CHEMICAL ENGINEERING TRANSACTIONS
VOL. 58, 2017

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Remigio Berruto, Pietro Catania, Mariangela Vallone

ISBN 978-88-95608-52-5; **ISSN** 2283-9216

DOI: 10.3303/CET1758115

Impacts of Rainwater Harvesting and Rainwater Management on Upstream – Downstream Agricultural Ecosystem Services in Two Catchments of Southern Tigray, Ethiopia

Giulio Castelli[a]*, Andrea Minelli[b], Meron Lakew Tefera[b], Elena Bresci[a], Eyasu Yazew[c], Tesfa-alem Gebreegziabher Embaye[c], Mulugeta Sebhatleab[d]

[a]Department of Agricultural, Food and Forestry Systems (GESAAF), University of Florence (Italy)
[b]University of Florence (Italy)
[c]Institute for Water and Environament, Mekelle University (Ethiopia)
[d]Department of Land Resource Management and Environmental Protection (LaRMEP), Mekelle University (Ethiopia)
giulio.castelli@unifi.it

Rainwater management and rainwater harvesting are vital for the resilience of social and agricultural systems in arid and semiarid regions. Nevertheless, the intensification of their use in the upstream areas of river catchments may result in the concentration of rainfall harvesting in the highland parts of the watershed, leading to changes in water allocation and to harms to lowland rural systems.
The aim of this paper is to evaluate the impact of rainwater management and rainwater harvesting on upstream-downstream agricultural ecosystem services in two catchments located in Tigray Region (Ethiopia). Oda catchment, with no rainwater management, and Guguf catchment, under heavy water management, were considered for the evaluation of the different watershed management strategies. Participatory Rural Appraisal and field questionnaires were used to assess agricultural ecosystem services of watershed management in upstream and downstream areas for both catchments and a comparative assessment has been carried out.
Results show that watershed management in both upstream and downstream part of Guguf catchment provided reduction of soil erosion, leading to an increased agricultural production, and to the increase of fodder and pasture availability, resulting in increased livestock production. In Oda catchment, heavy erosion problems and seasonal droughts remain unsolved. The analysis shows that watershed management in Guguf catchment triggered the implementation of irrigation system in the upstream areas. Due to this, farmers reported a decrease of water availability. The relationship between watershed management and the consequent implementation of new irrigation systems should be monitored to avoid potential conflict in the future.

1. Introduction

Rainfed agriculture is the dominant form of land use in Ethiopia. The economy of the country is highly sensitive to climate, and extreme variability on intensity of rainfall and frequency of dry spells are the main causes of drought and responsible for the partial to complete crop failure in the country (Dile et al., 2016b). In this context, rainwater management and rainwater harvesting represent fundamental tools for land and water development, because they allow the management, the storage and the use of scattered and intense precipitation for productive purposes, allowing to overcome dry spells and to enhance local ecosystems rather than generating violent runoff flows, erosion and sediment loads in downstream areas (Rockström et al., 2002; Dile et al., 2013). These interventions represent an important factor in the upstream watershed areas (Rockström et al., 2002), but they can also affect the flow of water to downstream users (Dile et al., 2016a). In recent years, two opposite school of thoughts have developed: the first one suggests that intense rainwater management can have negative effects on downstream agri-ecosystems, due to the reduction in water availability for downstream areas, while the second one affirms that the intensification of these interventions may lead to a global increase in the catchment ecosystem services, in particular by reducing peak flows and

Please cite this article as: Castelli G., Minelli A., Tefera M., Bresci E., Yazew E., Embaye T.G., Sebhatleab M., 2017, Impacts of rainwater harvesting and rainwater management on upstream – downstream agricultural ecosystem services in two catchments of southern tigray, ethiopia, Chemical Engineering Transactions, 58, 685-690 DOI: 10.3303/CET1758115

