Tropentag, September 10-12, 2025, hybrid conference

"Reconcile land system changes
with planetary health"

interplay between technological transformation, rural welfare, collective action and water conflicts - a system approach.

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Abstract

Fostering the adoption of sustainable water management practices by smallholder farmers is becoming a pressing challenge in Kenya, where increasingly erratic rainfall patterns are leading to prolonged dry spells and intense flash floods. Over-abstraction is common in several catchments, causing river degradation and highland-lowland water conflicts between users. As water represents the major constraint to agricultural productivity and rural development, rainwater harvesting (RWH) and farm ponds are being promoted as a central climate adaptation strategy. However, many farmers struggle with increasing energy costs driven by inflation and global crises. In this context, the demand for Photovoltaic technologies for both irrigation practices and domestic use is rising. A few champion farmers have begun implementing integrated systems of RWH and solar-powered irrigation, effectively operationalizing the Water-Energy-Food (WEF) Nexus at the household level. Yet, uptake remains slow due to high initial costs, technical barriers, low willingness to invest, and limited access to knowledge and finance. This study conceptualises the adoption of integrated RWH and solar irrigation technologies as a complex adaptive system, constituting of dynamic feedbacks between ecological processes, governance structures, socio-economic context, and technological components. Using a participatory System Dynamics (SD) modelling approach and Causal Loop Diagrams (CLDs) developed through in-depth interviews and focus group discussions, the study identifies key leverage points, systemic constraints, and mutual influences between innovation uptake and broader socio-ecological dynamics in the Timau sub-catchment, located between Mount Kenya and southern Laikipia. By proposing a Socio-Techno-Ecological System (STES) approach to better capture the dynamic interactions among social, ecological, governance, and technological subsystems, this study bridges the gap between socio-technical and socio-ecological research in sustainability transitions. Findings reveal that ineffective monitoring and enforcement of water abstraction, high upstream water availability, and flat-rate water fees disincentivize upstream farmers from investing in RWH, while encouraging inefficient flood irrigation practices. Resulting downstream water scarcity contributes to retaliatory acts such as equipment theft and vandalism. Strengthening grassroots water governance and farmer cooperatives is key to promoting technology adoption, enhancing access to credit, and fostering a sustainability-oriented mindset. However, inadequate extension services remain a major barrier due to widespread knowledge gaps.

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Keywords: Causal Loop diagrams, participatory modelling, rainwater harvesting, social-ecological systems, socio-technical systems, solar powered irrigation systems, systems dynamics modelling, technological transition, water governance