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A socio-hydrological approach for incorporating gender into biophysical models and implications for water resources research

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A B S T R A C T

Men and women interact with water resources and landscapes in different ways, and there are frequent criticisms that little research is undertaken across disciplines to address this issue. Biophysical scientists in particular struggle with how to integrate "gendered" water uses into models that are necessarily based on prevailing laws and equations that describe the movement of water through the hydrological cycle, independent of social constructs. We explore the challenges faced in developing interdisciplinary and transdisciplinary research approaches and then present a simple yet innovative socio-hydrological approach using participatory three-dimensional maps. As a case study, we describe undertaking this process in Ethiopia where two three-dimensional maps (men's and women's) were separately generated to represent the same 20 km^2 landscape. Mapping results indicated important distinctions in how men and women view landscapes with regard to the number and types of ecosystem services identified. For example, only women identified holy water sites along streams, while men identified twice as many sacred trees on the landscape. There was a clear focus and detailed knowledge about soils among participants in both groups. Maps developed as part of this exercise were successfully used as the principal land use input for the Soil and Water Assessment Tool (SWAT) and results indicate that this is a valid strategy that enhances scientific knowledge and understanding of overall landscapes and ultimately adds value to research for development questions.

1. Introduction

For most rural households throughout sub-Saharan Africa there is a lack of access to safe water resources on the premises, which results in women and children often walking long distances to procure enough water to fulfill even basic daily requirements (Pickering & Davis, 2012). While women are known to be the primary drawers of water across the African continent (Thompson et al., 2001), they also fill a complex and dominant role in agricultural activities that require access to and management of water resources, though they are often operating at the margins of society due to limited access to land, labor, and inputs (Doss, 1999). Fletschner and Kenney (2014) report that women's lack of access to financial markets and services – often a direct result of social norms and women's legal rights – represent a hindrance in rural development. In a study by Davis et al. (2012), however, the authors found that when given opportunities such as access to farmer field schools, women demonstrate greater gains than men in terms of increased and improved agricultural outputs. As a consequence, we see that such disparate access to resources and opportunities leads to men and women interacting with natural resources and landscapes in different ways.

Women in rural societies are disproportionately more impacted by the health and sustainability of ecosystems due to having livelihoods directly related to natural resources (Masika, 2002). As the principal drawers of water in many rural communities, it is well understood that women and girls face challenging physical circumstances on a near daily basis and that this has increased over the past three decades despite efforts to improve women's access to water (Thompson et al., 2001; White, Bradley, & White, 1972). In addition, women are overly reliant on livelihood practices where water productivity plays a key role (*e.g.*, domestic water needs, agricultural productivity, and biomass energy). The underlying assumption in development – that merely including women in water resources decision making groups leads to equitable

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access – misses the mark as it does not account for the social complexities governing water access, use, or management (Cleaver & Nyatsambo, 2011; Udry, 1996). It is now standard practice for development programs to be built upon "gender mainstreaming" approaches, but the result is often nothing more than satisfying a quota under the guise of "participation" (*e.g.*, having a certain number of women sit on management boards), rather than actual participation in or influence on decisions made (Brett, 2003; Cleaver & Nyatsambo, 2011; White, 1996). Cleaver and Nyatsambo (2011) point out that even in situations where men recognize the needs and constraints that women face, certain social responsibilities take precedent. They highlight an example where livestock may still have priority in water queues causing women to seek out other less desirable water sources despite men acknowledging that this places an undue burden on women in terms of time and health or safety issues.

Poor women and girls in rural areas are particularly at risk from the predicted impacts of climate change on water resources as, for example, they are required to walk further distances from their homes to find water resources (Lambrou & Piana, 2006; Masika, 2002). At the same time, women are often routinely absent from local decision making processes on how to mitigate or address impacts of climate change, as well as at the international level where few women water professionals are involved in negotiations by world governing bodies and governments (Masika, 2002). This lack of women water professionals is of particular concern. Feminist technology studies in recent years have called attention to the pervasive idea within societies of equating masculinity with technological or engineering fields of research (Faulkner, 2000). Women are expected to "fit in" to these fields and this alludes to an assumption that women with non-traditional approaches to technological and engineering challenges do not bring something unique or useful to bear on these research areas (Faulkner, 2000). As such, women's value systems and approaches to problem solving are missing at even the highest levels with ripple effects on research for development efforts.

A significant predicted consequence of climate change is an overall decrease in available water resources in many already water scarce regions (Vörösmarty, Green, Salisbury, & Lammers, 2000), which will result, for example, in increased physical labor undertaken by women and girls to fetch water required to meet daily household needs (Lambrou & Piana, 2006; Mellor, Watkins, & Mihelcic, 2012). Changes in climate that cause reduced precipitation may lead to an increased need for irrigation in many regions, though coincidently overall water resources scarcity will make productive water use availability low (Vörösmarty et al., 2000). Coupled with limited and complex access rights to land and other agricultural inputs (Doss, 1999; Snyder & Cullen, 2014), women are likely to suffer disproportionately with regard to water resources access (Cleaver & Nyatsambo, 2011). This will have a potentially cascading effect on food security in areas such as sub-Saharan Africa where women are responsible for up to 50% of the agricultural work force (FAO, 2011).

Identifying, including, and addressing the unique needs of women and their access to water resources is of a normative nature in that researchers are given explicit goals or measures of success for including women in water resources decision making (*e.g.*, millennium development goals and now the sustainable development goals), but no guidelines on how this ought to occur. This often leads to quota systems that do not involve any transformative changes within the system (Brett, 2003; White, 1996). To go beyond lip-service and make these goals truly actionable, socio-technological approaches are required that enable the development of novel transdisciplinary methods.

Ecosystem services are human defined in that they represent benefits derived by humanity from the natural environment (Daily, 1997; MA, 2005; TEEB, 2010; WLE, 2014). Ecosystem services are commonly divided into four distinct broad categories (TEEB, 2010; WLE, 2014):

- Provisioning services are obtained directly from an ecosystem and include benefits such as food, fresh water, fuel, construction materials, fiber, and medicines.
- Regulating services are those that result when ecosystem processes are controlled either by natural or artificial infrastructure and includes benefits such as flood mitigation, climate regulation, or water quality.
- Cultural services are comprised of both material and non-material benefits and can include aesthetic values of a landscape, spiritual places or opportunities to carry out ceremonies, and recreational activities.
- Habitat services are processes that support species life cycle maintenance and genetic diversity.

Many ecosystem services are mediated either directly or tangentially through access to water and have direct linkages to human well-being (Brauman, 2015).

From an ecosystem services standpoint, women are often consigned to accessing only marginal scarce resources. Small fluctuations in a system can affect resource availability and therefore access to a given service. For example, land use management that reduces water availability during the dry season can result in women and girls having to walk further to seek alternative sources, which in turn may impact how much water they are able collect as well as how much time they spend on other activities (Sorenson, Morssink, & Campos, 2011). Given these circumstances, rural women living in poverty are projected to be disproportionately impacted by factors such as climate change or policy changes that influence land management (Masika, 2002).

To address this challenge, there is an urgent need to identify critical ecosystem services and how they are utilized differently by men and women. A recent review of 92 research articles on ecosystem services comprising a database of 231 actual or potential tradeoffs found that not a single study disaggregated ecosystem services trade-offs across gender (Howe, Suich, Vira, & Mace, 2014). Consequently, the authors identified this lack of disaggregating trade-offs across gender as a major gap in ecosystem services assessments. Further, Brauman (2015) found that in an assessment of 381 peer-reviewed studies involving water related ecosystem services, few if any papers made the direct linkage among people and biophysical processes. In fact, the majority of studies assessed (93%) did not identify a beneficiary of the water related service being assessed. This immediately brings into question how services at the center of research questions were identified and defined in the first instance given the definition of ecosystem services is people oriented.

1.1. *Multidisciplinary, interdisciplinary, and transdisciplinary research*

While on the surface it appears that efforts are actively being undertaken to address challenges faced by the world's rural poor – particularly women – there is also mounting criticism that little research is successfully undertaken across disciplines (*e.g.*, interdisciplinary or multidisciplinary approaches) in such a way to truly address ecosystem services management and sustainability issues. Rather, research questions are being driven by myopic disciplinary approaches because they are simpler and perhaps less confrontational (Janssen & Goldsworthy, 1996; Uiterkamp & Vlek, 2007).

