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Household Socio-Economic Factors Influencing the Adoption of Rainwater Harvesting Technologies for Beekeeping in Itiko Sub-Location, Kitui County

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Abstract

This study examined household socioeconomic and institutional factors associated with the adoption of rainwater harvesting (RWH) technologies for beekeeping in Itiko Sublocation, Kitui County, Kenya. RWH is important for improving water availability in semi-arid areas, where unreliable rainfall and prolonged dry periods constrain access to water for beekeeping. However, adoption varies among households, potentially limiting its contribution to sustainable beekeeping livelihoods. The study adopted a convergent mixed-methods design. From a population of 456 households, a sample of 82 was planned, but 70 households participated and constituted the final analysed sample. Quantitative data were collected using structured questionnaires, while qualitative data were obtained through key informant interviews and focus group discussions. Quantitative data were analysed using descriptive statistics, cross-tabulations, and association tests, while qualitative data were analysed thematically. Education was significantly associated with adoption, with full adoption increasing from 0 per cent among respondents without formal education to 71.4 per cent among those with post-secondary education. Household financial capacity, technology costs, availability of construction materials, labour requirements, and maintenance needs were also associated with adoption and continued use. Extension services, training, and community information networks improved awareness and technical knowledge. Harvested rainwater improved water availability for beekeeping during dry periods. The study recommends affordable RWH technologies, strengthened extension and training services, and improved institutional support for beekeepers. The findings provide evidence to guide interventions aimed at improving water security, climate resilience, and sustainable beekeeping livelihoods in semi-arid Kenya.

Key terms: Beekeeping, household adoption, institutional support, rainwater harvesting, semi-arid areas.

1.0 INTRODUCTION

Access to reliable water is a major challenge for rural households in arid and semi-arid lands (ASALs), where low and erratic rainfall, recurrent droughts and prolonged dry periods constrain agricultural production and other livelihood activities. In Kenya, approximately 80 per cent of the land area is classified as arid or semi-arid (Republic of Kenya, 2016). These conditions increase households' vulnerability to water scarcity and create a need for locally appropriate strategies to capture and store water during rainfall. The problem is particularly significant in households whose livelihoods depend on activities that require reliable water resources, including livestock production, crop farming and beekeeping.

Rainwater harvesting (RWH) refers to the collection and storage of rainfall and surface runoff for subsequent use in domestic consumption, livestock production, irrigation and other productive uses (Critchley & Siegert, 1991; Kahinda et al., 2007). RWH can provide an alternative source of water during dry periods and is therefore potentially important for rural households in water-scarce environments. In semi-arid environments, however, the availability or technical suitability of RWH technologies does not necessarily translate into household adoption. Adoption may also depend on households' access to financial and material resources, labour, information and technical knowledge, as well as institutional support. Previous research on agricultural technology adoption has highlighted the role of education, household economic capacity, labour availability, social networks and access to extension services in shaping adoption decisions (Feder et al., 1985; Knowler & Bradshaw, 2007; Fadeyi et al., 2022).

These factors are particularly relevant to beekeeping, an important livelihood diversification activity in Kenya's ASALs. Beekeeping requires relatively little land and can complement crop and livestock production. Nevertheless, water remains essential for bee colony survival, brood development and thermoregulation, particularly during periods of high temperatures and prolonged drought (Winston, 1987; Le Bivic et al., 2026). Consequently, inadequate water availability may affect hive management and the sustainability of beekeeping activities during dry periods. Providing households with appropriate means of harvesting and storing rainwater may therefore contribute to improved water availability for beekeeping.

In this study, adoption refers to a household's decision to acquire and use one RWH technology for beekeeping-related purposes. Socioeconomic factors refer to household characteristics and resources that may influence this decision, including education, household economic capacity, labour availability, and access to materials. Institutional factors refer to external forms of support and access to services that may facilitate adoption, including extension services, training, credit, membership in farmer or beekeeping groups, and access to technical information. Previous research on agricultural technology adoption has highlighted the role of education and household economic capacity. Labour availability, social networks and access to extension services shape adoption decisions (Feder et al., 1985; Knowler & Bradshaw, 2007; Fadeyi et al., 2022). Research in Kenya has also examined RWH adoption mainly in relation to household water supply, crop production and smallholder agriculture (Ahmed et al., 2013; Muriu-Ng'ang'a et al., 2017; Irungu et al., 2024).

