COLLECTION AND ANALYSIS OF WATERSHED HYDROLOGICAL DATA (PRECIPITATION, RUNOFF, SEDIMENT AND NUTRIENTS YIELDS)

Reducing Land Degradation and Farmers' Vulnerability to Climate Change in the Highland Dry Areas of North-Western Ethiopia

TECHNICAL REPORT OF EXPERIMENTAL ACTIVITIES

JUNE 2016

Implemented by

ICARDA
Science for Better Livelihoods in Dry Areas

In collaboration with

ARARI

BOKU

Funded by

AUSTRIAN DEVELOPMENT COOPERATION

Contributes to

CGIAR RESEARCH PROGRAM ON Dryland Systems

About the Project

Implemented By

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01 April 2013 to 30 June 2016

Project coordinator

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Partners

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About ICARDA

The International Center for Agricultural Research in the Dry Areas (ICARDA) is the global agricultural research Center working with countries in the world's dry and marginal areas, supporting them for sustainable agriculture development to help increase their productivity, raise incomes for smallholder farmer families, improve rural nutrition and strengthen national food security. With partners in more than 40 countries, ICARDA produces science based-solutions that include new crop varieties (barley, wheat, durum wheat, lentil, faba bean, kabuli chickpea, pasture and forage legumes); improved practices for farming and natural resources management; and socio-economic and policy options to enable and empower countries to improve their food security. ICARDA works closely with national agricultural research programs and other partners worldwide in Central Asia, South Asia, West Asia, North Africa, and Sub-Saharan Africa.

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Synthesis

Activity type: Monitoring

Report submitted by: Muuz Gebretsadik, Project coordinator at GARC (muuzgg@yahoo.com)

Summary report

Specific objective of this activity was to monitor the meteorological variable, surface hydrology and sediment and nutrients (available P, Total N and Organic carbon) yields at the Gumara-maksegnit watershed and to use these data for the calibration and validation of hydrological and bio-economic models and as reference information for similar watersheds. The selected watershed Gumara Maksegnit watershed has an area of 5,600ha and includes several sub-watersheds among which Abakaloye and Ayaye with respective surface area of about 32ha and 24ha, which were selected for sub-watershed scale monitoring. Monitoring and assessment have been conducted since 2011, generating a 6 years long data series that is being used for calibration and validation of hydrological models. This report summarizes the data collected during the project duration (2013 to 2015) at both watershed and sub-watershed scale. Long term partners of this specific activity are ICARDA, ARARI, and Boku. It has to be noted that the data presented here are currently being elaborated for publication and fr reasons of space are incomplete. This report is only aimed at illustrating the nature and quality of the dataset, and to broadly visualize the information collected.

Schematic summary of information

Location (locality, town, province….):	Dogola-chinachaye and Dinzaz kebeles
Gumara-Maksegnit watershed	
Longitude:	37o 33' 55'' to 37o 35' 39'',
Latitude:	12 o 26'44'' to 12 o 25'41.7''
Altitude:	1933 to 2852 m a.s.l.
Abakaloye sub-watershed	
Longitude;	1374440 to 1373633,
Latitude;	0345953 to 0346692
Altitude	1991 to 2134m a.s.l.
Ayaye sub-watershed	
Longitude;	1373856 to 1374583
Latitude;	0346633 to 0347108
Altitude	2012 to 2136m a.s.l.
Period of implementation:	June, 2013 to March, 2016
Duration of trials:	3 years, 3 rainy seasons
Activity leader(s):	Muuz Gebretsadik, Atikilt Abera
Other researchers involved:	Nigus Demelash, Hailu Kinde
Technical staff involved:	Melkamu Adane

1 Background and rationale

Hydrology is a science built on observations and measurements. Hydrologic theories either has emerged from insights gained through analysing data or have been confirmed through data that support the theory. Soil nutrient loss from the watershed area through runoff was a great concern of the project due to the importance of these variables in the agricultural production. Identifying how severe is the loss of the soil chemical components can influence the decision makers. The need to develop accurate long-term hydrologic data bases to improve scientific understanding is vital. An example is the development of flow gages and water quality sampling stations that can become benchmarks against which changes in rivers caused by climate change and human development could be evaluated. The expanding role of models for water management and environmental monitoring and prediction has resulted in the need for continuous time (storm and inter storm) modelling of stream discharges and river basin water balances. Nonetheless, long-term accurate data sets are needed to determine site-specific constants for hydrological models.

2 Objective

The main objective of this research activity were to monitor and assess the climate, surface hydrology and soil nutrient loss of Gumara-Maksegnit watershed and using this monitored data for calibration and validation of hydrological models in the study and for other similar watersheds.

3 Experimental Methods

Description of the watershed and sub-watersheds

The research was conducted in the Gumara-Maksegnit watershed in Gondar Zuria district in North Gondar Administrative zone. The geographical location of the watershed ranges from 37033'20''-37037'10'' longitude and 12024'25''-12030'41''latitude. The altitude ranges from 1953-2851m above sea level. The area has a temperature ranging from 11 to 32 ºC. Mean annual rainfall ranges from 995 to 1175 mm. The study area in described in detail in the book published by the project in 2015 (Ziadat & Wondimu, 2015).

Abakaloye sub-watershed is located within UTM coordinates of 1374440 to 1373633 North and 0345953 to 0346692 East. The elevation ranges between 2134 and 1991masl. The area of the sub-watershed is about 36ha, of which up to 60% is cultivated land. Ayaye sub-watershed is in the lower part of the Gumara-maksegnit watershed, within UTM coordinates of 1373856 to 1374583 North and 0346633 to 0347108 East. The elevation in the highest and lowest point of the watershed is 2136 and 2012masl respectively. Its area is about 25ha, of which about 71% is cultivated land. Detail watershed assessment was conducted to identify the land use type, and to map it using Geographic Information Systems (GIS). A detailed digital elevation model was created for the two sub-watersheds by recording precise geographic coordinates and elevation using a total station. For Abakaloye sub-watershed, predominant crops during the rainy season are cereal crops such as: sorghum, teff, faba-bean, lentil, etc. The following figures show some maps that summarize some land use and hydrological features of the sub-watersheds.

