IWMI Research Report

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A Participatory Approach for Hydrometeorological Monitoring in the Blue Nile River Basin of Ethiopia

Birhanu Zemadim, Matthew McCartney, Simon Langan and Bharat Sharma

IWMI International Water Management Institute

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Front cover photograph shows Monitoring shallow groundwater level in Meja watershed, Jeldu District, Oromia Region, Ethiopia (Photo: Birhanu Zemadim, 2011).

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Project

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Contents

Acronyms and Abbreviations

ARARI	Amhara Regional Agricultural Research Institute
AWS	Automatic Weather Station
CPWF	CGIAR Challenge Program on Water and Food
EIWR	Ethiopian Institute of Water Resources
GPS	Global Positioning System
IP	Innovation Platform
ITCZ	Inter-Tropical Convergence Zone
IWMI	International Water Management Institute
MoWE	Ministry of Water and Energy
NHS	National Hydrological Services
NMA	National Meteorology Agency
PT	Pressure Transducer
RMS	Rainwater Management Strategies
RWH	Rainwater Harvesting
SWAT	Soil and Water Assessment Tool

Summary

The continuous monitoring of hydrological and meteorological variables is a prerequisite for informed water resources management. However, in many developing countries, such as Ethiopia, observational networks remain very scarce. Even those in existence are rarely adequately maintained and many have deteriorated over the past decades. One possible way of enhancing monitoring networks is through the active involvement of local stakeholders and communities.

This report describes the development of hydrometeorological monitoring networks in three watersheds in the highlands of the Blue Nile River Basin of Ethiopia: Dapo (18 km^2), Mizewa (27 km^2) and Meja (96 km^2). The aim of establishing these networks was to provide high-quality data to inform rainwater management strategies that will help to improve the livelihoods of farmers. In all three watersheds, relevant stakeholders and communities participated in the planning, installation and management of the networks.

The networks were designed and installed between May and August, 2011. Both local people and national experts participated in this by providing information on equipment design, methods of installation, and good and potentially poor locations (e.g., in relation to flooding) as well as information on the best sites in terms of access and safety.

Manual and automatic data collection commenced immediately after installation of the networks. Local communities were involved in the collection of much of the manual data, obtained daily. More frequent, hourly and even sub-hourly measurements were obtained using automatic instruments. Insights derived from the research were fed back to the communities through 'learning alliances' developed in each of the three watersheds.

This participatory approach proved to be beneficial for several reasons. First, it instilled trust and goodwill amongst the communities. Second, it provided the opportunity for local people to gain insights into the hydrological regime of their locality, which in turn contributed to a better understanding of the likely impacts of different rainwater management strategies. Third, it contributed to the establishment of a conducive atmosphere for the flow of knowledge between researchers and the communities, and vice versa.

Currently, discussions are ongoing with four universities (Addis Ababa, Ambo, Wollega and Bahir Dar), in conjunction with regional agricultural research centers and the Ministry of Water and Energy (MoWE), to transfer the monitoring networks and maintain community monitoring activities sustainably in the future.

A Participatory Approach for Hydrometeorological Monitoring in the Blue Nile River Basin of Ethiopia

Birhanu Zemadim, Matthew McCartney, Simon Langan and Bharat Sharma

Introduction

The monitoring of hydrological and meteorological variables from watersheds is one of the principal tasks of hydrology and water resources management. Hydrological and meteorological data are the basis of hydrological science (Rodda 1995; Vorosmarty et al. 2001). High-quality hydrological data are also needed to support decisions on rainwater management strategies and water allocation practices (Gomani et al. 2010).

Despite the recognized importance of hydrological and meteorological data, collection and sharing of data are not straightforward. Both technical and financial constraints hamper data collection and sharing efforts. Technical constraints relate to the size of the watersheds being monitored, type of monitoring equipment used and availability of skilled labor. National hydrometric networks tend to focus on larger river basins (> 1,000 km^2) which, whilst being appropriate for water resources assessment, are inadequate for hydrological research. To gain insights into hydrological processes, monitoring at much greater resolution (i.e., typically catchments < 100 km^2) is necessary. Financial constraints relate not only to the capital cost of sophisticated monitoring equipment, but also to the ongoing costs of maintenance, often in remote locations. These problems are exacerbated in developing countries, such as Ethiopia, where both the financial and human capital needed to establish and maintain good monitoring networks are in short supply.

Very often, involvement of the local community and other stakeholders is neglected in the establishment of hydrological monitoring networks. Most research institutions engaged in biophysical research tend to pay little attention to the engagement of local communities and other stakeholders in research design and implementation (Kongo et al. 2010). Yet, the involvement of these people in establishing and contributing to such networks, and indeed any management intervention at a watershed scale, is key to their reliability and a prerequisite for long-term sustainability (Gomani et al. 2010).

Past studies have reported several constraints to establishing hydrological monitoring systems (Meirovich et al. 1998; Mul 2009). The most commonly reported problems are (i) installation of equipment in catchments where little is known about the catchment characteristics, (ii) theft and vandalism, (iii) post-installation damage due to floods or other natural events, and (iv) institutional and policy barriers that hinder operation and maintenance of monitoring stations.

These problems arise, in part, due to the lack of local stakeholder involvement in the establishment and operation of hydrological monitoring systems. Monitoring is usually a task carried out by specialized agencies such as the National Hydrological Services (NHS). These agencies have their own technicians, staff, and procedures for network design and implementation. In addition to a lack of perceived relevance, documented reasons for failure to establish community involvement in monitoring networks are complexity of the technology, conflicting information, institutional factors, lack

of flexibility, the transaction costs (both financial and human capital) of involving communities, and incompatibility with other aspects of local farming and livelihood objectives or management (Sturdy et al. 2008).

In recent years, there have been some successful examples of data collection at watershed scale, with the involvement of various stakeholders (e.g., Gomani et al. 2010; Kongo et al. 2010; Laurent et al. 2010; Munyaneza et al. 2010; EFLUM 2011; STRI 2011). In places where the hydrological monitoring activities were undertaken, local communities were consulted and involved in both the establishment and maintenance of the networks. These efforts are deemed to have been effective, in part, because a number of different stakeholders were consulted and they contributed in a useful manner to the monitoring activities from the commencement of the work.

The study reported here focused on the establishment of monitoring networks in three watersheds in the Blue Nile River Basin of Ethiopia. These networks were established to provide data to assist in the design and implementation of rainwater management strategies. Three districts, which are administrative subdivisions encompassed within regional administrations, were selected to represent different locations and dominant agroecological zones. A watershed was selected from each district to conduct biophysical research. The objectives of establishing monitoring networks in the three watersheds were to:

- monitor a wide range of hydrological and meteorological processes, in order to gain an in-depth understanding of the hydrological regime of the watersheds;
- establish, in collaboration with various stakeholders, capacity to assess, monitor and manage water and environmental resources in the local communities; and
- provide an opportunity for future hydrological research and capacity building.

In the current study, several stakeholders were engaged in the collection of both hydrological and meteorological data from 2011. In this report, 'stakeholders' refer to people from the Ministry of Water and Energy (MoWE), National Meteorology Agency (NMA), three universities located in proximity of the watersheds (i.e., Bahir Dar, Ambo and Wollega), regional research institutes and local communities. 'Local communities' are people who live in the watersheds and come from a range of backgrounds: farmers and their households, agricultural extension workers, farmers' representatives, tradespeople, local government officials and administrators, and other professional people as well as those involved in non-farm activities.

Review of a Participatory Approach for Establishing Watershed Monitoring Networks

Participatory research focuses on a process of sequential reflection and action, carried out with and by local people. Not only are the knowledge and perspectives of local people acknowledged, but they also form the basis for research and planning (Cornwall and Jewkes 1995). In the available literature, there are only a few case studies of the establishment of watershed monitoring networks through a community participatory approach. Not much experience exists outside of Europe and North America, in particular (Fagerström et al. 2003; Gomani et al. 2010; Kelkar et al. 2008; Kongo et al. 2010; Nare et al. 2006, 2011; Sang-Arun et al. 2006;

Souchère et al. 2010; Sturdy et al. 2008; Uysal and Atis 2010; Welp 2001).