erosion, increasing base flow and groundwater recharge (Dile et al., 2013). Anyway, the most recent studies on the effect of rainwater management intensification are based on a modelling approach (Welderufael et al., 2013; Dile et al., 2016a; Glendenning and Vervoort, 2011), while practical field analysis are lacking.
In the region of Raya Valley, Ethiopia, a dryland plateau bordered by mountains around 2500 – 3000 m a.s.l., scattered precipitations of the summer rainy seasons represent the main source of water for the rural population and the environment. The region is characterized by the presence of wadis, namely ephemeral rivers that are created in mountainous areas and flood into flatlands (Yazew et al., 2014). In the flat areas, local population takes advantage of ephemeral flows in Flood Based Farming Systems (FBFS), using the technique of Spate Irrigation, which is based on the diversion of floods from the riverbed to fields through diversion structures, made in local material or improved with concrete structures (Van Steenbergen et al., 2010). FBFS take also great advantage by small discharges or residual discharges, after flow events, that can be properly handle and used for supplementary irrigation. Due to the importance of rainwater and watershed management, the regional government of Tigray launched the conservation based agricultural development program within the framework of the national Agricultural Development-Led Industrialization (ADLI) policy adopted in 1992 (National Regional State of Tigray, 1997). In the following 20 years many hillsides have been rehabilitated and multiple rainwater harvesting (such as deep trenches) and rainwater management structure (such as terraces) have been implemented in the area. The objective of the works was to stabilize upstream hillside areas to prevent land degradation and erosion.
It is still unknown if the implementation or the intensification of these measures have an impact on downstream FBFS and the related ecosystems supported by the floods. In this framework, a methodology that can assess the trade-offs related to watershed management is still missing, and decision makers are still lacking the necessary information to share equally the benefits of the investment in watershed management (Water Land and Ecosystem program CGIAR, 2016). The aim of this research is to increase the knowledge for decision making concerning rainwater management and rainwater harvesting in the wadi catchments of Raya Valley. Two river catchments have been analysed, one under heavy watershed management, the second with scarce watershed management implementation. A participatory assessment of rainwater management benefits and impacts on rural ecosystem services has been realised within local communities through the use of Participatory Rural Appraisal methodology (Chambers, 1994). A comparative assessment has been realised by considering the trade-offs in the ecosystem services of upstream hillside areas and downstream flatland areas, enhancing the differences for the case of fully managed and un-managed catchment, to inform future watershed planning and management at regional and national level.

2. Materials and Methods

2.1 Study areas

Raya Valley is a highland plateau, located in the southern part of Tigray region (Ethiopia), between 12° 05' and 12° 55' latitude and 39° 21' and 39° 55' longitude, having an extension of about 2,750 km^2.

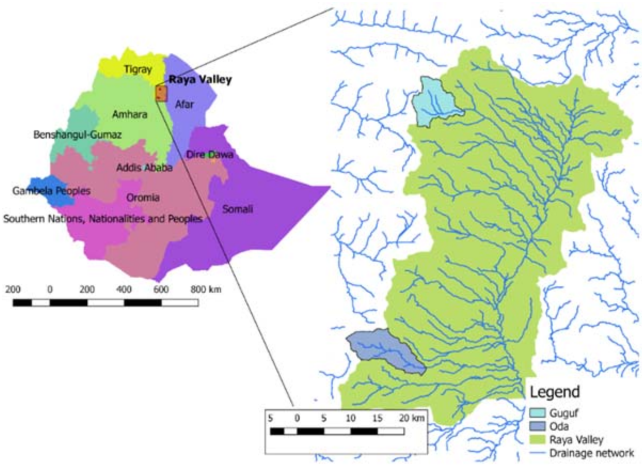

Figure 1 – Location of Raya Valley and study areas

Raya valley catchments can be divided in two different agro-ecological zones: the low-lying area (downstream area) with an altitude of less than 1000 m a.s.l. and an average annual rainfall estimated at below 350 mm; and the upstream area at above 1500 m a.s.l., with a mean annual rainfall that ranges from 600 to 775 mm

(Water Land and Ecosystem program CGIAR 2016). Guguf catchment is located in the northern part of valley, while Oda catchment is located in the southern part of the area (Figure 1). Oda watershed is largely bare land and there is no yet watershed management intervention, while the Guguf watershed is characterized by interventions, including bench terraces and deep trench based on agricultural development programmes. Each catchment has been divided in one upstream sub-catchment and a downstream sub-catchment, selected as the areas over or below the average altitude of the watershed. In particular, four sub-catchments have been defined: (1) Guguf downstream, (2) Guguf upstream, (3) Oda downstream, (4) Oda upstream.

2.2 Research framework

The research has been based on the comparison of upstream-downstream ecosystem services within the two catchments, characterized by different watershed management strategies, namely intense rainwater management and harvesting interventions (Guguf), and no intervention (Oda).

