuals vs Fitted Plot)

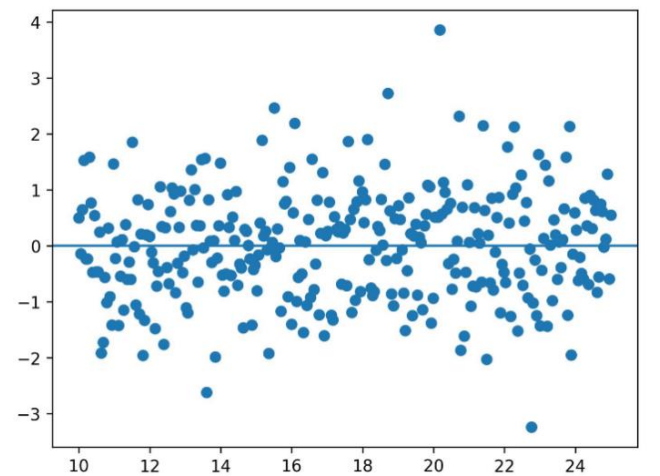


Figure A2. Scatter plot of standardized residuals versus fitted values. Residuals show random dispersion around zero with no visible funneling or systematic pattern, confirming homoscedasticity.

Appendix IV: Linearity Diagnostics (Partial Regression Plots)

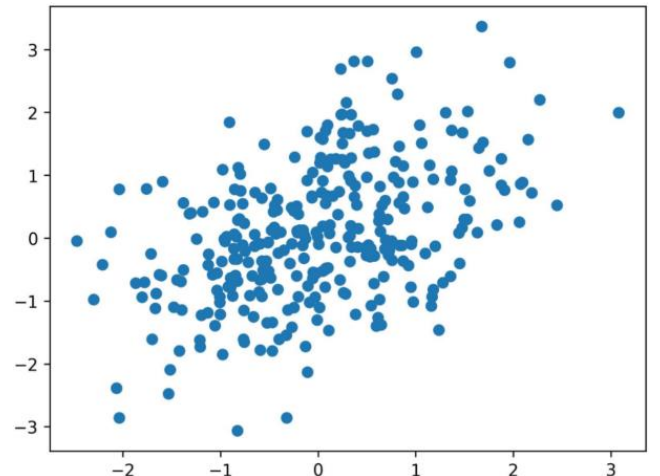


Figure A3. Partial regression plot illustrating linear relationship between predictor and KAP score. The absence of curvature or systematic deviation confirms the appropriateness of the linear functional form.

Appendix V: Independence of Errors (Durbin–Watson Test)

Durbin–Watson statistic ≈ 2.01 , indicating independence of residuals and absence of autocorrelation.

