Improved Water and Land Management in the Ethiopian Highlands: Its Impact on Downstream Stakeholders Dependent on the Blue Nile

Intermediate Results Dissemination Workshop
February 5-6, 2009, Addis Ababa, Ethiopia

Summary Report, Abstracts of Papers with Proceedings on CD-ROM

Organized by

IWMI Subregional Office for East Africa and Nile Basin

Compiled by

Seleshi B. Awulachew, Teklu Erkossa, Vladimir Smakhtin and Ashra Fernando

IWMI International Water Management Institute · ILRI International Livestock Research Institute

Photo of participants of the workshop

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Awulachew, S. B.; Erkossa, T.; Smakhtin, V.; Fernando, A. (Comp.). 2009. *Improved water and land management in the Ethiopian highlands: Its impact on downstream stakeholders dependent on the Blue Nile. Intermediate Results Dissemination Workshop held at the International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia, 5-6 February 2009*. Summary report, abstracts of papers with proceedings on CD-ROM. Colombo, Sri Lanka: International Water Management Institute. doi:10.3910/2009.201

/ river basin management / water governance / simulation models / reservoirs / sedimentation / hydrology / water balance / erosion / soil conservation / watersheds / irrigation schemes /Blue Nile / Ethiopia / Sudan /

ISBN 978-92-9090-716-9

All photographs: IWMI

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ACKNOWLEDGEMENTS

This proceedings booklet and the attached CD contain the results of the workshop conducted during February 5- 6, 2009 and present findings from PN19 'Improved Water and Land Management in the Ethiopian Highlands and its Impact on Downstream Stakeholders Dependent on the Blue Nile (Upstream/ Downstream in Blue Nile)". The CGIAR Challenge Program on Water and Food (CPWF) supported the project, the workshop and the outputs reported here. The International Water Management Institute (IWMI) together with International Livestock Research Institute (ILRI), Cornell University (CU), USA, the Omdurman Islamic University, UNESCO Chair in Water Resources (OIU, UNESCO-CWR), Sudan, Bahir Dar University (BDU), Addis Ababa University (AAU), Amhara Regional Agricultural Research Institute (ARARI), Forum for Social Studies (FSS), Ethiopia, have implemented the project and were involved in the papers presented here. The authors of the papers and beneficiaries of the project would like to thank the support rendered to implement the project and conduct the workshop.

Project

The reports and papers included in this booklet and on the CD are part of the projects related to the Nile Basin supported by the CGIAR Challenge Program on Water and Food (CPWF).

Partners

About the CPWF

Water scarcity is one of the most pressing issues facing humanity today. The Challenge Program on Water and Food (CPWF), an initiative of the Consultative Group on International Agricultural Research (CGIAR), contributes to efforts of the inter-national community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multiinstitutional research initiative that aims to increase water productivity for agriculture-that is, to change the way water is managed and used to meet international food security and poverty eradication goals-and to leave more water for other users and the environment.

The CPWF deals with complex agriculture-related systems, for which there are a growing number of stakeholders generating information. Its community-of-practice works in innovative ways to collate, unify, organize, extract, distill and share the ideas, information and knowledge to allow next-users to gain insights and deduce principles, concepts and cause-and-effect relationships from its research results. To help achieve this, the CPWF focuses on building multi-disciplinary north-south and south-south partnerships, as demonstrated by the work produced in this special journal of Water Policy.

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Improved Water and Land Management in the Ethiopian Highlands: Its Impact on Downstream Stakeholders Dependent on the Blue Nile

SUMMARY

The Project

The need for improved water access and to alleviate poverty and food insecurity through the development and management of water resources, especially in semi-arid Africa where over 80% of rural livelihoods depend on land and water resources, cannot be overemphasized. Recent strides in sustainable resource management have recognized the need for a broad-based, integrated approach that coordinates the activities of people dependent on a common resource base to achieve resource use efficiency, equity and sustainability. In the Nile Basin, water from the Ethiopian Highlands, particularly from the part of the Blue Nile Basin (BNB) known as Abbay (where 62% of Nile flow at Aswan High Dam is obtained), has in the past benefited downstream people in Sudan and Egypt in different ways – agriculture, livestock, industry and electrical power. However, such free benefits are now shifting due to dramatically changing land, water and livestock management practices upstream. High population pressure, lack of alternative livelihood opportunities and the slow pace of rural development are inducing deforestation, overgrazing, land degradation and declining agricultural productivity. Poor water and land management upstream reduces both potential runoff yields and the quality of water reaching downstream. The result is a vicious cycle of poverty and food insecurity for over 14 million poverty-stricken people within the catchment, and for millions of downstream users, including those across international borders. It is widely recognized that improved water management in the Blue Nile Basin will significantly increase water availability for various stakeholders within the catchment. This will also help alleviate the impacts of natural catastrophes such as droughts and reduce conflicts among stakeholders dependent on the Nile.

With its high population density, about two-thirds of the BNB (Ethiopian part of the Blue Nile) fall in the highlands and hence receive high levels of rainfall of 800 to 2,200 millimeters (mm) per annum. The rainfall is erratic in terms of both spatial and temporal distribution, with dry spells that significantly reduce crop yields and sometimes lead to total crop failures. The population located in the downstream part of the Blue Nile is entirely dependent on the river water for irrigation. Because of poor land management in the highlands, canal and reservoir siltation is a major problem and results in major cutoff areas, exacerbating socioeconomic burdens on the poor riparian farmers.

It is widely believed that improving land and water management and conserving water at all levels by all water users, both within Ethiopia and downstream communities dependent on the Nile, would optimize the benefits while suppressing the unwanted consequences. Though well-known in principle, the technologies required for overcoming the poor and extreme distribution of water resources are not applied

because of poor adaptation to the local conditions, unavailability of capital, institutional constraints and inadequate scientific knowledge from a systems perspective. The "*Improved water and land management in the Ethiopian highlands and its impact on downstream stakeholders dependent on the Blue Nile*" (in short *"Upstream Downstream (USDS)"*) project, supported by the Consultative Group on International Agricultural Research (CGIAR) Challenge Program on Water and Food (CPWF), was among the studies conducted in the basin to bridge the knowledge gap.