Despite this evidence, comparatively limited empirical attention has been given to the household socioeconomic and institutional factors associated with RWH adoption within beekeeping livelihood systems in semi-arid Kenya. This is important because households facing similar climatic conditions may

differ in their ability and willingness to adopt RWH technologies depending on their education, economic resources, access to technical knowledge and interaction with extension and community information networks.

Technology adoption is therefore not simply a response to environmental need. From the perspective of Diffusion of Innovations Theory, adoption involves a process through which potential users acquire information about an innovation, evaluate its perceived benefits and compatibility with their circumstances, and decide whether to adopt and continue using it (Rogers, 2003). In the context of this study, the theory provides a basis for considering how information, knowledge, perceived usefulness and household circumstances may influence the adoption of RWH technologies for beekeeping.

Against this background, the study examined household socio-economic and institutional factors associated with adopting rainwater harvesting technologies for beekeeping in Itiko Sub-location, Kitui County, a semi-arid area of Kenya. Specifically, the study considered household sociodemographic characteristics, economic factors, institutional support and technical knowledge, and the contribution of harvested rainwater to beekeeping activities. The study contributes empirical evidence on how household resources and institutional support intersect with technology adoption in a water-scarce rural livelihood setting. The paper presents the methodology used in the study, followed by the results and discussion and concludes with the conclusions and recommendations arising from the findings.

2.0 LITERATURE REVIEW

Adoption of Rainwater Harvesting Technologies in Semi-Arid Areas

Rainwater harvesting (RWH) is widely recognised as an important strategy for improving water availability in areas characterised by unreliable rainfall, recurrent droughts, and prolonged dry periods. Critchley and Siegert (1991) described rainwater harvesting as an approach for collecting and conserving rainfall and runoff for subsequent use, while Kahinda et al. (2007) highlighted its potential to improve water availability and support livelihoods in water-scarce environments.

These studies provide a conceptual and practical basis for understanding RWH as a strategy for addressing water scarcity. However, the broad focus on water harvesting does not explain why households exposed to similar water constraints differ in their decision to adopt particular technologies.

Adoption of agricultural and conservation technologies has consequently received attention beyond the technical performance of the technologies themselves. Feder et al. (1985) demonstrated that agricultural technology adoption is influenced by factors such as household resources, access to information, and the perceived benefits and costs associated with an innovation. Similarly, Knowler and Bradshaw (2007) demonstrated that adoption of agricultural and conservation technologies is shaped by a combination of socioeconomic, institutional, and farm-level factors. The contribution of these studies to the present research is the recognition that water scarcity alone cannot explain household adoption; household capacity, information, perceived benefits, and institutional conditions must also be considered.

In the African context, these issues are particularly important because many rural households depend on rain-fed livelihoods and face recurrent drought and water shortages. RWH provides an opportunity to capture water during relatively short rainfall periods and make it available during dry periods. However, the effectiveness of RWH as a livelihood strategy depends not only on physical water availability, but also

on households' ability to invest in, operate, and maintain appropriate technologies. The African perspective therefore extends the global understanding of RWH by highlighting the importance of household capacity and local institutional conditions in determining whether technologies can be translated into sustained livelihood benefits.

In Kenya, evidence demonstrates the importance of household-level conditions in the adoption and utilisation of RWH technologies. Muriu-Ng'ang'a et al. (2017) found that socioeconomic characteristics influenced the utilisation of RWH and water-saving technologies among farmers in semi-arid Tharaka South. Their findings indicated that factors such as household size, farm size, land tenure, training, age, farming history, and formal education were associated with the utilisation of different technologies. Similarly, Irungu et al. (2024) reported that socioeconomic, sociodemographic, and institutional factors significantly influenced the adoption of different RWH technologies among smallholder farmers in Murang'a County. These Kenyan studies contribute empirical evidence showing that adoption is multidimensional and that household characteristics, training, and institutional conditions are relevant within the Kenyan context**.**

However, the Kenyan studies have largely examined RWH in relation to crop production, household water supply, and general agricultural water management. They provide limited evidence on RWH adoption within beekeeping livelihood systems. The present study builds on this literature by examining whether the socioeconomic and institutional factors identified in broader agricultural settings also explain adoption among households using harvested rainwater to support beekeeping in a semi-arid area of Kitui County.