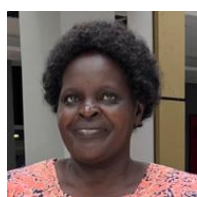
References

- [1] Adewumi, A. A., Olaleye, V. F. Pond aquaculture production trends in Nigeria: A review. *Journal of Applied Aquaculture*. 2011, 23(2), 113–127.
<https://doi.org/10.1080/10454438.2011.556217>
- [2] Ahmed, N., Thompson, S., Turchini, G. M. Environmental sustainability of aquaculture: Analysis of resource use and environmental impacts of pond-based aquaculture systems. *Aquaculture Research*. 2019, 50, 1823–1835.
<https://doi.org/10.1111/are.14034>
- [3] Asfaw, S., Scognamiglio, A., Di Caprera, G., Sitko, N., Ignaciuk, A. Heterogeneous impact of improved agricultural technologies on household welfare: Evidence from Sub-Saharan Africa. *Food Policy*. 2020, 91, 101871.
<https://doi.org/10.1016/j.foodpol.2019.101871>
- [4] Aura, C. M., Musa, S., Yongo, E., Okechi, J. K., Njiru, J. M., Ogello, E. O. Integration of aquaculture into the Lake Victoria Basin farming systems: Impacts on livelihoods and food security. *Aquaculture Research*. 2018, 49, 3638–3650.
<https://doi.org/10.1111/are.13835>
- [5] Bartley, D. M., De Silva, S. S., Hasan, M. R. Improving productivity and environmental performance of aquaculture. *FAO Fisheries and Aquaculture Proceedings*. 2015, 39, 1–12.
- [6] Boone, H. N., Boone, D. A. Analyzing Likert data. *Journal of Extension*. 2012, 50(2), Article 2TOT2.
- [7] Boyd, C. E. Soil and water quality management for pond aquaculture. *Aquaculture Engineering*. 2015, 69, 1–11.
<https://doi.org/10.1016/j.aquaeng.2015.08.001>
- [8] Boyd, C. E., Tucker, C. S. *Pond Aquaculture Water Quality Management*. New York, NY: Springer; 2012.
<https://doi.org/10.1007/978-1-4615-5407-3>
- [9] Boyd, C. E., Tucker, C. S. *Pond Aquaculture Water Quality Management*. New York, NY: Springer; 1998.
- [10] Boyd, C. E. Guidelines for aquaculture effluent management at the farm-level. *Aquaculture*. 2003, 226(1–4), 101–112.
[https://doi.org/10.1016/S0044-8486\(03\)00471-X](https://doi.org/10.1016/S0044-8486(03)00471-X)
- [11] Brummett, R. E., Williams, M. J. The evolution of aquaculture in African rural and economic development. *Ecological Economics*. 2000, 33(2), 193–203.
[https://doi.org/10.1016/S0921-8009\(99\)00143-8](https://doi.org/10.1016/S0921-8009(99)00143-8)
- [12] Bryman, A. *Social Research Methods*. 5th ed. Oxford, UK: Oxford University Press; 2016.
- [13] Charo-Karisa, H., Rezk, M. A., Bovenhuis, H., Komen, H. Heritability of growth traits of Nile tilapia (*Oreochromis niloticus*) in earthen ponds. *Aquaculture*. 2005, 246, 125–134.
<https://doi.org/10.1016/j.aquaculture.2005.01.021>
- [14] Cochran, W. G. *Sampling Techniques*. 3rd ed. New York, NY: John Wiley & Sons; 1977.
- [15] Creswell, J. W., Creswell, J. D. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. 5th ed. Thousand Oaks, CA: Sage; 2018.
- [16] Dapieve, A., Valenti, W. C., Portella, M. C. Socio-economic and environmental determinants of small-scale pond aquaculture sustainability. *Aquaculture International*. 2023, 31, 115–130. <https://doi.org/10.1007/s10499-022-00959-8>
- [17] DeVellis, R. F. *Scale Development: Theory and Applications*. 4th ed. Thousand Oaks, CA: Sage; 2017.
- [18] El-Sayed, A. F. M. *Tilapia Culture*. 2nd ed. London, UK: Academic Press; 2019.
<https://doi.org/10.1016/C2016-0-01732-3>
- [19] El-Sayed, A. F. M., Fitzsimmons, K. Tilapia culture: Biology, production systems and sustainability. *Aquaculture*. 2023, 569, 739394.
<https://doi.org/10.1016/j.aquaculture.2023.739394>
- [20] El-Sayed, A. F. M. *Tilapia Culture*. Wallingford, UK: CABI Publishing; 2006.
- [21] El-Sayed, A. F. M. Tilapia culture and sustainability. *Aquaculture*. 2019, 507, 263–272.
<https://doi.org/10.1016/j.aquaculture.2019.03.062>
- [22] Food and Agriculture Organization of the United Nations (FAO). *The State of World Fisheries and Aquaculture 2020: Sustainability in Action*. Rome, Italy: FAO; 2020.
<https://doi.org/10.4060/ca9229en>
- [23] Food and Agriculture Organization of the United Nations (FAO). *The State of World Fisheries and Aquaculture 2022: Towards Blue Transformation*. Rome, Italy: FAO; 2022.
<https://doi.org/10.4060/cc0461en>
- [24] Food and Agriculture Organization of the United Nations (FAO). *Small-Scale Aquaculture in Sub-Saharan Africa*. FAO Fisheries and Aquaculture Technical Paper No. 647. Rome, Italy: FAO; 2018.
- [25] Food and Agriculture Organization of the United Nations (FAO). Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture. FAO Fisheries and Aquaculture Technical Paper No. 588. Rome, Italy: FAO; 2017.
- [26] Kothari, C. R. *Research Methodology: Methods and Techniques*. 2nd ed. New Delhi, India: New Age International Publishers; 2004.
- [27] Saunders, M., Lewis, P., Thornhill, A. *Research Methods for Business Students*. 8th ed. Harlow, UK: Pearson Education Limited; 2019.
- [28] Kisumu County Government. *Kisumu County Integrated Development Plan (CIDP) 2018–2022*. Kisumu, Kenya: Kisumu County Government; 2018.
- [29] Kenya National Bureau of Statistics (KNBS). *2019 Kenya Population and Housing Census. Volume I: Population by County and Sub-County*. Nairobi, Kenya: KNBS; 2020.
- [30] Yamane, T. *Statistics: An Introductory Analysis*. 2nd ed. New York, NY: Harper & Row; 1967.