Proposed by diverse stakeholders, this study *hypothesizes* that, with increased scientific knowledge of the hydrological, hydraulic, watershed, and institutional processes of the Blue Nile in Ethiopia (Abbay), constraints to upscaling management practices and promising technologies within the catchment can be overcome, resulting in significant positive benefits ('win-win' scenarios) for both upstream and downstream communities, reducing 'win-lose' scenarios.

The major research questions are as follows:

- What are the successful interventions that help improve productivity and reverse degradation?
- What are the impacts downstream?
- What are the opportunities and constraints enhancing rural livelihoods and food security?

The specific objectives of the project are to:

- Identify major water, land and livestock management constraints and opportunities in the Abbay catchment as well as impacts of current and future water, land and livestock management interventions within the catchment and downstream;
- Adapt and apply existing hydrological, watershed, and economic models that can be used to estimate such impacts both basin-wide and locally in selected communities, including their costs and benefits, and identify 'best-bet' interventions;
- Create a better overview of 'best-bet' management practices and interventions, and the hydrological and socioeconomic conditions for upscaling them; and
- Build capacity of research partners, NGOs, community leaders and policymakers, through collaboration with local institutions and universities to facilitate student research, stakeholder consultation, facilitation and engagement of stakeholders in dialogues on resource management issues and innovative approaches as well as generating knowledge for planners and policymakers.

The Workshop

The project had been implemented one and half years prior to start of the workshop. Various institutions including the International Livestock Research Institute (ILRI), Cornell University, Omdurman Islamic University-UNESCO Chair in Water Resources, Addis Ababa University, Bahir Dar University, Amhara Regional Agricultural Research Institute (ARARI) and Forum for Social Studies have implemented the project in partnership.

The two-day workshop was organized at the International Water Management Institute (IWMI) office in Addis Ababa, Ethiopia, during the period of February 5-6, 2009, to discuss the intermediary results of the projects. The workshop attracted about 85 participants representing over 36 institutions including universities, international research institutes, national and regional research institutes, international non-governmental organizations, government line ministries, civil society organizations, and PhD and MSc students.

The main objectives of the workshop were to:

- Bring together the key stakeholders relevant to the project;
- Present, debate and validate the intermediate results of the project;
- Disseminate key results to wider audiences through the stakeholders participating in the workshop; and
- Follow up on the progress of the project and plan the way forward for the remaining tasks of the project.

About 27 technical papers and 10 posters were presented during the workshop. The presentations and discussions were organized under four major themes, including:

- General characterization of the Blue Nile Basin;
- Water demand, and allocation modeling and simulation;
- Watershed modeling and analysis; and
- Policy and institutions of water management in the Blue Nile Basin.

A methodical discussion, and at times a heated debate, was held at the end of each session, which is believed to have improved the quality of the papers. A brief account of the issues discussed in each session is highlighted below:

General characterization of the Blue Nile Basin

In the opening session where the general papers were presented, the objectives of the CPWF and USDS project were outlined and the major goal of the USDS project, which was to identify major water, land and livestock management opportunities, constraints and impact of interventions in the catchments, was elaborated. The characteristics and GIS database of the Blue Nile, focusing on the Ethiopian and Sudan parts as developed by the project, was also introduced, and copies of the Blue Nile Atlas was distributed to participants. The database includes information on the geographic, Digital Elevation Model (DEM), climate, geology, land cover, population density, etc., of the Blue Nile. In-depth information on selected sub-basins has been included in the database.

Impacts of improving water management of smallholder agriculture in the Upper Blue Nile Basin, with particular reference to the green-blue water management on the livelihoods of upstream communities and water quality and quantity downstream, was also looked at during this session. Nine farming systems were identified in the Abbay Basin, in which cereal-based farming systems were reported as being dominant - covering about 70% of the area. The productivity of the farming systems was reported to be very

low as compared to the national and international average for most crops, and this was related to constraints such as poor land and water management, climatic variation, waterlogging and other factors. Multifaceted interventions were recommended, and technologies such as integrated watershed management, improved agricultural water management, and water access, etc., were suggested. Possible influences of some of the suggested interventions on upstream/downstream users of water resources were also highlighted.

Water demand, and allocation modeling and simulation

In this session, it was revealed that various researchers attempted to use several models such as the Water Evaluation And Planning (WEAP), WaSiM-ETH[1], Hydraulic Engineering Center- Reservoir Simulation (HEC-ResSIM), and MIKE BASIN models to assess the hydrology and water resources at various scales in the basin. The WEAP model was used to assess the impact of environmental flows on the water level of Lake Tana and the reliability of water resource projects planned in the BNB. Climate change assessment and economic analysis were recommended as future enhancements to the current study.

WaSiM-ETH was used for rainfall-runoff modeling while HEC5 was used for optimization of water allocation in the basin. The primary focuses of the study were regionalization of rainfall-runoff relationships of unguaged catchments, and derivation of operation policy for multi-reservoir systems using multi-objective optimization methods. Kohonen Neural Network was applied to identify homogenous hydrological regions whereas the WaSiM-ETH model was used for rainfall-runoff modeling. The optimization (modified single-objective) and simulation (HEC5) modules were coupled to optimize water allocation in multi-reservoir systems. It was pointed out that the water balance had performed better in the wet season than in the dry season, which may be attributed to leakage from the dam.

The study has also considered detailed reservoir operation using the HEC-ResSIM model in the process of performing water allocation simulation in the Upper Blue Nile (Abbay) Basin. Water allocation for the production systems has been simulated for both

existing and planned projects in the Abbay River Basin, adopting three development scenarios, including the reference scenario. A mere 3% reduction in the annual flow volume at the border of Sudan was estimated because of implementing projects in the Abbay Basin. In addition, a Water Simulation Modeling framework was developed for the Sudan part of the Blue Nile, and implications on water availability have been deduced.

Integrated Simulation of Blue Nile Water using the WEAP model under Current and Future Scenarios has preliminarily evaluated two basic scenarios (current and the year 2015), considering both existing and planned schemes. It was reported that the results of the simulation at major gauging stations and reservoirs have fairly reproduced

[1] WaSiM-ETH is a water balance simulation model

observations. As environmental flow was not considered in the simulation, it was recommended that future studies should take into account environmental flows and the impact of climate change on supply and demand.