Socioeconomic Factors Influencing Adoption of Rainwater Harvesting Technologies

Household socioeconomic characteristics can influence both the capacity and willingness to adopt agricultural technologies. Education is one of the commonly examined factors because it may enhance a household's ability to access information, understand technical recommendations, and assess the potential benefits of an innovation. Feder et al. (1985) identified education and access to information among the factors that can influence technology adoption, while Knowler and Bradshaw (2007) noted that human capital characteristics may contribute to differences in the adoption of agricultural conservation practices.

Across Africa, the socioeconomic dimension of technology adoption is particularly relevant because rural households often face financial and labour constraints that affect their ability to invest in agricultural innovations. RWH technologies may require expenditure on construction materials, storage facilities, installation, labour, and maintenance. Households with limited economic resources may therefore find adoption difficult even where they recognise the benefits of improved water availability. This perspective is relevant to the present study because it suggests that financial capacity and access to household resources should be examined alongside the perceived usefulness of RWH technologies.

Evidence from Kenya provides more specific support for these relationships. Irungu et al. (2024) found that household income and access to credit were among the socioeconomic factors associated with RWH adoption. This suggests that even where households perceive RWH as beneficial, limited financial resources may constrain their ability to invest in the technologies. Muriu-Ng'ang'a et al. (2017) also found that household size is significantly associated with the utilisation of some RWH and water-saving technologies in semi-arid Kenya. These findings contributed directly to the present study by identifying

socio economic characteristics that can be tested among beekeeping households, particularly education, financial capacity, household size, labour availability, and access to productive resources.

For beekeeping households, socioeconomic factors may be particularly important because the resources available to the household can determine whether investment in water-harvesting infrastructure is considered feasible. A household with limited income, labour, or technical capacity may prioritise other immediate livelihood needs, even when water scarcity affects beekeeping. Examining these characteristics therefore provides a basis for understanding differences in RWH adoption among households operating under similar climatic conditions. Despite these contributions, most existing studies have examined socioeconomic factors among crop-oriented farmers rather than beekeeping households. The present study therefore extends the existing literature by examining how household socioeconomic characteristics influence RWH adoption where the harvested water is intended to support beekeeping activities. This is important because beekeeping households may allocate their limited financial and labour resources differently from households whose primary livelihood is crop production.

Institutional Support and Technical Knowledge

Institutional support can influence technology adoption by improving access to information, technical advice, training, financial services, and social networks. Extension services are particularly important because they can increase household awareness of available technologies and provide guidance on their appropriate use and maintenance. Feder et al. (1985) identified access to information and institutional services as important elements in agricultural technology adoption, while Fadeyi et al. (2022) emphasised the importance of institutional and knowledge-related factors in the adoption of agricultural innovations.

In the African context, the importance of institutional support is heightened by the technical and financial requirements associated with many agricultural innovations. Extension services and training can help rural households understand how technologies operate, assess their suitability, and maintain them after adoption. Community networks can also facilitate the exchange of information and experiences among technology users. The African evidence therefore suggests that adoption should be examined not only in terms of whether households have access to a technology, but also whether they have the knowledge and institutional support necessary to use it effectively.

In Kenya, Muriu-Ng'ang'a et al. (2017) found that training was associated with utilisation of RWH and water-saving technologies in semi-arid Kenya. This suggests that technical knowledge may influence adoption by increasing households' confidence in their ability to implement and maintain the technologies. These studies contribute to the present study by demonstrating the relevance of training, technical knowledge, and institutional support to technology adoption within rural Kenyan settings.

Access to extension services may also facilitate the transfer of knowledge between agricultural institutions and rural households. Extension officers can provide information on appropriate RWH technologies, construction techniques, water management, and potential applications of harvested water.

Nevertheless, existing Kenyan research has paid little attention to the combined influence of institutional support and technical knowledge on RWH adoption, specifically among beekeeping households. The present study addresses this gap by examining extension services, training, information networks, group

membership, credit, and technical knowledge as potential factors associated with RWH adoption for beekeeping.

