# Developing A Participatory Decision Support Tool for Soil and Water Management in Kakia-Esamburmbur Catchment of Narok, Kenya

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## Graphical Abstract

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**Abstract**

Soil and water management are crucial for sustainable agriculture and environmental conservation. This study developed a decision support tool for managing soil and water in the Kakia-Esamburmbur catchment, Narok, Kenya. Using experimental data, interviews, questionnaires, field measurements, and simulations, the study assessed runoff, soil loss, and sediment yield under different land management practices. The average annual sediment yield was 21.19 t/ha, soil loss was 37.02 t/ha, and runoff was 276.52 mm. The highest values were observed in farm 1, which had a fallow section and the steepest slope. The WEPP model's predictions were inaccurate due to limited soil loss measured data. Incorporating 15m forest/grass strips at 50-meter intervals or 30-meter forest strips at key locations was recommended for sustainable management. Although grass strips reduced soil loss slightly more, forest strips were better at reducing sediment yield. The study highlights the importance of the tool in managing resources but has limitations such as the lack of insufficient observed data for model calibration. This work supports UN SDGs 2, 6, and 15 and aligns with the Science, Technology, and Innovation Strategy for Africa (STISA-2024) by addressing critical environmental challenges and promoting sustainable development goals through innovative solutions. Future research should focus on improving data accuracy for model calibration.

**Keywords:** Soil and water management; participatory decision support tool; WEPP model; land management practices; model simulations.

# 1 Introduction

Soil and water degradation is a pressing global concern, impacting agricultural productivity, ecosystem services, and human well-being. [1, 2]. In the Kakia-Esamburmbur catchment of Narok County, Kenya, these issues are particularly pronounced. The catchment experiences significant soil erosion, sediment yield, and runoff, leading to a decline in soil fertility, reduced water quality, and increased flood risks. This degradation poses a major threat to the livelihoods of local communities who depend on the land for agriculture, livestock grazing, and other economic activities. Addressing these challenges requires a comprehensive approach that involves sustainable land management practices and participatory decision-making. [3,4]. While various strategies for soil and water conservation exist, their implementation have ineffective and unsustainable outcomes. This highlights the need for a participatory decision support tool that can empower local communities to make informed choices regarding land management practices. This paper presents the development of such a decision support tool for the Kakia-Esamburmbur catchment. The tool is based on the widely recognized Water Erosion Prediction Project (WEPP) model, which allows for simulating soil loss, sediment yield, and runoff under different land management scenarios. The tool integrates participatory approaches, ensuring that local knowledge and perspectives are incorporated into the decision-making process. By combining scientific modeling with community engagement, this tool aims to provide a valuable platform for developing sustainable soil and water management strategies in the Kakia-Esamburmbur catchment. The initiative aligns with and supports the objectives of the Science, Technology, and Innovation Strategy for Africa (STISA-2024), which emphasizes the integration of science and technology for sustainable development. The potential impact of this tool extends to post-STISA initiatives by contributing to Africa's environmental and agricultural goals through innovative and practical solutions In Kenya, the Kakia-Esamburmbur catchment, like many other regions, experiences significant soil erosion and water runoff, leading to degraded land and compromised water resources [5]. Addressing this issue requires a holistic approach that integrates scientific understanding with local knowledge and participatory decision-making [6]. The Water Erosion Prediction Project (WEPP) model has been widely used for simulating soil erosion and runoff, providing valuable insights into the impact of land management practices [7, 8]. WEPP has been successfully applied in various regions to assess erosion rates, identify critical areas, and evaluate the effectiveness of conservation measures [9, 10]. However, effectively utilizing WEPP for decision-making requires integrating it with participatory approaches that actively involve local stakeholders in the modeling process [11, 12]. Participatory decision support tools (DSTs) have emerged as powerful instruments for facilitating collaborative decision-making in natural resource management [13]. By integrating scientific knowledge, local expertise, and stakeholder values, DSTs can empower communities to develop and implement sustainable solutions [14, 15]. Studies have demonstrated the effectiveness of participatory DSTs in promoting sustainable land use planning, water resource management, and biodiversity conservation [16, 17]. Integrating WEPP with participatory approaches has shown promising results [18, 19]. By involving local communities in the calibration, validation, and interpretation of WEPP simulations, researchers can ensure that the model outputs are relevant and actionable for local decision-making. This participatory approach fosters ownership and builds capacity within communities to effectively manage their natural resources [20]. The DST leveraged the predictive capabilities of WEPP while actively engaging local stakeholders in the modeling process, ensuring that the tool is tailored to their specific needs and priorities. Such a tool aligns with STISA-2024 objectives by promoting sustainable land management and advancing scientific and technological solutions for environmental challenges.

