Research Project Completion Report

1. Project details

Title of project: Assessing Catchment Sediment Yield and Siltation Impacts on Reservoir Capacity under Land Cover/Use Changes: · the Case Study of the Fincha Dam, Ethiopia (https://sites.google.com/view/lulc-fincha/home)
Project financed by: National Science Centre, Poland
Grant Number: 2019/35/O/ST10/00167
Period: October 1, 2020- November 30, 2024
Case study of the research: HGW, Oromiyaa, Ethiopia

2. Researcher Details

Name of Researchers: Dr. hab. Inz. Michael Nones (Supervisor) & Motuma Shiferaw Regasa (phD student)
Institution/Organization: Institute of Geophysics, Polish Academy of Sciences in Warsaw, Poland
Department/Program: Hydrology and Hydrodynamics
Host Institution for PhD student: Wallagga University, Ethiopia
Supervisor at Host Institution: Dr. Dereje Adeba (Associate professor)
Research Period: February 1, 2022 to August 1, 2022 (six months)

3. Abstract of the Project

Like many developing nations, Ethiopia faces a significant issue with soil erosion, primarily driven by human-induced Land Use and Land Cover (LULC) changes. The Fincha watershed, in particular, is severely impacted by erosion, posing challenges to local infrastructure, such as dam reservoirs. To address this issue, identifying potential mitigation strategies is crucial to ensure the sustainability of the environment and its resources.

This project has the following objectives: i) to review spatiotemporal LULC changes in Ethiopian basins over recent decades; ii) to analyze historical LULC changes and predict future conditions; iii) to assess the impact of LULC changes on soil erosion; and iv) to evaluate how different management practices can reduce sediment yield. The study utilized ArcGIS and Land Change Modeller (LCM) for analyzing historical and future LULC changes, while the Soil & Water Assessment Tool (SWAT) model was used to investigate the effects of LULC changes on soil erosion and evaluate the effectiveness of various best management practices (BMPs) for reducing sediment yield. The findings reveal that, over the past 30 years, the Fincha watershed has seen a decrease in forest and shrub cover by approximately 40% and 13%, respectively, largely due to expanding agricultural activities. The loss of natural forests is a major factor contributing to increased soil erosion, which exacerbates sedimentation in nearby water bodies. The study shows that without proper management strategies, erosion risks will escalate in the future. Four BMPs were tested: filter strips, soil or stone bunds, contour bunds, and terraces for crop fields. The application of these BMPs can reduce sediment yield by 58-85%, depending on the method and time frame. While these practices help reduce sediment yield, they are not fully effective in controlling soil erosion within acceptable limits. Thus, combining these BMPs with other management strategies is necessary.

The results of this study provide important insights for managing watersheds in arid and semi-arid regions, aiming for sustainable land and resource management.

4. Background

In Ethiopia, the lack of land use planning and growing demand for development has led to the conversion of forests, shrubs, and grasslands into agricultural land. Over 97% of the country's forest cover has been lost, and the Fincha watershed is a prime example of significant land use changes. When hydroelectric reservoirs were built, large swamp areas, grazing, and agricultural lands were submerged, displacing many people. As a result, displaced farmers began clearing forests, shrubs, and grasslands for agriculture in steeper areas, contributing to increased soil erosion. This erosion leads to siltation in reservoirs, harming both water quality and agricultural productivity. Soil erosion is a major global environmental issue, impacting agriculture, the environment, and food security. In countries like the U.S., soil loss rates are around 16 t/ha/y, while in less developed regions, such as Africa and Asia, rates can range from 20-40 t/ha/y. In Ethiopia, soil loss averages between 25-30 t/ha/y, depending on factors like slope and rainfall. Water erosion in the Ethiopian highlands results in the loss of about 1.5 billion tons of fertile soil annually, threatening the agricultural livelihoods of the rural population, especially in the Blue Nile Basin. The Blue Nile supplies around 85.6% of the Nile's water during the rainy season, and soil loss continues to deplete nutrients faster than they can be replenished.

Watershed management is key to reducing soil, water, and nutrient losses, ensuring sustainable agriculture. Best Management Practices (BMPs) should be adopted in erosion-prone areas to reduce soil loss. Remote sensing, GIS, and erosion models can help identify vulnerable regions and guide management efforts. The Soil and Water Assessment Tool (SWAT) has proven effective in predicting agricultural watershed dynamics but faces challenges due to limited data in regions with monsoonal climates.

5. Research Methodology

This study examines the impacts of past and future Land Use and Land Cover (LULC) changes on hydrological processes and soil erosion within the Fincha watershed. It integrates remote sensing, geographic information systems (GIS), and hydrological modeling to analyze the dynamics of LULC changes, their effects on water resources, and sediment transport.