It is important here to first define the distinctions between *multidisciplinary* and *interdisciplinary* research. As described by Uiterkamp and Vlek (2007), multidisciplinary research is intended to consider a given issue through the lens of multiple disciplines and that through the confrontation of different methods, concepts, and findings, a picture will emerge that more fully describes the issue and possible solutions. It is often difficult for teams to successfully venture much further than explanations and truly move on to actionable activities, which may in part be due to the issue highlighted by Chamberlin (1965) that scientists quite naturally develop heavily value-laden and deep affections for their individual disciplines and hypotheses. In a best case scenario, Uiterkamp and Vlek (2007) propose that a research team may evolve toward an interdisciplinary approach whereby various outputs are integrated and form the basis for effective policy making. In other words, researchers work in parallel, but rarely do they make use of methods, findings, or concepts from different disciplines to develop or refine their own hypotheses or methodologies.

While social scientists to some extent may account for, though not completely integrate, the natural environment in their considerations of human–environment interactions, biophysical scientists perhaps struggle more with how to integrate social water uses into models that are necessarily based on physical laws describing the movement of water through the hydrological cycle. They may go so far as to recognize that people impact this cycle via their behaviors, but will maintain that the governing laws and equations exist independently and argue that inclusion of human perceptions is unimportant to understanding or outside biophysical processes.

Two interesting topics are worthy of deeper discussion at this point: how knowledge is understood or accepted in the hydrological sciences and the role of human perception in natural resources management. To the notion of knowledge in hydrological sciences, and science generally, Lane (2014) presents several important criticisms. In the classical sense, knowledge is gained in the sciences via the scientific method, which rests on a foundation of falsification. Hypotheses are accepted only when they cannot be falsified, but the method of inquiry is intended to bring about eventual falsification through succession and replication of experiments. Ideally, such action to falsify a given hypothesis should be undertaken by scientists other than the one (or ones) who developed the hypothesis. In reality, Lane (2014) argues this is rarely how science is practiced. Why might this be?

In part, as previously discussed, for scientists the ideas and hypotheses they develop become like their children who they naturally seek to protect (Chamberlin, 1965). Lane (2014) goes on to point out that while these acts of falsification are intended to improve science by generating further inquiry, such public displays of falsification may also bring into question the authority of science or even the legitimacy of scientists as the holders of knowledge.

Diekmann and Zwart (2014) suggest that modeling in the sciences is best served by adopting the Philosopher John Rawls' concept of modeling by overlapping consensus whereby models are developed by a broad range of stakeholders, which may include experts as well as non-experts. Examples of this type of approach are illustrated by Lane et al. (2011) and Maynard (2015). In both instances, knowledge was co-produced by experts and non-experts with regard to flood and river management respectively. Authors in both studies demonstrate that knowledge – expert and non-expert – is all to some degree experiential and that there is often little difference in how the universal knowledge of science is generated versus local understanding of phenomenon. This is not to say that the knowledge of science or scientific tools and methods are unnecessary, but rather as Maynard (2015) demonstrates, there are different stages of identifying and addressing an issue along with a continuum of certified and non-certified experts who should participate and contribute to the overall process. Through such mechanisms, a more holistic picture begins to emerge regarding not only the issue but approaches to addressing it as well.

Diekmann and Zwart (2014) also bring in an example of how scientists will use the concept of optimization modeling as a way to circumvent criticisms that they are pursuing value-laden solutions. Optimizing trade-offs, however, involves optimizing toward some set of values and norms based on some authority with no assurance that it is capturing the most relevant social values and norms. They argue that there is an ethical dilemma here going unaddressed because there are often unforeseen negative consequences of decisions made using models, which are derived from a set of values and norms held by the scientists who generate the models.

Furthering this is Lane's (2014) discussion on Manning's *n*, which is a widely accepted parameter, used to describe roughness in hydrological routing calculations. It has, Lane (2014) argues, become ingrained in mathematical models of hydrology despite there being ample evidence there are better ways of calculating roughness. Its original function as an empirical value derived by a scientist via observing relationships with other elements of the environment is now lost because as Lane (2014) points out, the value has been "inscribed" in models as part of the design. Other such "inscribed" parameters exist in hydrological sciences, and directly applicable to this research, Baker and Miller (2013) using SWAT in Kenya highlight the importance of looking beyond published curve number tables by developing location specific curve numbers and undertaking sensitivity analyses as part of the modeling process. More commonly, however, model users will take curve number tables as they are given and simply apply them, although like Manning's *n*, curve number is intended to be a value empirically derived by a scientist.

From the preceding, it is clear that values and norms influence the way science is done. Such values and norms are influenced by the role or place in which individuals find themselves in the world. In the field of environmental psychology it is well-established that an individual's perception of place is derived from a person's self-identity as well as social rules regarding particular settings (see Williams & Patterson, 1996 for an overview of environmental psychology). Greider and Garkovich (1994) present a particularly compelling example of this where they consider an open field from the viewpoint of a developer, a farmer, and a hunter. Each of these individuals envisions something different as possible in this open space: a suburban ranch home, rows of wheat, and a five-point buck grazing, respectively. The open field is transformed, according to Greider and Garkovich (1994), by who each actor *is* in society. In other words, the meaning of the field is derived from the viewpoint of the actor and not through the field. In this way, landscapes, similar to ecosystem services above, are human defined and therefore subjective. Who we are in society, the groups to whom we belong, and the experiences we bring with us to the table, all influence what we individually see when we stand at the edge of the hypothetical "open field".

From a research for development paradigm what this means is that when experts go out onto a landscape they see first what they are trained – through many years of rigorous study – to "see" and then they are also influenced by a predefined issue or problem to solve (*e.g.*, the reason they have been sent there by some authority in the first instance). Williams and Patterson (1996) argue that this is precisely the "wicked problem" described by Allen and Gould (1986) who put forth that there are no explicitly right or wrong technical solutions in land management because natural resources problems are complex, involve high levels of uncertainty, and solutions are driven by stakeholders and decision makers who necessarily have value-laden goals and objectives when approaching problems.

Socio-hydrology is a nascent field evolving to fill this niche using interdisciplinary approaches to understanding co-evolving human-water coupled systems, but it is still heavily focused on the biophysical sciences and in particular societal responses to and influence on extreme hydrological events (Baldassarre et al., 2013; Sivapalan et al., 2014; Srinivasan, Lambin, Gorelick, Thompson, & Rozelle, 2012). Within this emerging field, however, there is a resounding and clear recognition of an urgent need to seek more effective methods for embracing and integrating the social sciences (Sivapalan, Savenije, & Blöschl, 2012, 2014). Where previously people were considered only a boundary condition in hydrological studies, there is an emerging call to develop novel methods that illustrate human-water linked systems and how they co-evolve (Sivapalan et al., 2012). This is a departure from the Integrated Water Resources Management (IWRM) paradigm that focuses on scenario development and assessing those scenarios under stationary social conditions (*e.g.*, assuming that as water resources change, human behavior does not).

Information generated using methods with stronger socio-technical feedback mechanisms stand to deliver insight and understanding of how water influences social change and how changes in social dynamics further influence water. This is the type of knowledge that is needed to mitigate negative impacts of future uncertainties, as well as to influence decision making processes that have the potential to affect critical ecosystem services. We propose that a first approximation of this, in the context of research for development, is to integrate landscapes as people perceive and value them in terms of ecosystem services into the biophysical models traditionally used to assess natural systems.

Taking these factors into consideration, water resources management issues are uniquely, and necessarily, best approached through interdisciplinary methods that incorporate perspectives from both social and biophysical sciences but new methods are needed to facilitate this. Socio-hydrology, as mentioned previously, seeks to develop specifically interdisciplinary approaches to understanding water resources challenges by recognizing that people cannot be decoupled from the environment in which they live. Socio-hydrological approaches seek to describe two-way feedbacks in human-water coupled systems that account for historical trajectories and relationships between people and water, difference across spatial, temporal, socio-economic, and climatic gradients, and detailed studies of human-water systems (Baldassarre et al., 2013; Sivapalan et al., 2012). Once again, this is a break from the traditional IWRM paradigm that considers human behavior as an externality acting on water systems rather than an integral part of these systems (Sivapalan et al., 2012; Troy, Konar, Srinivasan, & Thompson, 2015).

For scientists (biophysical or social) involved in a given project, their selected methods of inquiry are more likely to be driven by the understanding they have of an issue via their own focused discipline rather than by the actual issue at hand. This is a subtle but critical difference that ultimately challenges all scientists to accept that their own discipline is not the sole place – or even always the most appropriate place – where hypotheses are developed and tested before being put into the public sphere for use in decision making. In other words, a scientist must be motivated by the issue or challenge itself, rather than by being to "solve" something in the context of the expertise they have. In addition to considering knowledge from other disciplines, there must be a willingness to integrate knowledge held by the people who are affected by the issue/challenge.