Table 1: Land use types of Abakaloye sub-watershed with their relevant area coverage

Id	Land use	Surface Area (m^2)	Areal coverage (%)
1	Cultivated land	220,000.00	60.9
2	Grassland	30,000.00	8.3
3	Grazing land	77,000.00	21.3
4	Gully	17,000.00	4.7
5	Homestead	17,000.00	4.7
Total		361,000.00	100.0

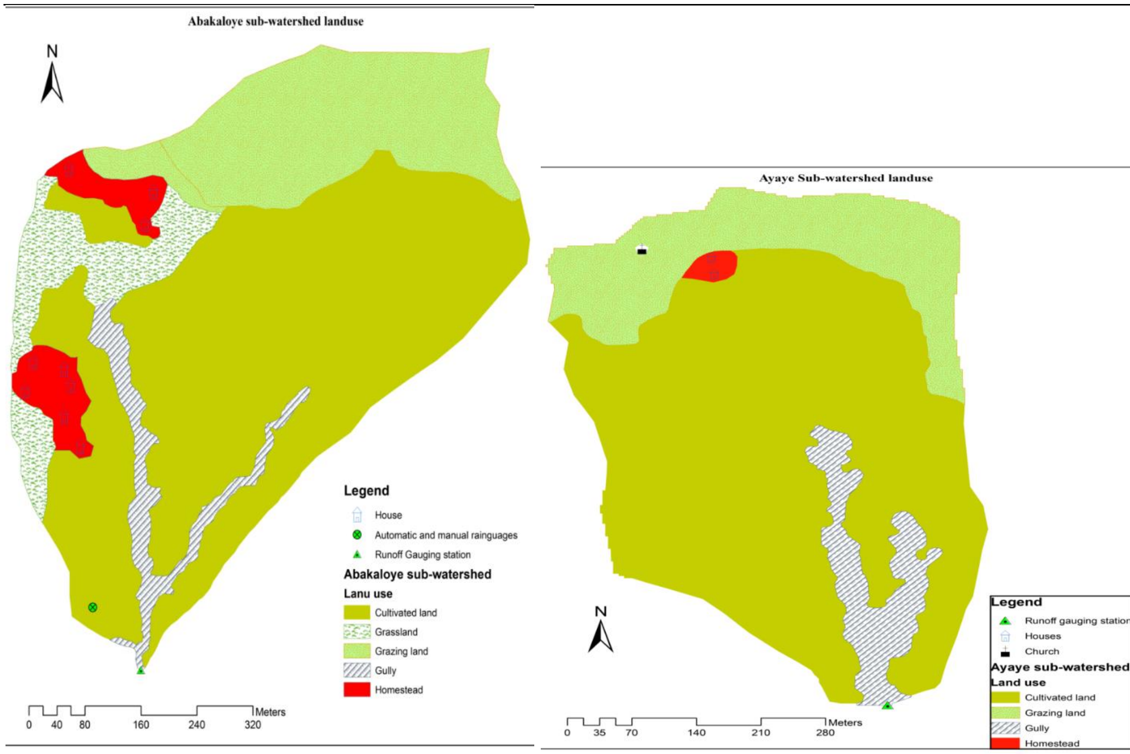

Figure 1: Land use types of Abakaloye sub-watershed (L) and Ayaye sub-watershed (R)

Table 2: Land use types of Ayaye sub-watershed with their relevant area coverage

Id	Land use type	Surface Area (m^2)	Areal coverage (%)
1	Cultivated land	180,000.00	71
2	Grazing land	52,000.00	20.4
3	Gully	20,000.00	7.9
4	Homestead	1,800.70	0.7
Total		253,000.00	100.0

