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Original Article

Trade-Off Between Agroforestry and Ecosystem Services among Smallholder Farmers in Machakos County, Kenya

Benjamin Mutuku Kinyili[1], Dr. Ezekiel Ndunda[2] & Dr. Esther Kitur[3]

[1]Kenya Forest Services, PO Box 2501-30100, Eldoret, Kenya, bmkiniyili@yahoo.com.
[2]Kenyatta University, PO Box 43844 – 00100, Nairobi, Kenya, estherkitur2015@gmail.com.
[3]Kenyatta University, PO Box 43844 – 00100, Nairobi, Kenya, ezndunda@gmail.com

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ABSTRACT

Agroforestry provides multiple ecosystem services. The understanding of the relationships between it and the ecosystem services can help to lessen undesired trade-offs. The aim of this study was to determine the trade-offs between agroforestry and ecosystem services among smallholder farmers in Machakos County, Kenya. This study demonstrated that smallholder farmers who had adopted agroforestry in the semi-arid areas of Machakos County achieved several ecosystem services from the practice. Ecosystem services supporting functions included nutrient recycling and soil formation which were the most important. These were followed by regulatory functions (soil erosion control, water infiltration, microclimate regulation, flood control and disease/pest control). Provision of ecosystem services such as fuelwood, fruit, nuts, poles, timber and fodder was the third most important function as perceived by the local community members while the least was cultural functions that are rarely performed within the agroforestry ecosystems. Given the low knowledge of the entire range of agroforestry ecosystem services in the area, there should be concerted effort to educate the local community members about the wide range of ecosystem services to maximize the exploitation of these services from agroforestry.

INTRODUCTION

Smallholder farmers practicing agroforestry integrate woody vegetation (trees or shrubs) with crop and/or animal production in a parcel of land to the benefit of the farmer. To optimize planning and decision-making about smallholder agroforestry adoption and practices, knowledge of the accrued ecosystem services beneficial to the local community members is important (Fagerholm *et al.*, 2016). Evidently, agroforestry provides suits of ecosystem services such as timber, food, fuel wood, fodder, ornamental and medicinal resources, or indirect benefits comprising services such as carbon sequestration, soil and water regulation and habitat for pollinating species and wildlife (Amare *et al.*, 2019; Fagerholm, 2016; Quandt *et al.*, 2018). These ecosystem services are generally in four categories as provisioning (e.g. production of food or fibre); regulating (control of climate or pests and diseases); supporting (e.g., nutrient cycling and plant pollination), and cultural (e.g. recreational, spiritual or aesthetic).

The nature of these ecosystem services and their link with human well-being has increasingly been the subject of increasing research (Brown *et al.*, 2018; Daw *et al.*, 2016; Fedele *et al.*, 2017). These stem from the recognition that economic and social components must be understood jointly and taking cognizance of the feedbacks and trade-offs between them (Hori & Makino, 2018; Mace *et al.*, 2018; Turkelboom *et al.*, 2018). The underlying assumption is that the provision of these ecosystem services will automatically translate to improvement of the livelihood of the smallholder agroforestry adopters (Quandt *et al.*, 2018). However, in some studies, it has been established that ecosystem services tend to only provide marginal sustenance to livelihoods wellbeing and/or prevent households from acceding further to abject poverty, rather than actively contributing to a steady improvement of the situation for the household (Feintrenie *et al.*, 2019). Most of the studies dealing with ecosystems and their impacts on the socio-economic wellbeing are often valuation studies. For example, Kay et al. (2019) Mercer et al. (2017) and Temesgen et al. (2018) studies focused on assessing the value (usually monetary) value of ecosystem services and their utilization. Valuation and monetary contribution of ecosystem services appear to work well in developed countries where detailed valuation tools are available but rarely work in developing countries especially in Africa.

Garrity (2004) and Owombo *et al.* (2018) posit that the adoption and practice of agroforestry has increased among smallholder farmers in the developing countries especially in the Sub Saharan Africa There are several reports that indicate that African agroforestry systems improve energy, food and housing conditions through tree domestication (Benjamin *et al.*, 2018; Ofori *et al.*, 2014; Temesgen *et al.*, 2018). Nonetheless, little attention has been accorded to comprehending whether the local community members comprehend the ecosystem services and the trade-offs between ecosystem services and livelihood in smallholder agroforestry.