In a few countries, such as Zimbabwe and South Africa, government policies and legislation encourage stakeholder participation in research design and implementation (Nare et al. 2006, 2011). Participatory approaches help stakeholders to share their views about the project, describe its relation to their environmental conditions (Sang-Arun et al. 2006; Souchère et al. 2010) and understand the principles of improved water resources management. It also helps to improve farmers' awareness of environmental problems and solutions as well as to link local and scientific knowledge (Fagerström et al. 2003). Communities can be engaged in several ways, ranging from conducting face-to-face discussions to understand stakeholder perceptions, to full engagement in the design and implementation of research projects.

Establishment of a hydrological monitoring network in a 2,780-km^2 watershed, located in the tropical climate region of Tanzania, involved local communities in the installation of equipment and data monitoring (Gomani et al. 2010). Monitoring included weather and streamflow data.

The establishment of a hydrological monitoring network in the Potshini watershed in Bergville District of South Africa was initiated in early 2004. The work involved smallholder farmers and other stakeholders from the initial preparatory stages to the actual construction of the various structures and instruments as well as their involvement in monitoring activities. The work was conducted in two nested watersheds, with areas of 1.2 km^2 (manually monitored) and 10 km^2 (automatically monitored). The network monitored streamflows, overland flow from experimental runoff plots, sediment load, shallow and deep groundwater bodies, volumetric soil moisture content, crop transpiration rates and meteorological variables (Kongo et al. 2010).

Also, in the Bergville District in South Africa, but in the Okhahlamba Local Municipality, a participatory approach was adopted to facilitate farmer-driven gardening experiments. The experiments were conducted in an area of 2.5 km^2 covering 400 homesteads. A range of equipment (i.e., rain gauges, wetting front detectors, nested watermark sensors and capacitance probes) was placed in the gardens of the six farmers that were chosen for the detailed case studies (Sturdy et al. 2008). The farmers recorded daily rainfall, irrigation timing and quantity, and wetting front detector activation events. This information was supplemented with laboratory-generated soil analyses and in-field soil hydraulic characterization tests. Data were used to estimate changes in water balances for different designs of garden beds over the summer. The data were also used to provide farmers with information on the optimal times to irrigate, and the amount of water that should be applied during irrigation events for the various designs of garden beds and irrigation methods chosen for the experiments.

The approach allowed farmers to systematically assess the value of the innovations they chose to implement while providing researchers with an avenue for learning about socioeconomic as well as biophysical influences on farmers' decisions. Also, this approach improved farmers' confidence and they were better able to explain innovative approaches to others. Similarly, researchers in the district were able to use farmers' manually collected data and observations to supplement laboratory-generated and electronically-recorded information on soil-water dynamics, in order to better understand water balances. It was reported that farmers who participated in the research and experimental process became proficient in gardening systems (Sturdy et al. 2008).

Conducting participatory workshops has been found to be a successful means of capturing perceptions of local communities regarding soil erosion in northern Thailand (Sang-Arun et al. 2006). The use of indigenous knowledge to improve existing practices and design a better water quality monitoring network was found to be successful in the Mzingwe watershed in Zimbabwe (Nare et al. 2006). In another example of participatory monitoring, the sharing of modeling results of surface runoff, soil moisture, lateral runoff and groundwater recharge was found to be an effective means of tracing past developments that have impacted the lives and

livelihoods of people in the Lakhwar watershed in Uttarakhand State of India (Kelkar et al. 2008). Krishanan et al. (2009) used the wisdom of well drillers to construct digital groundwater databases across the Indo-Gangetic Basin.

The development of a community-based river monitoring system in a sub-humid region of Mexico proved to be useful in monitoring suspended sediment yields (Duvert et al. 2011). To establish the optimum frequency of data sampling, intensive monitoring was conducted together with the local community over a year in four contrasting catchments (3 km^2 to 630 km^2). The study found that, for an accurate estimation of suspended sediment yield, a twice-daily sampling regime was required at the outlet of bigger catchments, but an hourly estimate was required in smaller catchments (3 km^2 to 12 km^2). The study concluded that, to strengthen linkages between local groups, management authorities and researchers, it is necessary to promote the development of community-based monitoring of catchments in Mexico and elsewhere in the world (Duvert et al. 2011).

There are issues and constraints as well. Out of the six farmers who were provided with rain gauges and encouraged to conduct their own monitoring and experiments in Bergville District in South Africa, only three were given the entire set of technical instruments. The other three failed to take notes and maintain records. Their failure was attributed to their involvement in other social activities and local employment (Sturdy et al. 2008). Hence, the participatory approach should be viewed as a developing paradigm or method in which there is a need for strong commitment from both researchers and stakeholders, and a need for good regular communication in order to ensure greater acceptance by the stakeholders concerned (Quinn et al. 2003; Sturdy et al. 2008).

The Study Areas

This study focused on three watersheds that are located in the highlands of the Blue Nile (known locally as the Abbay) River Basin. The Blue Nile River Basin is characterized by considerable spatial and temporal variability in hydro-climatic conditions. Within this wider basin, rainfall varies significantly with altitude and is, to a large extent, controlled by the movement of air masses associated with the Inter-Tropical Convergence Zone (ITCZ). There is considerable inter-annual variability, but rainfall increases from about 1,000 mm near the Sudanese border to between 1,400 and 1,800 mm over parts of the upper basin, and exceeds 2,000 mm in some places in the south (Awulachew et al. 2010).

The three watersheds (Figure 1; Table 1) were selected as sites to study the dominant hydrological processes and biophysical characteristics of the highland areas in the Blue Nile River Basin. The watersheds represent a gradient of farming types, land degradation and varying socioeconomic conditions. The following watersheds were selected for this study:

(i) Dapo watershed (18 km^2) in Diga District.

(ii) Mizewa watershed (27 km^2) in Fogera District.

(iii) Meja watershed (96 km^2) in Jeldu District.

The three study watersheds are characterized by high annual rainfall, but with considerable seasonal and inter-annual variability. Each year, the rain falls within a very short period of time (typically 4 months). Communities experience significant water shortages during the dry season as a result of poor and ineffective rainwater management practices (Ayana 2011; Megersa 2011; Taffese 2012). A description of the three watersheds is given below.

FIGURE 1. Location of the three study watersheds in the Blue Nile (Abbay) River Basin.

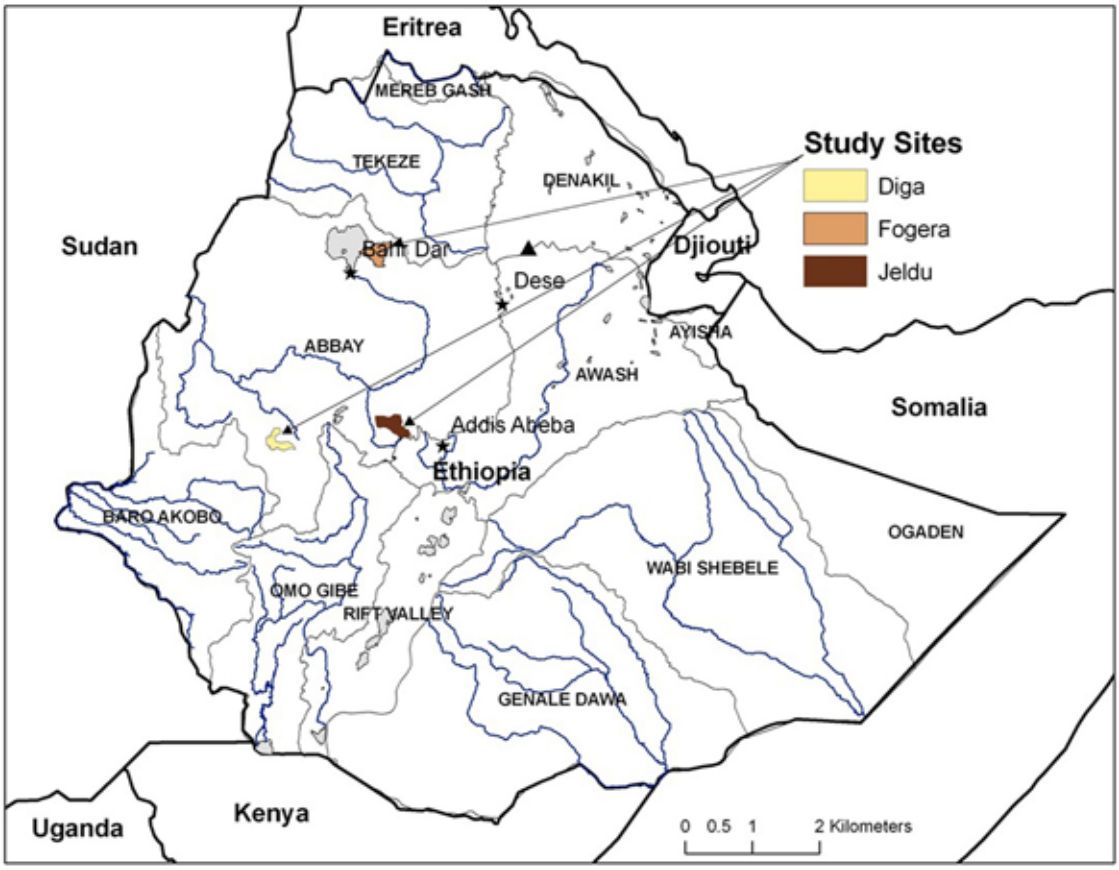


TABLE 1. Summary of the biophysical and social demographic characteristics of the three study watersheds.