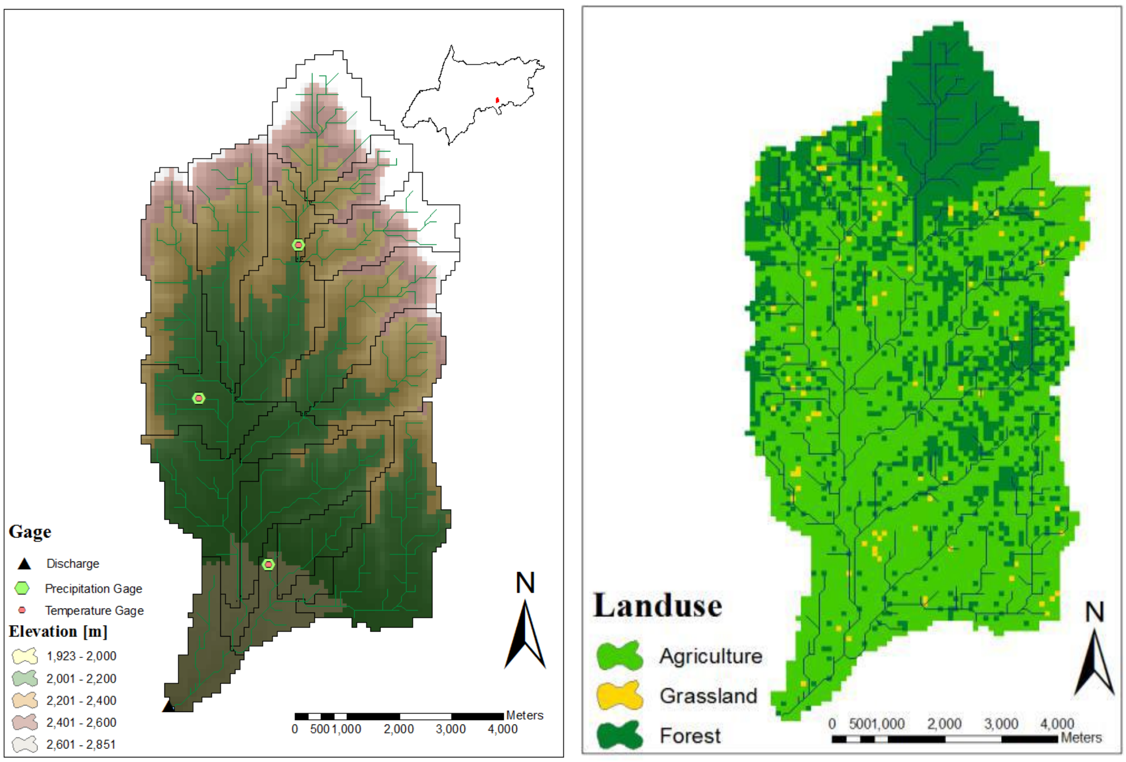

Figure 2: Hydrology (left) and land use (right) of Gumara-maksegnit watershed

Measurements and monitoring

The variables measured in the three catchments are listed in figure 5. The materials employed to fulfil quality measurements in the watershed and in each sub-watersheds were: fixed cross sectioned rectangular weir, WL-16 Water Level Logger, DOERR automatic digital camera, Global Water Flow Probe, Hobo rain-gauge, 1liter capacity plastic bottles, ISCO® 3700 Series Automatic Sampler for sequential collection. In order to have reliable and consistent hydro-meteorological data with better accuracy and representativeness, the main watershed's and sub-watersheds' outlets were constructed with appropriate weirs, and these weirs were equipped with purposely selected electronic devices that measure the targeted parameters. The targeted hydro meteorological parameters were surface runoff, sediment load and rainfall. For each variable, convenient devices were used to measure their respective parameter.

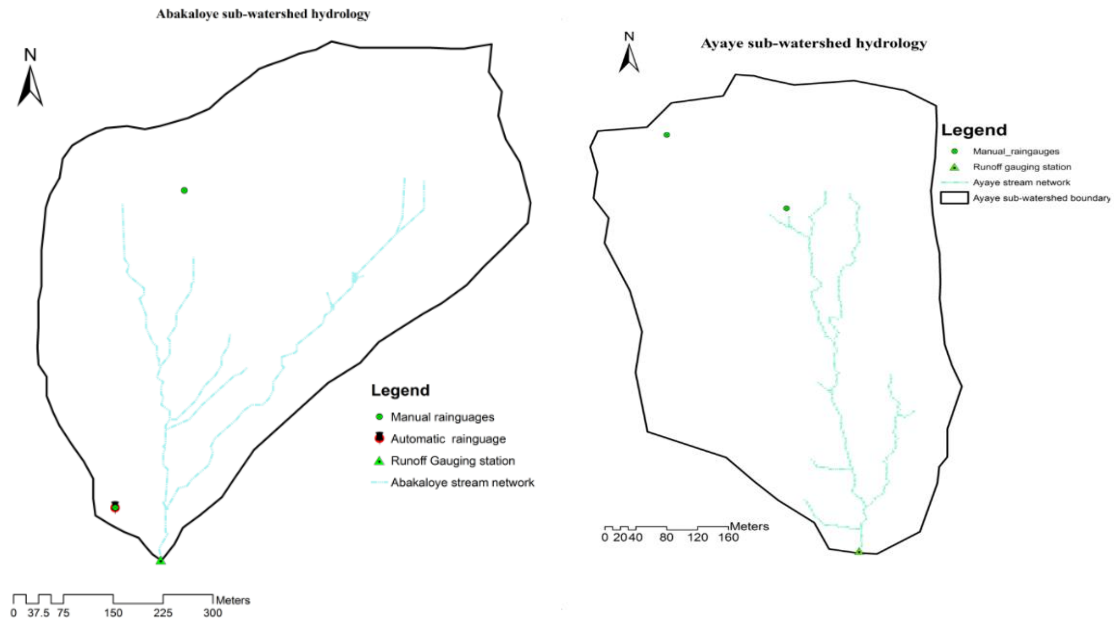

Figure 3: Stream network of Abakaloye (left) and Ayaye (right) sub-watershed

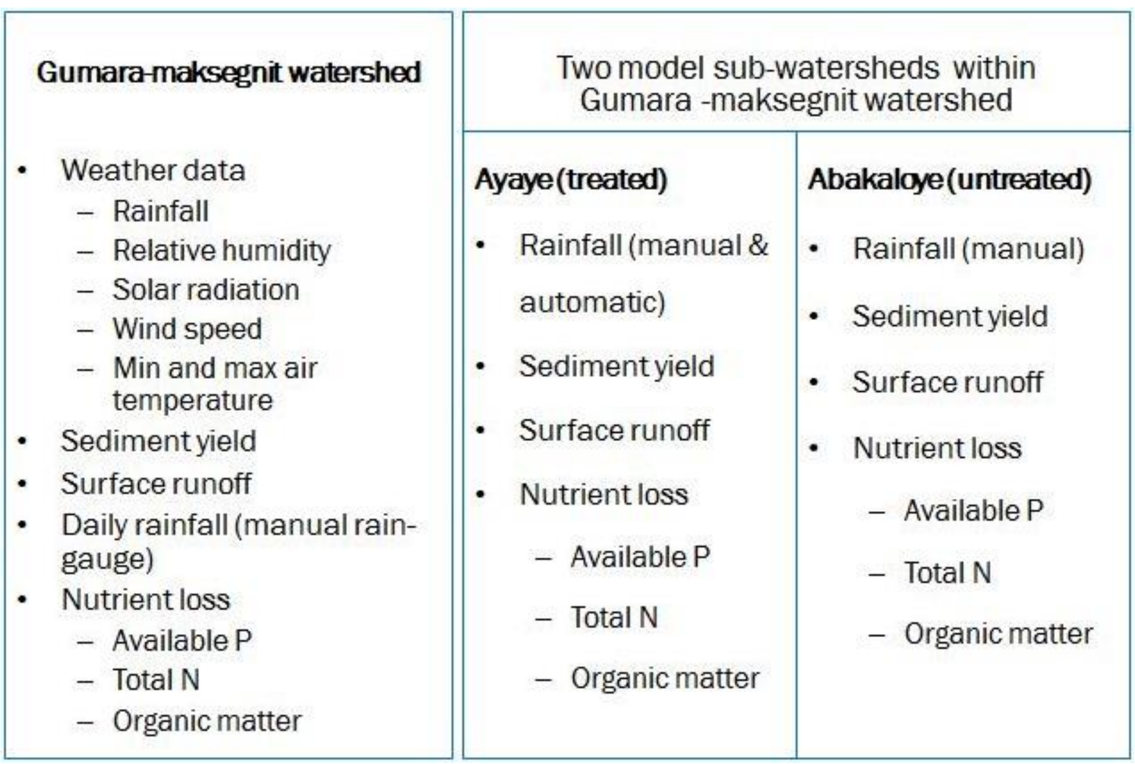

Figure 4: Variables measured in the three catchments. Remark: N=nitrogen, P=phosphorus

Pressure transducers were used to measure runoff level; turbidity meter was used to measure sediment load; Hobo data logging rain-gauge was used to record rainfall amount, duration and intensity in the study area. Basic climatic variables other than rainfall, such as maximum and minimum air temperature, solar radiation, wind speed and humidity were monitored using automatic weather station. The automatic digital camera, DOERR, was not applied for the Gumara-Maksegnit watershed outlet. The important components of surface hydrology in this study area are surface runoff (over land flow) and suspended sediment concentration.