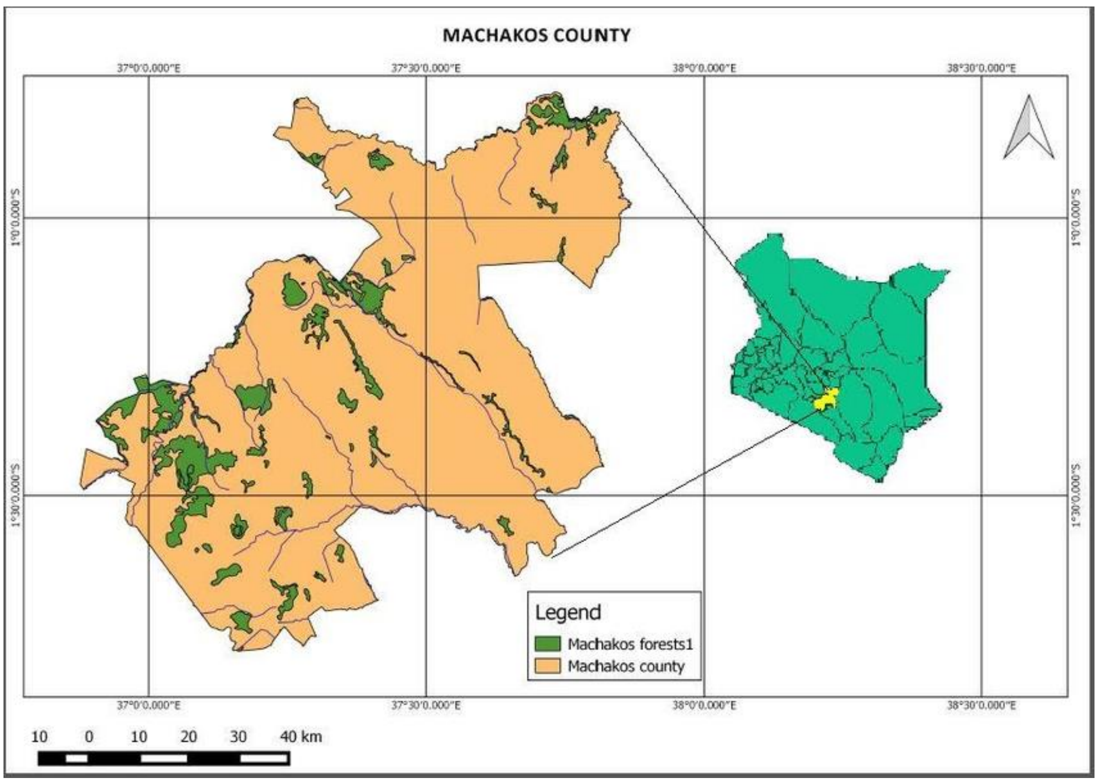
Large parts of the African landscape fall under the arid and semi-arid area characterized by prolonged droughts and scarcity of water and food (Huang *et al.*, 2016). There are several studies that have denoted an increased agroforestry adoption in the semi-arid areas (Iiyama *et al.*, 2017; Quandt *et al.*, 2017). In the semi-arid areas of Kenya, there have been concerted efforts to encourage adoption of agroforestry practices to help in building and enhancing the livelihood resilience to floods and drought (Maluki *et al.*, 2016; Quandt *et al.*, 2017). However, there has been little attempt at establishing the balances between the adoption of agroforestry and knowledge of the ecosystem services. Despite the increased recognition and advocacy on the multi-dimensionality of livelihood, most studies have remained limited to the income and assets accruing from the agroforestry systems side-lining the combination with non-economic impacts to poverty (Benjamin & Sauer, 2018). Few researches have empirically attempted to evaluate relationships at lesser levels than a macro or aggregate as most ignore investigating the existence of any ecosystem benefits to the poor especially in developing countries.

Questions about the nature of the nexus between the adoption of agroforestry systems, ecosystem services and their link to the multiple scopes of destitution as well as about the mechanisms and consequences on different aspects of well-being resulting from the alteration of the ecosystem provision. According to Liebenow *et al.* (2012), it is imperative to determine causal pathways and relationships most importantly with respect to the development of apt and effective policies potent enough to translate to both the poverty alleviation and sustainable management of ecosystem services. Therefore, the aim of this study was to determine the indigenous knowledge of the ecosystems services from agroforestry and its links to rural livelihood in semi-arid area in Kenya.