Data for this study were collected from multiple sources, including satellite imagery (Landsat), climate data from local weather stations, soil data from national databases, and field observations. Field evidence, such as photographs and site observations, played a key role in validating satellite-derived data and improving the accuracy of LULC classifications. Satellite imagery from Landsat 5 (1989, 2004) and Landsat 8 (2019) was used to assess historical LULC changes. The classification was done using both supervised and unsupervised methods, with supervised classification applied to the 2019 Landsat 8 imagery, supported by field data, and unsupervised classification used for the older Landsat 5 imagery due to resolution and reference data limitations. Classification accuracy was assessed using ground-truthing techniques.

To model future LULC changes, the Land Change Modeler (LCM) was used. This tool integrates remote sensing data with GIS to predict LULC transformations based on transition potential maps, which are created using factors like elevation, slope, proximity to roads, streams, and urban areas. The LCM model employs the Cellular Automata - Markov Chain (CA-MC) method to simulate both spatial and temporal LULC changes. Transition probabilities for different land classes were calculated through Markov Chain analysis, and future land cover was projected using these transition matrices.

Soil and Water Assessment Tool (SWAT) was applied to simulate the impacts of LULC changes on hydrology, sediment yield, and erosion within the watershed. SWAT is a semi-distributed, physically-based hydrological model that simulates surface runoff, groundwater flow, sediment transport, and nutrient cycling. The model was selected for its suitability in simulating long-term hydrological processes, especially in data-scarce regions. The model was calibrated and validated using limited observed data from the watershed. Inputs included topographic data (elevation, slope), LULC maps, soil properties, and climate data. The model accounted for spatial heterogeneity to ensure accurate predictions of erosion and sediment yield.

Assessment Soil erosion was evaluated using the SWAT model's erosion module, which estimates soil loss based on rainfall intensity, soil properties, and land cover. The study calculated the mean annual soil erosion rates across different sub-watersheds and classified erosion risk into categories to identify high-risk areas. The potential impacts of Best Management Practices (BMPs), such as terracing, contour farming, and soil bunds, on reducing sediment yield and soil erosion were also assessed through SWAT simulations. These simulations provided insights into the effectiveness of BMPs in mitigating soil loss across the watershed.

GIS and remote sensing technologies were extensively used to map the spatial distribution of LULC, hydrological changes, and erosion-prone areas. GIS tools helped process, analyze, and visualize spatial data, such as delineating sub-watersheds and identifying areas vulnerable to erosion. Remote sensing enabled the identification of LULC changes over time, providing a detailed view of the watershed's evolving environment.

The SWAT model was calibrated using observed streamflow and sediment data from monitoring stations within the watershed. Calibration involved adjusting model parameters to match observed data, with performance evaluated using statistical measures such as the Nash-Sutcliffe Efficiency (NSE) and coefficient of determination (R^2). Validation was performed by comparing simulated data with independent observed datasets from different time periods to assess the model's robustness.

The study also conducted scenario analysis to evaluate the potential impacts of different future LULC change scenarios on hydrology and sediment yield. These scenarios included projections of land use transformations based on past trends, assumptions about future population growth, agricultural expansion, and urbanization.

The findings from this study contribute to watershed management strategies aimed at reducing soil erosion and improving water resource management in the Fincha watershed. The results identified critical areas where soil conservation measures, such as BMPs, could be most effective in mitigating erosion and enhancing water retention. The study's recommendations offer valuable guidance to decision-makers on prioritizing actions to protect the watershed's environmental sustainability and promote socio-economic development.

It is important to note that the study intentionally excluded future climate projections from the modeling process to focus solely on the effects of LULC changes. While climate change can influence hydrological processes and sediment transport, this study isolates the effects of land use changes. Additionally, the SWAT model, despite being a powerful hydrological tool, has limitations, including the need for extensive data for calibration, model complexity, and challenges in accurately representing small-scale processes, especially in data-scarce regions.

In conclusion, this methodology combines remote sensing, GIS, hydrological modeling, and soil erosion analysis to assess the effects of LULC changes in the Fincha watershed. The approach provides a comprehensive understanding of these changes and their impact on water resources and soil conservation, offering valuable insights for future watershed management strategies.