Watershed modeling and analysis

The problems of soil erosion and sediment transport in the basin were addressed in the watershed simulation modeling part of the project. The causes, degree, extent and impacts of land degradation on hydrologic structures, productivity, and livelihoods, both upstream and downstream, were highlighted. The overall study of the erosion-sediment transport and sediment deposition processes are envisaged to be undertaken as a nested approach covering micro-watershed, watershed, sub-basin and basin levels. Emphasis was given to the effects of sediment deposition on the downstream sites and the problems of data quality and availability. It was highlighted that the famous curve number developed for USA does not reflect the situation during monsoonal rainfall as it underestimates runoff. It was suggested that this shortcoming can be overcome if longer periods are considered. Integrating a water balance approach into the Soil and Water Assessment Tool (SWAT) instead of a curve number provides reasonable estimates of runoff and sediment. In the various studies, the SWAT was used alone, in combination with SOBEK[2], or as a modified SWAT at watershed and basin levels to quantify sediment loss, identify vulnerable areas, and study the impact of management alternatives such as filter strip on sediment loss. The studies suggested that the SWAT satisfactorily simulates both stream flow and sediment yield for the Blue Nile Basin, but results can improve significantly if the modified SWAT is used. Attempts were made to identify 'hot spot' regions for erosion and deposition in the basin.

It was revealed that subsurface flow is an important component in the hydrological flows in the landscape, and including this in the model improves the predictions made by simulation models for both river flows and locations of discharges. The study on soil erosion and gully formation in a catchment in the basin depicted that predictions based on the Universal Soil Loss Equation (USLE) correlates well with observed data for the upland erosion (rill and inter rill). However, there is a strong correlation between the water table above the gully bottom and the amount of erosion due to gully erosion.

Policy and institutions of water management in the Blue Nile Basin

The session on policy and institutions gave importance to the assessment of local land and water institutions, benefit-sharing framework in transboundary rivers, the transboundary water governance institutional architecture, the prospect of payments for environmental services (PES), and determinants of adoption of improved land and water management practices. In carrying out an analysis of institutional arrangement issues, a framework encompassing several criteria was developed for use in the basin. Although a stronger emphasis on the sharing of benefits rather than just sharing of water is believed to be efficient, and the fact that over the years many agreements have

[2] SOBEK is a one-dimensional open-channel dynamic numerical modeling system, equipped with the user shell and is capable of solving the equations that describe unsteady water flow, sediment transport, morphology and water quality.

been made for the Nile Basin, the study revealed that effective transboundary relations and benefit-sharing mechanisms have not been achieved. It was recommended that a 'basket of benefits', both water and non-water related, need to be identified and see how these can be achieved by all. As the perception of benefits alters over time, it was suggested that the benefit-sharing agreements and terms be revised at certain time intervals.

PES will work on the premise that, by improving water and land management in the upstream part of the basin can provide ecosystem services to the downstream part. The role of PES would then be, to internalize benefits and channel these to the upstream as an incentive to pursue improved management practices. In order to arrange PES, it is necessary to see what the Willingness to Pay (WTP) and Willingness to Compensate (WTC) are amongst people who would eventually be part of a PES scheme. The results of a household survey conducted in a watershed in the basin indicated that while there was willingness to pay and willingness to compensate, the amounts suggested were not enough to make the scheme feasible. The key determinant factors for WTP include asset holdings, and household and institutional factors while access to credit and extension services are also additional issues for WTC.

The study identified plot size, land registration, soil fertility, soil depth and land affected by erosion as determinant factors for adoption of technologies in the basin. In addition, plot distance from home, plot area, tenure and soil type are important factors determining the intensity of adoption, but security of tenure affected both adoption and intensity of use of technologies.

How the Proceeding is organized

The above summary provided just a glimpse of the project and some of the highlights of the workshop. The booklet provides two further sections, an annex and a CD. The next section of this booklet provides a list of the papers that were presented during the workshop. The following sections provide the abstracts of each of those papers. The corresponding formatted papers, presentations and posters are included on the CD. Note that the proceeding is formatted and minor corrections are made, and as such they do not represent peer-reviewed material. Thus, the authors/contributors are responsible for the content of the material, and this should not be considered as an IWMI peer-reviewed/referred publication. Finally, the annex of this booklet provides details of participants of the workshop.

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ABSTRACTS

BLUE NILE BASIN CHARACTERIZATION AND GEOSPATIAL ATLAS

Aster Denekew Yilma[1] and Seleshi Bekele Awulachew[1]

[1]*International Water Management Institute, Addis Ababa, Ethiopia*

The Blue Nile is the most important tributary river of the Nile. It provides 62% of the flow at Aswan. Information related to GIS layers and commonly available data are not easily accessible to researchers and practitioners, and repeated duplication of efforts has been observed to generate such information. The paper deals with the characterization of the Blue Nile Basin and its subbasins. The characterization generally looks into the topography, climatic conditions, hydrology and land use/cover, soil, and other related properties. The basin, as well as selected subbasins, watersheds, and micro-watersheds are considered and presented separately to help provide basic information at watershed to basin level, and lay the basis for other studies and researches. The basic information in this paper comes from the Blue Nile Geospatial Database, which has been developed for the upstream/downstream project. Several maps describing various aspects of spatial information of the basin, subbasins, selected watersheds and micro-watersheds based on the database are produced in the form of an atlas. It provides over 270 various maps and figures, and the digital information system can be accessible for various uses.

IMPACTS OF IMPROVING WATER MANAGEMENT OF SMALLHOLDER AGRICULTURE IN THE UPPER BLUE NILE BASIN

Teklu Erkossa[1], Seleshi Bekele Awulachew[1], Amare Haileslassie[2] and Aster Denekew Yilma[1]

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With its total area of about 200,000 square kilometers (km^2), which is 20% of the country's land mass, and accommodating 25% of the population, the Upper Blue Nile Basin (Abbay) is one of the most important river basins in Ethiopia. About 40% of agricultural products and 45% of the surface water of the country are contributed by this basin. However, the characteristic-intensive biophysical variation, rapid population growth, land degradation, climatic fluctuation and resultant low agricultural productivity and poverty are posing daunting challenges to sustainability of agricultural production systems in the basin. This calls for technological interventions that not only enhance productivity and livelihoods in the basin, but also bring about positive spillover effects on downstream water users. In this study, the farming systems in the basin have been stratified and characterized; and promising agricultural water management technologies, which may upgrade the productivity of smallholder rainfed agriculture while improving downstream water quality, have been identified. As a consequence, supplementary and full irrigation using rainwater and drainage of waterlogged soils are recognized as being among the promising agricultural water management technologies that can be easily scaled-up in the basin. The magnitude of the impacts of these technologies on the productivity of the upstream farming systems and the concomitant effects on the downstream water flow and quality are under investigation, assuming an assortment of scenarios.