MATERIALS AND METHODS

The study was conducted in Machakos County (*Figure 1*) which covers an area of 5,953 km². It lies between latitudes 0º45´ South and 1º31´ South and longitudes 36º45´ East and 37º45´ East. Most of the land is semi-arid with a population of 1,098,584 as per the 2009 Kenya National census (Kenya National Bureau of Statistics, 2010). Administratively the county is divided into 11 divisions: Kalama, Kangundo, Kathiani, Machakos Central, Masinga, Matungulu, Mavoko, Mwala, Ndithini, Yathui and Yatta. In terms of political structure, the county has eight constituencies including Kangundo, Kathiani, Machakos Town, Masinga, Matungulu, Mavoko, Mwala and Yatta. The overlap between division and constituency is sometimes not clear and constituencies are in some cases referred to as sub counties. Among the division and constituencies, Kathiani, Mavoko and Machakos Town practice agroforestry. Four sites where agroforestry is practiced included Mua (Mavoko, Machakos Town and Kathiani) and Iveti Hills (Machakos Central and Kathiani), Kima-Kimwe and Kalama in Machakos Constituency.

Figure 1: Map of Machakos County showing the study area



The local climate is semi-arid with hilly terrain and an altitude of 1000 to 2100 metres above sea level. The area is composed of hilltops rising to 1594-2100 m above sea level. The annual average rainfall is 1000 mm (range, 500 mm to 1300 mm) and is bimodal; short rains occur in October to December and long rains from March to May. Temperatures range between 18.7 °C and 29.7 °C. The soils are well-drained shallow dark red volcanic on hilltops and clay soils in the plains. Irrigation farming is practiced utilizing the permanent rivers and streams that flow from the hilltop catchment areas towards South Eastern to join Athi River. Crops such as maize, beans, pigeon peas, vegetables are dominant. Dairy and beef cattle, sheep, and goats are the major livestock kept.

RESEARCH DESIGN

This study was conducted through an exploratory survey design. Surveys are normally used to systematically gather factual quantifiable information necessary for decision-making (Nardi, 2018). Surveys are efficient methods of collecting descriptive data regarding the characteristics of populations, current practices and conditions or needs. They also help to gather information from large populations by use of samples hence cutting down on costs. Survey research design was adopted in this study in order to capture descriptive data from selected samples and generalize the findings to the populations from which the sample was drawn.

The study targeted household heads from Mua Hills (Mavoko, Machakos Town and Kathiani), Iveti Hills (Machakos Central and Kathiani), Kima-Kimwe and Kalama Hills in Machakos constituencies. Since the actual population was not easy to determine due to changes in the rate of adoption with respect to time, the sample size of the households adopting agroforestry as earlier established in the region was used. According to Nzilu (2015), 80% of the households had adopted agroforestry in Mwala (Machakos County). The appropriate sample size was therefore computed using the formula described in Mugenda and Mugenda (Mugenda and Mugenda, 2003): $n = \frac{z^2p(1-p)}{d^2}$; where *n* is the desired sample size, *z* is the z score at the required confidence level α = 0.05 (1.96), *p* is the proportion in the target population assumed to be adopters, d is permissible marginal error (the level of statistical significance, set at α = 0.05). Using the values of *z*, *p* and *d*, the value of *n* was computed as follows

$$n = \frac{1.96^2 \times 0.8(1-0.8)}{0.05^2} = 245.86 \approx 246$$

The sample size was 246 but the research assistance who hail from the area also provided additional information resulting in 248 respondents. Samples were selected through stratified, random sampling at each of the selected spatial units and used to identify the adopters and non-adopters. Adopters were households practicing any form of agroforestry.

This study used primary data. Data on income, expenditure and rural livelihood among the respondents was collected using structured researcher administered questionnaires. The designing of the instruments was such that they endeavoured to ensure an in-depth exploration of personal views, feelings and opinions on agroforestry and benefits accrued. Before data collection, the respondents were contacted in advance and asked to organize their time for the research. Two research assistants were recruited and trained to aid in the collection of collection. The questionnaires were administered by physical drop and pick by the researcher and two research assistants. The researcher personally administered the instrument. The researcher made prior visits to assist in defining timings and distribution of research instruments. The researcher developed the research instruments based on examining the research objectives and the related literature. The salience of the instruments was sought through expert judgment. The experts examined the face, content and construct validities in order to determine whether items measured what they were supposed to determine. They established whether the numbers of items are adequate for the purpose intended researcher and thus their expert judgments ensured validity of the instruments. The reliability of instruments was established through a pilot study among 12 household members who did not participate in this study. The results of the study were used to compute the reliability of the instruments. Cronbach's coefficient alpha was used to determine the reliability of the instruments (Bonett & Wright, 2015). The study considered the instrument reliable and acceptable if the computation yielded a reliability coefficient of 0.7 and above. For this study, the reliability coefficient was 0.83, which was determined to be suitable for the research. All questionnaire data were coded into Statistical Package for Social Sciences (SPSS 23) for analysis. Differences in rural income, expenditure and livelihood were evaluated using chi-square analysis and ANOVA. All analyses were declared significant at $P < 0.05$.