Table 3: Description of runoff and sediment load measurements in Gumara-Maksegnit watershed, and on the two sub-watersheds

Type of measurement	Measuring device/method	Specification of the device	Year of measurement*	Time resolution
Runoff	Manual	Observational reading	2013 to 2015	Three times per event
	Automatic digital camera	DOERR	2014 to 2015	5minute interval
	ISCO sampler	ISCO® 3700 Series Sampler	2014 to 2015	Summarized max., min. and average values
Sediment load	Manual	1litter capacity plastic bottle	2013 to 2015	3times per event
	ISCO	ISCO® 3700 Series Sampler	2014 to 2015	Summarized max., min. and average values

**Data of 2014 and before has been sent to ICARDA data base*

Surface runoff

In order to measure surface runoff, runoff measurement structures were constructed considering the wide range of discharges measurement in such small catchments. Considerations were also taken regarding the tolerance of the weir structure for sedimentation. The selected runoff measuring structure for both Abakaloye and Ayaye sub-watersheds is a triangular broad crested weir with truncated triangular control section.

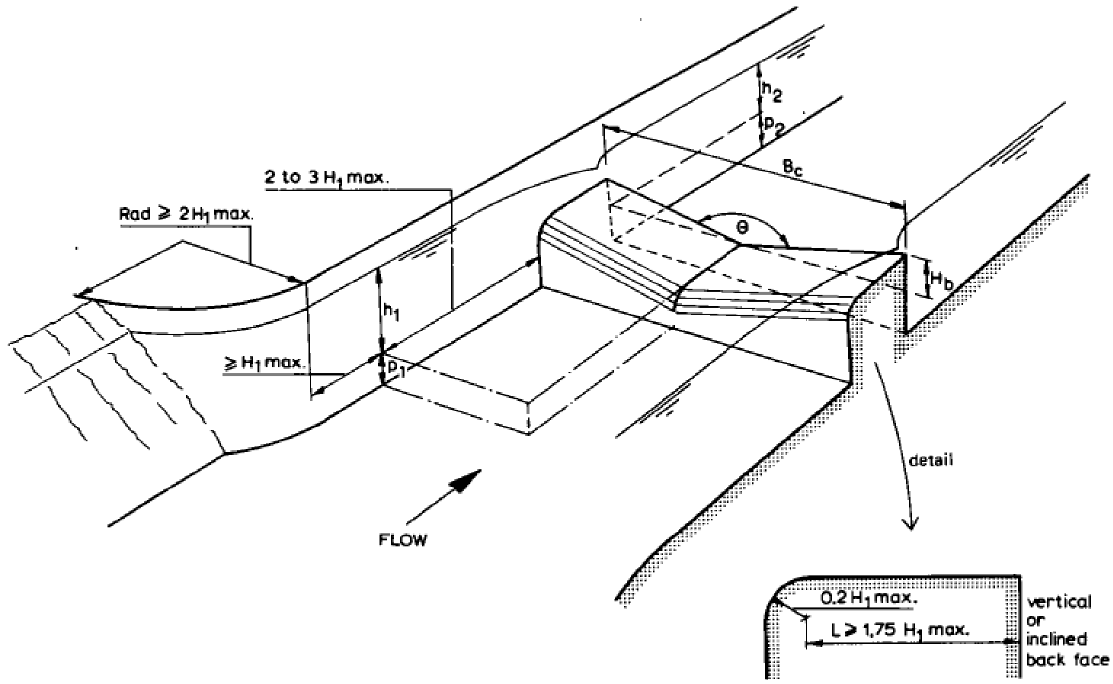

Figure 5: Broad-crested weir with truncated triangular control section

Two different equations were applied for this weir structure to make runoff estimation. Equation 1 is applied for conditions where runoff discharge is defined by the triangular (h1 ≤ 1.25Hb) and the second equation is valid for higher water levels (h1 ≥ 1.25Hb) in which the vertical side walls are considered. The Cd is the discharge coefficient, that depends on shape and type of the measuring weir while Cv is the velocity coefficient, those two equations are as follows:

$$Q = C_d C_v \frac{16}{25}\left[\frac{2}{5}g\right]^{0.5} \tan\frac{\theta}{2} h_1^{2.50}$$ ……………equation.1

$$Q = C_d C_v \frac{2}{3}\left[\frac{2}{3}g\right]^{0.5} B_c\left(h_1 - 0.5H_b\right)^{1.50}$$ … …equation.2

In order to measure surface runoff level (h1) Global water level logger was used from 2011 to 2012 The second method, only applied for 2014 and 2015 followed to get liable stage record data in time, is through the use of self-shooting digital cameras mounted in one side wall of the weir. To secure the surface runoff data loss due to technical and mechanical reasons, manual data record was done by observing the rise of runoff level. Runoff level was labelled in either wall situated near the stilling basin of the weir.

The recorded height values were used to develop rating curve as a graph in which flow discharge is plotted against its related water level. This curve was used to convert the measured water level into flow discharge. Equation 1 and 2 were simplified to equation 3 that fits the relevant water level (m) to discharge (m3/s) with coefficient of determination (R2) of 99. 6%.