Hydrologists typically assess a watershed's response to changing land management in terms of biophysical responses, such as changes in stream discharge or sediment delivery downstream. In a post-processing decision support environment, there may then be efforts to loosely couple outputs to social and economic models or variables such as domestic water uses and demands, economic valuation for water derived products, or human health among others. Such examples are numerous throughout the literature (see Fiksel, Bruins, Gatchett, Gilliland, & ten Brink, 2014; Girard, Rinaudo, Pulido-Velazquez, & Caballero, 2015 for recent framework examples and see Herath & Prato, 2006; Kersten, Mikolajuk,, & Yeh, 1999; El-Swaify & Yakowitz, 1998 for overviews of such systems and tools), generally comprise an interdisciplinary approach, and are widely accepted as best practices in integrating the social and biophysical sciences for improved decision making (Uiterkamp & Vlek, 2007). Results, however, often present an incomplete picture of people's needs or value systems (Fagerholm & Käyhkö, 2009).

At the root of the issue here is that traditional methods used to describe social and economic aspects of communities (*e.g.*, surveys, participatory rural appraisal, focus groups, and ethnographic studies) are not well-suited for direct inclusion into biophysical modeling frameworks. At best, scenario development supported by socio-economic data may be employed to account for agricultural productivity, land management, and water allocation within biophysical models. Such exercises have difficulty, however, capturing the essence of what it means to hold a set of values, and are unable or unwilling to include many aspects of human–landscape interactions (Fagerholm & Käyhkö, 2009). In addition, scenario development exercises are driven by problems predefined by outsiders (*e.g.*, policy makers, donors, scientists) and only give an illusion of being stakeholder driven and participatory (Brett, 2003).

While a detailed discussion or evaluation of the field of participation and participatory approaches is beyond the scope of this paper, it is important to consider where on a participatory continuum this research lays. As such, we refer to White's (1996) four types of participation (Table 1). Within this typology, the interests of designers or implementers of development programs are represented in the "Top-Down" column, while the interests of the participants are indicated in the "Bottom-Up" column. Finally, the "Function" of each participation level is specified in the final column. Where research or a program falls within this typology is not fixed. For example, individual components of a program may fall into different participation categories or may move between categories.

Research presented in this paper illustrates an example of how a project can fall into different categories. The intention of the researchers who developed the pilot study was for *representative* participation, where local people generate maps of the landscape within which they live with no prompting or interaction from researchers regarding what should be represented on the map. These researchers believed that increasing their understanding of local landscape perceptions – including *how* people name elements as well as *what* they choose to name them – would present insight regarding how to plan *sustainable* research and program implementation activities. This would coincidentally give local people

Table 1
Four types of participation and their linked attributes.

Form	Top-down	Bottom-up	Function
Nominal	Legitimation	Inclusion	Display
Instrumental	Efficiency	Cost	Means
Representative	Sustainability	Leverage	Voice
Transformative	Empowerment	Empowerment	Means/End

Source: White, 1996.

leverage in steering research and program directions toward immediate and pressing community interests by giving them a *voice*.

Whether or if outputs (maps in this case) or knowledge gained from activities are utilized to inform other research questions or decisions can be subject to the actions of others. This may then move participation into the *nominal* category whereby a program or project is able to show they have done something to *include* local people, thereby *legitimizing* a broader set of top-down driven activities but effectively only serving as a *display*. This is the type of challenging crossroads where interdisciplinary research often finds itself. The works by Lane et al. (2011) and Maynard (2015) show clear *transformative* and *empowering* benefits to science and communities when a more participatory and overlapping consensus approach is undertaken, but it requires scientists to see themselves as part of the process of creating knowledge rather than outside the process and as the sole keepers and purveyors of knowledge.

Thus far, the focus of this discussion has been more so on scientists and their interactions with one another while taking multidisciplinary or interdisciplinary approaches to research. The topic of participation facilitates a more explicit consideration of *transdisciplinary* research, which can be described as crossing the boundaries between scientific and non-scientific communities (Lang et al., 2012; Rist & Dahdouh-Guebas, 2006). Such approaches create a multidirectional learning environment for scientists and society to learn from one another to support decision-making processes for sustainable use and management of natural resources.

1.1.1. Maps as transdisciplinary research

Recent years have seen a shift in development from “doing to” or “doing for” to one of participatory approaches that emphasize “doing with” people, which necessarily encourages transdisciplinary approaches (Brett, 2003; Chambers, 1997; Chambers, 2002; Craig, Harris, & Weiner, 2002; Kyem, 2001; Vajjhala, 2005). From this perspective, the merits of geographic information systems (GIS) and participatory mapping have been widely heralded as the next step in more transdisciplinary development practices and approaches (Chambers, 2006; Dwamena, Banaynal, & Kemausuor, 2011; Rambaldi, 2005; Rambaldi, Chambers, McCall, & Fox, 2006; Vajjhala, 2005). That said, even when such methods are used, there is a noted lack of provisions to ensure that research questions, approaches, and solutions are truly stakeholder driven.

Participatory mapping is an exercise generally initiated by communities or researchers to obtain social data (*i.e.*, perceptions or observations about a landscape) and arrange it spatially. Participatory GIS (PGIS) is more commonly planned and implemented by researchers, where spatial data are arranged in such a way to generate better understanding of social phenomenon. Koti and Weiner (2006) and Kristjanson, Radeny, Baltenweck, Ogutu, and Notenbaert (2005) provide excellent examples of using participatory mapping in Kenya to clarify *how* people are actually living in the world as opposed to what data layers provided by government agencies tell us about *where* they are living. Differences here are subtle, but important to understand because many spatial data, particularly those obtained from government agencies, are meant to focus only on where people live and yet they are commonly used to drive any number of spatial analyses about poverty or access to resources.

In Zimbabwe, Mapedza, Wright, and Fawcett (2003) used aerial photos to better understand land use change in the Mafungabusi Forest Reserve. Interviews and mapping led to additional discoveries and allowed researchers to generate maps with more localized information about vegetation. Drivers of land use change also came into focus and were different than previously understood, which may have been in part because researchers obtained information from government officials who possibly had a stake in maintaining interventionist policies. Similarly in Burkina Faso, Hessel et al. (2009) found that using participatory mapping approaches greatly enhanced scientific research and understanding about drivers and consequences of land use change. The integration of scientific and indigenous knowledge about local landscapes led to the development and sustained implementation of improved land management practices with regards to factors affecting soil erosion, soil fertility, and grazing.

Fagerholm and Käyhkö (2009) used participatory mapping methods in Zanzibar to identify areas of the landscape that are considered culturally and socially important. They analyzed this information using Shannon diversity index and Getis-Ord Gi* statistics to identify relevant hot spots and inform land use planning. Typically, the Shannon diversity index is used to assess the number of species at a given spatial scale (Krebs, 1999); however, in this instance the authors take a novel approach where they calculate the index as a representation of the diversity of social values expressed by informants within a given 0.25 ha cell. On the other hand, Getis-Ord Gi* is a clustering algorithm that indicates whether features and their attributes are spatially clustered (Ord & Getis, 1995). In this case the authors calculated that statistic based on the intensity of a social value (*e.g.*, how often different informants identify the same social value) at a given 0.25 ha cell and within a 100 m distance of that cell. They found distinct differences in how men and women identified and mapped important features as well as how they were clustered across the landscape giving rise to “hot spots” that were valued differently by men and women.

To facilitate a more active participation process, Dwamena et al. (2011) employed participatory three-dimensional mapping (P3DM) in Northern Ghana. Using this mapping method, participants add features to a three-dimensional scaled model of the landscape. They do this using pushpins, yarn/string, and paints to depict point, line, and polygon features, respectively, on the blank model (Rambaldi, 2005). This model can then be photographed and digitized for use, but the model remains with the community.

Participants found the P3DM exercise carried out in Ghana engaging and the process allowed people from diverse educational and social backgrounds (*i.e.*, literate and non-literate, professional and farmers, rich and poor, etc.) to participate in the process, and the authors noted increased communication among these diverse groups over more traditional participatory methods. As part of the study, researchers engaged NGOs and government actors to participate. NGO workers discovered, for example, that many of them were supporting the same farmers and in the same way, yet unknowingly.