# 2 Methods

## 2.1 Methodology

This section outlines the methodology employed in developing the participatory decision support tool for soil and water management in the Kakia-Esamburmbur catchment. The methodology encompassed four key components: data collection, model calibration, stakeholder engagement, and running model simulations.

## 2.2 Data Collection

The study involved collecting various data essential for model calibration and analysis. These data included:

### Soil Properties

This included data on soil type, texture, organic matter content, and infiltration rate. Soil samples were collected from different locations within the catchment, and laboratory analyses were conducted to determine the properties.

### Rainfall Data

Historical rainfall data for the Kakia-Esamburmbur catchment was obtained from the Kenya Meteorological Department. This data was used to simulate rainfall patterns in the WEPP model.

### Land Use and Land Cover

Through observations and interviews with farmers, the current and past land use and land cover patterns in the catchment were established. This information was used to define the different land management practices within the WEPP model.

### Topographic Data

Digital Elevation Models (DEMs) were used to determine the slope, elevation, and aspect of the catchment. This information was crucial for simulating water flow and soil erosion in the WEPP model.

### Socio-economic Data

Information on farming practices, land tenure, and community demographics was collected through surveys and interviews with local farmers and stakeholders. This data helped to understand the social and economic context of land management practices. The farmers also gave suggestions on future land use practices that they considered practical for model simulations.

## 2.3 Model Calibration

The Water Erosion Prediction Project (WEPP) model was selected as the primary tool for simulating soil loss, sediment yield, and runoff. The model was calibrated using the field-measured soil loss data.

## 2.4 Stakeholder Engagement

A participatory approach was adopted throughout the study, ensuring the involvement of local stakeholders in the decision-making process. This involved:

### Workshops

Two workshops, one at the start of the study and one at the end of the study, were conducted with local farmers, community leaders, and government officials to discuss the objectives of the study, understand their perspectives on soil and water management, and solicit feedback on model simulations.

### Field Visits

Field visits were conducted to collect data on the simulated farms and demonstrate the application of the WEPP model. This provided stakeholders with a hands-on understanding of the model's functionality.

### Data Sharing

Model results and outputs were shared with stakeholders, facilitating a dialogue on the potential impacts of different land management practices.

### Decision-Making

The decision support tool was designed to be user-friendly and accessible to local stakeholders, enabling them to explore different management scenarios and make informed decisions based on the simulation results.
This participatory approach aimed to ensure the relevance and applicability of the decision support tool to the specific needs and priorities of the Kakia-Esamburmbur community.

# 3 Results

This section presents the results of the WEPP model simulations, comparing soil loss, sediment yield, and runoff under different land management practices in the Kakia-Esamburmbur catchment. A land management practice was considered acceptable if it achieved soil loss below the permissible sediment yield of 10 t/ha/year and was acceptable by the locals (color-coded green as shown in the tables). The percentage of reduced soil loss and sediment yield are referenced on the current land management values for each farm (coded as S/No.1) to deduce the extent to which each simulated land management will reduce the current problem.