SIMULATION OF WATER RESOURCE DEVELOPMENT AND ENVIRONMENTAL FLOWS IN THE LAKE TANA SUBBASIN

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Lake Tana is a natural reservoir for the Blue Nile River which has huge potential for hydropower and irrigation development. Water resource development is being encouraged by the government to stimulate economic growth and reduce poverty. In this study, the Water Evaluation And Planning (WEAP) model was used to simulate planned hydropower and irrigation development scenarios. Simulation of water demand and estimated downstream environmental flows was conducted for a 36-year period of varying flow and rainfall. Based on the simulation results, water availability for the different proposed irrigation and hydropower schemes was determined. The likely impact of future water resource development on water levels of the lake was assessed based on the simulation results of three development scenarios. The simulation results revealed that, if the full future development occurs, on average, 2,207 $GWhy^{-1}$ of power could be generated and 548 Mm^3y^{-1} of water could be supplied to irrigation schemes. However, the mean annual water level of the lake would be lowered by 0.33 meters (m) with a consequent decrease of 23 km^2 in the average surface area of the lake. Besides having adverse ecological impacts, this would also have significant implications for shipping and the livelihoods of many local people.

WATER BALANCE ASSESSMENT OF THE ROSEIRES RESERVOIR

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Roseires Reservoir on the Blue Nile River was completed in 1966 to serve the purposes of hydropower generation, irrigation and flood retention. During its lifetime, the reservoir suffered from serious sedimentation, to the limit that its present capacity is less than 2 cubic kilometers (km^3). Operation of the reservoir is maintained closely together with the Sennar Dam according to the operation policy. Operation of reservoirs depends on rules set for that purpose, which is based mainly on the water balance of the system among other factors. Such rules are rarely revised during the lifetime of the reservoirs. Roseires is not an exception. This paper presents an attempt to look closely at the different aspects of the operation and water balance parameters to gain an insight into the whole operation of the reservoir. In addition, an attempt is also made to find an accurate balance formula for the system, taking into account the part of the intervening catchment (14,578 km^2) that is totally ungauged. The flow from the Ethiopian Highlands is monitored at Eddeim Station. The mean annual rainfall in the area amounts to approximately 700 mm. The daily evaporation rates were derived from monthly data available in the operation rules of the Blue Nile reservoirs. The change in reservoir storage (Δs), and surface area were computed from the bathymetric surveys conducted during 1985, 1992 and 2005. Water balance computations were carried out for 1985, 1995 and 2005, corresponding to the availability of data. The ten years bathymetric data survey intervals give enough time for changes in water balance to take place, if any. Daily and 10-day water balances were computed using Eddeim flow data as the only inflow to the reservoir for the whole year, and for the dry and rainy periods. It was found that outflow from the reservoir can be reproduced with an efficiency of 97% R^2, indicating that the contribution of the intervening catchment to the inflows is negligible.

IMPROVING WATER MANAGEMENT PRACTICES IN THE RAHAD SCHEME

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This study aims to investigate and develop proper operational water management tools for the Rahad irrigation scheme. The Rahad project is considered as being among one of the schemes that could have a huge potential for expansion in the near future after the heightening of the Roseires Dam. The water supply sources for the Rahad scheme are the Blue Nile River and the Rahad seasonal river. The study explores options of augmenting the supply from the Rahad River during the wet season with the goal of minimizing sedimentation problems on the supply canals, reducing operation and maintenance costs associated with the Mena pumping station. Crop water requirements for the Rahad scheme were computed based on the historical cultivated areas of the different crops for the period 2000-2004. The Water Delivery Performance (WDP) Indicator for the scheme was evaluated. Frequency analysis and flow duration curves for the historical records of the Rahad seasonal stream were conducted in order to establish the yield of the Rahad River at different assurance levels. It is found that the yield from the Rahad seasonal river with 90% assurance level could be adequate to maintain an optimum performance of the irrigation system. Such proposed water management tools would improve the WDP by more than 25%. The dependence on the Rahad River during the wet season to meet the project irrigation water demands is anticipated to significantly minimize the maintenance and operation cost of diverting water from the Blue Nile.

ANALYSIS OF WATER USE ON A LARGE RIVER BASIN USING MIKE BASIN MODEL - A CASE STUDY OF THE ABBAY RIVER BASIN, ETHIOPIA

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The purpose of this study is to simulate water allocation for major activities (existing and planned) in the Abbay Basin using up-to-date water allocation and simulation models. The model, MIKE BASIN, is used to gain an insight into the potential downstream consequences of the development of physical infrastructure and water abstraction in a number of different future development scenarios. Seventeen irrigation projects covering an area of 220,416 hectares (ha) of land have been selected from different gauged catchments of the subbasin in addition to 4,800 megawatt (MW) hydropower projects on the main stream of the study area (Ethiopian part of Blue Nile). From the analysis, the total water extracted for these irrigation projects was estimated to be 1.624 billion cubic meters (BCM) annually. A reduction in the border flow volume as a result of the implementation of these irrigation projects under the reservoir scenario is 3.04% of the estimated mean annual flow of **50.45** BCM. Similarly, from the analysis, the total power generated due to the development of the major hydropower projects on the main stream, having an installed capacity of 4,800 MW, is 18,432 gigawatt hours (GWh) per year. This implies, while these interventions provide significant opportunities with respect to interventions and energy generations, their impact on downstream water availability is minimal.