Through participatory mapping, unspoken and previously unknown landscape uses and values can be discovered as well as information regarding access to services. When people are engaged in mapping activities, they identify physical landscape features, daily activity routes, and landmarks, which can help guide the development of appropriate and relevant research questions and ultimately solutions. With regard to women and water, in using these methods researchers may begin to understand emerging socio-biophysical patterns whereby girls and women – the primary drawers of water in rural communities – are more exposed to water and vector borne diseases such as typhoid or malaria. In such a case, we have facilitated an interdisciplinary and transdisciplinary research environment that utilizes multiple equally valid accountings of a landscape's resources and uses. In this way, local knowledge enhances scientific knowledge and is shown to be a powerful tool in parameterizing biophysical models of the natural environment.

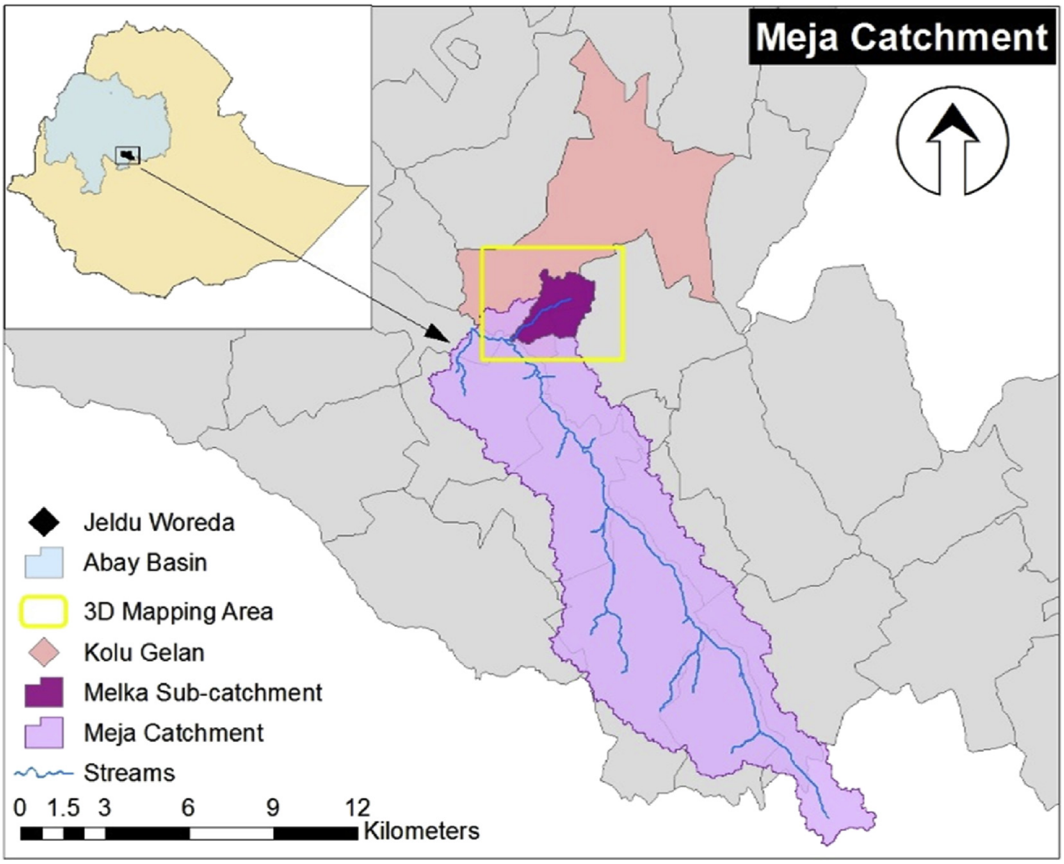

Fig. 1. Study site location within Ethiopia.

1.2. *Ethiopia case study*

This pilot study was carried out in the Melka tributary of Meja River, which is one of the primary rivers draining Jeldu woreda in Ethiopia's Oromiya region, with numerous tributaries draining the watershed through deeply incised mountain streams with relatively small catchment areas (averaging 3–4 km^2). A 20 km^2 area within the woreda was selected as a case study site for this research (Fig. 1). This site was selected as a case study site due to the longstanding relationship researchers have with the local community beginning with the Nile Basin Development Challenge program (http://nilebdc.org/) in 2010 and the data availability for hydrological analyses.

As reported by Snyder and Cullen (2014), a typical household in this area will be comprised of the core family unit and potentially host relatives from afar who are employed as laborers or domestic servants. The authors also report that gender is an important factor in access and control of land and other resources. Population in the pilot site is ethnic Oromo, with religious affiliation being either Orthodox Christian or Protestant.

With regard to land and resources access in Ethiopia, Snyder and Cullen (2014) report several key political and gender focused considerations, which are summarized here. For example, land rights come directly through the local government in most instances and that when it does come from the family; it is through the husband's parents. In addition, land distribution is highly fragmented such that a family may have plots scattered across the landscape rather than adjacent to one another. In addition, land distribution was based on family size at the time of redistribution programs under the Derg and may no longer be adequate for a given family, which has resulted in a large number of landless sharecroppers in the community at Jeldu.

There are 3 urban kebeles[1] and 38 rural kebeles in Jeldu woreda. Kolu Galan is considered the largest of all the kebeles, as it is made up of three kebeles that were merged. According to local government data, there are approximately 1687 households in Kolu Galan kebele (or *ganda* in *Afaan Oromo*), excluding ‘landless farmers’. From these households 1461 are male headed, 226 are female headed.

The Melka catchment is 5 km^2 and characterized by a high relief landscape typical of the Ethiopian Highlands, with elevations ranging from 2469 to 2867 masl. Seasonal rainfall patterns consist of two rainy seasons (*belg* short rains from February–April and *kremt* long rains from May–October) and one dry season (*bega* from October–February) with localized rainfall estimates varying from 900 mm to 1350 mm. Soils in the catchment are considered clayey and prone to low permeability due to development of clay pans below the surface (FAO/UNESCO, 2003).

Agriculture in the Kolu Galan area is a mixed crop-livestock system, and slopes up to 80° are cultivated. Common crops grown are potatoes, barley, teff, wheat, maize, and sorghum. There is variation in crop type according to elevation. Research indicates that farmers in Kolu Galan identify two distinct zones determined

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[1] Kebele is the smallest administrative unit in Ethiopia that was introduced across the country with the onset of the Derg regime. Woreda is the next level administrative unit that consists of several kebeles. While kebeles are divided into villages, these don't have administrative authority. (Amharic kebele (sg) kebeloch (pl)).

by elevation, temperature and moisture: *baddaa* and *baddaa darree*. These zones influence the type of crops grown and associated cropping practices. Crops, particularly staple crops, are often rotated with fallow every third year, although this depends on land availability. Erosion is a major challenge in the site, causing prominent gullying and high levels of sedimentation to occur. Eucalyptus *spp.* are planted over approximately 10% of the catchment area in small plots as they are considered a valuable cash crop for farmers.

2. Methods and data

2.1. Participatory three-dimensional mapping

During January 2014, participatory three-dimensional mapping (P3DM) was carried out in Kolu Galan kebele, Ethiopia over six days. Local participants in the exercise included male and female secondary students and men and women farmers from Kolu Galan kebele. They were both elders and younger farmers and were selected with the help of the local agricultural extension agents (Development Agents) based on the suggestions from ILRI and IWMI social scientists. Due to the complex political context in Ethiopia, researchers were unable to influence the selection beyond suggesting basic criteria such as: male and female, youths, and young adult and elder farmers. Various groups and individuals are brought in at different points to ensure a wider degree of and opportunities for participation.

A 20 km^2 area was selected for the mapping exercise, with men and women creating separate maps for the same landscape. The entire mapping process took place at a local secondary school. Over six days, there were several map development phases: building the blank, legend making, mapping exercises, digital photographs of the final maps, presentation of final maps to the community, and follow-up interviews with participant and community members. A pre-mapping phase was carried out from Addis Ababa that entailed building and printing a base map (contours) and planning logistics for the mapping exercise.

Base map contours were prepared by a GIS technician at IWMI using a 30 m ASTER GDEM v2 (METI/NASA, 2009) in ArcMap 10.0 (ESRI, 2011). The DEM was resampled using the Focal Statistics tool in ArcToolBox and a two cell circular radius. Contours were then generated at a scale of 1:5000 with a 10 m contour interval in accordance with methods described by Rambaldi (2010).