Rainwater Harvesting and Beekeeping Activities

Beekeeping is an important livelihood activity in Kenya, particularly in areas where crop and livestock production are constrained by limited rainfall. Its relatively low land requirement makes it suitable for livelihood diversification among rural households. However, climatic conditions, particularly high temperatures and prolonged dry periods, can affect beekeeping activities. Water is important to honeybee colonies for physiological functions and thermoregulation, making its availability relevant to colony management during hot and dry conditions (Winston, 1987). This literature provides the biological basis for considering water availability as relevant to beekeeping, rather than treating RWH solely as a general agricultural water-management technology.

In Africa, the importance of water availability for livestock and agricultural livelihoods becomes particularly pronounced under high temperatures and recurrent drought. Dryland beekeeping households may face periods when natural water sources become unreliable. The African context therefore highlights the potential value of household-level water-management strategies that can supplement naturally available water during dry periods.

In Kenya's ASALS, beekeeping provides an opportunity for livelihood diversification, where crop and livestock production are constrained by limited and variable rainfall. Le Bivic et al. (2026) further highlight the importance of water availability in relation to honeybee responses under climatic stress. This reinforces the relevance of water-management strategies in maintaining beekeeping activities under increasingly variable climatic conditions. This contribution is relevant to the present study because it strengthens the rationale for examining whether RWH can provide a supplementary water source for beekeeping during periods of climatic stress.

Existing literature on RWH adoption has largely concentrated on agricultural production and household water needs (Ahmed et al., 2013; Muriu-Ng'ang'a et al., 2017; Irungu et al., 2024). Consequently, there remains limited understanding of how RWH adoption relates specifically to beekeeping and the socioeconomic and institutional characteristics of beekeeping households. Examining this relationship is important because beekeeping households may have distinct water requirements, livelihood priorities, and technology-adoption decisions compared with households primarily engaged in crop production.

Theoretical Perspective: Diffusion of Innovations Theory

The adoption of RWH technologies can be understood through Diffusion of Innovations Theory, developed by Rogers (2003). The theory explains how new ideas and technologies are communicated, evaluated, adopted, and incorporated within a social system. The theory proposes that individuals assess innovations according to characteristics such as relative advantage, compatibility, complexity, trialability, and observability (Rogers,2003). These characteristics can influence whether households perceive a technology as useful and suitable for their circumstances.

The theory is appropriate for this study because adoption of RWH for beekeeping involves more than physical availability of water or technology. Households are likely to consider whether a technology provides sufficient benefits relative to its financial, labour and technical requirements. Relative Advantage

is relevant because households compare the observable benefits of harvested rainwater with the cost of alternative water sources. Compatibility is important because households may assess whether an RWH technology fits their existing beekeeping practices, available resources, and local conditions. Complexity is relevant where households require technical knowledge to construct, operate, or maintain the technology. Trialability and observability may also influence adoption where households can experiment with a technology or observe its benefits among neighbouring households.

The theory also emphasises the role of communication channels and social systems in the diffusion process (Rogers, 2003). Extension services, training, community groups, and interactions among farmers and beekeepers can provide channels for transmitting information about RWH technologies. Institutional support and technical knowledge may therefore affect adoption by improving awareness and reducing uncertainty.

Consequently, Diffusion of Innovation Theory is used in this study as a guiding framework rather than as a complete explanation of adoption. Its concepts help interpret the roles of perceived benefits, technical knowledge, information, communication networks, and institutional support, while the socio economic variables examined in the study address factors that the theory does not sufficiently explain. This combination provides a more appropriate basis for examining RWH adoption among beekeeping households in Itiko Sub-location.

3.0 METHODOLOGY

The study was conducted in Itiko Sub-location, Mutitu North Sub-county, Kitui County, Kenya, a semi-arid area characterised by erratic rainfall, recurrent drought, and prolonged dry seasons. A convergent mixed-methods design was employed, with quantitative and qualitative data collected concurrently, analysed separately, and integrated during interpretation (Creswell & Creswell, 2023). The household was the unit of analysis. The accessible population comprised 456 households across seven villages. A sample of 82 households was planned using Nassiuma's (2000) formula, proportionately allocated across the villages and selected through simple random sampling. Seventy households participated and provided complete quantitative data, constituting the effective sample and yielding an 85.4 percent response rate**.** Quantitative data were collected from the 70 households using structured questionnaires covering sociodemographic characteristics, economic factors, institutional support, technical knowledge, RWH adoption, and beekeeping practices.