Study watershed/ district	Watershed area (km^2)	Altitude range (masl)	Mean annual rainfall (mm)	Predominant farming systems and crops cultivated	Typical characteristics of the watershed
Dapo/Diga	18	1,200-2,342	1,376-2,037	In the lowland, the cultivation of maize and sorghum (mono-cropping) is practiced, with crop rotation every 3 to 4 years. In the midland, teff, millet and maize are important. Farming system: Mixed crop-livestock system.	Population pressure, deforestation, absence of soil conservation measures, overgrazing and local water scarcity.
Mizewa/ Fogera	27	1,784-2,400	974-1,516	Maize is the major crop cultivated followed by millet, teff and barley. Farming system: Mixed crop-livestock system.	Flooding is a regular challenge, and soil conservation structures are commonly used by local farmers to reduce erosion.
Meja/Jeldu	96	1,328-3,200	900-1,350	Potato is the dominant crop cultivated. Barley and teff are also common. Crop rotation is also practiced within the year, with the land left fallow every third year. Farming system: Mixed crop-livestock system.	Mountainous and rugged topography with gorges and valleys. Slopes up to 80 degrees are under cultivation. Accelerated soil erosion due to slope steepness.

Dapo Watershed

Dapo watershed (Figure 2) is located in Diga District, which lies in the southwest of the Ethiopian Blue Nile River Basin. It is one of the regions that receives the highest level of rainfall in the Ethiopian Highlands. In some places, mean annual rainfall exceeds 2,000 mm. The altitude in the area varies from 1,200 to 2,342 meters above sea level (masl) and comprises two agroecological zones: the lowlands and midlands (Table 1). The midlands are steep, formerly forested, terrain which is rapidly being cleared of trees. Large areas of forest have been cleared in the last 10 years. Scattered communities tend to cultivate the tops and bottoms of slopes, because the slopes themselves are steep. However, the increasing cultivation of the slopes is leading to problems of soil erosion and loss of soil fertility. In some places, all the topsoil (sandy clay loams and sandy clay) has been lost. Once the productivity declines too far, farmers simply move on and clear more forest. The lowland, bordering the Didessa River, is less steep than the midlands and comprises more rolling terrain. In recent years, there has been a large influx of people into this lowland area.

The selected watershed is drained by the Dapo River, which is a perennial river. However, in recent years, scarcity of water for livestock and people during the dry season has become an increasingly common phenomenon. Local experts attribute the water scarcity to: (i) population pressure, (ii) lack of soil conservation measures to reduce erosion, (iii) deforestation, and (iv) overgrazing.

Table 2 provides details of the hydrological and meteorological stations installed in the Dapo watershed.

There is a large potential for irrigation, particularly on the flatter terrain of the lowland areas. Traditional biological and physical land management interventions (e.g., strip cropping, crop rotation, intercropping, conservation tillage, and mulching or crop residue) are being exercised by a few farmers to improve cropland productivity. However, these attempts are insufficient to overcome the problem of land degradation and loss of soil fertility (Megersa 2011).

Mizewa Watershed

Mizewa watershed (Figure 3) is located in Fogera District, which lies in the northeast of the Blue Nile River Basin, to the east of Lake Tana. The watershed is drained by the Mizewa River, which is a perennial river and flows approximately from south to north with two main tributaries: (a) the main Mizewa River,

FIGURE 2. Hydrological and meteorological monitoring stations in the Dapo watershed.

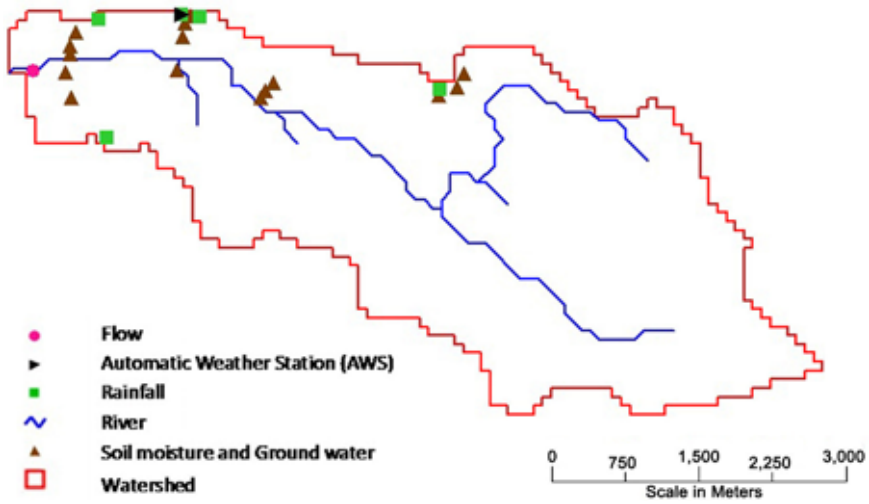


TABLE 2. Hydrological and meteorological stations installed in the Dapo watershed.

Parameter	Station location	Station code	Period of data availability	Coordinates		Altitude (m)
				Northing	Easting	
Water level	Dapo Bridge	DIGA FG*	From August, 2011	09°03'08.5''	036°17'39.1''	1,343
Precipitation	Haro	DIGA RG* 1	From August, 2011	09°03'03.6''	036°19'56''	1,548
	Soyoma Primary School	DIGA RG 2	From August, 2011	09°03'28.0''	036°18'32.1''	1,427
	Church	DIGA RG 3	From August, 2011	09°03'26.0''	036°18'01.2''	1,414
	Humbo	DIGA RG 4	From August, 2011	09°02'46.6''	036°18'04.1''	1,456
Weather	Soyoma Primary School	Diga AWS	From August, 2011	09°03'27.9''	036°18'29.0''	1,423
Groundwater and soil moisture	Dapo Peasant Association	SM* DIGA 1	From August, 2011	09°03'21.7''	036°17'53.4''	1,377
		SM DIGA 2	From August, 2011	09°03'17'.2''	036°17'51.7''	1,375
		SM DIGA 3	From August, 2011	09°03'14.5''	036°17'51.6''	1,364
		SM DIGA 4	From August, 2011	09°03'08.3''	036°17'50.11''	1,377
		SM DIGA 5	From August, 2011	09°02'59.9''	036°17'51.9''	1,415
	Meka Soyoma Peasant Association	SM DIGA 6	From August, 2011	09°03'27.3''	036°18'32.0''	1,437
		SM DIGA 7	From August, 2011	09°03'25.3''	036°18'30.3''	1,433
		SM DIGA 8	From August, 2011	09°03'20.6''	036°18'29.3''	1,422
		SM DIGA 9	From August, 2011	09°03'11.4''	036°18'28.8''	1,384
		SM DIGA 10	From August, 2011	09°03'05.3''	036°19'00.0''	1,444
		SM DIGA 11	From August, 2011	09°03'02.6''	036°18'57.5''	1,427
		SM DIGA 12	From August, 2011	09°03'00.3''	036°18'55.7''	1,411
	Haro Peasant Association	SM DIGA 13	From August, 2011	09°03'03.6''	036°19'56.0''	1,548
		SM DIGA 14	From August, 2011	09°03'03.6''	036°19'56.0''	1,527
		SM DIGA 15	From August, 2011	09°03'03.6''	036°19'56.0''	1,491

Note: * FG - Flow Gauge, RG - Rain Gauge, SM - Soil Moisture.

which has a drainage area of 19 km^2; and (b) the Ginde Newur River, which has a drainage area of 8 km^2. The principal crop grown in the catchment is maize. In the watershed, most of the communities remain food-insecure and are extremely poor. A few local farmers have protected their farmland using stone bunds and practice contour plowing to reduce upland erosion. However, most farmers do not undertake sustainable agricultural practices, and they lack effective land and rainwater management practices (Taffese 2012). The communities complain of water shortages in the dry season, attributed to upstream pumping of water and the planting of eucalyptus trees.