After District Agents selected participants for the mapping exercise, a professional participatory mapping facilitator was brought in provide an orientation of the process to the community as well as facilitate the stages described above. The facilitator was assisted by an anthropology PhD student from Addis Ababa University and the exercises were largely facilitated using the local language, *Afaan Oromo*. This student also recorded in writing and via digital voice recording interactions among participants, including the facilitator and researchers.

Eight boys and eight girls worked side-by-side along with two male teachers to assemble the three-dimensional landscape known as a “blank”. This entailed tracing the base map contours onto 3 mm thick 80 cm × 100 cm cardboard, cutting them out, and then assembling the layers to create a three-dimensional 1:5000 scaled representation of the local topography.

Four local Kolu Galan elders (two male and two female) jointly developed the initial map legend that detailed resources they perceived as most valued by the community. No instruction was given to the elders on what to specifically include in the legend; however, the community has a long-standing relationship with IWMI and the International Livestock Research Institute (ILRI) through the Challenge Program on Water and Food under which fodder interventions and soil and water conservation activities were carried out and are still are under way. This may have influenced what people chose to map.

Developing the legend took place over two days and elders and community members engaged in long discussions, often several hours, surrounding colors for point data as well as whether certain items should be shared on the map or not. For example, mapping sites of significance for traditional religion (*i.e.*, not Ethiopian Orthodox or Protestant) were controversial in terms of how important or useful it was to map them.

After the blank was assembled and the initial legend developed, eight additional farmers (four men and four women) participated with the elders in painting and identifying point, line, and polygon features on the “blanks”. Male and female groups were set up with their respective “blanks” in different locations at the secondary school. Groups were informed that they did not have to map all items identified during the legend development stage nor was there a requirement to share information they consider sensitive or that they collectively or individually did not want to reveal to researchers. In addition, participants were encouraged to elaborate on the legend if they chose to do so.

Following White's definition of four types of participation (Table 1), in the case of this project, the participation was ‘representative’ as it allowed the participants to express their own interests and gave them a voice in the project (White, 1996).

The process, as well as participant dynamics, were observed and documented by anthropologists familiar with the area and local community members. Following the mapping exercises, focus group discussions and individual interviews were carried out with participants to assess their experience of the overall process from participant selection through map presentation. This information was used to develop and refine subsequent participatory mapping activities to ensure participant questions or concerns about such activities are addressed early in the process, that more work is undertaken to facilitate a broader participant selection when possible, and allowed participants to express views on what they consider to be positive and negative aspects of such activities. Participants were also asked to comment on the map generated by the other group (*e.g.*, men commenting on the women's map and vice versa). Finally, the map was presented to the community and handed to the school in an official ceremony on the school premises. Teachers intend to use the maps in their classes to teach students local geography.

High resolution photos were taken of each map and then digitized in ArcGIS 10.0 (ESRI, 2011) and male and female geodatabases were built for later use in SWAT hydrologic modeling and spatial analysis research. Digitized maps and photos are stored in a non-public storage space with restricted access.

2.2. SWAT hydrological model

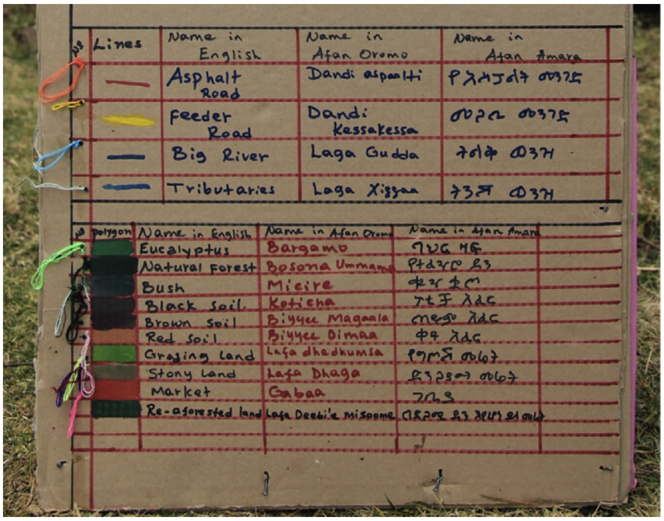
For this research, a partially distributed physically-based hydrological model, the Soil and Water Assessment Tool (SWAT; Nietsch et al., 2005), was selected for use. We used ArcSWAT version 2012.10_0.11 released 9/16/2013 Rev. 591. SWAT is one of the most commonly applied hydrologic models worldwide and based on the SCS (Soil Conservation Service of the United States Department of Agriculture) curve number methodology. The model operates at multiple timescales (daily, monthly, and annually) and was originally designed to assess the relative impact of land management decisions in large ungauged agricultural basins (Arnold & Allen, 1996).

SWAT calculates runoff using series of equations representing an empirical water balance relationship (Eq. (1); Nietsch et al., 2005; Arnold & Allen, 1996).

Table 2
Spatial data inputs to SWAT.

Data type	Resolution	Source
Digital elevation model	30 m	METI/NASA
Land use	10 m	IWMI
Soils	90 m	FAO
Weather	Daily precipitation, minimum and maximum temperature	IWMI

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (1)$$



№	Lines	Name in English	Name in Afan Oromo	Name in Afan Amara
		Asphalt Road	Dandi aspaalti	የአስፋልት መንገድ
		Feeder Road	Dandi Kessakessa	መጋቢ መንገድ
		Big River	Laga Gudda	ትልቅ ወንዝ
		Tributaries	Laga Xiqqaa	ትንሽ ወንዝ

№	polygon	Name in English	Name in Afan Oromo	Name in Afan Amara
	🟩	Eucalyptus	Bargamo	ባህር ዛፍ
		Natural Forest	Bosona Ummama	የተፈጥሮ ደን
		Bush	Micire	ቁጥቋጦ
		Black Soil	Koticha	ጥቁር አፈር
		Brown Soil	Biyyee Magaala	ቡናማ አፈር
		Red Soil	Biyyee Dimaa	ቀይ አፈር
	🟩	Grazing land	Lafa dhedhumsa	የግጦሽ መሬት
		Stony Land	Lafa Dhaga	ድንጋያማ መሬት
	🟥	Market	Gabaa	ገበያ
		Re-aforested land	Lafa Deebi'e misoome	በድጋሚ ደን የለማ መሬት

Fig. 2. Partial legend developed for Kolu Galan mapping exercise. Point data are not included here because they represent sensitive and often private information.

where, Q is the direct runoff (mm); P is the total rainfall (mm); and S = 1000/CN, with CN related to soil and land cover conditions, and is commonly estimated from published tables (Rawls, Ahuja, Brakensiek, & Shirmohammadi, 1993; USDA SCS, 1986), though for this study initial curve numbers follow Baker and Miller's (2013) work in Kenya and were then modified during calibration.

A principal benefit to using SWAT for this study is that as a deterministic model, each successive model run using the same inputs will produce the same outputs. This isolates hydrologic response to changes in a single variable, such as land use change (*e.g.*, gender differentiated land use maps) and the non-stationarity of the model accounts for variation through time.

2.2.1. SWAT model setup and data

SWAT requires four principal data inputs: digital elevation model (DEM), land use, soils, and weather. Additional information regarding land use management practices, such as crop rotation, grazing, and fertilizers among others, can be added when known. Catchments are subdivided into hydrological response units (HRUs), as defined by unique combinations of soil, land use, and slope. Data inputs used for the initial parameterization of the Melka sub-catchment are shown in Table 2.

Using the ASTER 30 m DEM, topographic characteristics required to run SWAT, such as slope and slope length, were calculated and the catchment was discretized into 17 subcatchments.