Qualitative data were obtained through semi-structured interviews with purposively selected extension officers, local administrative leaders, and experienced beekeepers. Quantitative data were analysed using frequencies, percentages, cross-tabulations, Pearson's chi-square test, Cramér's V, Monte Carlo procedures where appropriate, and Spearman's rank-order correlation at $p < .05$. Qualitative data were analysed thematically. Findings were integrated by comparing quantitative and qualitative results to identify convergence, divergence, and complementarity, with qualitative findings used to explain quantitative associations and develop integrated themes. The questionnaire was pretested in a comparable area outside the study site. Permission to conduct the study was obtained from relevant ward administrator and the Area Chief. Informed consent, confidentiality, anonymity, and secure data management were maintained throughout the study.

4.0 FINDINGS AND DISCUSSION

Household Socio Demographic Characteristics and Adoption of Rainwater Harvesting Technologies

The study obtained responses from 70 households. Male-headed households accounted for 67.1 per cent (n = 47) of the respondents, while female-headed households constituted 32.9 per cent (n = 23). Respondents were distributed across different age and educational categories, with the largest proportion falling within the 41–50-year age group. Secondary education was the most common level of educational attainment.

Table 1: Sociodemographic Characteristics of Respondents (n = 70)

Characteristic	Category	Frequency (n)	Percentage (%)
Sex of household head	Male	47	67.1
	Female	23	32.9
Age (years)	18–30	7	10.0
	31–40	15	21.4
	41–50	20	28.6
	51–60	18	25.7
	Above 60	10	14.3
Education	No formal education	9	12.9
	Primary	24	34.3
	Secondary	30	42.9
	Post-secondary	7	10.0

The gender and age distributions describe the participating households but do not independently establish their relationship with adoption. The available data did not provide sufficient evidence to conclude that either gender or age independently influenced adoption of RWH technologies. Education, however, showed a clearer pattern when examined against adoption status.

Education and Adoption of Rainwater Harvesting Technologies

Educational attainment was significantly associated with RWH adoption status. As shown in Table 2, none of the respondents without formal education were full adopters. Full adoption increased progressively to 25.0 per cent among respondents with primary education, 43.3 per cent among those with secondary education and 71.4 per cent among respondents with post-secondary education.

Table 2: Educational Attainment and Adoption of Rainwater Harvesting Technologies (n = 70)

Education level	Non-adopters	Partial adopters	Full adopters	Total	Full adoption (%)
No formal education	6	3	0	9	0.0
Primary education	8	10	6	24	25.0
Secondary education	5	12	13	30	43.3
Post-secondary education	0	2	5	7	71.4
Total	**19**	**27**	**24**	**70**	**34.3**

Pearson's chi-square test indicated a statistically significant association between educational attainment and RWH adoption status, χ^2 (6, N = 70) = 16.17, p = .013, with a moderate effect size (Cramér's V = .340). Since some expected cell frequencies were below five, a Monte Carlo permutation test was conducted and confirmed that the association remained statistically significant (p ≈ .011).

Spearman's rank-order correlation further showed a moderate positive association between educational attainment and level of RWH adoption (ρ = .456, p < .001), indicating that higher educational attainment was associated with higher levels of adoption.

The findings suggest that education may enhance households' ability to access, interpret and apply technical information, assess available technologies and engage with extension and other information sources. This is consistent with Diffusion of Innovations Theory, which emphasises knowledge acquisition and information processing in the innovation-decision process (Rogers, 2003). However, the association should be understood within the broader household economic and institutional context, including affordability, access to materials, labour, extension services, training and community information networks. Given the cross-sectional design, the findings establish an association but do not demonstrate that education independently causes RWH adoption.

Household Economic Factors and Adoption

Households depended on multiple livelihood activities. Crop and livestock production constituted the principal livelihood source for 48.6 per cent (n = 34) of respondents, while poultry keeping accounted for25.7 per cent (n = 18). Beekeeping, salaried employment, and remittances accounted for smaller proportions. These findings are descriptive and are presented to characterise the livelihood context of the participating households rather than as evidence of a statistically significant relationship with RWH adoption. The relatively limited contribution of beekeeping to household livelihoods is relevant because investment in RWH infrastructure may occur alongside competing household and agricultural expenditure priorities.