RESULTS AND DISCUSSION

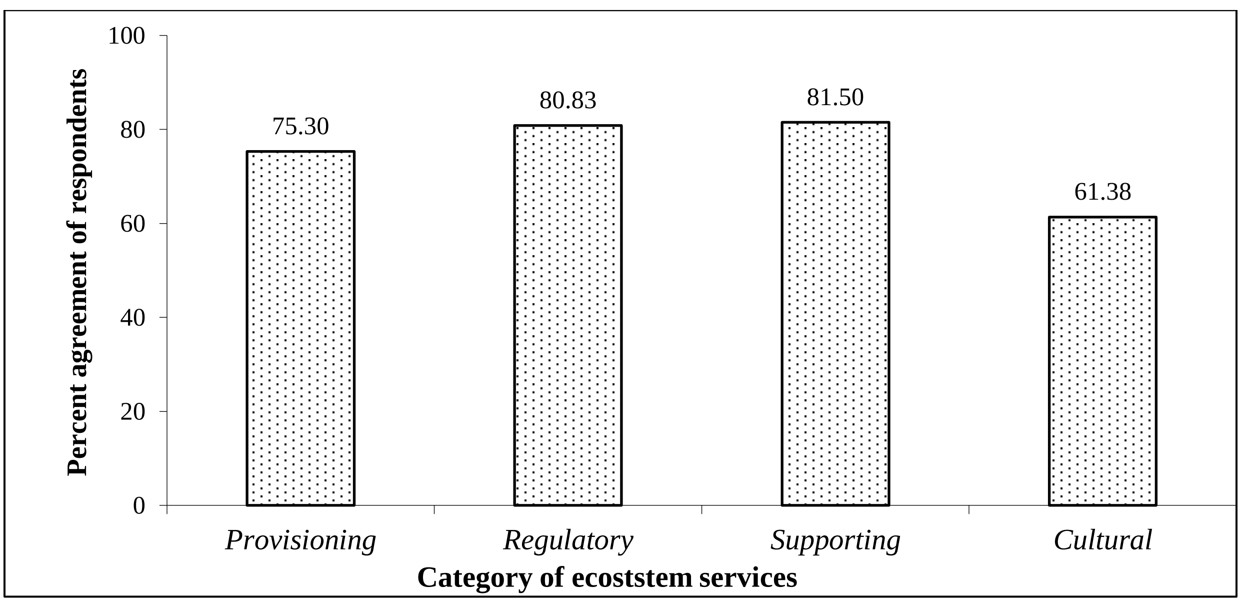
The ecosystem services by the smallholders who adopted agroforestry practices are shown in *Table 1*.

Table 1: Ecosystem services by the smallholder farmers who adopted agroforestry practices

Category of services	**Specific ecosystem services**	**Frequency of responses**				
		Strongly Disagree	**Disagree**	**Uncertain**	**Agree**	**Strongly Agree**
Provisioning	Fuel wood	9	0	7	68	40
	Timber	29	2	7	63	23
	Poles	19	4	8	75	18
	Fodder	21	4	9	71	19
	Fruits and Nuts	13	8	16	61	26
Regulatory	Soil erosion control	4	1	11	76	32
	Water infiltration	3	2	10	79	30
	Micro climate	3	1	12	68	40
	Flood control	6	14	16	61	27
	Disease/pests control	7	18	17	59	23
Supporting	Nutrient Recycling	3	1	14	79	27
	Soil formation	3	4	22	72	23
Cultural	Spiritual	76	8	10	25	5
	Recreation	9	2	17	74	21
	Education	40	5	14	56	9
	Aesthetic	34	2	10	58	20

The computed percentages rank scores of the value of the aggregated ecosystem services obtained by the local community members are provided in *Figure 2*.