Two focuses have been considered. The first one based on the difference between upstream and downstream zones of the same watershed, to understand trade-offs of the two watershed management strategies at catchment scale; the second one based on the analysis of the variations between (1) the upstream areas of the two catchments and (2) the downstream areas of the two catchments, to identify possible changes of the upstream-downstream allocation of ecosystem services depending on the watershed management strategy.

2.3 Participatory Rural Appraisal (PRA)

Participatory Rural Appraisal (PRA) represents a useful tool for the analysis of rural systems (Chambers, 1994). PRA is based on a collection of participatory techniques in which the researcher acts as a facilitator while the rural population carries out its own analysis to have a direct response of the actual situation of the rural area. Researchers, as outsiders not expert of the rural system, encourage and allow local people to determine much of the agenda, to gather, express and analyse information, and to plan (Chambers, 1994). PRA has been used to gather direct information about the rural systems located in the four sub-catchments, included in the analysis. The activity was organized in the period between 27/7/2016 and 1/8/2016, with preliminary visits on the field from the 18/7/2016 until 20/7/2016. Participatory maps, questionnaires and semi-structured interviews (SSIs), focusing on constraints, causes, coping strategies and opportunities for the area, have been considered for the analysis. For participatory maps, groups of 3 farmers were organized for each sub-catchment, the number of questionnaires collected is shown in Table 1 (for a full collection and description of the techniques, PRA programme Egerton University (1995) and Narayanasamy (2009) can be consulted).

Table 1: Number of SSIs and questionnaires

Sub-catchment	SSIs	Questionnaires
Guguf downstream	2	5
Guguf upstream	3	6
Oda downstream	2	5
Oda upstream	2	5

3. Results

3.1 Participatory maps and spatial description of the study area

The upstream area of Guguf catchment is characterised by mountainous landscape. Soil and water conservation works (SWC) have been implemented since 1992, including trenches, bench terraces and soil bunds. An irrigation system has been implemented around the city of Maichew. The downstream part of Guguf catchment is characterized by the presence of irrigable land under spate irrigation. “Area closures” are visible, namely areas forbidden for agriculture and grazing in which reforestation has been done. Thanks to the restored ecosystem, honey production has been also implemented. Embankments along the gully banks have been built to control gully erosion, leading to a decrease of soil loss. Fruit production is also present. Irrigation canals in the downstream FBFS are available to distribute the floodwater.

The upstream part of Oda watershed has mountainous areas with few SWC intervention. Farmers reported low soil moisture and high erosion, including land sliding. The main crops are Sorghum and Teff. Livestock production is limited to goats and few sheep, and problem of fodder availability are present. Honey is produced only in the upstream of the basin, fruit is not common due to water shortages, and most of trees are used for timber. Farmers also reported that is very difficult for them to implement new SWC structures in autonomy, due to the high slope of the hillsides. In the downstream part of Oda catchment, farmers highlighted the presence of high damage in the cropping land, high sedimentation load on the irrigation water and gully erosion due to floods. Free grazing and drought problem are present from February to June for animals, as well as food availability problems from June to September for local population.

3.2 SSIs on constraints, causes, strategies, opportunities

Table 2: SSIs on constraints, causes, strategies, opportunities – Guguf catchment

	Constraints	Causes	Coping Strategies	Opportunities/Results of past strategies
		GUGUF UPSTREAM		
PAST	Erosion, low production	Lack of soil conservation	SWC	Reduced erosion, fodder and grazing land availability, soil moisture increase, increase of livestock production, increased agricultural production
		Lack of water	irrigation canal	increase of livestock production, increased agricultural production
PRESENT	Deforestation	Increase of livestock production	Area closure, national law against deforestation	
	Erosion	Aging of SWC structures	New management plan	
		GUGUF DOWNSTREAM		
PAST	Low productivity Lack of animal fodder	Floods, siltation Lack of pastures	SWC implementation	Higher productivity
PRESENT	Lack of irrigation water	Reservoir in upstream	New water management rules	

Table 3: SSIs on constraints, causes, strategies, opportunities – Oda catchment

	Constraints	Causes	Coping Strategies	Opportunities/Results of past strategies
		ODA UPSTREAM		
PAST	Overgrazing Deforestation		Area closures	Honey production Grazing land creation
PRESENT	Excessive runoff Gully erosion Lack of animal feed	Low infiltration rate Lack of grazing land	SWC implementation (regreening, bench terraces)	Creation of stable hillslopes, increased infiltration rate
		ODA DOWNSTREAM		
PRESENT	Flooding and erosion Lack of animal fodder Drought	Excessive runoff Lack of available grazing land Lack of rainfall	SWC implementation	Creation of new grazing land Flood and erosion mitigation