- [31] Israel, G. D. Determining Sample Size. University of Florida IFAS Extension. 2013.
- [32] Lohr, S. L. *Sampling: Design and Analysis*. 2nd ed. Boca Raton, FL: Chapman & Hall/CRC; 2019. <https://doi.org/10.1201/9780429296284>
- [33] Kish, L. *Survey Sampling*. New York, NY: John Wiley & Sons; 1965.
- [34] Hair, J. F., Black, W. C., Babin, B. J., Anderson, R. E. *Multivariate Data Analysis*. 8th ed. Boston, MA: Cengage Learning; 2019.
- [35] Nunnally, J. C., Bernstein, I. H. *Psychometric Theory*. 3rd ed. New York, NY: McGraw-Hill; 1994.
- [36] Tavakol, M., Dennick, R. Making sense of Cronbach's alpha. *International Journal of Medical Education*. 2011, 2, 53–55. <https://doi.org/10.5116/ijme.4dfb.8dfd>
- [37] Resnik, D. B., Shamoo, A. E. Reproducibility and research integrity. *Accountability in Research*. 2017, 24(2), 116–123. <https://doi.org/10.1080/08989621.2016.1257387>
- [38] Likert, R. *A Technique for the Measurement of Attitudes*. Archives of Psychology, No. 140. New York, NY: The Science Press; 1932.
- [39] Joshi, A., Kale, S., Chandel, S., Pal, D. Likert scale: Explored and explained. *British Journal of Applied Science & Technology*. 2015, 7(4), 396–403. <https://doi.org/10.9734/BJAST/2015/14975>
- [40] Field, A. *Discovering Statistics Using IBM SPSS Statistics*. 5th ed. London, UK: SAGE Publications; 2018.
- [41] Hecht, T. A review of small-scale aquaculture in Sub-Saharan Africa. *Aquaculture Economics & Management*. 2000, 4(1–2), 1–14. <https://doi.org/10.1080/13657300009380260>
- [42] Kassam, L., Dorward, A., Longhurst, R. A comparative assessment of the poverty impacts of pond and cage aquaculture in Ghana. *World Development*. 2011, 39(9), 1621–1635. <https://doi.org/10.1016/j.worlddev.2011.03.011>
- [43] Kunda, M., Phiri, M., Mwansa, C. Determinants of pond aquaculture adoption in Sub-Saharan Africa. *Aquaculture Economics & Management*. 2020, 24(3), 245–261. <https://doi.org/10.1080/13657305.2020.1722523>
- [44] El-Sayed, A. F. M. (2013). Tilapia culture in warm water systems: Water quality and management challenges in small-scale aquaculture. *Aquaculture Research*, 44(12), 1875–1888. <https://doi.org/10.1111/are.12167>
- [45] Njiru, M., Aura, C. M., Okechi, J. K. Knowledge gaps and extension needs in Kenyan aquaculture. *Aquaculture International*. 2021, 29, 131–145. <https://doi.org/10.1007/s10499-020-00616-3>
- [46] Boyd, C. E. *Water Quality: An Introduction*. Cham, Switzerland: Springer; 2020. <https://doi.org/10.1007/978-3-030-23335-8>.
- [47] Munguti, J. M., Kim, J. D., Ogello, E. O. An overview of Kenyan aquaculture: Current status, challenges and opportunities. *Fisheries and Aquatic Sciences*. 2014, 17, 1–11. <https://doi.org/10.5657/FAS.2014.0001>
- [48] Limbu, S. M., Shoko, A. P., Mgaya, Y. D. Pond productivity and soil–water interactions in tropical aquaculture. *Aquaculture International*. 2016, 24, 1559–1574. <https://doi.org/10.1007/s10499-016-0045-9>
- [49] Beveridge, M. C. M. *Cage Aquaculture*. 3rd ed. Oxford, UK: Wiley-Blackwell; 2004.
- [50] Tesfahun, A. Site selection and management of small-scale fish ponds. *Aquaculture Reports*. 2020, 17, 100365. <https://doi.org/10.1016/j.aqrep.2020.100365>
- [51] Belton, B., Little, D. C. Immanent and interventionist inland Asian aquaculture development and its outcomes. *Development Policy Review*. 2011, 29(4), 459–484. <https://doi.org/10.1111/j.1467-7679.2011.00542.x>
- [52] Kahindi, J. H. P., Maina, J. G., Muturi, G. M. Climate variability and pond aquaculture productivity in Kenya. *Aquaculture International*. 2018, 26, 1161–1176. <https://doi.org/10.1007/s10499-018-0283-1>
- [53] Gomiero, T., Pimentel, D., Paoletti, M. G. Environmental impact of climate variability on aquaculture systems. *Aquaculture International*. 2021, 29, 2147–2163. <https://doi.org/10.1007/s10499-021-00729-1>
- [54] Munguti, J. M., Musa, S., Ogello, E. O. Environmental and institutional constraints to aquaculture development in Kenya. *Aquaculture International*. 2020, 28, 1–18. <https://doi.org/10.1007/s10499-019-00476-1>
- [55] Funge-Smith, S. Review of the state of aquaculture in Sub-Saharan Africa. *FAO Fisheries and Aquaculture Circular*. 2018, No. 1135.
- [56] Martins, C. I. M., Eding, E. H., Verreth, J. A. J. The effect of water quality on fish welfare and productivity. *Reviews in Aquaculture*. 2019, 11(3), 673–690. <https://doi.org/10.1111/raq.12251>
- [57] Ndirangu, S. N., Nyonje, B. M., Maina, J. G. Market access and profitability of smallholder aquaculture. *Aquaculture Economics & Management*. 2017, 21(4), 421–436. <https://doi.org/10.1080/13657305.2017.1312546>
- [58] Ngugi, C. C., Bowman, J. R., Omolo, B. O. *A New Guide to Fish Farming in Kenya*. Corvallis, OR: Aquaculture CRSP, Oregon State University; 2007.
- [59] Kifle, D., Desta, Z., Tesfahun, A. Constraints to small-scale aquaculture development in Ethiopia. *Aquaculture Reports*. 2019, 15, 100214. <https://doi.org/10.1016/j.aqrep.2019.100214>
- [60] Njiru, M., Aura, C. M., Okechi, J. K. Challenges facing pond aquaculture development in East Africa. *African Journal of Aquatic Science*. 2017, 42(3), 221–231. <https://doi.org/10.2989/16085914.2017.1355066>