APPLICATION OF THE WATER EVALUATION AND PLANNING (WEAP) MODEL TO SIMULATE CURRENT AND FUTURE WATER DEMAND IN THE BLUE NILE

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The riparian countries of the Nile have agreed to collaborate in the development of its water resources for sustainable socioeconomic growth. Currently there is significant potential for expansion of hydropower and irrigation in the Blue Nile River in both Ethiopia and Sudan. However, the likely consequences of upstream development on downstream flows have not been fully assessed and the water resource implications of development in both countries are unclear. Against this background, the Water Evaluation And Planning (WEAP) model was used to provide an assessment of both the current situation and a future (2015) scenario. The future scenario incorporated new irrigation and hydropower schemes on the main stem of the Nile and its principal tributaries. Data for all existing and planned schemes were obtained from the basin master plans as well as from scheme feasibility studies. Water use was simulated over a 32-year period of varying rainfall and flow. Preliminary results indicate that currently irrigation demand in Sudan is approximately 8.5 Bm^3y^{-1} for 1.16 million hectares (mha). This compares to a total irrigation demand in Ethiopia of just 0.2 Bm^3y^{-1}. By 2015, with many existing schemes being extended in Sudan and new schemes being developed in both countries, irrigation demand is estimated to increase to 13.4 Bm^3y^{-1} for 2.13 mha in Sudan and 1.1 Bm^3y^{-1} for 210 thousand hectares (tha) in Ethiopia. The flow of the Blue Nile is estimated to decline from an average of 46.9 Bm^3y^{-1} to 44.8 Bm^3y^{-1} at the Ethiopia-Sudan border and from a current average of 43.2 Bm^3y^{-1} to 36.2 Bm^3y^{-1} at Khartoum (including evaporation from all reservoirs). Although total flows are reduced, greater regulation results in higher dry season flows at both locations.

SEDIMENT ACCUMULATION IN ROSEIRES RESERVOIR

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Sedimentation is a serious problem faced by natural and man-made reservoirs. It is a major problem which endangers and threatens the performance and sustainability of reservoirs. It reduces the effective flood control volume, presents hazards to navigation, changes water stage and groundwater conditions, affects operation of low-level outlet gates and valves, and reduces stability, water quality, and recreational benefits. Reservoirs are often threatened by loss of capacity due to sedimentation. While there being many causes of reservoir sedimentation watershed, sediment and river characteristics are among the main natural contributing factors. Other important factors are reservoir size, shape and reservoir operation strategy. Man-made activities also play a significant role particularly in land use patterns. This paper is an attempt to assess sediment accumulation as well as the rate of sedimentation in the Roseires Reservoir. The basis for the study is the previous bathymetric surveys carried out on the reservoir in the years 1976, 1981, 1985, 1992, 2005 and 2007. Analysis and comparative studies were carried out between the different surveys to quantify the amount of sediment deposited as well the rate at which sedimentation took place. The design storage capacity of 1967 for the different reservoir levels was taken as a baseline. The sediment accumulation rates for the different bathymetric surveys are obtained as the difference between baseline capacity and the computed capacity at the respective levels during the specific survey. It was found that sedimentation in the Roseires Reservoir resulted in the reduction of the reservoir capacity from design storage of 3.0 Bm^3 in 1966 to 1.9 Bm^3 in 2007, i.e., a loss of approximately 1.1 Bm^3 during 41 years of operation. The sedimentation rate varies with both time and levels in the reservoir.

SOIL AND WATER ASSESSMENT TOOL (SWAT)-BASED RUNOFF AND SEDIMENT YIELD MODELING: A CASE OF THE GUMERA WATERSHED IN LAKE TANA SUBBASIN

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Land degradation is a serious threat in the Gumera watershed which is reflected in the form of soil erosion. Erosion is a major watershed problem causing significant loss of soil fertility and productivity. Increased sediment loads that shorten the useful life of the reservoir, the lives of other water-related structures, and increase the cost of maintenance and sediment remediation are off-site impacts of erosion. To develop effective erosion control plans and to achieve reductions in sedimentation, it is important to quantify the sediment yield and identify areas that are vulnerable to erosion. In recent decades, several simulation models have been developed in order to estimate, quantify, enhance understanding of spatial and temporal variability of erosion, and identify areas which are high contributors of sediment at micro-watershed level and over large areas. We used SWAT (Soil and Water Assessment Tool) to predict sediment yield, runoff, identify spatial distribution of sediment, and to test the potential of watershed management interventions in reducing sediment load from 'hot spot' areas. The tool was calibrated and validated against measured flow and sediment data. Both, calibration and validation results, showed a good match between measured and simulated flow and suspended sediment. The model prediction results indicated that about 72% of the Gumera watershed is erosion potential area with an average annual sediment load ranging from 11 to 22 tonnes/ha/yr exceeding tolerable soil loss rates in the study area. The model was applied to evaluate the potential of filter strips with various widths to reduce sediment production from critical micro-watersheds. The investigation revealed that implementing vegetation filter strips can reduce sediment yield by 58 to 74%.

DEVELOPMENT OF RAINFALL-RUNOFF-SEDIMENT DISCHARGE RELATIONSHIP IN THE BLUE NILE BASIN

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The Blue Nile (Abbay) Basin lies in the western part of Ethiopia between 7^0 45′-12^0 45′ N and 34^0 05′-39^0 45′ E. The Blue Nile region is the main contributor to flood flows of the Nile, with a mean annual discharge of 48.5 km^3. Soil erosion is a major problem in Ethiopia. Deforestation, overgrazing, and poor land management accelerated the rate of erosion. The SWAT was successfully calibrated and validated for measured streamflow at Bahir Dar near Kessie and at the border of Sudan for flow gauging stations, and for measured sediment yield at Gilgel Abbay, Addis Zemen and near Kessie gauging stations in the Blue Nile Basin. The model performance evaluation statistics (Nash–Sutcliffe model efficiency (E_{NS}) and coefficient of determination (r^2)) are in the acceptable range (r^2 in the range 0.71 to 0.91 and E_{NS} in the range 0.65 to 0.90). It was found that the Guder, N. Gojam and Jemma subbasins are the severely eroded areas with 34% of sediment yield of the Blue Nile coming from these subbasins. Similarly, the Dinder, Beshilo and Rahad subbasins only cover 7% of sediment yield of the basin. The annual average sediment yield is 4.26 t/ha/yr and the total is 91.3 million tonnes for the whole Blue Nile Basin in Ethiopia.