## 3.1 Farm 1 Simulation

From Table 1, the current land management (1) had the highest runoff, soil loss, and sediment yield values. The 30 meters of forest strips at the top, middle, and bottom of the farm resulted in the lowest soil loss and sediment yield rates among all practices. Replacing fallow land with forest significantly reduced soil loss and sediment yield, though not to acceptable levels as shown in Table 1 and Figure 1 below

Table 1: Land management treatments and their impacts.

| S/No. | Length (m) | Slope (%) | Management | Treatment | Precipitation (mm/yr) | Runoff (mm/yr) | Runoff (%) | Soil loss (t/ha/yr) | Sediment yield (t/ha/yr) | Soil loss Reduction (%) | Sediment yield Reduction (%) | Land management Acceptable? (Y/N) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 336 | 1 to 2.5 | Maize-100m, Beans-50m, Maize-36m, Grazing-150m | None | 1017.90 | 288.82 | 28.37 | 23.96 | 23.70 | 0.00 | 0.00 | N |
| 2 | | | | 15m forest strips at 50m intervals | 1017.90 | 228.21 | 22.42 | 19.11 | 12.11 | 20.24 | 48.91 | N |
| 3 | | | | Replace Maize with wheat | 1017.90 | 266.94 | 26.22 | 20.16 | 20.16 | 15.86 | 14.93 | N |
| 4 | | | | 30m forest strips at the top, middle, and bottom of the farm | 1017.90 | 228.25 | 22.42 | 14.00 | 5.61 | 41.57 | 76.35 | Y |
| 5 | | | | 15m grass strips at 50m intervals | 1017.90 | 228.38 | 22.44 | 18.89 | 13.36 | 21.16 | 43.65 | N |

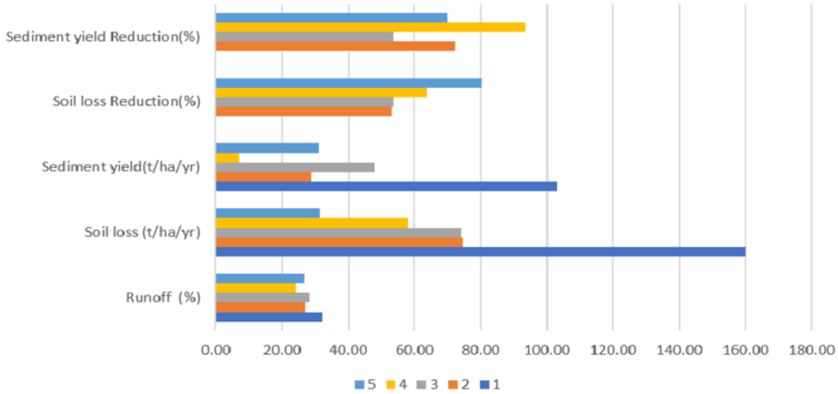


Figure 1: Farm 1 Results Analysis

## 3.2 Farm 2 Simulation

All sediment yield rates in Table 2 below are higher than 10 t/ha/yr except for the 30-meter forest strip. Wheat outperformed maize in reducing runoff, soil loss, and sediment yield from Figure 2 below. The 15-meter forest strips had less sediment yield and runoff but slightly higher soil loss compared to grass strips as per Table 2 below.

Table 2: Land management treatments and their impacts.

| S/No. | Length (m) | Slope (%) | Management | Treatment | Precipitation (mm/yr) | Runoff (mm/yr) | Runoff (%) | Soil loss (t/ha/yr) | Sediment yield (t/ha/yr) | Soil loss Reduction (%) | Sediment yield Reduction (%) | Land management Acceptable? (Y/N) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 336 | 1 to 2.5 | Maize-100m, Beans-50m, Maize-36m, Grazing-150m | None | 1017.90 | 288.82 | 28.37 | 23.96 | 23.70 | 0.00 | 0.00 | N |
| 2 | | | | 15m forest strips at 50m intervals | 1017.90 | 228.21 | 22.42 | 19.11 | 12.11 | 20.24 | 48.91 | N |
| 3 | | | | Replace Maize with wheat | 1017.90 | 266.94 | 26.22 | 20.16 | 20.16 | 15.86 | 14.93 | N |
| 4 | | | | 30m forest strips at the top, middle, and bottom of the farm | 1017.90 | 228.25 | 22.42 | 14.00 | 5.61 | 41.57 | 76.35 | Y |
| 5 | | | | 15m grass strips at 50m intervals | 1017.90 | 228.38 | 22.44 | 18.89 | 13.36 | 21.16 | 43.65 | N |