6. Key Results

This research investigates the impact of past and future human-driven Land Use and Land Cover (LULC) changes on hydrological processes and sediment yield in the Fincha watershed, aiming to propose management strategies that can help reduce soil loss at both watershed and sub-watershed levels. The key points of this research are summarized as follows:

- Over the past thirty years, much of the forest cover in the Fincha watershed has been converted into agricultural land and grass/swamp areas. There has also been a noticeable increase in the extent of water bodies and built-up areas, primarily driven by growing human pressure and the construction of new hydropower reservoirs. This trend is evident not only in the study sub-basin but also across many other Ethiopian basins, indicating that LULC changes are a significant issue for the country as a whole. As the modeling results suggest, this trend is likely to continue in the future. Indeed, if management strategies are not adjusted toward more sustainable practices, including through necessary national reforms, we can expect an even greater decline in forest cover in favor of new settlement areas and cropland. While this shift may help local communities sustain their livelihoods in the short term, in the medium to long term, the reduction of forested areas will lead to a decline in biodiversity and ecosystem services, while promoting soil erosion and causing issues such as reservoir siltation.
- Due to increased human-driven LULC changes such as the expansion of agricultural fields and settlements at the expense of natural landscapes like forests. Surface runoff has increased at the watershed level, while groundwater and lateral flow have decreased. When examining each sub-watershed, regions experiencing a sharp decline in surface runoff corresponds to areas where groundwater flow has increased, highlighting the inverse relationship between groundwater and surface runoff. The increase in surface runoff, leads to the decline in groundwater and lateral flow, is likely driven by the ongoing expansion of agricultural land, urbanization, and periodic deforestation. The reduction in groundwater and lateral flow, along with the increase in surface runoff, could pose significant challenges for agriculture, as more water will be required for irrigation during the dry season.
- The ongoing LULC changes, which favour agricultural land and settlements over natural forests, have contributed to a rise in soil erosion. Soil loss in the watershed increased from 32.51 t/ha/year in 1989 to 41.20 t/ha/year in 2019, and is projected to reach 53.98 t/ha/year by 2050. Based on the estimated rates of mean annual soil loss, the erosion risk was classified into six categories, showing that over 91% of the watershed is expected to be at high to severe erosion risk, with the most severe erosion occurring in the central, north eastern, and north western sub-watersheds. Given that soil erosion represents a major threat to the region's socio-economic development, this classification provides a basis for prioritizing future management strategies aimed at mitigating soil loss and minimizing its impact on the local environment and population.
- The modeling of sediment yield, using various Best Management Practices (BMPs), demonstrated effectiveness ranging from 58.77% to 84.92%. These results are consistent with those of previous research. The implementation of different BMPs showed promising reductions in sediment yield, with terracing, contour farming, and soil or stone

bunds yielding the greatest reductions, while filter strips were the least effective. However, our findings suggest that while BMPs can significantly reduce erosion, sediment yield remains above the tolerable soil loss threshold. Therefore, to achieve a tolerable level of soil loss, the application of BMPs must be supplemented by additional soil and land management practices, including biological measures. Beyond reducing erosion at the watershed scale and enhancing agricultural productivity, BMPs can also help mitigate local issues, such as excessive sedimentation in dam reservoirs like the Fincha Dam. In summary, these findings provide valuable guidance for planners, decision-makers, and other stakeholders to develop and implement appropriate soil conservation techniques, particularly in areas with high erosion risks or significant socio-economic importance.

7. Published Outcomes

Article:

I. Regasa, M.S., Nones, M. and Adeba, D., 2021. A review on land use and land cover change in Ethiopian basins. Land, 10(6), 585. https://doi.org/10.3390/land10060585.

II. Regasa, M.S. and Nones, M., 2022. Past and Future Land Use/Land Cover Changes in the Ethiopian Fincha Sub-Basin. Land, 11(8), 1239. https://doi.org/10.3390/land11081239

III. Regasa, M.S. and Nones, M., 2023a. SWAT model-based quantification of the impact of Land Use Land Cover change on sediment yield in the Fincha watershed, Ethiopia. Frontiers in Environmental Sciences, 11, 1146346. https://doi.org/10.3389/fenvs.2023.1146346

IV. Regasa, M.S. and Nones, M., 2024a. Modeling the impact of historical and future land use land cover changes on the hydrological response of an Ethiopian watershed. Sustainable Water Resources Management, 10(1), 24. https://doi.org/10.1007/s40899-023-01011-0.

V. Regasa M.S. & Nones M., 2024b. Modeling best management practices to reduce future sediment yield in the Fincha watershed, Ethiopia, International Journal of Sediment Research, 39(5), 737-749. https://doi.org/10.1016/j.ijsrc.2024.04.010.

VI. Regasa, M. S., & Nones, M. (2024c). Evaluating Management Practices to Reduce Sediment Yield in the Fincha Watershed, Ethiopia. Advances in Hydraulic Research: 40th International School of Hydraulics (pp. 305-315). Springer International Publishing. http://doi.org/10.1007/978-3-031-56093-4_24.