MODELING OF SOIL EROSION AND SEDIMENT TRANSPORT IN THE BLUE NILE BASIN USING THE OPEN MODEL INTERFACE APPROACH

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Rapid land use change due to intensive agricultural practices in the Ethiopian Highlands, results in increasing rates of soil erosion. This manifested in significant impacts downstream by reducing the storage capacity of reservoirs (e.g., Roseires, Sennar), and high desilting costs of irrigation canals. Therefore, this paper aims to provide a better understanding of the process at basin scale. The Soil and Water Assessment Tool (SWAT) was used to model soil erosion in the upper catchments of the Blue Nile over the Ethiopian Plateau. The SWAT output forms the input sediment load for SOBEK, a river morphology model. The two models integrated using the principles of the Open Model Interface (OpenMI) at the Ethiopia-Sudan border. The Nash-Sutcliffe coefficient was found to be 0.72 and 0.66 for results of SWAT daily sediment calibration and validation, respectively. The SOBEK results also show a good fit of the simulated river flows at Roseires and Sennar reservoirs, both for calibration and validation. The results of the integrated modeling system showed 86 million tonnes/year of sediment load from the Upper Blue Nile, while SOBEK computes on average 19 Mm^3/year of sediment deposition in the Roseires Reservoir. The spatial variability of soil erosion computed with SWAT showed more erosion over the northeastern part of the Upper Blue Nile, followed by the northern part. The overall exercise indicates that the integrated modeling is a promising approach to understand soil erosion, sediment transport, and sediment deposition in the Blue Nile Basin. This will improve the understanding of the upstream-downstream interdependencies, for better land and water management at basin scale.

RAINFALL-DISCHARGE RELATIONSHIPS FOR MONSOONAL CLIMATES

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Methods for estimating runoff that have been developed for temperate climates may not be suitable for use in the monsoonal climates of Africa, where there is a distinct dry season during which soils dry out to a considerable depth. This has a distinct effect on runoff generation that is not captured by "the temperate climate" models. The scope of this tool is to develop a simple water balance method for predicting river discharge. Water balance models have been shown to better predict river discharge in regions with monsoonal climates than alternative methods based on the United States Department of Agriculture-Soil Conservation Service (USDA-SCS) curve number. The latter is an empirical-based model developed in the USA that does not apply to monsoonal climates with distinct dry and wet periods.

A WATER BALANCE-BASED SOIL AND WATER ASSESSMENT TOOL (SWAT) FOR IMPROVED PERFORMANCE IN THE ETHIOPIAN HIGHLANDS

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The Soil Water Assessment Tool (SWAT) is a watershed model widely used to predict water quantity and quality under varying land use and water use regimes. To determine the respective amounts of infiltration and surface runoff, SWAT uses the popular Curve Number (CN). While being appropriate for engineering design in temperate climates, the CN is less than ideal when used in monsoonal regions where rainfall is concentrated into distinct time periods. The CN methodology is based on the assumption that Hortonian flow is the driving force behind surface runoff production, a questionable assumption in many regions. In monsoonal climates water balance models generally capture the runoff generation processes and thus the flux water or transport of chemicals and sediments better than CN-based models. In order to use SWAT in monsoonal climates, the CN routine to predict runoff was replaced with a simple water balance routine in the code base. To compare this new water balance-based SWAT (SWAT-WB) to the original CN-based SWAT (SWAT-CN), several watersheds in the headwaters of the Abay Blue Nile in Ethiopia were modeled at a daily time step. While long term, daily data is largely nonexistent for portions of the Abay Blue Nile, data was available for one 1,270 km2 subbasin of the Lake Tana watershed, northeast of Bahir Dar, Ethiopia, which was used to initialize both versions of SWAT. Prior to any calibration of the model, daily Nash-Sutcliffe model efficiencies improved from -0.05 to 0.39 for SWAT-CN and SWAT-WB, respectively. Following calibration of SWAT-WB, daily model efficiency improved to 0.73, indicating that SWAT can accurately model saturation-excess processes without using the Curve Number technique.

ASSESSMENT OF HYDROLOGICAL CONTROLS ON GULLY FORMATION AND UPLAND EROSION NEAR LAKE TANA, NORTHERN HIGHLANDS OF ETHIOPIA

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For the past five decades, gully erosion has been the dominant degradation process in the Ethiopian Highlands. Gully erosion negatively affects soil resources, lowers soil fertility in inter-gully areas, reduces the pastureland available for livestock, and aggravates siltation of reservoirs. Assessing the location and rate of gully development and changes in the controlling factors (climate, soil, hydrology and land cover) of gully erosion will help explain the acceleration in land degradation that is faced. The study was performed in a gully system in the 800 ha Debre-Mewi Watershed south of Bahir Dar, Amhara region, Ethiopia. Analyses comprised monitoring gully development through profile measurements, air photograph interpretations, and semi-structured interview techniques. Gully hydrological processes were investigated based on measurements of gully runoff and water levels in 24 piezometers in the gully contributing area. Upland erosion was also assessed. The Debre-Mewi gully is still an actively eroding gully system. A comparison of the gully area estimated from a 0.5 m resolution QuickBird image with the current gully area, walked with a Garmin GPS, showed that the eroded gully area increased by 30% from 0.51 ha in 2005 to 0.735 ha in 2008. Based on measurements of several gully cross-sections, an approximate gully volume of 7,985 cubic meters (m^3) and an average gully erosion rate of 24.8 t ha^{-1} a^{-1} could be estimated. Gully erosion rates accelerated since 1991 through the increased degradation of the vegetation cover and clearance of indigenous vegetation on the hillsides, leading to an increase of surface and subsurface runoff from the hillsides to the valley bottoms. Gully heads retreat into the hillslope through concentrated runoff during the rainy season, erodes existing soil pipes and cracks in the vicinity of the gully head and banks. Piping and tunneling facilitate the slumping of the gully wall and their retreat. The sediment produced from the collapsing walls is exported during heavy storm events. The loss of erosion due to gulley formation is many times that of upland erosion. We find that alteration of the runoff response due to reestablishing the natural vegetation on the hillside and improvement of existing farming practices will be most important to decelerate current erosion rates.