Table 2 and Table 3 show the synthesis of SSIs collected in the four sub-catchments. Where possible, the analysis was carried out considering the past situation (before watershed management works) and the present situation. In both Guguf sub-catchments, SWC measures provided an increase in crop and livestock production, and a reduction of erosion. The intensification of grazing, triggered by higher fodder availability, and the aging of old structures represents a factor that could generate again watershed degradation, and should be considered in the future. SWC caused also stabilization of water flows in Guguf upstream watershed that triggered irrigation development in upstream areas. This has caused conflicts between upstream and downstream farmers for the use of water during low flows period, namely when, after heavy rainfall, the last gentler part of runoff produces moderate discharges in the wadi bed. If this discharge is used in the upstream areas, is no longer available for downstream farmers. In Oda catchment, area closures provided an incentive to honey production and more grazing lands. On the other hand, the lack of watershed management caused erosion and lack of animal fodder in both upstream and downstream areas, and flooding in downstream parts of the catchment.

3.3 Questionnaires

The main information derived from questionnaires are referred to the situation of livestock production in the four sub-catchments and on the water amount available in Guguf downstream area. Questionnaires data shows that 100% of household increase their livestock production in Guguf upstream, while the increase is for the 71% of farmers interviewed in Guguf downstream area. In Oda upstream sub-catchment around the 60% of farmers experienced a decrease in the amount of livestock units, while in Oda downstream the percent is up to 83%. No household in Oda catchment experienced increase in the number of animals in last years. The information about water availability for Guguf downstream watershed is still uncertain. 3 out of 5 farmers observed a decrease in wadi flows, one farmer reported no change and one farmer reported an increase. Table 4 shows the results of the comparative evaluation of ecosystem services realized with PRA.

Table 4: Comparison of ecosystem services in the two catchments of the study

Ecosystem Service	**Guguf upstream**	**Oda upstream**
Reduced erosion	Yes (SSIs + questionnaires)	No, erosion problems (SSIs + questionnaires)
fodder and grazing land availability, created with the bench terraces	Yes (increasing of livestock number - questionnaires)	Yes, moderate increase of grazing land
soil moisture increase	Yes (SSIs)	No, low infiltration rate
Increase of livestock production	Yes (SSIs + Questionnaires)	No, decreasing (questionnaires)
increased agricultural production	Yes (SSIs)	No (questionnaires)
Irrigation	Yes, triggered by watershed management	Not present
Ecosystem Service	**Guguf downstream**	**Oda downstream**
Reduced floods and siltation	Yes (SSIs + Questionnaires)	No, erosion problems
fodder and grazing land availability, created with the bench terraces	Yes (SSIs + Questionnaires)	No, lack of grazing land
Increase of livestock production	Yes (SSIs + Questionnaires)	No, decrease due to drought in 2015
increased agricultural production	Yes (SSIs + Questionnaires)	No
Amount of water	Decrease	No change
Upstream irrigation	Caused water availability decrease	Not present

4. Discussion

Like in other regions of Ethiopia (Dile et al., 2016b), intensive watershed management provided reduction of erosion, increase of fodder and grazing land availability, increase of soil moisture, increase of agricultural and livestock production. Intense SWC also stabilized water flows and triggered irrigation in Guguf upstream area. In Oda upstream area, area closures provided an increase of grazing land, but the other effects are not present. Erosion and production problems remained unsolved. In Guguf downstream areas flood and siltation problems were reduced by upstream watershed management strategy. Due to this, and to the increase of grazing land availability, agricultural and livestock production were increased. On the other hand, upstream irrigation systems seem to threat downstream water availability. In Oda downstream area, flood and siltation problems remains, but there is no decrease in overall water availability for flood-based irrigation. The remarkable increase of livestock production given by the environmental restoration effects of SWC was also observed by Descheemaeker et al. (2010) in other areas of Ethiopia. On the other hand, it was noticeable to observe how SWC triggered the possibility of traditional irrigation, by regulating water flows in upstream areas. However, to confirm the PRA results, a more specific hydrological-based approach, including modelling, should be applied.