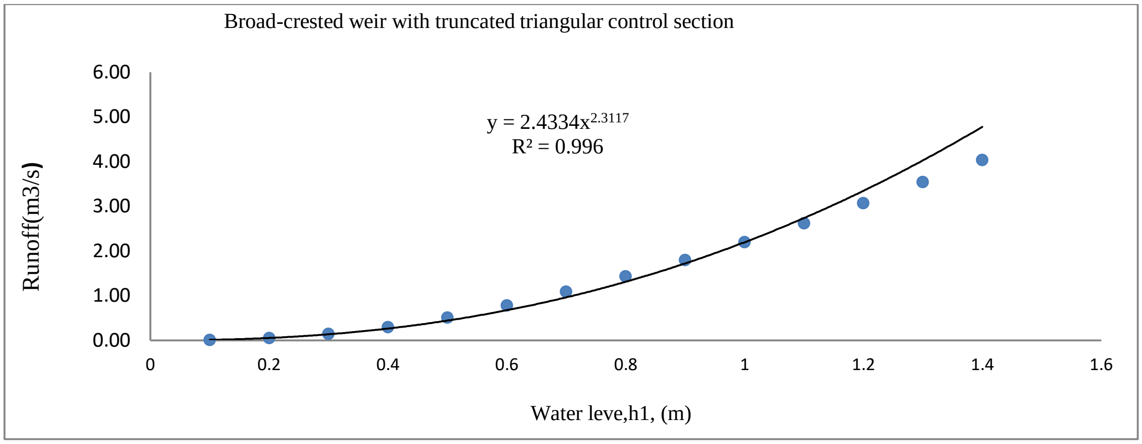

Figure 6: Fitting curve that relates water level (m) and runoff discharge (m3/s) for Abakaloye sub-watershed

$Q = 2.4334 h_1^{2.3117}$ equation.3

Where Q is runoff discharge (m3/s) and h1 is the water level (flow depth)

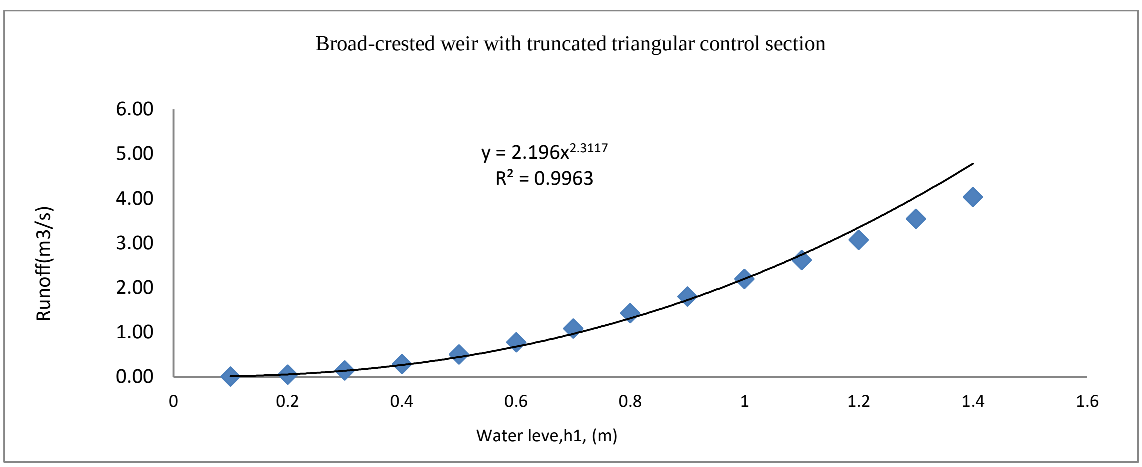

Figure 7: Fitting curve that relates water level (m) and runoff discharge (m3/s) for Ayaye sub-watershed

$Q = 2.196 h_1^{2.3117}$ equation.4

Runoff measurement was done in the outlet of Gumara-maksegnit watershed. The type of structure used to measure the cross sectional area was a rectangular fixed cross sectioned weir. Flow velocity in this cross section was measured using Global Water Flow Probe. The runoff discharge of Gumara-maksegnit watershed was therefore, determined from a rating curve developed using the measured velocity and cross sectional area of the fixed rectangular section. The rating curve found from this measurement is displayed in figure 8.

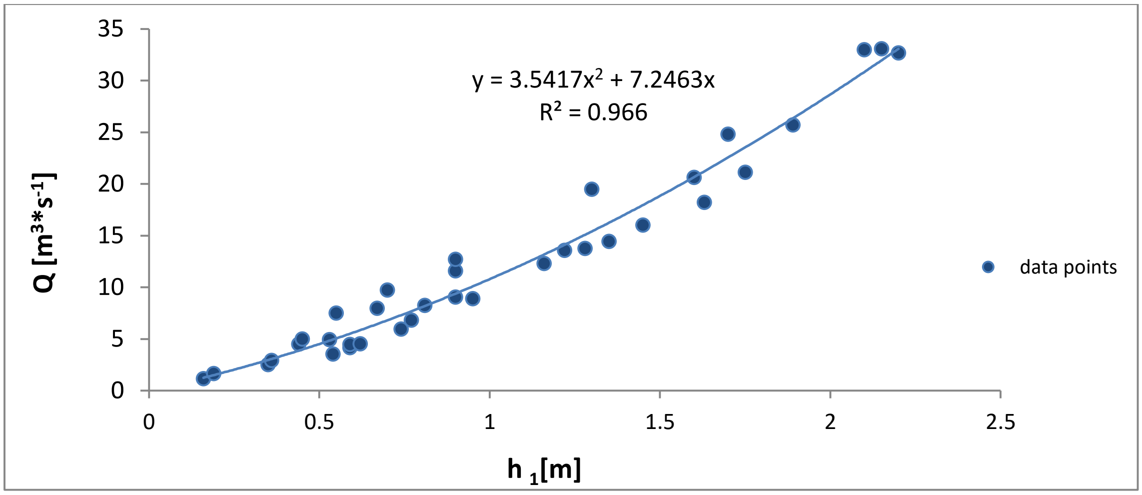

Figure 8: Water level versus runoff discharge, rating curve of Gumara-maksegnit watershed outlet rectangular shaped weir

$Q = 3.5417 h_1^2 + 7.2463 h_1$ equation.5

Suspended sediment load

Suspended sediment load (g/l) was also assessed from manually taken runoff sample three times per event in the years 2013 to 2015. Sampling time of this variable is near onset of runoff, on the peak and on late of the runoff event. The sampled runoff water is analyzed for sediment using filter type of Whatman Ashless, Grade 42 Filtration Paper. Total sediment lost per annum from the sub-watersheds (ton/ha) was determined from the total runoff left this watershed.