Figure 2: The value of aggregated ecosystem services obtained by the local community members

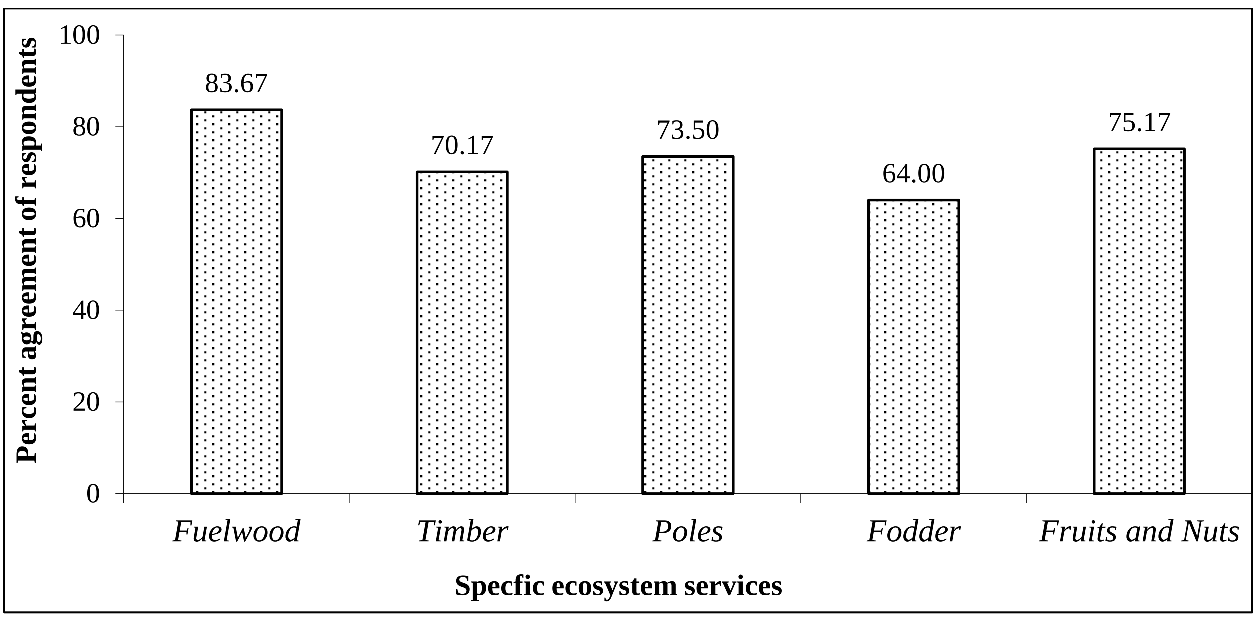


Based on calculated percent rank scores, the most common benefit derived from the local community members was ecosystem-supporting functions (81.5%) followed by regulatory functions (80.8%). Provisioning ecosystem service was the third most important function as perceived by the local community members (75.3%) while the least was cultural functions (61.4%).

Smallholder agroforestry contribution to multiple ecosystem services that support the rural livelihood of smallholder farmers is widely recognized. Given the dearth of information on local knowledge of the ecosystem services in semi-arid drylands within Sub Saharan Africa, this study determined the local community understanding of the ecosystem benefit derived from smallholder agroforestry in Machakos in Kenya. The study established that ecosystem supporting functions, which included nutrient recycling and soil formation, were the most important (see *Table 1*). This is one of the reasons often stated for the adoption of agroforestry with a view of provision of services such as climate regulation and restoration of soil quality (Edwards *et al.*, 2014; Lal, 2015). A study by Edwards *et al.* (2014) established that improved soil fertility was perceived as the main benefit derived from practicing agroforestry. However, in other studies in the Sub Saharan Africa, ecosystem supporting function is often lowly ranked by local community members due to lack of knowledge about nutrient recycling and soil formation (Corbeels *et al.*, 2019; Jose & Bardhan, 2012), which also concur with other studies in the Amazon basin (Pinho *et al.*, 2012). Therefore, it is inherent that the poor quality of soil and nutrient levels in the area (Maluki *et al.*, 2016) makes local knowledge of any activity that helps to improve the soil a priority.

The study also determined the percent rank scores for each of the individual provisioning ecosystem services among the local community respondents (*Figure 3*).