ASSESSMENT OF HYDROLOGICAL AND LANDSCAPE CONTROLS ON GULLY FORMATION AND UPLAND EROSION NEAR LAKE TANA

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Gully formation and upland erosion were studied in the Debre-Mewi Watershed in the Gilgil Abay Basin south of Lake Tana. Gully erosion rates were found to be equivalent to over 500 tonnes/ha/year for the 2008 rainy season when averaged over the contributing watershed. Upland erosion rates were twentyfold less. Gully formation is accelerated when the soils are saturated with water as indicated by water table readings above bottom of the gully. Similarly, upland erosion was accelerated when the fields were close to saturation during the occurrence of a rainfall event. Height of the water table is an important parameter determining the amount of erosion and should, therefore, be included in simulation models.

LESSONS FROM UPSTREAM SOIL CONSERVATION MEASURES TO MITIGATE SOIL EROSION AND ITS IMPACT ON UPSTREAM AND DOWNSTREAM USERS OF THE NILE RIVER

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A study was conducted to evaluate the effects of soil bunds stabilized with vetiver grass (V. zizanioides) and tree lucerne (C. palmensis) on selected soil physical and chemical properties, bund height, inter-terrace slope and barley (Hordeum vulgare L.) yield in Absela site, Banja Shikudad District, Awi administrative Zone of the Amhara National Regional State (ANRS) located in the Blue Nile Basin. The experiment had five treatments that included non-conserved land (control), a 9-year old soil bund stabilized with tree lucerne, a 9-year old soil bund stabilized with vetiver grass, a 9-year old sole soil bund, and a 6-year old soil bund stabilized with tree lucerne. Data were analyzed using one-way analysis of variance (ANOVA) and mean values for the treatments were separated using the Duncan Multiple Range Test. Results of the experiment indicated that organic carbon (OC), total nitrogen (N), bulk density, infiltration rate, bund height, and inter-terrace slope are significantly ($p \leq 0.05$) affected by soil conservation measures. The non-conserved fields had significantly lower OC, total N, and infiltration rate; whereas higher bulk density as compared to the conserved fields with different conservation measures. However, no significant differences in bulk density were observed among the conservation methods. The field treated with 9-year old soil bund stabilized with tree lucerne or sole soil bund had significantly higher OC content than all other treatments. Fields having 6-year old soil bunds had lower OC and total N when compared to fields having 9-year old soil bunds irrespective of their method of stabilization. Fields with soil bunds stabilized with vetiver grass had the highest bund height and the lowest inter-terrace slope than fields with the remaining conservation measures. Barley grain and straw yields were significantly ($P \leq 0.05$) greater in both the soil accumulation and loss zones of the conserved fields than the non-conserved (control) ones. In the accumulation zone, fields with the 9-year old soil bund stabilized with tree lucerne and those with the 9-year old sole soil bund gave higher grain yields (1878.5 kg ha^{-1} and 1712.5 kg ha^{-1}, respectively) than fields having 9-year old soil bund stabilized with vetiver grass (1187 kg ha^{-1}) and 6-year old soil bund stabilized with tree lucerne (1284.25 kg ha^{-1}). When we compare the accumulation and the loss zones, the average grain yield obtained from the accumulation zones (averaged over all the treatments) was 29.8% higher than the average grain yield obtained from the loss zones. The causes of soil erosion in the region could be the rugged nature of the topography, high and erratic rainfall patterns, extensive deforestation, continuous cultivation and complete removal of crop

residues from the field, overgrazing and free-grazing, improper farming practices and development efforts, overpopulation and poverty, socioeconomic problems, lack of awareness on the effect of erosion, and poor land use policy enforcement. From the study it was possible to conclude that soil bunds stabilized with vegetative measures (such as tree lucerne and vetiver) better held the soil in-situ and improve inter-terrace soil physical and chemical properties compared to the non-conserved fields. This suggests that by applying soil conservation measures upstream, the erosion rate will be minimized and the amount of silt entering streams and ultimately the Blue Nile River will be minimized. This, in turn, will significantly improve land productivity in the upstream areas and cut the huge costs of silt cleaning in the dams and irrigation canals of the downstream countries that use the Blue Nile River.

ASSESSMENT OF LOCAL LAND AND WATER INSTITUTIONS IN THE BLUE NILE AND THEIR IMPACT ON ENVIRONMENTAL MANAGEMENT

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Land and water institutions play a vital role in managing and sustaining land and water resources as well as enhancing economic development and poverty alleviation efforts. While a lot has been done in terms of understanding the micro-determinants of farmers' decisions in land and water conservation, there is little attempt to understand the broad macro-institutional and organizational issues that influence land and water management decisions. The objective of the study was to assess institutional arrangements and challenges for improved land and water management in the Ethiopian part of the Blue Nile Basin (Tana and Beles subbasins). Focus group discussions and key informant interviews were held in Amhara and Benishangul Gumuz regions with important stakeholders such as the bureaus of Agriculture and Rural Development, Water Resources Development, Environmental Protection and Land Use Administration (EPLUA), National Agricultural Research Systems, and important NGOs, operating in the area of land and water management, and selected community members. As the major findings in this study, we outlined major land and water-related institutional arrangements that are currently in place and their design features, in order to identify those institutions related to superior performance. We highlighted major institutional and policy gaps and actions that are required to respond to emerging issues of environmental degradation, upstream/downstream linkages and climate change. Such analysis of institutions and their design features provides useful insights and contributes to the debate on institutional reform for improved land and water management in the Blue Nile Basin, in general. By doing so, it identifies the gaps in institutional arrangements and policies and potential remedies.