Soil nutrients loss

The major soil nutrients which were under monitoring in the watershed and sub-watersheds are total nitrogen, available phosphorus and organic carbon. Those variables were analysed from sampled runoff leaving the watershed through the outlet control section using plastic bottles of 1litter capacity. Analysis was done for total Nitrogen, available Phosphorus and Organic carbon in Gondar Soil Laboratory. Total nitrogen was determined using Kjeldhal; available phosphorus was analysed using Olsen and organic carbon was analysed using Walkely and Blalck method.

Climate

Except rainfall which was measured throughout the whole watershed, the other climatic variables were measured 1.5km away to the south of the watershed outlet.

Table 4: Climate data monitoring in Gumara-maksegnit watershed

Type of measurement	method	Availability in database *	Resolution/frequency of data collection	Location relative to the watershed
Rainfall	Manual recording	2013 to 2015	Daily	Systematically distributed within the watershed
Rainfall	Hobo data logging rain-gauge	2013 to 2015	5minutes interval	Systematically distributed in 3 locations of the watershed
Rainfall	Campbell Scientific	2013 to 2015	Every hour	1.5km away to south of watershed outlet
Temperature	Campbell Scientific	2013 to 2015	Every hour	
Solar radiation	Campbell Scientific	2013 to 2015	Every hour	
Relative humidity (%)	Campbell Scientific	2013 to 2015	Every hour	
Wind speed(m/s)	Campbell Scientific	2013 to 2015	Every hour	

** Data of 2014 and before has been sent to ICARDA data base*

Rainfall information was recorded using hobo tipping bucket and Campbell Scientific Automatic Weather Station. Hobo tipping bucket rain-gauges were also installed in three purposely selected locations of the watershed. The purposive sampling site selection was based on evenness of distribution, location representativeness and their nearness to safe areas. The sampling time in the hobo depends upon the rainfall intensity. The working mechanism of these gauges is through counting water drops equivalent to 0.2 mm per drop which is recorded on magnetic tape or in solid state memory systems.

Manually collected daily rainfall information of the watershed was done with temporally employed data collectors. The data collectors do collection of rainfall once a day at 7:00AM in the morning using plastic non-recording type rain gauge. These rain-gauges were located throughout the watershed in purposively scattered locations that are relatively secured.

Both minimum and maximum air temperatures of the watershed were recorded using the automatic weather station installed 1.5km away from the outlet of Gumara-Maksegnit watershed. The instrument was adjusted to record both minimum and maximum temperatures in an interval of one hour. The same procedure was used to record solar radiation, relative humidity and wind speed.

Table 5: Rainfall measurement methods in Gumara-maksegnit watershed

Measuring device/method	Measurement time*	Time resolution
Manual rain-gauges	2013 to 2015	Daily
Automatic weather station	2013 to 2015	Every hour/every day
Automatic hobo logger tipping bucket	2013 to 2015	Varies as per the rain intensity (seconds to minutes interval)

** Data of 2014 and before has been sent to ICARDA data base*

MS Excel 2010 was used to estimate the rainfall on each event and on each day out of the tipping buckets with hobo data logger. The rainfall out of the automatic weather station was summarized in daily basis automatically on the instrument. Graphs, tables and descriptive statistics were applied to visualize the results for of each variable.

4 Results & Discussion

Rainfall, temperature, radiation, wind at Gumara-Maksegnit watershed

Figure 9, displays a rainfall distribution of an area which is 1.5km to south the watershed. Figure 10 shows the rainfall amount in the three automatic raingauges as measured in 2015.

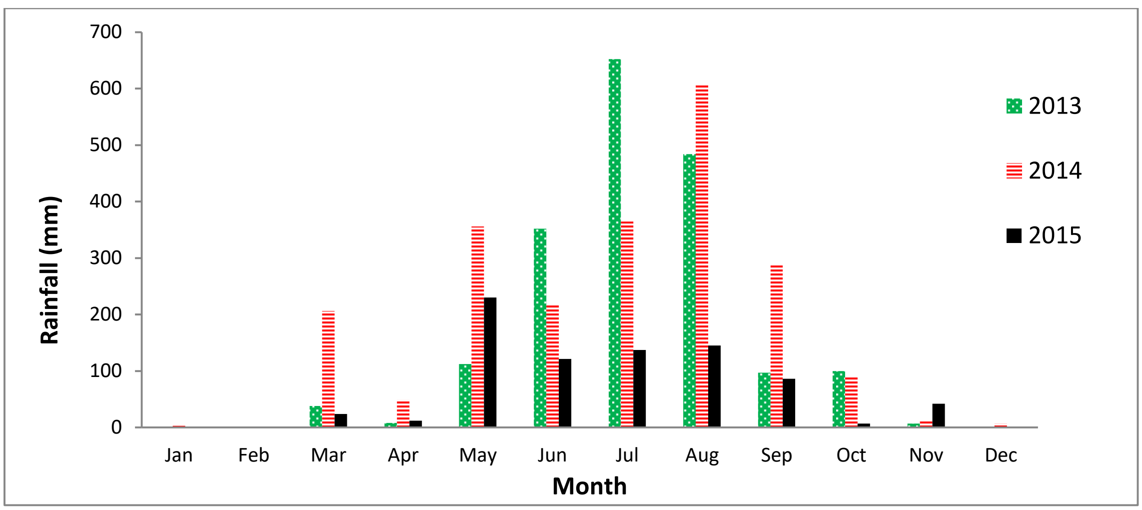

Figure 9: Monthly rainfall distribution (mm) in the year between 2013 and 2015, from automatic weather station