Fig. 3. Female map depicting a highly degraded landscape with sparse forested or grazing areas. Pink tags indicate mapped features, many of which constitute ecosystem services. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

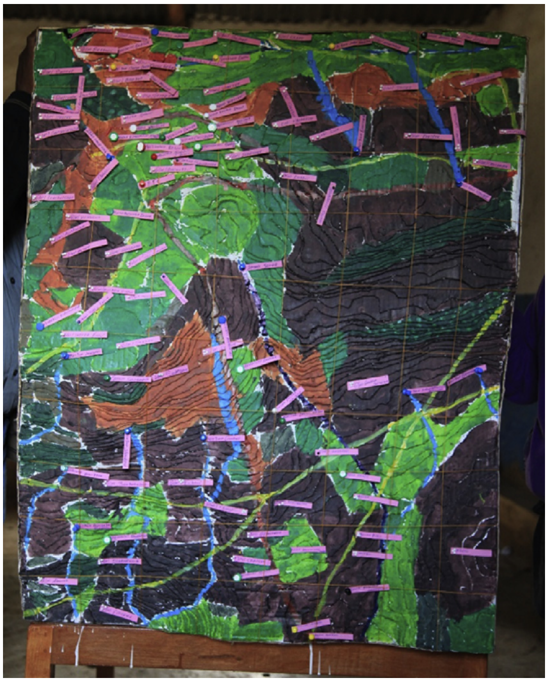


Fig. 4. Male map illustrating higher quality soils and more green vegetation in the form of grazing lands and forests. Pink tags indicate mapped features, many of which constitute ecosystem services. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

A land use map for the catchment was developed through field surveys and GoogleEarth and is comprised of 75% barley-teff-potato farming systems, 9% eucalyptus, 13% grazing lands, and 3% residential (Debela, 2012). Soils in the areas have a high clay content with the potential for forming clay hard pans close to the surface. Such soils are considered to be in hydrologic soil group C due to the impermeable layer (hard pan) that causes them to favor high surface runoff due to poor infiltration capacity. The entire study site was modeled using only one FAO soil type: Ne13-3b-158.

The Meja watershed was instrumented as part of the Nile Basin Challenge Program on Food and Water and weather data from 2011 to 2014 and observed stream flow during the same period were available for use in model calibration.

2.2.2. Model performance metrics

Following recommendations from Moriasi et al. (2007) in their extensive review of techniques used to evaluate hydrological models, two model evaluation methods were selected to assess model performance in this study: Nash-Sutcliffe efficiency (NSE) and percent bias (PBIAS). These metrics are not without limitations; however, because they are widely used in hydrology to assess model efficiency, there is extensive information in the literature for comparison.

Nash-Sutcliffe efficiency is a measure of how well a model performs based on a ratio of the residual variance to measured data variance (Nash & Sutcliffe, 1970). Values for NSE can vary from 1 to negative ∞. When NSE is equal to 0, then the model is said to predict no better than simply using average runoff as a predictor of runoff. An NSE value of 1 would indicate a perfect alignment of simulated and observed values. Positive values indicate that the model simulates a response better than simply using an average. A limitation of NSE is that it performs poorly when data variance is at the high or low extreme.

Percent bias (PBIAS) adds to the value of NSE and strengthens confidence in model efficiency because it is a measurement of the tendency for simulated data to be greater or less than their corresponding observed data (Gupta, Sorooshian, & Yapo, 1999). For SWAT, Moriasi et al., suggest that for stream flow calibration values are ranked as follows: $\pm$ 10% is Very Good, $\pm 10 \le \text{PBIAS} \ge \pm 15$ is Good, $\pm 15 \le \text{PBIAS} \ge \pm 25$ is Satisfactory, and $\text{PBIAS} \ge \pm 25$ is Unsatisfactory.

3. Results and discussion

This pilot study sought to engage researchers in a transdisciplinary process for generating and then implementing land use maps in SWAT. Results indicated, however, that while researchers went into the process focused on land use and crop type, community participants viewed the landscape through a soils lens with detailed local terminology, understanding, and descriptions of the different soil types and fertility limitations. Projects currently implemented in this region by development organizations focus on agricultural intensification and increasing yields through improved land management practices and with a focus on specific cropping systems and available soils maps for

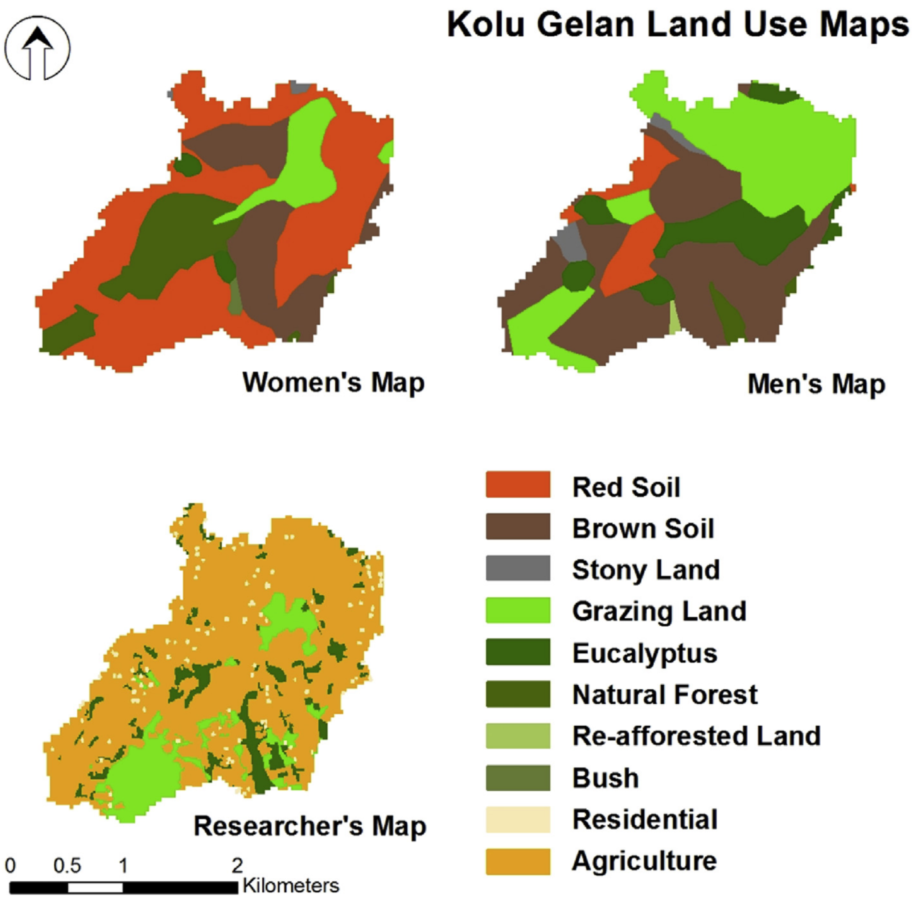


Fig. 5. Land use illustrated by different groups. Maps shown here represent only what is in the modeled subcatchment and were used to parameterize the SWAT model.

SWAT modeling designate the area as having only one soil type.

This work consequently illustrates a clear example of where both researchers (considered "experts") and community members (considered "non-experts") bring valuable information to the process and that this co-generated knowledge has a great potential to enhance research in the area in particular by broadening experts' perception of the landscape and where key areas are on the landscape to focus. Due to the open source and flexible nature of "building" a SWAT model, there is a clear opportunity to explore modeling using the concept of overlapping consensus (Diekmann and Zwart, 2014).

3.1. Participatory three-dimensional mapping

3.1.1. Designing the legend

Soils dominated the legend rather than more general land use, though grazing land and eucalyptus also featured prominently in discussions and in mapping, and represent land productivity or degradation. Three soil types were mapped and designated as *koticha* or "black soil", *biyyee magaala* or "brown soil", and *biyyee dimaa* or "red soil", which represent a continuum from high to poor quality. Poor quality soils were identified as being highly degraded, subject to increased erosion, and requiring the most fertilizer inputs for productivity.

There are some likely reasons for this. First, as previously noted, the region is dominated by poor quality soils, which are ill-suited for agricultural production without significant inputs. Eucalyptus is a high value crop more tolerant of the poor quality soils, though also contributes to further decreasing soil quality (through acidification) and altering the water balance due to high water demands. Regardless of these negative tradeoffs, it often replaces food crops in recent years due to high demands for construction materials in Addis Ababa (Cronin et al., 2013; Cullen, Belay, & Adie, 2012). Next, there have been widespread reforestation programs undertaken in recent years by the Ethiopian government and so forests and reforestation as a mechanism for decreasing soil erosion is a dominant theme in agricultural programs, especially in the highlands. This is echoed by Mûelenaere et al., (2012) who used historical photos and Landsat satellite imagery to detect land use and land cover changes in the Ethiopian Highlands. They found that over thirty years, bare soil areas had been reduced to a quarter of their original area and that while natural forest decreased slightly, overall vegetation cover had increased with Eucalyptus *spp*. plantations nearly doubling since the mid-1980s.

The final legend contained 22 point data types, 4 line data types, and 10 polygon land use types. The legend for line and polygon data is illustrated in Fig. 2. Point data types are not displayed to protect community privacy.