Financial capacity was identified as an important consideration in the acquisition and maintenance of RWH technologies. Respondents reported that the costs of tanks, gutters, pipes, and other construction materials constrained investment, particularly in larger storage systems. Labour requirements were also reported for construction, cleaning, and routine maintenance. Descriptive findings showed that approximately 30 per cent of respondents reported difficulties maintaining tanks, gutters, and pipes, while 35.7 per cent indicated that cleaning storage facilities was labour-intensive and costly**.** These findings were further supported by qualitative evidence from key informants, who described the cost of materials, availability of labour, and maintenance requirements as challenges affecting households' ability to establish and sustain RWH systems.

The findings suggest that recognition of the usefulness of RWH does not necessarily translate into adoption where households lack the financial, material, or labour resources required to install and maintain the technologies. This interpretation is consistent with Feder et al. (1985) and Fadeyi et al. (2022), who emphasise the importance of household resources and investment requirements in agricultural technology adoption.

Institutional Support and Technical Knowledge

Institutional support provided households with access to information and technical knowledge concerning RWH technologies. Agricultural extension personnel, training activities and community-based networks were identified as important sources of information. While 69 per cent of respondents were aware of RWH technologies for general water conservation, only 32 per cent understood their application to beekeeping.

The difference between general awareness and knowledge of RWH application to beekeeping suggests that awareness of a technology does not necessarily translate into knowledge of its application to a specific livelihood activity. Training and extension support are therefore important not only for creating awareness but also for providing practical knowledge on technology selection, installation, utilisation, and maintenance.

Agricultural extension services provided households with technical information on water storage, system maintenance and the productive use of harvested water. Training was also obtained through NGOs and farmers' groups. Knowledge was not transmitted exclusively through formal institutions. Farmer groups, beekeeper groups, village meetings, church-based associations and local water-project committees provided platforms through which households exchanged information and learned from people with practical experience.

These findings are consistent with Diffusion of Innovations Theory, which emphasises communication channels and interpersonal networks in the diffusion of innovations within a social system (Rogers, 2003). Formal extension and informal community networks therefore appear to play complementary roles in helping households understand, evaluate and use RWH technologies.

Gendered Participation in Water Management and Decision-Making

The study revealed a marked difference between women's involvement in household water management and their participation in decisions concerning investment in RWH infrastructure.

Table 3: Women's Participation in Household Water Management and RWH Decision-Making (n = 70)

Aspect of participation	Frequency (n)	Percentage (%)
Responsible for water collection and storage management	56	80.0
Participated in financial decisions concerning RWH infrastructure	14	20.0

The findings show that 80.0 per cent (n = 56) of respondents reported women's responsibility for water collection and storage management, whereas only 20.0 per cent (n = 14) reported women's participation in financial decisions concerning RWH infrastructure.

This contrast provides a more substantive understanding of gender than the sex distribution of household heads alone. It indicates that responsibility for the day-to-day management of household water does not automatically translate into comparable participation in decisions concerning investment in water infrastructure.

This difference is important because investment in tanks, gutters and other RWH infrastructure requires control over household financial and material resources. The finding is consistent with evidence that gendered access to productive resources and household decision-making can shape participation in agricultural technology adoption (Doss & Morris, 2001).

RWH interventions should therefore recognise women's practical knowledge and responsibility for household water management while also strengthening their participation in decisions concerning investment in water infrastructure.

Rainwater Harvesting and Beekeeping Activities

Water availability emerged as an important requirement for beekeeping among households in the study area. Respondents reported that accessible water was required for bee hydration, cleaning beekeeping equipment, maintaining apiary hygiene and supporting routine hive management. During extended dry periods, inadequate water availability disrupted these activities.

Beekeepers with reliable access to harvested rainwater reported greater continuity in beekeeping activities during periods of water scarcity. Harvested water reduced dependence on seasonal rivers, shared community dams and distant water sources and enabled households to maintain water availability around their apiaries during dry periods.

The contribution of RWH to beekeeping should nevertheless be interpreted within the broader household livelihood context. Beekeeping was not the principal livelihood activity for most households, and harvested water also served broader household needs. RWH should therefore not be presented as being adopted exclusively or primarily for apiculture.