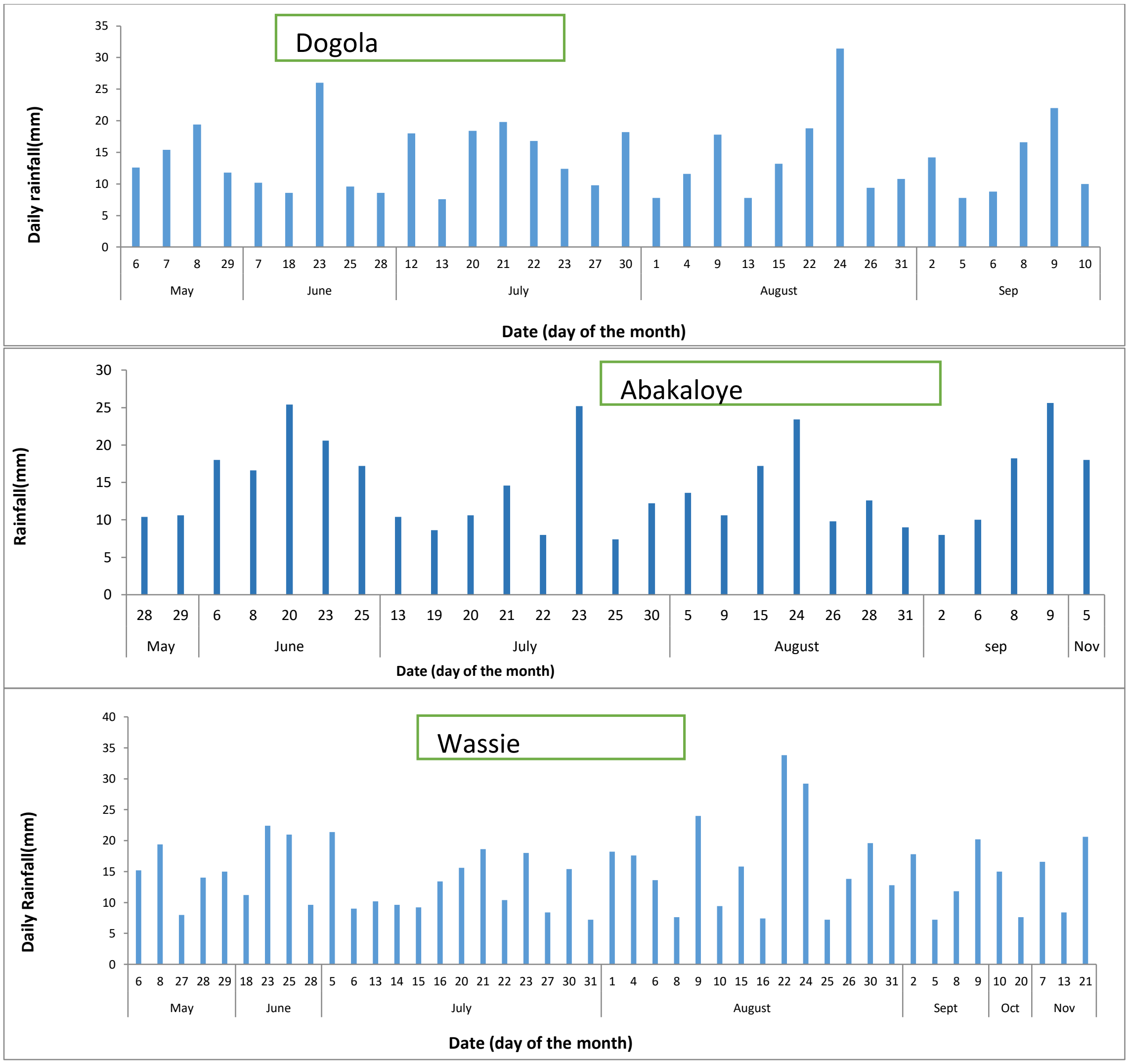

Figure 10: Daily rainfall of Gumara-Maksegnit watershed as measured at Abakaloye, Dogola and Wassie sites, 2015.

Minimum and maximum temperatures (figure 11), solar radiation (figure 12) and wind speed (figure 13) were measured in the study area from 2013 to 2015.