Table 3 provides details of the hydrological and meteorological stations installed in the Mizewa watershed.

There are at least three locations within the watershed where water was pumped for irrigation. This was reported to result in the drying of the Ginde Newur tributary in the dry season. The communities also stated that already constructed rainwater harvesting (RWH) ponds were failing for a variety of 'unforeseen' reasons.

FIGURE 3. Hydrological and meteorological monitoring stations in the Mizewa watershed.

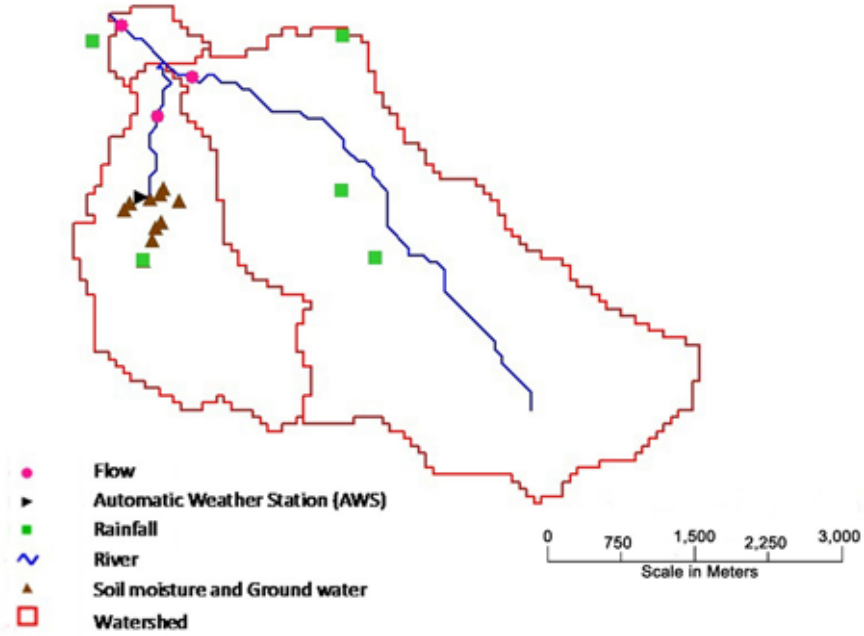


TABLE 3. Hydrological and meteorological stations installed in the Mizewa watershed.

Parameter	Station location	Station code	Period of data availability	Coordinates		Altitude (m)
				Northing	Easting	
Water level	Mizewa Bridge	MIZEWA FG*	From September, 2011	11°56'10.4"	037°47'10.1"	1,848
	Upstream of confluence	GINDE NEWUR	From September, 2011	11°55'33.6"	037°47'25.1"	1,883
	Upstream of confluence	MIZEWA	From September, 2011	11°55'48.1"	037°47'38.8"	1,885
Precipitation	Jigudguad	Mizewa RG* 1	From September, 2011	11°55'06.6"	037°48'44.1"	1,836
	Dokmit	Mizewa RG 2	From September, 2011	11°54'35.4"	037°47'19.4"	1,938
	Woji Terara	Mizewa RG 3	From September, 2011	11°56'06.9"	037°48'41.5"	1,968
	Timinda	Mizewa RG 4	From September, 2011	11°55'06.6"	037°48'44.1"	1,946
	Guntr	Mizewa RG 5	From September, 2011	11°54'36.6"	037°48'54.9"	1,987
Weather	Awramba Primary School	FOGERA AWS	From September, 2011	11°55'00.6"	037°47'18.0"	1,903
Groundwater and soil moisture	Awramba community	SM* MIZEWA 1	From September, 2011	11°54'55.7"	037°47'11.5"	1,941
		SM MIZEWA 2	From September, 2011	11°54'58.4"	037°47'13.8"	1,922
		SM MIZEWA 3	From September, 2011	11°55'00.3"	037°47'21.7"	1,908
		SM MIZEWA 4	From September, 2011	11°55'02.3"	037°47'25.9"	1,918
		SM MIZEWA 5	From September, 2011	11°55'04.5"	037°47'27.6"	1,928
	Woji community	SM MIZEWA 6	From September, 2011	11°54'35.4"	037°47'19.4"	1,938
		SM MIZEWA 7	From September, 2011	11°54'43.3"	037°47'22.8"	1,935
		SM MIZEWA 8	From September, 2011	11°54'48.7"	037°47'24.3"	1,927
		SM MIZEWA 9	From September, 2011	11°54'50.6"	037°47'26.6"	1,922
		SM MIZEWA 10	From September, 2011	11°54'59.5"	037°47'34.0"	1,932

Note: * FG - Flow Gauge, RG - Rain Gauge, SM - Soil Moisture.

Meja Watershed

Meja watershed (Figure 4) is located in Jeldu District, which lies in the south of the Blue Nile River Basin to the northeast of Ambo town. The major river draining the watershed is the Meja River, a tributary of the Guder River, which flows approximately from south to north. The river originates just outside Jeldu in the Ginchi District in a place locally referred to as the Galessa Hills. Most communities live on the ridge tops, but cultivate the steep valley sides. Slopes of up to 80 degrees are being cultivated. The area has been heavily deforested in the last 10 to 20 years and soil erosion is a major problem. Both slope slumping and gullying are common phenomena in the watershed.

Table 4 provides details of the hydrological and meteorological stations installed in the Meja watershed.

Within the Meja watershed there are not many interventions related to soil water conservation or rainwater management strategies (RMS). Farmers plant eucalyptus trees (currently occupying approximately 10 to 15% of the watershed) along gully lines and on degraded areas to mitigate gulley expansion and generate cash. In the district, some farmers believe that productivity has 'halved' in recent years. People living in the watershed are food-insecure and face seasonal water scarcity. There are some traditional water diversions for irrigating potatoes. However, water scarcity prevails during the dry season, and there are severe problems of land degradation, soil erosion, and low crop and livestock productivity (Ayana 2011).

Detailed descriptions of the hydrological features and further physical characteristics of the three study watersheds are presented in Zemadim et al. (2011). In common with most places in Ethiopia, the major soil and water conservation interventions that have been practiced in the watersheds are soil bunds, stone bunds and grass strips. These are intended primarily as conservation structures to reduce soil erosion, although they may also conserve water *in-situ* (Alem 1999). However, to date, they are limited in extent and have not brought significant change to the livelihoods of the rural communities.

FIGURE 4. Hydrological and meteorological monitoring stations in the Meja watershed.

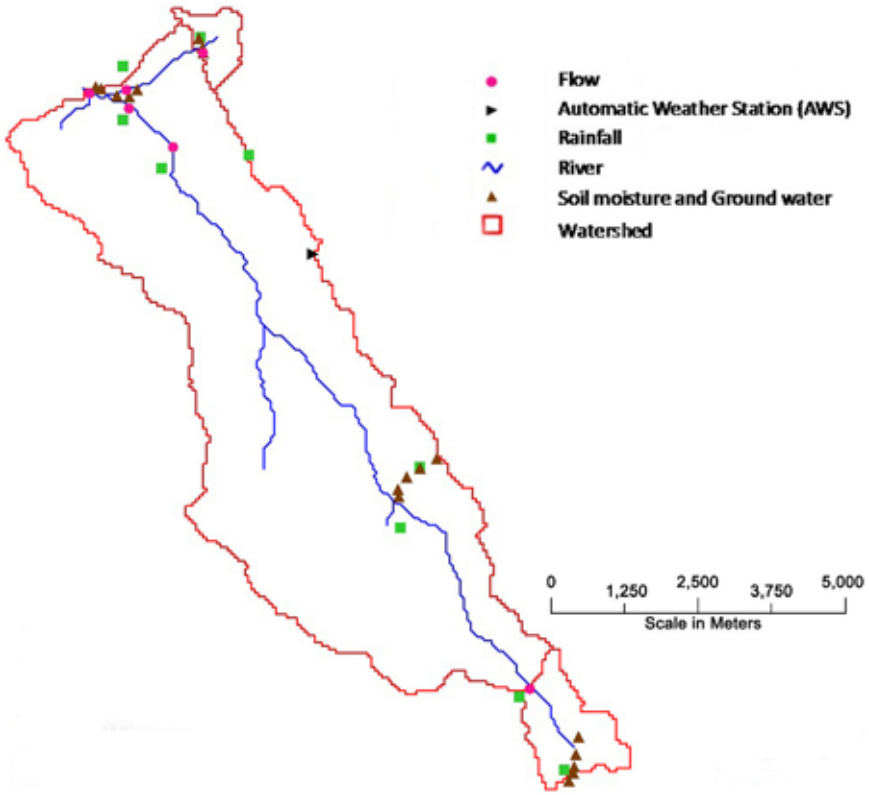


TABLE 4. Hydrological and meteorological stations installed in the Meja watershed, Jeldu District.