3.1.2. Gender disaggregated mapping

Men and women in Kolu Galan kebele produced two distinct maps of the 20 km^2 study area (Fig. 3, Fig. 4). Maps revealed striking differences not only in how men and women perceive the landscape but also in how researchers and local people illustrate the landscape. Male and female maps contained only selected information from the map legend developed and agreed upon during previous days by elders and the community (Fig. 2), with women mapping the landscape using greater detail.

After digitizing the male and female maps and displaying them alongside the land use map generated by Debela, 2012 (Fig. 5), a principal difference that emerged was that women in particular focused their map on soils, which they defined as representing aspects of productivity and land degradation, rather than by crop types or farming systems. Soils information available from the FAO does not give this level of detail or perspective. When asked to elaborate on the different soil types, community members indicated that "black soil" is fertile and productive, even without additional inputs such as fertilizer, though they are often advised to do so by researchers and government agricultural workers. On this soil, they will largely produce barley, wheat, and beans. "Brown soil" was described as less fertile and only sometimes productive and used primarily for teff production. "Red soils" were described as least productive soils. Brown soils were described as being converted to red soils when the fertile upper (brown) part is eroded

Table 3
Land uses mapped within the Melka catchment. For SWAT modeling purposes, areas mapped as soil were parameterized as agriculture.

Researcher		Female		Male	
Land use	%	Land use	%	Land use	%
Eucalyptus	9	Red soil	55	Red Soil	8
Barley-teff-potato	75	Brown soil	19	Brown Soil	41
Grazing land	13	Stony land	<1	Stony land	2
Residential	3	Grazing land	8	Grazing land	33
		Eucalyptus	2	Eucalyptus	14
		Natural forest	15	Natural forest	2
		Bush	1	Re-afforested	<1

Table 4
Key features mapped by gender, which illustrate many direct linkages to reliance on ecosystem services. Maps are not presented of these point features to protect the privacy of the community.

Feature	Female	Male
Schools	3	2
Orthodox churches	3	3
Protestant churches	10	8
Sacred sites	4	3
Bridges	4	3
Peasant Association Office	1	1
Human health posts	3	2
Animal health posts	1	1
Police station	1	1
Residence areas	41	57
Mills	3	2
River fords	2	2
Sacred trees [*Delci*]	2	3
Sacred trees [*Selger*]	1	3
Springs	15	11
Horse arenas	2	2
Stores	2	1
Farmer training center	1	1
Small factory	1	0
Holy water sites	2	0
Quarries	4	0

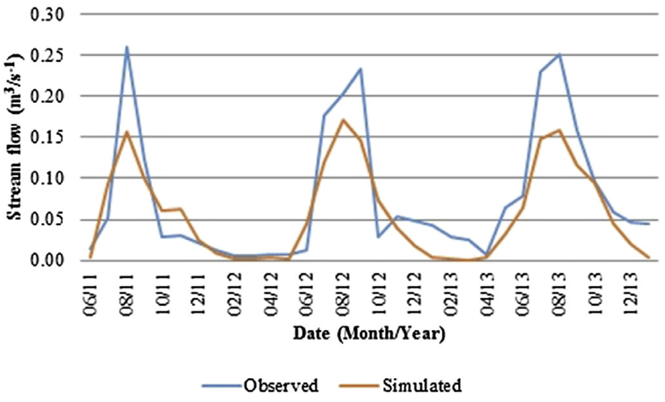


Fig. 6. Uncalibrated stream flow results from SWAT.

Table 5
Paramters used for SWAT model calibration.

Parameter	Definition	Default Value	Calibration Value
Alpha-bf	Baseflow recession constant indicates whether groundwater has a rapid or slow response to recharge. This unitless value varies from 0 to 1.0.	0.048	0.67
CN2	Initial curve number.	Varies by land and soil type	−10%
ESCO	The soil evaporation compensation factor indicates how much water is extracted from lower soil levels through capillary action for soil evaporative processes. This unitless value may vary from 0.1 to 1.0. As the value decreases, the model is able to draw more water from lower depths to account for demand.	0.95	1
EPCO	The plant uptake compensation factor accounts for water required on a given day by plants for transpiration. This unitless value may vary from 0.1 to 1.0 and as it approaches 1.0, plant water demand can be met by water from lower soil depths.	1.0	0.1
GW DELAY	Groundwater delay time (days) indicates the time from when water exits the soil profile and enters the shallow aquifer.	31 Days	20 Days
REVAPMN	Depth of water required in the shallow aquifer for percolation to the deep aquifer can occur.	750 mm	100 mm
PET Method	Potential evapotranspiration refers to the amount of evapotranspiration that would occur if sufficient water were available. SWAT allows for three methods to estimate Potential Evapotranspiration: Hargreaves, Priestly-Taylor, and Penman-Monteith. Method selection is often driven by available data, with Penman-Monteith requiring a detailed suite of weather data. Hargreaves on the other hand is based on air temperature, which is more widely available worldwide.	Penman-Monteith	Hargreaves

away. Such soils have almost no natural fertility and are completely non-productive in the absence of fertilizers.

Men on the other hand, mapped larger areas for grazing lands. Here it is important to note that maps are static representations of a point in time and so depicting complex seasonal variation is not possible. This limitation of the mapping process was commented on in group discussions and interviews with participants. Within Kolu Galan, grazing practices shift throughout the year but the men, who are responsible for grazing animals, were not able to depict this dynamic system via a static map. Some areas are communal grazing land used throughout the year and never for agricultural production. These are the only are static grazing areas. Farmers also employ shifting cultivation practices whereby an individual may use part of their land for grazing rather than crop production during the growing season. Individuals may also manage some plots explicitly for grazing and then coordinate with others farmers for use. Finally, during the dry season when lands are not under cultivation, all the land is communally grazed. Men identified that expanding and changing agricultural practices are a problem because they limit the land available for grazing livestock.

Ultimately, the most important differences among the three maps were less about land use because the distributions of land use types modeled and their hydrological response to rainfall in SWAT are similar (Table 3). Instead, it is soil fertility as well as the identification of ecosystem services hotspots for the community that were more prominent (Table 4).

Assessment of the resulting gendered maps indicate that there are key differences among several ecosystem services valued by men and women (Table 3). Most notable was the complete absence of quarries or holy water sites on the men's map. Men also mapped fewer springs and mills.

Across both maps, sacred areas (sites and trees) were mapped, though initially their inclusion was controversial. From a cultural-ecological perspective, the traditional Oromo religion of *Waaqeffata* (Kelbessa, 2001) and Ethiopian Orthodox churches play a critical role in biodiversity preservation on landscapes (Cardelús, Baimas-George, Lowman, & Eshete, 2013; Cardelús, Lowman, & Eshete, 2012; Cardelús, Scull, et al., 2013), and several churches and ultimately sacred trees were noted across both maps.

Both groups identified the same ford locations on the map indicating that for men and women these are important river crossings and so any changes in the hydrological pulse that changes accessibility to these two locations could pose a significant burden. All of these locations are indicative of ecosystem services hotspots on the landscape and can be effectively integrated into biophysical models as points or outlets where model outputs, such as stream discharge or sediment, can be used in assessing trade-offs among different land management scenarios. Because men and women mapped different features, it is then possible to assess how these scenarios may impact the two groups separately.

3.2. SWAT hydrological model

We manually calibrated SWAT on a monthly time step at the Melka bridge, which is the outlet for the Melka sub-catchment within the Meja Catchment, using data collected by IWMI between 2011 and 2014. Using the default parameters in SWAT, the model performed reasonably ($NSE = 0.86$; $PBIAS = 26\%$), though under-predicted stream flow during the rainy season (Fig. 6).

To improve model calibration and to more adequately represent the water balance, several key parameters within SWAT were modified (Table 5). In addition, management for crop rotations, tillage, harvesting, and livestock grazing were added to the model database. Evapotranspiration was calculated using the Hargreaves method rather than Penman-Monteith because it requires only temperature. These changes greatly improved model performance, resulting in $\text{NSE} = 0.86$ and $\text{PBIAS} = 16\%$ (Fig. 7). Model validation was not possible given the short time series available. A benefit in using SWAT, however, is that it was originally developed for use in ungauged agricultural basins and as a deterministic model, its strength is that it can be used to assess the *relative* magnitude and direction of change among different management scenarios.