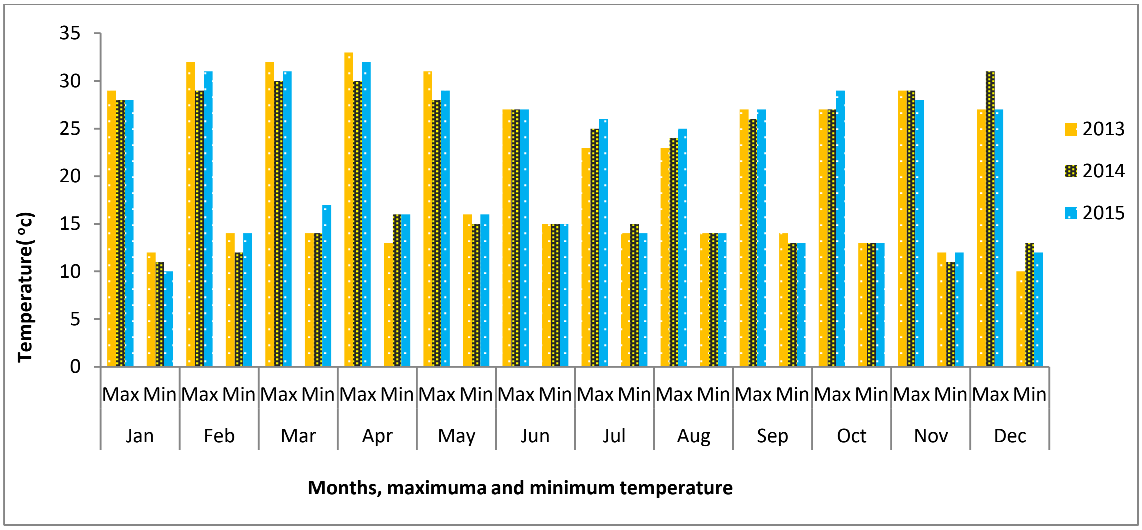

Figure 11: Maximum and minimum monthly temperature in the year 2013 to 2015

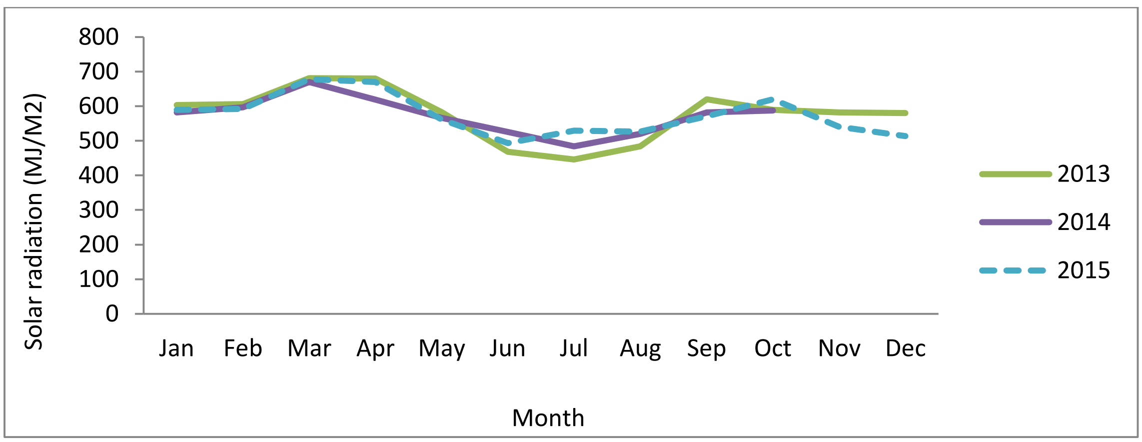

Figure 12: Total solar radiation in the study area (MJ/m2) in between 2011 and 2015

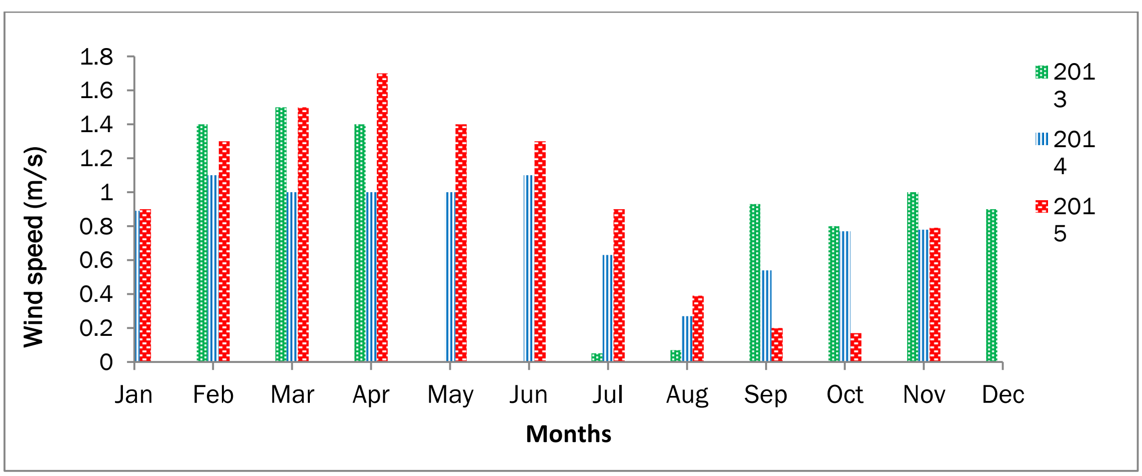

Figure 13: Average wind speed (m/s) in between 2013 and 2015

Surface hydrology of Gumara-Maksegnit watershed

Tables 6 and 7 show the temporal distribution of rainfall, runoff, total surface runoff and sediment load (Table 6), and nutrients (Table 7) recorded at the outlet of the Gumara-Maksegnit watershed.

Table 6: Temporal distribution of rainfall, runoff (mm), total surface runoff (m3) and sediment load (g/l)

Year	Month	Rainfall (mm)	total surface runoff (m^3)	Runoff (mm)	Sediment load (g/l)	Remark
2013	June	121	975,558	17	37.7	Taken since 15/6/2013
	July	255	2,116,269	38	27.0	
	Aug	295	4,444,429	79	20.5	Taken up to 16/08/2013
	Sep	36	NA	NA	NA	
2014	June	10	NA	NA	NA	
	July	216	356,797	6	8.65	Since 14/07/2014
	Aug	236	3,842,960	69	12.6	
	Sep	97	953,696	17	8.32	Taken up to 22/09/2014
2015	June	66	91,955	2	59.00	Taken since 25/06/2015
	July	205	736,010	13	24.10	
	Aug	415	1,050,110	16	36.60	
	Sep	95	312,186	6	43.30	Taken up to 10/09/2015

Table 7: Temporal distribution of soil nutrients (total nitrogen, available P and organic carbon)

Year	Month	Organic carbon (%)	Total Nitrogen loss (%)	Total available Phosphorus loss (ppm)	Remark
2013	June	1.6	0.12	6.92	
	July	1.4	0.11	6.24	
	Aug	1.4	0.10	6.52	
	Sep	0.7	0.07	4.78	
2014	June	NA	NA	NA	
	July	3.79	0.19	23.04	
	Aug	2.62	0.17	15.28	
	Sep	2.61	0.12	16.86	
2015	June	1.49	0.17	27.35	
	July	1.42	0.13	22.90	
	Aug	NA	NA	NA	
	Sep	1.45	0.14	24.21	

Rainfall, temperature, radiation, wind at Ayaye and Abakaloye sub-watersheds

Rainfall

Daily data are available for stations located at sub-watersheds. Table 8 shows seasonal average rainfall data.

Surface hydrology of the sub-watersheds

Runoff water level in the weirs was measured for both sub-watersheds from 2013 to 2015. However, lately the morphology of the weirs in the two sub-watersheds has changed, because their stilling basin was filled with sediment. For this reason equation 3 and 4 can't be applied for the latest data. These will be re-processed after a new calibration of the rating curves for the sub-watersheds will be determined.

5 REFERENCES

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Klik, A., Strohmeier, S., Schuerz, C., Brenner, C., Zehetbauer, I., Kluibenschaedl, F., Schuster, G., Ziadat, F., Bayu, W., 2015. Monitoring of surface runoff and soil erosion processes in the Gumara-Maksegnit watershed – Ethiopia, in: Ziadat, F., Bayu, W. (Eds.), Mitigating land degradation and improving livelihood: An integrated approach. Rutledge, Taylor & Francis Group, New York, pp. 127-152.

***NOTE**: The data presented in this report are currently being elaborated for scientific publication, thus some of them are not final. The aim of this report is to summarize the nature and quality of the activities conducted and of the dataset generated, and to illustrate the main results obtained.*

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Science for Better Livelihoods in Dry Areas