Parameter	Station location	Station code	Period of data availability	Coordinates		Altitude (m)
				Northing	Easting	
Water level	Galesa	Galesa FG*	From June, 2011	09°09'03.7''	038°09'03.7''	2,806
	Kolu	Laga Jaba FG 1	From June, 2011	09°18'03.3''	038°03'27.1''	2,732
		Laga Jaba FG 2	From September, 2012	09°15'00.0''	038°36'	2,512
		Meja FG 1	From June, 2011	09°17'29.1''	038°01'49.9''	2,409
		Meja FG 2	From June, 2012	09°14''14.4''	038°30'	2,444
		Meja FG 3	From September, 2012	09°17'29.1	038°01'49.9''	2,477
Precipitation	Galesa	Galesa RG* 1	From July, 2011	09°07'55.0''	038°08'37.5''	2,960
		Galesa RG 2	From June, 2012	09°08'00.4''	038°08'	3,035
	Serity	Serity RG 1	From July, 2011	09°12'12.3''	038°06'33.2''	2,946
		Serity RG 2	From June, 2012	09°11.34'.0''	038°2.31'	2,903
	Kolu	Kolu RG 1	From July, 2011	09°18'17.0''	038°03'24.9''	2,786
		Kolu RG 2	From July, 2011	09°17'52.2''	038°02'18.6''	2,531
		Kolu RG 3	From June, 2012	09°17.11''	038°02.31' 0''	2,522
		Kolu RG 4	From June, 2012	09°16.42'	038°02.8' 0''	2,578
		Edensa Gelan RG	From July, 2011	09°16'37.1''	038°04'06.6''	2,862
Weather	Gojjo Town	Jeldu AWS	From August, 2011	09°15'13.4''	038°05'00.9''	2,942
Groundwater and soil moisture	Galesa	SM* Galesa 1	From July, 2011	09°07'46.0''	038°08'41.1''	3,020
		SM Galesa 2	From July, 2011	09°07'52.9''	038°08'45.1''	2,990
		SM Galesa 3	From July, 2011	09°07'58.0''	038°08'45.8''	2,973
		SM Galesa 4	From July, 2011	09°08'08.9''	038°08'47.5''	2,964
		SM Galesa 5	From July, 2011	09°08'23.5''	038°08'49.3''	2,990
	Serity	SM Serity 1	From July, 2011	09°12'19.6''	038°06'48.1''	3,007
		SM Serity 2	From July, 2011	09°12'11.8''	038°06'33.7''	2,944
		SM Serity 3	From July, 2011	09°12'04.4''	038°06'22.5''	2,933
		SM Serity 4	From July, 2011	09°11'53.8''	038°06'14.5''	2,904
		SM Serity 5	From July, 2011	09°11'47.8''	038°06'15.3''	2,846
	Kolu	SM Kolu 1	From July, 2011	09°18'16.2''	038°03'23.7''	2,792
		SM Kolu 2	From July, 2011	09°18'08.1''	038°03'26.7''	2,740
		SM Kolu 3	From July, 2011	09°18'04.1''	038°03'27.1''	2,710
		SM Kolu 4	From July, 2011	09°17'35.2''	038°01'55.2''	2,480
		SM Kolu 5	From July, 2011	09°17'33.8''	038°02'00.0''	2,463
		SM Kolu 6	From July, 2011	09°17'27.2''	038°02'13.4''	2,488
		SM Kolu 7	From July, 2011	09°17'26.5''	038°02'24.0''	2,494
		SM Kolu 8	From July, 2011	09°17'33.1''	038°02'30.7''	2,518

Note: * FG - Flow Gauge, RG - Rain Gauge, SM - Soil Moisture.

Methodology

In this study, two basic approaches were combined in the establishment and operation of the monitoring networks. First, a participatory approach involving both the local community and other stakeholders. Second, a scientific approach entailing the application of scientific and engineering principles in the design, construction and installation of the component structures and equipment that comprise the monitoring networks.

The design of the monitoring networks established in the three watersheds was based on expert judgment and experience, as well as lessons learned from literature review of previous projects (Gomani et al. 2010; Laurent et al. 2010; Kongo et al. 2010; Munyaneza et al. 2010; EFLUM 2011; STRI 2011). In addition, local expert knowledge was utilized. Overall, a six-step process was adopted, with the participation of a range of stakeholders at all stages:

(i) Inception of the idea and identification of stakeholders.

(ii) Designing the networks.

(iii) Installing the networks.

(iv) Monitoring and maintaining the networks.

(v) Collating, quality control, archiving and use of data.

(vi) Communication and feedback.

Inception of the Idea and Identification of Stakeholders

During the inception phase of the project, consultations were held with several stakeholders to determine the detailed design and specific needs of each of the monitoring networks. The primary objectives of the monitoring were identified as: i) determining the magnitude of different hydrological fluxes, ii) 'closing' the water budget for the watersheds, and iii) providing baseline data for modeling. Several stakeholders and different research groups, including regional research organizations (e.g., Amhara Regional Agricultural Research Institute [ARARI] and Ethiopian Institute of Water Resources [EIWR]), were identified, and efforts were made to bring them together to interact and learn from each other.

The involvement of local communities was initiated at this stage. In the local communities, district government officials and community elders were initially approached, and the objectives of the research and the monitoring were presented. The nature of the planned research was explained and they were made aware of the objectives. The project team explained the benefits of conducting the research, and how it would benefit the community in terms of local capacity building and an increased understanding of the hydrology of the watershed as well as the contribution the monitoring would make to the wider project. In later discussions, the possibility of engagement and possible community responsibilities (e.g., safeguarding the equipment) were discussed. These discussions usually took place on a Sunday, after the local people returned from church (Figure 5).

Designing the Networks

Establishment of the monitoring networks in the watersheds started with identifying possible locations for monitoring sites. An initial survey was conducted from August 04 to August 11, 2010 (Zemadim et al. 2010), with the local communities. Subsequently, more detailed surveys were conducted, involving stakeholders from government institutions (i.e., MoWE and NMA), to identify the type of monitoring stations and more exact locations for possibly establishing stations. The intention was to ensure that the equipment installed in this project should, in future, contribute to existing national hydrometric networks. Hence, where appropriate, equipment (e.g., rain gauges and flow gauges) was chosen to meet national standards.

FIGURE 5. Example of a community consultation in the Dapo watershed.

Photo: Birhanu Zemadim, 2011.

Several factors were considered in designing the networks. Local and expert experience of the hydrological characteristics of the watersheds, such as high and low flow regimes, precipitation patterns, vegetation types, topographic variations and agronomic conditions, was collected. Similarly, information on elevation range, watershed outlet locations, major tributary lines and local knowledge on flood-prone areas was also obtained.

Expert knowledge was important to identify the most appropriate locations for installing the equipment, based on, for example, river morphology, river bank stability, stream cross-section, various land use and land cover conditions, and flow directions. Local knowledge was also used to identify flood markings, and to assist with identifying flood-prone areas and locations used for cattle herding. In addition, advice was obtained from local communities to try and ensure the safety of equipment. To the extent possible, equipment was located in places where regular observations could be made by farmers.

Installing the Networks

The monitoring networks were installed between May and August, 2011. Some of the equipment (e.g., stands for bank-operated cables and bracings for stage boards) was made by local craftsmen and local people assisted with the installation. These people initially assisted by providing labor for installation, but many were later given training on how to be observers for manually read hydrological and meteorological monitoring equipment. Local people also constructed fences to ensure that the equipment was protected from damage by livestock.

To facilitate the collection of data with a high temporal resolution, automatic equipment is required. However, there are risks associated with using highly technical equipment in isolated locations in developing countries. For instance, maintenance is not easy and if the equipment fails, for whatever reason, it may be hard to repair. There is, therefore, the risk that data collection may cease for long periods of time. Hence, in such circumstances, building redundancy into monitoring networks is a sensible precaution. Manual gauges provide a backup to the data collected by automatic gauges and help to minimize losses that may occur due to equipment malfunctioning or vandalism. In this project, financial constraints also limited the amount of expensive automatic equipment that could be installed in the study watersheds.