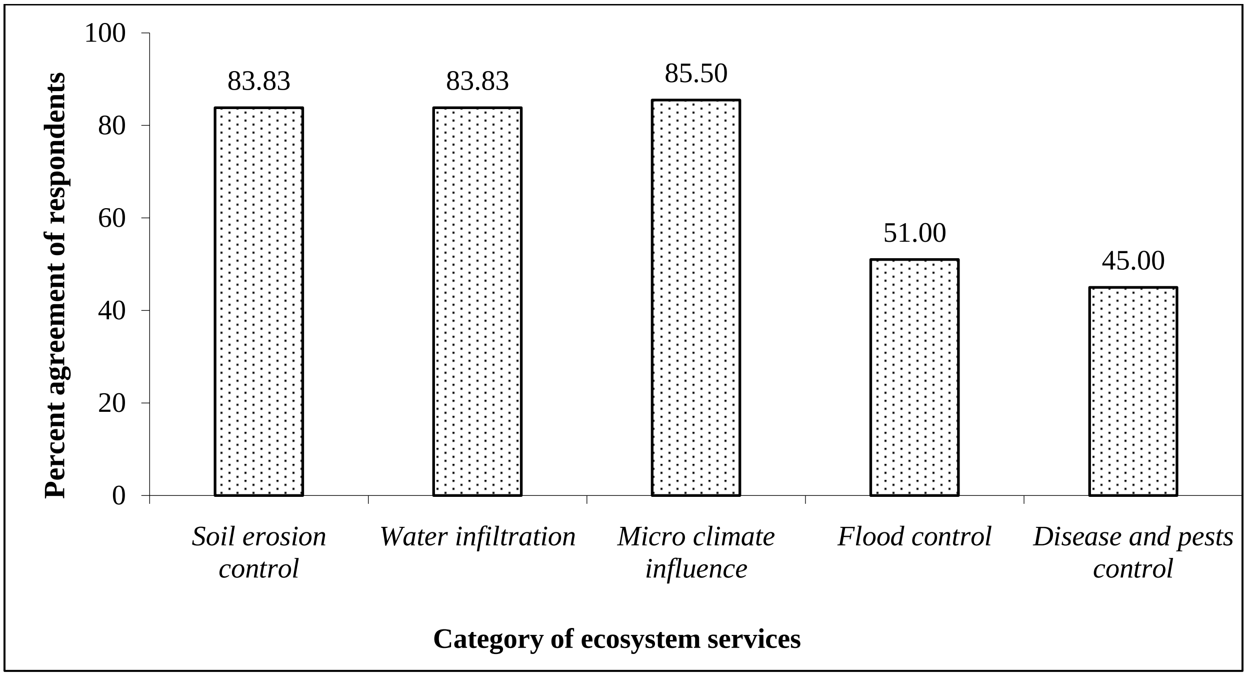
Figure 3: Percent rank scores for individual provisioning ecosystem services



According to computed aggregated Likert scoring scheme used, the highest percentage rank on ecosystem provisioning services among the local community members was fuelwood (84%), followed by fruit and nuts (75%), poles (74%), timber (70%) and least for fodder (64%). Provisioning ecosystem services such as fuelwood, fruit and nuts, poles, timber and fodder was the third most important function as perceived by the local community members. These ecosystem services have been highlighted as of great importance when it comes to fuelwood for energy in the region (Maingi, 2019) and within the sub Saharan Africa (Toth *et al.*, 2017). In support of the current study, provisioning functions including the provision of fuel wood, timber, poles, fodder and fruits are often ranked as the most important services derived from agroforestry (Waldron *et al.*, 2017).

The percent rank scores for individual ecosystem regulatory services among the respondents were also determined (*Figure 4*) where it was established that the highest percentage rank on the ecosystem regulatory functions was micro-climate regulation (85%), followed by soil erosion control (83.5%), water infiltration (83%), flood control (51%) and least for disease and pest control (44%).