- [61] Mrosso, H. D. J., Limbu, S. M., Mgya, Y. D. Farmer decision-making and pond management in Tanzania. *Aquaculture International*. 2019, 27, 153–168. <https://doi.org/10.1007/s10499-018-0321-z>
- [62] Nguyen, T. T., Rada, N., Pham, T. H. Adoption of improved aquaculture technologies. *World Development*. 2018, 105, 190–203. <https://doi.org/10.1016/j.worlddev.2017.12.019>
- [63] Kassam, L., Subasinghe, R., Phillips, M. Aquaculture farmer behaviour and adoption of improved practices. *Aquaculture*. 2019, 512, 734289. <https://doi.org/10.1016/j.aquaculture.2019.734289>
- [64] Phiri, M., Chisanga, B., Musuka, C. Extension services and aquaculture adoption in Africa. *Aquaculture International*. 2018, 26, 1041–1056. <https://doi.org/10.1007/s10499-018-0273-3>
- [65] Onyango, P. O., Owiti, D. O., Ogello, E. O. Role of extension in aquaculture development. *Aquaculture International*. 2019, 27, 965–978. <https://doi.org/10.1007/s10499-019-00364-8>
- [66] Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., Mekuria, M. Adoption of interrelated sustainable agricultural practices. *Agricultural Economics*. 2015, 46(3), 1–16. <https://doi.org/10.1111/agec.12153>