Consequently, the networks comprised a mix of highly technical automatic equipment and less sophisticated manually read instruments.

The following equipment was installed in each study watershed:

- Automatic weather stations (one in each study watershed).
- Manual rain gauges (distributed across altitude and space) to record rainfall data and read by local residents.
- Pressure transducers to measure river stage (converted to flow using a rating equation, determined from current meter measurements), maintained and downloaded by local residents who had studied at university.
- Stage boards at the catchment outlet and in the sub-catchments to enable manual measurement of stage, read and collected by local residents.
- Soil moisture profiles (determined using a Delta-T probe) arranged in a number of transects perpendicular to the drainage line of the main stream.
- Shallow groundwater depth (determined using pressure transducers and manual dip meters), located close to the soil moisture transects.

In addition, selected residents were provided with cameras to photograph stage boards and changes in land use in the watershed.

To study the water fluxes and water use systems, monitoring stations were installed at locations on rain-fed farmland, irrigated farmland, grazing areas, and inside or near eucalyptus plantations. The location and approximate elevation of all equipment was determined using handheld global positioning system (GPS) units. The locations derived from the GPS units were overlaid on a digital elevation model (DEM), and watershed boundaries and the geographic locations of monitoring stations were mapped (Figures 2 to 4; Tables 2 to 4).

The involvement of local people in the installation process helped to build trust with the individuals, who in turn informed their families and friends of the activities being undertaken and helped to create awareness of the project. Local people also benefited from the small payments they were given as compensation for their assistance in the field. The involvement of local artisans and the use of workshops close to the watersheds as well as, where possible, local construction materials, helped to minimize the cost of equipment installation.

Details of the type of equipment, methods of installation and measurement techniques for all the monitoring equipment used are presented below.

Weather Station Data

Automatic Weather Stations (AWS) from Campbell Scientific, Inc.[1], were used to monitor the following variables at a resolution of one hour: rainfall, average air temperature, minimum and maximum air temperature, relative humidity, net radiation, corrected net radiation, solar radiation, wind speed, wind direction, soil temperatures at two depths, and barometric pressure. Data were recorded in a data logger and downloaded approximately monthly using a computer.

Rainfall Data

Ordinary metallic rain gauges (Figure 6(b)) were produced at the NMA workshop (to meet the national standard design) and installed in networks around each catchment to cover a range of altitudes and different agroecological zones. Local community members were trained to read these gauges manually each day (Figure 6(c)). By doing this, local people appreciated how rainfall was recorded.

[1] Name of the company is provided only for reference purposes and the authors/IWMI do not endorse any company or its products/services.

FIGURE 6. Local participation in monitoring: (a) soil moisture, and (b) and (c) rainfall.

(a)

(b)

(c)

Photos: (a), (b) Matthew McCartney; and (c) Birhanu Zemadim, 2011.

Stream Water Level

Measurement of stream water level was undertaken manually using Shelley Signs[2] stage boards and automatically using SEBA[3] pressure transducers. The researchers also used staff gauge boards manufactured locally by MoWE. Staff gauges were installed after identifying suitable locations in terms of river bank stability and accessibility (Figure 7(b)). Manual measurements were taken twice daily (at 06:00 and 18:00). Automatic water level measurements were taken hourly. Discharge measurements were made using current meters over a range of flow conditions, to establish rating equations (Figure 7(c)). These were used to convert water level measurements into discharge.

Soil Moisture

Soil moisture was measured using Delta-T profile probes called PR2/6[4]. These probes measure the soil moisture at six depths down to 100 cm below the ground surface (Figure 6(a)). Plastic access tubes were installed in augered holes and profile probes were inserted into these to take the measurements. In addition to the profile probe, near surface soil moisture was measured using an ML2[5] ThetaProbe sensor, which measures the soil moisture to a depth of 10 cm. Soil

[2] See note 1.

[3] See note 1.

[4] See note 1.

[5] See note 1.

FIGURE 7. Local participation in the installation of monitoring networks: (a) site surveying, (b) installing stream stage board, and (c) current meter measurement.

(a)

(b)

(c)

Photos: Birhanu Zemadim, 2011.

moisture measurements were taken manually approximately weekly.

Shallow Groundwater

In the study watersheds, there were no shallow groundwater observation wells. Consequently, it was necessary to auger shallow wells for groundwater-level observation (Figure 8(c)). Measurements were taken both manually and automatically in the augered wells. The wells were located along transects, and strategically installed at sites where they would not interfere with farming activities. Manual groundwater level measurements were taken daily using a dip meter. In selected wells, pressure transducers and SEBA[6] data loggers were used to obtain data every hour.

Monitoring and Maintaining the Networks

The watershed monitoring networks have been operating since the beginning of August, 2011. Details of the monitoring regime and frequency of data collection are summarized in Table 5. For monitoring activities, the project employed local gauge readers who lived in close proximity to the networks. Five, seven and eight 'gauge readers' were employed for the Dapo, Mizewa and Meja watersheds, respectively. These gauge readers collected data on a daily basis and also provided security to individual pieces of equipment. They were trained by the project team to read water level data from staff gauges and record rainfall using rain gauges (Figures 7(b) and 6(c)).

[6] See note 1.

FIGURE 8. Local participation during the installation of access tubes for monitoring: (a) and (b) soil moisture, and (c) shallow groundwater level.

(a)

(b)

(c)

Photos: (a), (b) Birhanu Zemadim, 2011; and (c) Matthew McCartney.

TABLE 5. Summary details of the hydrometeorological networks established on the three watersheds.

Measurement	Dapo watershed		Mizewa watershed		Meja watershed	
	Type	Number (frequency)	Type	Number (frequency)	Type	Number (frequency)
Weather station data	Automatic	1 (hourly)	Automatic	1 (hourly)	Automatic	1 (hourly)
Rainfall from ordinary rain gauge	Manual	4 (daily)	Manual	5 (daily)	Manual	9 (daily)
Soil moisture	Manual	15 (4 to 6 days per week)	Manual	10 (4 to 6 days per week)	Manual	18 (4 to 6 days per week)
Groundwater level from dip meter and pressure transducer	Manual and automatic	6 manual (daily) 4 automatic (hourly)	Manual and automatic	7 manual (daily) 3 automatic (hourly)	Manual and automatic	12 manual (daily) 6 automatic (hourly)
Water level from staff gauge	Manual	1 (twice daily)	Manual	3 (twice daily)	Manual	6 (twice daily)
Water level from pressure transducer	Automatic	1 (hourly)	Automatic	1 (hourly)	Automatic	2 (hourly)

In addition, they collected soil moisture data and recorded groundwater levels in shallow wells. Each reader was paid a small monthly stipend to compensate for their time.

To enhance the amount and quality of data collected in the watersheds by the local community, graduate level researchers from Ambo University, Bahir Dar University and Wollega University were engaged as 'watershed coordinators'. The watershed coordinators spent a great deal of time in the field each week. They were involved in the following activities:

- Assisting with the installation of hydrological and meteorological equipment, and subsequently attending to routine operation and maintenance requirements of the instruments.
- Supervising the gauge readers, quality control of the data, and converting the hard copy format of the data to soft copy (spreadsheets) which was then forwarded to the IWMI East Africa and Nile Basin office in Addis Ababa.
- Participation in the local Innovation Platform (IP) (see section, *Communication and Feedback).*

The watershed coordinators were financially compensated for their efforts and they reported directly to the field hydrologist, who was located at the IWMI office in Addis Ababa.

Mechanisms for manual data collection and archiving from each of the study watersheds were based on standard data collection and archiving protocols of MoWE and NMA. For example, MoWE supplied a standard booklet that provides details on manual data collection of stream water level from staff gauges. Similarly, protocols of the NMA were adopted for daily rainfall collection from ordinary rain gauges.

Automatic data archiving was based on downloading data recorded in data loggers. Even though some of the automatic gauges had data transmission capabilities, the lack of telecommunications network coverage meant that it was not possible to use these facilities in the study watersheds. Thus, data were downloaded monthly from the loggers. The temporal resolution of the data from automatic sensors ranged from hourly to daily.