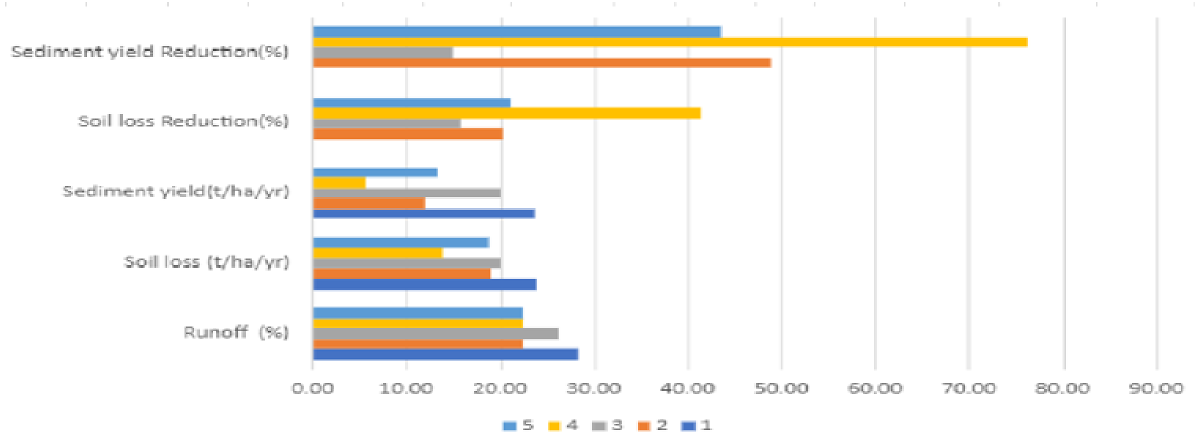


Figure 2: Farm 2 Results Analysis

## 3.3 Farm 3 Simulation

Based on Table 3 below, three land management practices met the criterion for maximum allowable sediment yield. Increasing the forest to 56m resulted in lower soil loss rates compared to the 30-meter forest strips, which recorded the lowest sediment yield rate. Replacing maize with wheat led to slightly reduced soil loss and sediment yield rates, with barley performing better than maize but not as well as wheat as depicted in Figure 3 below.

Table 3: Land management treatments and their impacts.

| S/No. | Length (m) | Slope (%) | Management | Treatment | Precipitation (mm/yr) | Runoff (mm/yr) | Runoff (%) | Soil loss (t/ha/yr) | Sediment yield (t/ha/yr) | Soil loss Reduction (%) | Sediment yield Reduction (%) | Land management Acceptable? (Y/N) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 131 | 1.5 to 6.8 | Maize-45m, Grassland-20m, Forest-36m, Beans-30m | None | 1017.90 | 297.92 | 29.27 | 24.98 | 11.88 | 0.00 | 0.00 | N |
| 2 | | | | Replace Maize with barley | 1017.90 | 290.56 | 28.55 | 10.52 | 10.28 | 57.89 | 13.46 | N |
| 3 | | | | 30m forest strips at the top, middle, and bottom of the farm | 1017.90 | 225.13 | 22.12 | 16.97 | 3.06 | 32.07 | 74.25 | Y |
| 4 | | | | Replace Maize with wheat | 1017.90 | 288.15 | 28.31 | 10.09 | 10.01 | 59.61 | 15.71 | N |
| 5 | | | | 15m forest strips at 50m intervals | 1017.90 | 258.84 | 25.43 | 20.47 | 3.06 | 18.05 | 74.25 | Y |
| 6 | | | | Replace grassland with forest | 1017.90 | 285.04 | 28.00 | 14.90 | 7.93 | 40.35 | 33.25 | Y |