Water availability is important for bee survival and thermoregulation, particularly under hot and dry conditions. The contribution of RWH can therefore be understood as providing an enabling resource for maintaining beekeeping activities when natural water sources are unreliable.

The study did not directly measure changes in honey yield attributable to RWH. Consequently, the findings do not demonstrate that RWH adoption caused increased honey production. Rather, they show that harvested rainwater improved the availability and reliability of water required to sustain beekeeping activities.

Discussion

The findings demonstrate that adoption of rainwater harvesting (RWH) technologies for beekeeping in Itiko Sub-location is associated with an interaction of household socioeconomic capacity, knowledge, institutional support, and the practical requirements of the technologies. The findings therefore suggest that water scarcity alone does not determine adoption, since households exposed to similar semi-arid conditions may differ in their ability to respond to water shortages. Education showed a significant positive association with RWH adoption, with higher educational attainment corresponding to higher levels of adoption. This finding is consistent with Feder et al. (1985), who identified education and access to information as important considerations in agricultural technology adoption, and Knowler and Bradshaw (2007), who similarly found that socio economic characteristics influence adoption of agricultural conservation technologies. In the context of this study, the association suggests that education may

enhance households' ability to access, understand, and apply information concerning RWH technologies. However, because the mechanisms through which education relates to adoption were not directly measured, the findings should be interpreted as an association rather than evidence that education causes adoption.

Household economic circumstances provided an additional explanation for differences in adoption. Respondents identified the costs of tanks, gutters, pipes and construction materials as constraints, particularly for larger storage systems, while labour and maintenance requirements also presented challenges. These findings are consistent with Feder et al. (1985) and Fadeyi et al. (2022), who emphasize the importance of household resources and investment requirements in agricultural technology adoption. The implication is that households may recognise the usefulness of RWH but remain unable to invest in or sustain the technology when financial, material and labour resources are limited.

The livelihood structure of the households provides further context for this finding because crop and livestock production constituted the principal livelihood source for many respondents, while beekeeping represented a smaller component of household livelihoods. Investment in RWH for beekeeping therefore takes place alongside competing household and livelihood expenditure priorities. This livelihood context extends previous RWH research, which has largely focused on crop production, domestic water supply and general agricultural water management. Institutional support and technical knowledge were also important in understanding adoption. Extension services, training, farmer and beekeeper groups, and community information networks provided channels through which households obtained information concerning RWH.

This finding is consistent with Fadeyi et al. (2022) and Muriu-Ng'ang'a et al. (2017), who emphasised the importance of knowledge, training and institutional support in agricultural technology adoption. The findings further suggest a distinction between general awareness of rainwater harvesting and knowledge of its application to beekeeping. A household may recognize the benefits of harvesting rainwater but still lack the technical knowledge required to select, install, and maintain an appropriate system. This indicates that extension interventions should address practical, livelihood-specific knowledge rather than awareness alone. Community and beekeeper networks may also facilitate learning by enabling households to exchange experiences and observe technologies used by other households. However, the study measured access to institutional support and technical knowledge rather than the effectiveness of particular extension interventions; therefore, these findings should be interpreted as contextual evidence rather than proof of a causal institutional effect.

The gender findings provide an additional dimension to understanding household decision-making. Women were reported as responsible for water collection and storage management in 80.0 per cent of households, whereas only 20.0 per cent participated in financial decisions concerning RWH infrastructure. These figures are descriptive and should not be interpreted as evidence of a statistically significant gender association because no inferential test was conducted for these variables. Nevertheless, the pattern suggests a distinction between responsibility for managing water and influence over investment decisions. Women may therefore have substantial practical knowledge of household water needs without having equivalent influence over decisions concerning water infrastructure. This has implications for RWH interventions, which should involve women not only as users or managers of harvested water but also in discussions concerning technology selection and household investment.