Collating, Quality Control, Archiving and Use of Data

Once data were collected by local observers, the initial data quality checking (i.e., identification of any possible data gaps and outliers) was undertaken by the watershed coordinators. Regular communication between watershed coordinators and the gauge readers helped to identify erroneous recordings and explain data gaps. The watershed coordinator converted all hard copy data into spreadsheets prior to sending the details to the IWMI office in Addis Ababa each month. Once received by the IWMI office, the data were further quality controlled. This involved the plotting of time series to identify possible outliers that may have been missed by the watershed coordinator. Data collected by the automatic instruments were compared with the manually collected data. In instances where discrepancies were identified, the IWMI field hydrologist discussed the matter with the watershed coordinators to try and resolve them. Finally, a clean 'master' dataset was stored on a computer server to be used in analyses.

All the data collected, including photographs, have been made available to graduate students, researchers and others working directly on the project, and have been shared with NMA and MoWE on a regular basis. In future, data will also be stored on IWMI's Water Data Portal (http://waterdata.iwmi.org) and will be freely available to anyone who wants access to it.

Within the current project, data obtained from the three study watersheds were used in conjunction with computer models (e.g., the Soil and Water Assessment Tool (SWAT)) to determine water use and water productivity in different parts of the landscape, and to evaluate the possible implications (including downstream impacts) of scaling up possible rainwater management strategies (Schmidt and Zemadim Forthcoming).

Communication and Feedback

A participatory learning process must involve a feedback mechanism where continuous updating and responses are integrated into the learning process. Such feedback mechanisms should accommodate the opinions and ideas of the various stakeholders as much as possible (Gomani et al. 2010). As part of the broader CPWF project, Innovation Platforms (IPs) were established in each study landscape to communicate the research findings, and provide a forum for discussion of project concepts and learning. The watershed coordinators were part of the established IPs, and reported on the status and progress of the hydrological and meteorological monitoring activities. This helped to inform the local communities of the main research activities and progress made in data collection. It also helped to provide a greater understanding of the ongoing research and enabled the communities to better appreciate their contribution to the project. In future, IPs will be used to obtain ideas from the communities about what sort of RMS they would like to adopt and this can be integrated into the learning process.

In addition, there are plans to organize 'field days' to discuss results with local communities and seek their insights into the implications of the findings, specifically in relation to their farming practices and to the management of land and water resources. Similarly, there is also a plan to organize a field day at each site for university students and national research organizations. This will focus specifically on the instrument networks and their value for hydrological research. The involvement of local communities in monitoring activities and the protocols adopted will also be discussed.

The monitoring networks are appreciated by many who are carrying out similar activities, both in Ethiopia and elsewhere. As a result, there have been many requests by national and international institutions, and individual researchers, to utilize the data obtained from the networks. The requests were mainly from those seeking biophysical data. In some instances, proposals have been made to increase the network density through the installation of additional instrumentation and monitoring stations. For example, EIWR has installed three more automatic rain gauges in the Mizewa watershed. This improved data resolution both in time and space and helped to increase the reliability of data recording. It is an indication of the perceived value of the monitoring network and its sustainability.

Discussion

The participatory approach has contributed positively to the establishment and operation of the hydrometeorological monitoring networks in the Ethiopian Highlands. At the beginning of the project, the close cooperation between multiple stakeholders through meetings and visits to field sites helped in the identification of suitable research catchments in the three districts. Later, discussions held with the government, bilateral development institutions and local communities helped to identify appropriate instruments and locations for installation of monitoring networks. The equipment was purchased only after discussion of the requirements with NMA and MoWE, which ensured that it was appropriate for the Ethiopian context. Multiple stakeholders, both technical experts and those with local knowledge, assisted in the installation of equipment and continued to assist with data collection and maintenance of instruments. Summary details of the role of different stakeholders involved in the watershed monitoring programs are presented in Table 6.

TABLE 6. The role of stakeholders in the different phases of the watershed monitoring programs.

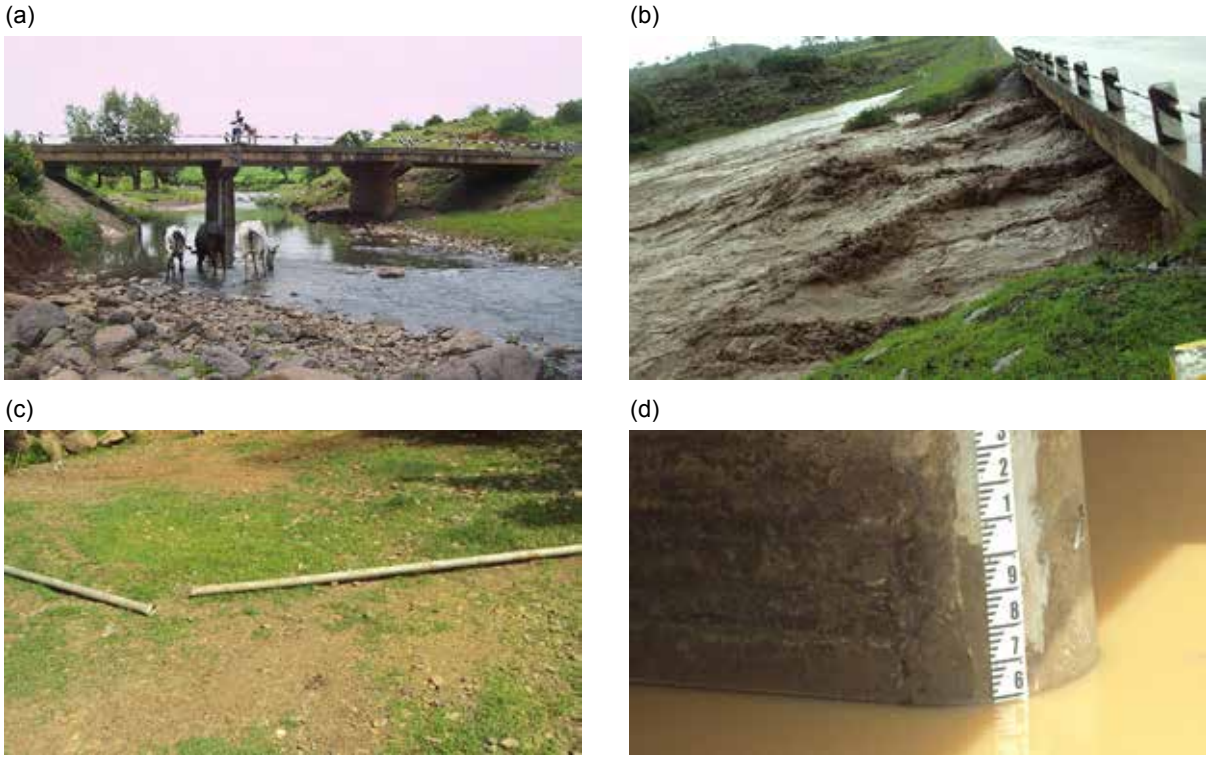
Phase	Stakeholder involvement	Task
Design	Ministry, university staff and students, regional research organizations and the local communities.	Provided knowledge on how the network fits into the national monitoring network, assessed the utility and design relative to local hydrometeorological conditions, and shared understanding on environmental and river dynamics of use in installing instruments.
Monitoring	Selected households that are located close to the installed equipment, as well as watershed coordinators.	Took meter readings from rain and staff gauges, and groundwater level and soil moisture access tubes. Also involved in the measurement of stream discharge. Maintained accurate, up-to-date records and downloaded data from technical networks and collated all data in the watershed.
Maintenance	MoWE, NMA, local craftsmen and watershed coordinators.	Maintained damaged gauge boards and soil moisture access tubes, and repaired protection fences around equipment.
Data collation and analyses	Watershed coordinators and IWMI staff.	Collated all data collected by local gauge readers and downloaded from automatic loggers, quality controlled data and created a database of information. Data used in analyses of water fluxes and computer modelling studies.
Feedback	Watershed coordinators, IWMI staff and the local communities.	Participation of watershed coordinators in the IPs. Field days to discuss results with local communities.

In the three study watersheds, the discussion held with local officials, village leaders and farmers helped to avoid unnecessary misunderstandings about the project. At the beginning of the project, some villagers thought that the research was being conducted with a view to identifying land suitable for purchase by foreign investors; a valid and unsurprising concern in a country where foreign direct investment in land is increasing. Understandably, the villagers were reluctant to cooperate. However, after the initial discussions and once the objectives of the research were explained, farmers participated willingly and, generally, without problems. For the most part, farmers were willing to have instruments installed on their land, and this equipment was well maintained and looked after.