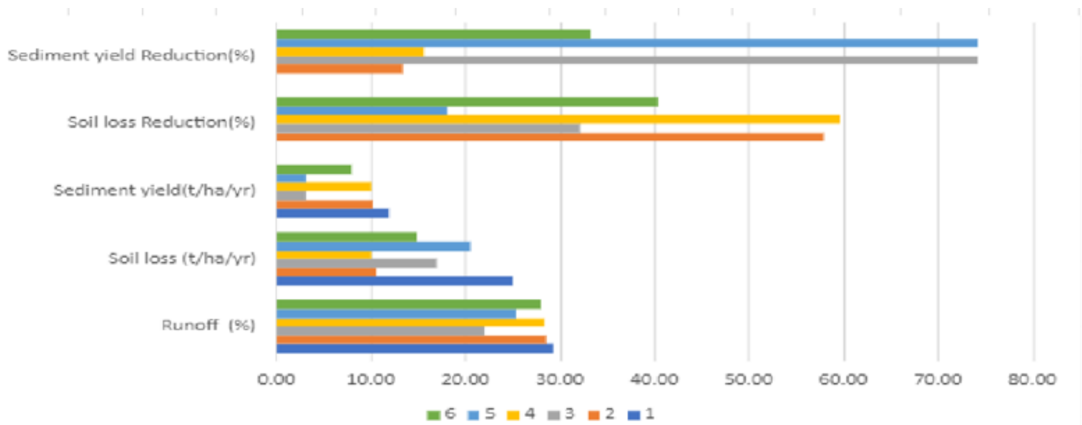


Figure 3: Farm 3 Results Analysis

### 3.4 Calibration Results

The WEPP model was calibrated using measured soil loss data collected from the study area. However, due to limitations in accurately measuring soil loss in the simulated farms, the model exhibited a poor performance in predicting soil loss as shown in Figure 4 below.

Table 4: Comparison of Simulated and Measured Soil Loss for Different Farms.

| **Farm** | **Simulated Soil Loss (t/ha/yr)** | **Measured Soil Loss (t/ha/yr)** |
|---|---|---|
| 1 | 79.65 | 19.78 |
| 1 | 159.97 | 1.099 |
| 2 | 19.22 | 17.20 |
| 2 | 23.96 | 0.956 |
| 3 | 16.32 | 3.62 |
| 3 | 24.98 | 0.403 |

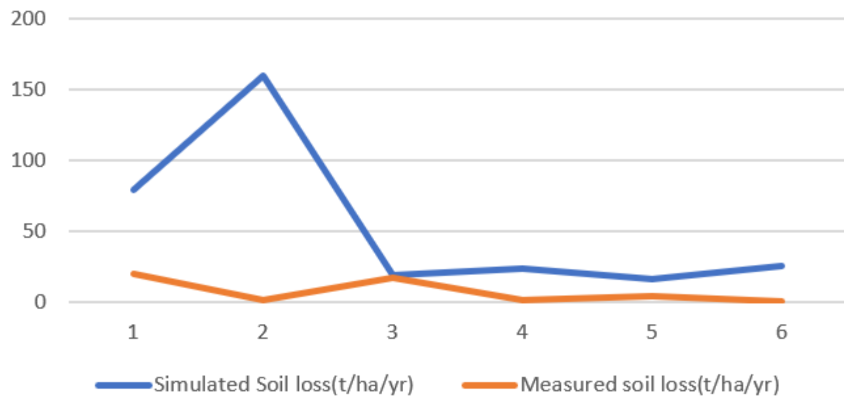


Figure 4: A graph of Simulated vs Measured Soil loss

### 3.5 Decision Support Tool

The decision support tool, Table 4, below combines simulation results from three farms. Planting 30m forest strips at the top, middle, and bottom of the farm results in acceptable soil loss and sediment yield rates. The tool shows that 15m grass and forest strips can manage soil loss and sediment yield and may be acceptable in some cases.