As previously mentioned, one of the benefits and reasons for using the SWAT model in this case study was that it is a deterministic model (*e.g.*, same model inputs always deliver the same model outputs) and so any input change results in a corresponding output change. This allows researchers to isolate and assess the impact of a given parameter. As a pilot demonstration case, only the impact of changing the land use maps was assessed. This is perhaps one of the more interesting learning moments for the researchers who had designed the study assuming that when people map, they will map land cover and use because much of the research in this study site has focused on crop and fodder

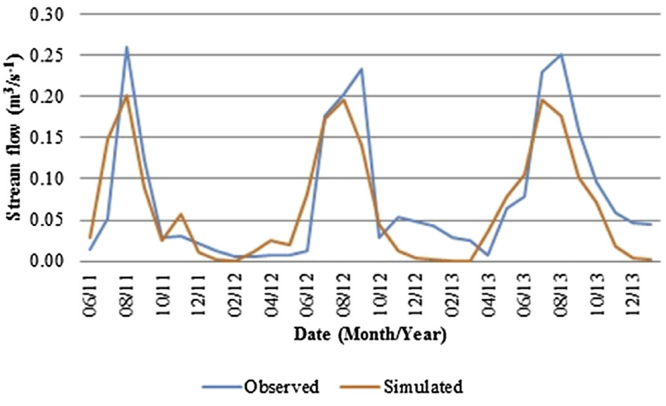


Fig. 7. Calibrated model output using SWAT.

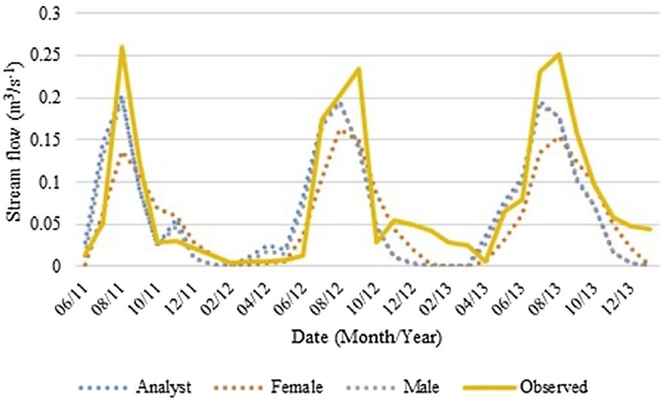


Fig. 8. Comparison of stream flow outputs against observed data and based on three different land use maps.

Table 6
Average annual values for elements of how rainfall is being partitioned.

	Female	Male	Researcher
Surface Runoff (mm)	207	319	308
Shallow Aquifer (mm)	639	566	577
Deep Aquifer (mm)	0	30	0
Evapotranspiration (mm)	513	486	488

interventions. For the local community, however, conversations during the mapping exercise as well as post-processing interviews focused more on soil fertility.

Using a model set up that relied on the current land use employed by researchers,[2] the men's and women's maps were implemented in SWAT to parameterize land use. There were effectively no major changes when changing the land use from the one currently used by researchers to the one developed by the men's group (Fig. 8); however, their map was most dissimilar to the one used by researchers in that it includes a much greater area for grazing lands.

Changes to *NSE* and *PBIAS* coupled with an assessment of resulting changes in how water was partitioned in the model when driven by different land use maps gave additional insight (Table 6). For example, *NSE* changed only marginally (female map = 0.84; male map = 0.87), but with both maps indicating increases in *PBIAS* (female map = 27%; male map = 20%).

From a water balance perspective, it is noted that the women's maps resulted in more water being partitioned into shallow groundwater and likely influencing baseflow, which is also apparent in the more gradual changes in the rising and falling limbs of the hydrographs (Fig. 8), and as evapotranspiration.

4. Conclusions

In this case study, we present a transdisciplinary approach to socio-hydrology. We showed that community derived maps can be integrated with biophysical models, and we also showed that those same maps can deliver insight regarding community priorities, drive research for development questions, and allow assessment of management strategies in a way that ensures gender disaggregated trade-offs are considered.

We showed that SWAT results using three different land use maps (researcher, female, and male), results were similar. This is because the land use from a rainfall-runoff perspective and curve number identification did not vary appreciably across the three maps. For example, researchers and women mapped relatively similar extents for agricultural areas. Consequently, it would be natural to ask, “Why then undertake such an exercise if the modeling results are the same?”

There are several reasons. First, in other locations or over larger areas there could be significant differences among maps produced. More importantly, from the post-process interviews carried out with the community afterwards, it was evident that participants through this exercise saw themselves as more engaged in the research process. This is different than the role they traditionally see themselves in during stakeholder consultations that are driven by pre-defined research agendas.

Because there were no promptings of what to map as valued from an outsider perspective, the community members mapped what they knew of their lands. This information and knowledge can now be integrated with other forms of scientific knowledge and tools, such as biophysical models, and used to drive research questions. This aspect surprised participants when discussed during interviews and they indicated that scientists typically come to their community with pre-identified ‘problems’ and tell them what they think is wrong. Such traditional approaches reinforce a value-laden system where scientists have special knowledge that is deemed “better” or “more correct” than other forms of knowledge, including gender influenced approaches, and that has been widely criticized as both short-sided and hampering scientific research (Faulkner, 2000; Lynam, De Jong, Sheil, Kusumanto, & Evans, 2007; Rist and Dahdouh-Guebas, 2006; Uiterkamp & Vlek, 2007).

Another question that quickly comes to the forefront is, “Which one is correct?” None of the maps are inherently correct or incorrect. Rather, they represent the values that different groups (men, women, researchers) place on the same landscape. As such, they represent unique insights and priorities regarding access to and use of natural resources. In simple terms, women showed a strong concern over soil fertility, men focus more on grazing lands and eucalyptus, and researchers are heavily focused on crops and farming systems. Considering the respective roles that each of these groups serves in society: feeding families (women), engaging in income generating activities involving livestock and eucalyptus (men), and seeking answers to food insecurity (researchers), the maps all provide knowledge that is important in driving research for development agendas and questions.

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[2] It is important to note that the model could have been set up with any of the three land uses and then separately calibrated and used. The purpose of the study is to assess the deterministic response of changing land use. Any changes here note only a change in model performance given a particular calibration parameter set, or which there can be many such sets resulting in varied performances, and are not an indication of “correctness” of landscape depiction by any of the three groups.

In all research for development projects, scaling up has become a driving factor in carrying out research. While directly scaling up the method here may be infeasible over large basins (*e.g.*, Nile, Volta, Ganges, Mekong, Andes), it is possible to easily integrate localized concerns into basin planning processes. In addition, three-dimensional maps have been developed across large landscapes covering over 100,000 km^2 (Dwamena et al., 2011). As indicated by Abbot et al., (1998), localized information could when appropriate be used to develop regional plans and that this local-level knowledge has the opportunity, within certain ethical boundaries, to become something more than the product of a dialogue between a community and an intervention agency. In addition, other types of participatory mapping activities that are less time and resource intensive can be employed over multiple scales and with different types of stakeholders to generate a transdisciplinary and therefore more informed understanding of priorities that can drive research agendas.

Participatory projects often argue that their methods and tools are educational and empowering for the community, but they vary widely on a spectrum of what it means to participate all the way from consulting or informing local communities to partnering or even ceding power over the development process to them (Brett, 2003). It is clear from this case study that researchers, through participation with stakeholders, stand to truly gain insight into ecosystem services most valued by communities and use this as an entry point to drive the research for development agenda.

Although many NGOs and donors have heralded participation in recent years, many still fail to recognize that community members often have no incentive to participate and may be excluded due to cultural reasons or that the participatory methods employed may be hijacked by local elites and used to further marginalize the poor (Brett, 2003; Cleaver & Nyatsambo, 2011; Cullen, Tucker, Snyder, Lema, & Duncan, 2014; Warner, 2006). Warner (2006) and Chambers (2006) both point out that it is also arrogant for researchers to assume that people are not already conducting themselves in participatory ways. For example, participatory mapping is only a novel approach from a development perspective in light of changing our focus from doing *to* or *for*, to doing *with*. It is unlikely that people were unaware of their geographical surroundings and resources prior to researchers facilitating the production of “official maps” (Chambers, 2006).

What we have proposed here is a socio-hydrological methodology within a research for development paradigm that can be used with local communities, governments, and NGOs to identify gendered ecosystem services and to then assess impacts on these services under various scenarios such as climate change, proposed land management plans, or interventions. This approach allows researchers to represent the realities of people who are living in the spaces where development activities are being carried out and who will be directly impacted by such work. We have shown that it is possible, and even desirable, to more fully integrate the biophysical and the social sciences by adopting transdisciplinary approaches that facilitate constructive feedbacks among local communities and scientists across multiple disciplines.

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