However, maintenance of the hydrometric networks was not completely trouble-free. Despite the involvement of local communities, vandalism was an issue. This related primarily to the automatic flow gauging stations, located on road bridges at the outlet of each watershed. In two of the watersheds, these gauges were deliberately damaged and items of equipment were stolen. Initially, in each case, it was assumed that the local community was responsible for the damage caused and the incident was reported to local government officials. Later, discussions were held with the officials and communities, and it transpired that the equipment had not been vandalized by local people. Rather, it was by people from other communities who were unaware of the purpose of the instruments, but who used the roads to commute between towns and villages. All incidents of vandalism occurred on market days, when many people travel on the roads on foot. Also, it was speculated that people under the influence of alcohol on market days may have had a role to play in these incidents. After these incidents of vandalism, the damaged equipment was replaced and local observers took the initiative to guard not only flow gauging stations installed on the bridges but also other monitoring stations that could be seen by outsiders.

Another problem, despite efforts to avoid it and advice from MoWE, was flood damage. The three watersheds are located in highland areas with steep slopes. In these areas, rainfall occurs rapidly in short-duration intense storms. It can take less than an hour for flash floods to reach the watershed outlets. Associated with the flood flows are logs and boulders swept along by the river water. These have damaged the gauging stations that were installed on the bridges in all the watersheds (Figure 9(b), (c)). This damage is largely unavoidable.

FIGURE 9. (a) Automatic flow gauge before flood damage, (b) heavy flooding in the Mizewa catchment, (c) dismantled items from a damaged automatic flow gauge, and (d) stage board on bridge pier after the flood.



Photos: Tewodros Taffese, 2011.

However, stage boards which were bolted to the concrete of the bridge piers withstood the flooding (Figure 9(d)). Following the damage caused to the flow gauges, observers were requested to make more frequent manual measurements and, consequently, daily and sub-daily readings were obtained throughout the periods that the automatic flow gauges were inoperable. Although not ideal, this highlights the value of having manual measurements in conjunction with those from automatic recorders.

Examples of the data gaps that were created due to vandalism and malfunctioning of equipment, and flood damage, and the actions taken to minimize the loss of data are presented in Table 7.

A sense of ownership of the monitoring equipment was created amongst the local people. They were the first to report any malfunctioning equipment. This minimized delays in taking appropriate corrective measures. However, the use of local observers for monitoring created another challenge. The involvement of a relatively small number of people, who were financially compensated for their efforts in the collection of data, created some tension with others in the community. However, discussions held with local government officials and village elders together with the community, to some extent, eased these tensions.

The main outcomes of using a participatory approach for hydrometeorological monitoring in the three watersheds can be summarized as follows:

(i) Identification of appropriate sites for hydrometeorological monitoring.

(ii) Reduction in the cost of installation and maintenance of monitoring equipment.

(iii) Provision of security for the instrument networks.

(iv) A sense of ownership of the monitoring equipment, created within the local communities.

TABLE 7. Examples of data gaps created due to vandalism and malfunctioning of equipment, and flood damage in the study watersheds, and the actions taken.

Watershed	Parameter	Station location	Station code	Data gap	Reason for data gap and action taken
Dapo	Water level	Dapo Bridge	Diga FG*	From December 09, 2011 to June 09, 2012	Equipment was vandalized. Measurement continued manually. Automatic gauge was replaced.
Mizewa	Water level	Mizewa Bridge	MIZEWA Bridge	From December 16, 2011	Automatic logger was vandalized. Monitoring was resumed manually.
		Upstream of confluence	GINDE NEWUR	From September 01, 2012	The location was filled by upstream sediment. The site was abandoned.
	Precipitation	Woji Terara	Mizewa RG* 3	From January 2, 2012	Equipment was vandalized. The site was abandoned.
	Groundwater and soil moisture	Awramba community	SM* MIZEWA 1	From December 16, 2011	Equipment used to measure groundwater level was damaged. Measurement was resumed manually.
		Woji	SM MIZEWA 8	From February 06, 2012	The area was flooded. Dip well and soil moisture access tubes were damaged by flood. The site was abandoned.
Meja	Water level	Meja Bridge	Meja FG 1	From December 07, 2011 to September 02, 2012	Automatic water level recorder was vandalized. Monitoring was resumed manually. Later, automatic station was installed upstream of the bridge (Meja FG 3).
	Groundwater and soil moisture	Kolu Kebele	SM Kolu 2	From June 05, 2011 to June 06, 2012	Soil moisture access tube was damaged. The access tube was re-installed.

Note: * FG - Flow Gauge, RG - Rain Gauge, SM - Soil Moisture.

From this project, some of the lessons learned about the process of participation include the following:

- The various government officials at all levels expect recognition and respect. It is important to consult these people or arrange short meetings and brief them regularly on the process and progress of the work undertaken. It is also important to build long and lasting relationships with key individuals in the government institutes.
- There is a need to identify key individuals who can influence the community. These individuals tend to gain respect from the community because of their dependable character and innovative ideas and decision-making skills. In the local context, these people are referred to as 'community model farmers'. If such people are seen to be in favor of the monitoring networks, it is a significant step in bringing about community support for research activities.
- There is a need to minimize over-expectation within the community. It is important to be clear what can be expected from the project (i.e., what it will and will not deliver).
- It is important that key figures within the local community (i.e., village elders and government officials) appoint people from the community to work on the project (i.e., as local observers). In this case, those who are not selected may feel that they have missed out on an opportunity. However, they cannot attribute the decision of not being selected to the project itself.

It is clear that a successful participatory approach requires constant effort and, as such, is associated with high transaction costs. However, these costs can be minimized, if appropriate institutional and social arrangements are put in

place at all levels with the full range of stakeholders. This will also help to ensure that conflict is minimized, and researchers, local people and other stakeholders benefit from the participatory approach.

Within the current project, the monitoring activities will continue to the end of 2013, at which point the monitoring activities will be reviewed with the intention of deciding on how best to continue. Project activities could possibly continue as an addition to the national hydrometric network or as study watersheds supported by the local universities. Currently, discussions are ongoing with the three universities located in close proximity to the study watersheds, regional research centers and MoWE on how best to transfer the monitoring networks and maintain community monitoring activities, including the associated costs. It is anticipated that the monitoring stations in the Mizewa watershed may be transferred to Bahir Dar University and ARARI. Similarly, it is anticipated that the monitoring stations in the Meja and Dapo watersheds could be taken over by EIWR of Addis Ababa University in close collaboration with Ambo University, Wollega University and the Hydrology Directorate of MoWE.

Conclusions

This report has described a participatory approach for establishing hydrometric networks in rugged and difficult locations in the Ethiopian Highlands. The monitoring networks were installed as part of ongoing research for a development project. The objective of the research was to gain an insight into the hydrological processes that may affect the viability of rainwater management practices. All monitoring networks were installed in areas where there was no hydrological and meteorological infrastructure previously.

The four major benefits of the participatory approach can be summarized as shown below:

- Increased resilience and enhanced sustainability of the monitoring networks, as a consequence of several factors: local knowledge was used to ensure that equipment was installed in the best possible locations; a sense of community ownership was created and meant that, to some extent (though not totally), equipment was protected from vandalism; and a combination of measurements were taken from automatic recorders and manually collected data, which meant that there was a 'backup' of many observations.
- Greater cost-effectiveness was achieved, because as much equipment as possible was manufactured locally and local observers were used for data collection, which meant that less costly automatic equipment was needed. Also, having local observers on the ground meant that additional information (e.g., taking photographs of land-use change, and recording of activities such as gravel extraction from riverbeds and flooding events) could be collected for only a marginal extra cost.
- Recommendations were made for rainwater management interventions that are believed to be both more suitable and more effective as a consequence of the two-way flow of knowledge between researchers and the communities and vice versa.
- Increased awareness was created of the importance of the management of water and natural resources within local communities through the established IPs.

In conclusion, although problems related to equipment vandalism and flooding remain, the inclusion of local communities and other stakeholders in the data collection efforts has been largely beneficial. The monitoring networks are perceived to be of value by local universities and national research institutes, and will hopefully be

integrated into the national hydrometric networks in the long-term. The high transaction costs associated with the approach are warranted by the trust garnered within communities, the assistance that they provided and the increased likelihood that the findings will prove to be useful to the communities. To ensure that the findings are utilized successfully, participation of local communities and a range of stakeholders should continue to be encouraged, and similar approaches should be promoted elsewhere in the country.

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