## 4 Discussion

### 4.1 Discussion

The results of the WEPP model simulations demonstrate the potential of the proposed land management practices to address soil erosion and water runoff challenges in the

Table 5: Land management treatments and their impacts.

| S/No. | Length (m) | Slope (%) | Current Management | Modification | Precipitation (mm/yr) | Runoff (mm/yr) | Runoff (%) | Soil loss (t/ha/yr) | Sediment yield (t/ha/yr) | Soil loss Reduction (%) | Sediment yield Reduction (%) | Sediment yield Acceptable? (Y/N) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 336 | 1 to 2.5 | Maize-100m, beans-50m, maize-36m, Grazing-150m | None | 1017.90 | 288.82 | 28.37 | 23.96 | 23.70 | 0.00 | 0.00 | N |
| 2 | | | | 15m forest strips at 50m intervals | 1017.90 | 228.21 | 22.42 | 19.11 | 12.11 | 20.24 | 48.91 | N |
| 3 | | | | Replace Maize with wheat | 1017.90 | 266.94 | 26.22 | 20.16 | 20.16 | 15.86 | 14.93 | N |
| 4 | | | | 30m forest strips at the top, middle, and bottom of the farm | 1017.90 | 228.25 | 22.42 | 14.00 | 5.61 | 41.57 | 76.35 | Y |
| 5 | | | | 15m grass strips at 50m intervals | 1017.90 | 228.38 | 22.44 | 18.89 | 13.36 | 21.16 | 43.65 | N |
| 6 | 131 | 1.5 to 6.8 | Maize-45m, Grassland-20m, Forest-36m, Beans-30m | None | 1017.90 | 297.92 | 29.27 | 24.98 | 11.88 | 0.00 | 0.00 | N |
| 7 | | | | Replace Maize with barley | 1017.90 | 290.56 | 28.55 | 10.52 | 10.28 | 57.89 | 13.46 | N |
| 8 | | | | 30m forest strips at the top, middle, and bottom of the farm | 1017.90 | 225.13 | 22.12 | 16.97 | 3.06 | 32.07 | 74.25 | Y |
| 9 | | | | Replace Maize with wheat | 1017.90 | 288.15 | 28.31 | 10.09 | 10.01 | 59.61 | 15.71 | N |
| 10 | | | | 15m forest strips at 50m intervals | 1017.90 | 258.84 | 25.43 | 20.47 | 3.06 | 18.05 | 74.25 | Y |
| 11 | | | | Replace grassland with forest | 1017.90 | 329.31 | 32.35 | 159.97 | 103.13 | 0.00 | 0.00 | N |
| 12 | 195 | 2.5 to 10 | Beans-100m, Fallow-25m, Maize-50m, Maize/beans-20m (Current) | None | 1017.90 | 274.19 | 26.94 | 74.72 | 28.84 | 53.29 | 72.03 | N |
| 13 | | | | 15m grass strips at 50m intervals | 1017.90 | 274.19 | 26.94 | 74.72 | 28.84 | 53.29 | 72.03 | N |
| 14 | | | | Replace fallow land with forest | 1017.90 | 287.04 | 28.20 | 74.18 | 47.74 | 53.63 | 53.71 | N |
| 15 | | | | 30m forest strips at the top, middle, and bottom of the farm | 1017.90 | 245.59 | 24.13 | 57.85 | 6.98 | 63.84 | 70.53 | Y |

Kakia-Esamburmbur catchment. Land management practices with soil loss values below 10 but higher sediment yield values show the ability to minimize soil detachment but the inability to trap and contain the soil quantities that are detached due to insufficient sediment-trapping mechanisms.