BENEFIT-SHARING FRAMEWORK IN TRANSBOUNDARY RIVER BASINS: THE CASE OF THE EASTERN NILE SUBBASIN

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In some parts of the world, including Africa, problems related to water scarcity and water stress (which is even worse) is evident. Currently, about one-third of the African population is experiencing water scarcity. For countries sharing transboundary rivers, the adoption of water governance in all their strategies is of paramount importance. For this to happen, cooperation among riparian states becomes indispensable. Cooperation can help in availing more water in the basin, reducing soil erosion, mitigating drought and ensuring food security. At present, there is more emphasis on the sharing of transboundary benefits rather than physical water per se. Whereas the former can bring about a zero-sum negotiation the latter can yield a positive sum outcome. The benefits that can be accrued through cooperation could be economic, environmental, social and political. The aim of this study is to highlight the concept of benefit sharing and benefit-sharing framework in general terms as well as in the context of the Eastern Nile Subbasin. By doing so, the study looks into some of the ongoing and planned Eastern Nile projects, with particular emphasis on the Joint Multipurpose Program (JMP), to test the degree of relevance of the issue of the benefit-sharing framework and to suggest the way forward. The findings of the study have indicated that benefit sharing in transboundary river basins is an outcome of a collaborative effort by the co-riparian states to reduce costs and increase outputs. It could also mean the management of shared waters more efficiently and effectively across all sectors, so-called sectoral optimization. The effects and impacts of joint investments in both upstream and downstream states can yield a bundle of benefits including, but not restricted to, flood control, reduction of sedimentation, availability of more water in the basin and hydropower production. These, in turn, can ensure food security, mitigate drought and avail renewable energy. For transboundary rivers such as the Nile, attempts should be made to identify the typologies of benefits, aspects of benefit sharing, scenarios of benefit sharing, and the optimization/maximization of benefits. With the better management of ecosystems cooperation can provide 'benefits to the river'; with cooperative management of shared rivers benefits can be accrued 'from the river' (e.g., increased food production and power); with the easing of tensions between riparian states costs 'because of the river' could be reduced; and with cooperation between riparian states leading to economic integration comes 'benefits beyond the river'. In terms of aspects of benefit sharing, issues related to benefit sharing for whom, by whom and because of who need to be addressed. Similarly, scenarios of benefit sharing should be considered as phases or time perspectives by anchoring short-term works of strengthening the hitherto existing riparian links, medium-term tracking and improvement of in-country and transborder institutional arrangements for resource use and cooperation, and long-term efforts on investment in basin-wide joint development and programs. Due to the prevalence

of centuries of hydropolitical stalemates in the Nile Basin, costs 'because of the river' remained high. The lack of cooperation impeded many of the basin states to reap little or no benefits from the river. The establishment of the Nile Basin Initiative (NBI) in 1999 has been marked as a strong departure compared to its predecessors. The Eastern Nile Subsidiary Action Program (ENSAP) and with it the Eastern Nile Technical Regional Office (ENTRO) have identified a number of projects, of which JMP stands out as one of the most significant ones. It aims to undertake multipurpose and multi-country programs of activities encompassing watershed and environmental management; and enhanced agricultural production and renewable energy. When this project gets grounded, it could mitigate natural resources degradation, alleviate poverty and enhance agricultural production. There is a possibility for the three Eastern Nile countries to accrue transboundary benefits. As things stand now, the three Eastern Nile countries need to first and foremost identify the bundle of benefits that can be generated from the project and then agree on the mechanisms by which they can realize the 'equitable sharing of benefits'. They also need to formulate and sign a benefit-sharing treaty, develop a sound financial framework to realize the equitable sharing of benefits, costs and risks and the joint ownership of assets. Last but not least, the Eastern Nile countries should establish institutions that will manage benefit-sharing schemes and address issues such as mechanisms of delivering benefits.

TRANSBOUNDARY WATER GOVERNANCE INSTITUTIONAL ARCHITECTURE: REFLECTIONS FROM ETHIOPIA AND SUDAN

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Transboundary water resource governance is premised on equitable water and water-related benefit sharing. Using the case of the Blue Nile (Ethiopia and Sudan), we explore the conceptual issues that need consideration in the crafting of cross-border cooperation within the water sector. First, drawing on global experiences with transboundary water management, we evaluate how upstream and downstream concerns are addressed by transboundary water management institutions. Second, we explore the kinds of institutional design and the issues which need to be considered to result in 'win-win' scenarios for both upstream and downstream users, as well as the mechanisms of benefit sharing negotiated amongst different stakeholders. Third, we examine ways of addressing equity and livelihoods in transboundary institutional arrangements. Finally, we attempt to assess how transboundary institutions can address broader historical, political and economic issues and their implications for sustainable transboundary water governance. This paper raises key issues that need to be addressed in establishing transboundary governance institutions.

PROSPECT OF PAYMENTS FOR ENVIRONMENTAL SERVICES IN THE BLUE NILE BASIN: EXAMPLES FROM KOGA AND GUMERA WATERSHEDS, ETHIOPIA

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In transboundary river basins, like the Blue Nile, conflicts over the use of water resources are growing and recent advances in sustainable resource management recognizes the need for approaches that coordinate activities of people dependent on a common resource-base to realize sustainability and equity. Payments for Environmental Services (PES) are a component of a new and more direct conservation paradigm and an emerging concept to finance conservation programs by fostering dialogue between upstream and downstream land users. Those kinds of approach are particularly useful if applied in basins where irrigation schemes are emerging and the service life of reservoir and irrigation canals, in downstream areas are threatened by the sediments moved from upstream region. Here we report the results of our study on the determinants of Willingness to Pay (WTP) and Willingness to Compensate (WTC) for improved land and water management practices in the Blue Nile Basin (Gumera and Koga watersheds). A total of 325 sample households were selected using a multi-stage sampling technique, and a structured and pre-tested questionnaire was used to collect data from the sample households. We applied Contingent Valuation Method (CVM) to elicit WTP using monetary and material payment vehicles. Our results showed that more households are willing to pay in labor than in cash. The mean WTP for improved land and water management was estimated at US$1.06 and US$1.3 months^{-1} household^{-1} for upstream and downstream farmers, respectively. Besides, 83.56% of the sample farm households showed WTC the upstream farmers in cash. However, the aggregate WTP falls far short of the estimated investment cost needed for ecosystem restoration. Among others, the number of livestock, size of arable land, access to education and credit by the sample farm households were identified to positively influence sample farmers' WTP for restoration of ecosystem services and downstream farmers' WTC for improved ecosystem regulation services. Therefore, institutions and policy measures that enhance environmental education, reduce poverty and foster stakeholders' cooperation must be promoted.

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ISBN: 978-92-9090-716-9