Biography



Anne Mokoro is a Fisheries Officer and researcher affiliated with the University of Eldoret, Kenya, with professional expertise in fisheries management, aquaculture development, and aquatic resource conservation. She has actively participated in field-based research focusing on sustainable utilization of freshwater fisheries, community co-management approaches, and improvement of fish production systems in western Kenya and surrounding regions. Her work integrates scientific research with extension services to enhance livelihoods among fishing communities while promoting environmental sustainability. Anne has contributed to several applied research projects addressing fish stock conservation, water quality management, and aquaculture productivity. She is passionate about bridging the gap

between research and practice, ensuring that scientific findings translate into practical solutions for resource users and policy stakeholders. Her professional interests include climate-smart fisheries, ecosystem-based management, and capacity building for small-scale aquaculture enterprises.



Geraldine Matolla is a Senior Lecturer at the University of Eldoret, Kenya, specializing in fisheries science, aquaculture, and aquatic ecology. She holds advanced academic qualifications in fisheries and environmental sciences and has extensive experience in teaching, research supervision, and community outreach. Her research focuses on fish health management, sustainable aquaculture systems, aquatic environmental quality, and the impacts of human activities on freshwater ecosystems. Dr. Matolla has published in peer-reviewed journals and contributed to research projects aimed at improving food security through sustainable fisheries and aquaculture development. She actively mentors postgraduate students and participates in interdisciplinary research addressing environmental conservation and

aquatic resource sustainability. Her professional commitment lies in promoting science-based fisheries management and innovative aquaculture technologies to enhance productivity while safeguarding aquatic ecosystems.



James Njiru is a distinguished fisheries scientist at Kisii University and a former Director General of the Kenya Marine and Fisheries Research Institute (KMFRI). He possesses decades of experience in fisheries research, policy development, and aquatic resource management across both marine and inland waters of East Africa. His scholarly work includes fish stock assessment, fisheries governance, ecosystem-based management, and sustainable exploitation of aquatic resources. Professor Njiru has led numerous national and regional research programs and contributed significantly to fisheries policy formulation in Kenya. He has published extensively in high-impact scientific journals and supervised many postgraduate students who now serve in academia and fisheries institutions. His leadership at

KMFRI strengthened fisheries research capacity and regional collaboration. He remains actively involved in advancing sustainable fisheries science and evidence-based management.



Johnston Kimanzi is a Lecturer at the University of Eldoret, Kenya, with academic expertise in aquaculture, fisheries biology, and environmental sustainability. He is engaged in teaching undergraduate and postgraduate courses while conducting research on fish production systems, nutrition, and aquatic ecosystem health. His work emphasizes improving aquaculture productivity through sustainable feeding strategies, water quality management, and climate-resilient production practices. Dr. Kimanzi has participated in several research projects focused on enhancing food security, promoting smallholder aquaculture, and conserving aquatic biodiversity. He has published in peer-reviewed journals and contributes to community outreach programs that support capacity building among fish farmers. His

professional interests include sustainable aquaculture intensification, integrated farming systems, and ecosystem-based approaches to fisheries management.

Research Field

Anne Mokoro: Small-scale aquaculture, Pond site suitability, Farmer knowledge diagnostics, Aquaculture extension systems, Spatial planning for aquaculture, Sustainable tilapia production, Aquaculture livelihoods.

Geraldine Matolla: Pond aquaculture management, Farmer practices assessment, Aquaculture value chains, Extension and training, Aquaculture sustainability, Community-based aquaculture.

James Njiru: Fisheries science, Aquaculture development policy, Lake Victoria basin studies, Aquatic food systems, Resource management, Applied fisheries research.

Johnstone Kimanzi: Environmental management, Spatial analysis and planning, Natural resource governance, Landscape suitability assessment, Livelihoods and sustainability.