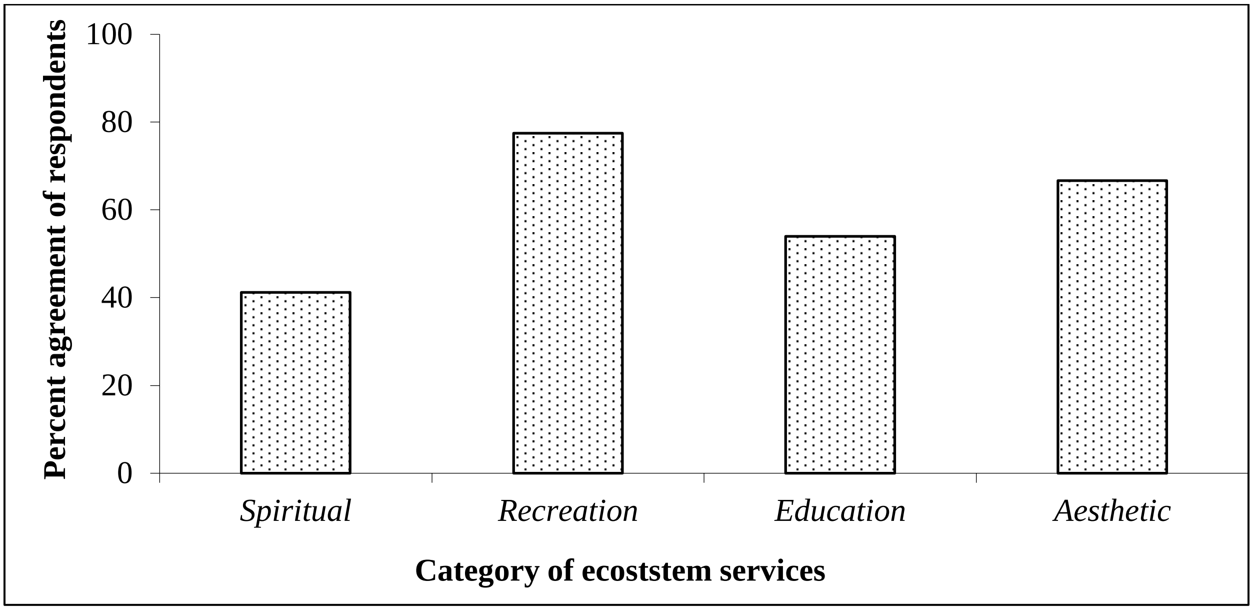
Figure 4: Percent response for regulatory ecosystem services



Regulatory functions (soil erosion control, water infiltration, microclimate regulation, flood control and disease/pest control) were the second most important ecosystem services. The use of agroforestry as mitigation for climate change among smallholder farmers is a practice now gaining much relevance (Mbow *et al.*, 2014) which has also been practiced within the region in the past (Quandt *et al.*, 2018). The region also has incidences of soil erosion which is high due to the hilly terrain of the study area (Baaru & Gachene, 2016; Karuma *et al.*, 2014), the climate in the region is also quite hot and dry and therefore agroforestry practices will modify this micro-climate to noticeable levels. Moreover, frequency of flooding was often high and therefore any action of the agroforestry crops towards control of floods would easily be noticed by the local community members.

The highest percentage rank on the ecosystem supporting functions among the local community members was nutrient cycling (83%) followed by soil formation (81%). The percent rank scores for individual ecosystem cultural functions among the respondents are shown in *Figure 5*. Based on the aggregated Likert scoring scheme, the highest percentage rank on the ecosystem cultural functions among the local community members was for recreation (77.5%), followed by aesthetic function (66.7%), education (54%) and least in spiritual functions (41.2%).

Figure 5: Percent response for cultural ecosystem services



A general tendency in ecosystem service assessments, depicted by the recent literature, is that the measurement of cultural services lags behind the regulating, provisioning, and supporting services categories (Meijer *et al.*, 2015). Most households in the area are currently moving away from several cultural undertakings and therefore it seems that there was not much importance attached to the cultural practices except for recreation, which is not considered a very strong cultural value.

CONCLUSION

This study demonstrates that smallholder farmers, who had adopted agroforestry in the semi-arid areas of Machakos in Kenya, achieved several ecosystem services from the practice. Ecosystem supporting functions including nutrient recycling and soil formation were the most important followed by regulatory functions (soil erosion control, water infiltration, microclimate regulation, flood control and disease/pest control). Provisioning ecosystem services such as fuelwood, fruit and nuts, poles, timber and fodder was the third most important function as perceived by the local community members while the least was cultural functions that are rarely performed within the agroforestry ecosystems. Given the low knowledge of the entire range of agroforestry ecosystem services in the area, there should be concerted effort to educate, create awareness, training and sensitize the local community members, smallholder farmers, stakeholders and County and National Governments the wide range of ecosystem service to maximize the provision of these services from agroforestry.

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