The findings also indicate that harvested rainwater supported beekeeping activities during periods of water scarcity, including bee watering, equipment cleaning, apiary hygiene and routine hive management. This livelihood-specific finding is important because existing RWH studies have concentrated mainly on domestic water supply and crop production. Water is relevant to honeybee physiological functions and thermoregulation, particularly under hot and dry conditions(Winston, 1987). The availability of harvested rainwater may therefore provide a supplementary source that supports apiary management when alternative water sources become unreliable. However, the study did not directly measure honey yield, colony survival, hive occupancy, or other indicators of beekeeping productivity. Consequently, the findings demonstrate support for water availability and routine beekeeping management rather than a direct effect of RWH adoption on productivity. Diffusion of Innovations Theory (Rogers, 2003) provides a useful framework for interpreting these findings, particularly the importance of education, training, extension services, and community information networks.

These findings are consistent with the theory's emphasis on communication channels and social systems through which information about innovations is transmitted. The findings concerning technology costs and maintenance can also be interpreted in relation to the concepts of relative advantage and compatibility. Households may recognise the advantage of having stored water for beekeeping but may find particular technologies difficult to adopt when their financial, labour or material requirements are incompatible with available household resources. Nevertheless, DOI Theory does not fully explain the economic and structural constraints identified in this study, and the study did not directly measure perceived relative advantage, compatibility, complexity, trialability or observability.

The theory is therefore used to interpret the observed patterns rather than to imply that these characteristics caused adoption. Its contribution to the study is to help explain how knowledge, communication and social interaction may shape the adoption process while recognising that household resources and institutional conditions also influence the capacity to act on that knowledge. The findings have practical implications for RWH and climate-resilience interventions in semi-arid beekeeping communities. Promoting RWH solely through awareness creation may be insufficient where households face financial, technical and labour constraints. Interventions should therefore combine affordable and locally appropriate technologies with practical training, extension support and community-based information networks.

The findings also highlight the importance of incorporating women into household and community discussions concerning investment in water infrastructure. The study has several limitations that should be considered when interpreting the findings. First, the quantitative analysis was based on 70 households that participated from the planned sample of 82, which may limit statistical power and generalizability. Second, the study was conducted in one sub-location, limiting the extent to which the findings can be generalised to other semi-arid communities in Kenya. Third, the cross-sectional design identifies associations but does not establish causal relationships. Finally, the study did not directly measure beekeeping productivity outcomes such as honey yield or colony survival. Overall, the findings indicate that sustainable RWH adoption for beekeeping depends on the interaction between household capacity, knowledge, institutional support, and the practical suitability of technologies within the livelihood context.

5.0 CONCLUSION AND RECOMMENDATIONS

Conclusion: This study examined household socio economic and institutional factors associated with the adoption of rainwater harvesting (RWH) technologies for beekeeping in Itiko Sub-location, Kitui County, Kenya. The findings demonstrate that RWH adoption is a multidimensional process shaped by household resources, education, technical knowledge, institutional support, and the financial, material and labour requirements of the technologies. Although water scarcity creates a need for reliable water sources in the semi-arid environment, households differ in their capacity to acquire, operate and maintain appropriate RWH technologies. Access to extension services, training and community information networks provides important opportunities for households to obtain technical knowledge and learn about RWH. The findings further indicate that harvested rainwater can supplement water availability for beekeeping during dry periods, particularly for bee watering, equipment cleaning, apiary hygiene and routine hive management. However, the study did not establish a causal relationship between RWH adoption and beekeeping productivity because outcomes such as honey yield and colony survival were not directly measured. Overall, strengthening RWH adoption for beekeeping requires an integrated approach that combines affordable technologies with technical support, institutional assistance, and inclusive household decision-making. The study highlights RWH as a potentially important component of livelihood resilience in water-scarce semi-arid beekeeping communities.

Recommendations: County and national climate-resilience programmes should promote affordable and locally appropriate RWH technologies that can be acquired and maintained by resource-constrained households in semi-arid areas. Agricultural extension agencies and development organisations should strengthen livelihood-specific training and extension services to provide beekeeping households with practical knowledge on the selection, construction, operation and maintenance of RWH technologies. Farmer groups, beekeeper associations and community information networks should be strengthened as platforms for peer learning and sharing practical experiences on RWH. RWH interventions should also encourage women's participation in household decisions concerning investment in water infrastructure, given their important role in household water management. Further research should examine the relationship between RWH adoption and measurable beekeeping outcomes, including colony survival, hive occupancy, colony development, and honey yield, as well as the economic feasibility of different RWH technologies.

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