VII. Regasa, M. S., & Nones, M. (2024d). Managing land to reduce sediment yield in the Fincha watershed, Ethiopia. In Recent Advances in Environmental Science from the Euro-Mediterranean and Surrounding Regions (2nd Edition) Proceedings of 5th Euro-Mediterranean Conference for Environmental Integration (EMCEI-5), Italy 2019 (pp. x-x). Springer International Publishing. (Accepted)

Extended Abstracts and Full Papers:

I. Regasa MS, Nones M. Reservoir Sedimentation and Sustainable Management on Fincha Dam, Ethiopia, under Land Use Land Cover Changes. Conference in 1st IAHR Online Forum. July 7, 2020.

II. Regasa MS, Nones M. Effects of land cover/use changes on the Ethiopian Fincha Dam Capacity. development. 2020 Nov;17(November):18. Conference in 1st IAHR Young Professional Congress. http://dx.doi.org/10.13140/RG.2.2.20845.6192

III. Regasa, M. S., & Nones, M Potential impacts of historical and future land use land cover changes on hydrological responses of Fincha Watershed watershed. Proceeding in International Sopot Youth Conference 2022 entitled Where the World is Heading, 10 June 2022.

IV. Regasa M, Dereje Adeba, Jiregna Nugusa, and Michael Nones. "Land dynamics and sustainable management of the Fincha River Basin, Ethiopia." (2022): 12-14. https://sites.google.com/view/lulc-fincha/news#h.w04076qq75pm

V. Regasa M, Nones M. Land Use Land Cover Changes in the Fincha Basin, Ethiopia. In Proceedings of the 39th IAHR World Congress 2022 Jun (Vol. 19, p. 24). http://dx.doi.org/10.3850/IAHR-39WC252171192022689

VI. Regasa MS, Nones M. Trends of Historical Land Use Land Cover Changes and Future Predictions for Ethiopia's Fincha Watershed. 4th Euro-Mediterranean Conference for Environmental Integration 01-04 November 2022

VII. Regasa M.S, Nones M. Managing land to reduce sediment yield in the Fincha watershed, Ethiopia. 5th Euro-Mediterranean Conference for Environmental Integration 02-05 October 2023

VIII. Regasa M.S, Nones M. Evaluating Management Practices to reduce sediment yield in the Fincha Watershed, Ethiopia. International School of Hydraulics on 23-26 May 2023.

IX. Regasa M.S, Nones M. Impact of land use on soil erosion: Fincha watershed case. In Proceedings of the 40th IAHR World Congress 2023, http://dx.doi.org/10.3850/IAHR-39WC252171192022689 9.

Because of the connection made during Internship process, time and the relation of PhD student has with Wollega University and staffs, the following articles beyond the projects are co-authored with Wollega University staffs.

I. Kenea U, Adeba D, Regasa M.S, Nones M. Hydrological responses to land use land cover changes in the fincha'a watershed, Ethiopia. Land. 2021 Aug 31;10(9):916. https://doi.org/10.3390/land10090916.

II. Merga DD, Adeba D, Regasa MS, Leta MK. Evaluation of surface water resource availability under the impact of climate change in the Dhidhessa Sub-Basin, Ethiopia. Atmosphere. 2022 Aug 15;13(8):1296. https://doi.org/10.3390/atmos13081296.

III. Kabeto J, Adeba D, Regasa M.S, Leta MK. Groundwater Potential Assessment Using GIS and Remote Sensing Techniques: Case Study of West Arsi Zone, Ethiopia. Water. 2022 Jun 7;14(12):1838. https://doi.org/10.3390/w14121838.

8. Significance of Findings

This study on soil conservation in Ethiopia's Fincha watershed has profound local and global significance. Locally, it can improve agricultural productivity, water management, and socio-economic conditions by offering data-driven insights for land and water conservation practices. Globally, it contributes to the larger conversation on combating soil erosion, preserving natural resources, and fostering sustainable land management practices to ensure food security, environmental health, and economic stability worldwide.

Confirmation for projects for the significancy of the projects

1. Name of PhD Students: Motuma Regasa Signature: ______
2. Name of the Supervisor: ______ Signature: Michael Nones Digitally signed by Michael Nones Date: 2025.03.03 13:33:04 +01'00'
3. Name of Advisor at host Institute: Dr. Dereje A. Signature: ______

Confirmation of higher official from Wollega University for the project's benefit

Kamal Mohammad
______ ______

Research, P/G&
A/Dean

Wollega University
College of Engineering and Technology