5. Conclusions

The study assesses a comparison between the ecosystem services related of two different watershed management strategies applied in two wadi catchments of Raya Valley area, Ethiopia, Guguf catchment, under heavy watershed management, and Oda watershed, with no watershed management.
Results have shown that in the upstream area of Guguf catchment, intensive watershed management contributed to reduce soil erosion, creating new pasture areas and increase soil moisture, for agricultural and

livestock production. Because of wadi flows regulation, upstream community started to implement new conventional irrigation systems. Guguf upstream and downstream farmers reported emerging conflicts and downstream flow reduction because of new irrigation development.

There is no doubt that intense rainwater management and rainwater harvesting can enhance ecosystem services in Raya Valley wadi catchments. The increase of livestock production triggered by the creation of new grazing lands represent a development opportunity. However, the stabilisation of wadi flows regime may lead to emerging conflicts between upstream and downstream users, if all or most of the gentle runoff produced as an effect of watershed conservation is abstracted in the upstream parts. On the other hand, in catchments where no watershed management is in practice, most of the runoff will be delivered directly to downstream FBFS, but causing also damages and flooding. Together with watershed management, also a wise policy for water allocation is required, to share benefits of newly available gentle flows between FBFS and upstream irrigation systems. New research-action is also required to capture the complexity of new upstream – downstream dynamics.

Acknowledgments

Authors are grateful to CGIAR WLE Program, Mekelle University and the Italian Ministry of Foreign Affairs for the funding that made possible the research on the field, and to the people of Raya Valley, farmers and agricultural officers, that shared their time, expertise and knowledge, to inform the study findings and results.

References

Chambers, R., 1994, Participatory rural appraisal (PRA): Analysis of experience, World Development, 22(9), 1253–1268.

Descheemaeker, K., Mapedza, E., Amede, T., Ayalneh, W., 2010, Effects of integrated watershed management on livestock water productivity in water scarce areas in Ethiopia, Phys. Chem. Earth 35, 723–729.

Dile, Y. T., Karlberg, L., Temesgen, M., Rockström, J., 2013, The role of water harvesting to achieve sustainable agricultural intensification and resilience against water related shocks in sub-Saharan Africa, Agriculture, Ecosystems and Environment, 181(2013), 69–79.

Dile, Y. T., Karlberg, L., Daggupati, P., Srinivasan, R., Wiberg, D., Rockström, J., 2016a, Assessing the implications of water harvesting intensi fi cation on upstream – downstream ecosystem services: A case study in the Lake Tana basin, Science of the Total Environment, 542, 22–35.

Dile, Y.T., Rockström, J. & Karlberg, L., 2016b, Suitability of Water Harvesting in the Upper Blue Nile Basin , Ethiopia : A First Step towards a Mesoscale Hydrological Modeling Framework, Advances in Meteorology, 1–12.

Glendenning, C.J., Vervoort, R.W., 2011, Hydrological impacts of rainwater harvesting (RWH) in a case study catchment : The Arvari River , Rajasthan , India Part 2 . Catchment-scale impacts, Agricultural Water Management, 98(4), 715–730.

National Regional State of Tigray, 1997, Integrated Food Security Program for Drought Prone Areas (IFSP-DPA) 1998 – 2002: Main Summary Document, Mekelle, Ethiopia.

Narayanasamy, N., 2009, Participatory Rural Appraisal Principles, Methods and Application, SAGE Publications Pvt. Ltd.

PRA programme Egerton University, 1995, PRA Field Hand- book for Participatory Rural Appraisal Practitioners, Njoro, Kenya, Egerton University.

Rockström, J., Barron, J., Fox, P., 2002, Rainwater management for increased productivity among small-holder farmers in drought prone environments, Physics and Chemistry of the Earth, 27(11–22), 949–959.

Van Steenbergen, F., Lawrence, P., Mehari, A., Salman, M., Anderson, I.M., Nawaz, K., Ratsey, J., 2010, Guidelines on spate irrigation, FAO, Rome

Water Land and Ecosystem program CGIAR, 2016, Harnessing floods to enhance livelihoods and ecosystem services: Ethiopia Report, Year 1.

Welderufael, W.A., Woyessa, Y.E., Edossa, D.C., 2013, Impact of rainwater harvesting on water resources of the modder river basin , central region of South Africa, Agricultural Water Management, 116, 218–227.

Yazew, E., Gebru, T., G/Egziabher, T., Mezgebu, A., Fessehaye, D., Habtu, S., Haile, A., Van Steenbergen, F., Wester, F., 2014, Spate Irrigation Network Overview Paper 13: Spate Irrigation Systems in Raya Valley (Ethiopia).