## 4.2 Farm 1

The current land management had the highest runoff, soil loss, and sediment yield values due to inadequate ground cover and poor soil conservation practices.
15-meter grass strips at 50-meter intervals as in Figure 1 significantly reduced soil loss because grass provides a good ground cover and resistance to soil detachment, but they have higher sediment yield because grass lacks the ability to trap and stop detached sediments.30-meter forest strips at the top, middle, and bottom of the farm result in the lowest soil loss and sediment yield rates because forests effectively intercept runoff and trap detached soil. Replacing fallow land with forest significantly reduces soil loss and sediment yield, but not to acceptable rates, because the forest strip is too small to substantially overcome soil detachment and sediment yield. Wheat performs better than maize by reducing soil loss and sediment yield because wheat's size and spacing provide better ground cover and act as filters for runoff.

### 4.3 Farm 2

All the sediment yield rates in Table 2 are higher than 10 t/ha/yr except for the 30-meter forest strip, which effectively traps and deposits detached soil.
Wheat outperformed maize slightly regarding reduced runoff, soil loss, and sediment yield due to better ground cover. The 15-meter forest strips had less sediment yield and runoff but a slightly higher soil loss rate compared to grass strips due to better interception and trapping capabilities. The 30-meter forest strips resulted in the lowest and acceptable soil loss and sediment yield rates. Both the 15-meter grass and forest strips need contour terraces to manage soil loss and sediment yield effectively, as they lack sufficient trapping mechanisms.

### 4.4 Farm 3

Three land management practices met the criterion for the maximum allowable sediment yield because the forest strip already existed in the current land management. Increasing the forest to 56m resulted in lower soil loss rates compared to the 30-meter forest strips, which recorded the lowest sediment yield rate. Replacing maize with wheat led to slightly reduced soil loss and sediment yield rates due to better ground cover. Barley performed slightly better than maize but was outperformed by wheat in reducing soil loss and sediment yield. Barley reduces soil loss as much as twice as maize, but the difference in reducing sediment is negligible. Wheat performs slightly better than barley because small-leaved and short crops provide better ground cover. Forest strips outperform all other land management practices in reducing sediment yield due to their robust structure to trap and deposit detached soil. (Table 3)
The findings of this study align with previous research, confirming the significant role of steep slopes, high rainfall intensity, and sparse vegetation cover in driving soil erosion and sediment yield [19,20,]. The study, however, provides a more detailed analysis of sediment yield, soil loss, and runoff in Kakia-Esamburmbur by developing a decision support tool for soil and water management. This tool can be used to evaluate the effectiveness of different management strategies, promote informed decision-making, and ensure the long-term sustainability of soil and water resources in the catchment.

## 5 Conclusions and future research

### 5.1 Conclusion

The participatory decision support tool developed in this study provides a valuable platform for informed decision-making in soil and water management in the Kakia-Esamburmbur catchment. The proposed land management practices are incorporating 15m forest or grass strips at 50-meter intervals, and 30m forest strips at the top, middle, and bottom of the farms. These practices significantly reduce soil loss, sediment yield, and runoff, with the 30m forest strips being the most effective, making them viable options for sustainable soil and water management in the Kakia-Esamburmbur catchment. The tool integrates scientific modeling with local knowledge and stakeholder engagement, ensuring the relevance and applicability of the proposed land management practices.
The study contributes to several United Nations Sustainable Development Goals (SDGs), including SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), and SDG 15 (Life

on Land), and aligns with the Science, Technology, and Innovation Strategy for Africa (STISA-2024) by addressing environmental challenges and promoting sustainable development through innovative solutions. The lack of sufficient observation data limited the accuracy of the WEPP model simulations. The study did not consider socio-economic factors that could influence the adoption of the proposed land management practices. Future studies should focus on collecting more comprehensive data and incorporating socio-economic factors to enhance the model's accuracy and relevance.

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