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Towards systematic planning of small-scale hydrological intervention-based research

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Abstract

Many small-scale water development initiatives are accompanied by hydrological research to study either the shape of the intervention or its impacts. Humans influence both, and thus one needs to take human agency into account. This paper focuses on the effects of human actions in the intervention and its associated hydrological research, as these effects have not yet been discussed explicitly in a systematic way. In this paper, we propose a systematic planning, based on evaluating three hydrological research projects in small-scale water intervention projects in Vietnam, Kenya, and Indonesia. The main purpose of the three projects was to understand the functioning of interventions in their hydrological contexts. Aiming for better decision-making on hydrological research in small-scale water intervention projects, we propose two analysis steps: (1) being prepared for surprises and (2) cost-benefit analysis. By performing the two analyses continuously throughout a small-scale hydrological intervention based project, effective hydrological research can be achieved.

1 Introduction

In supporting sustainable water resources management in developing countries, small-scale water development initiatives play an important role. Such projects are usually initiated and/or supported by local non-governmental groups, but also by larger donors such as USAID and others (Van Koppen, 2009; ECSP, 2006; Warner and Abate, 2005). Typical small-scale intervention projects include water harvesting development, improving small-scale irrigation schemes, and small dams for water use or hydropower (Lasage et al., 2008; Ertsen et al., 2005; Falkenmark et al., 2001; Farrington et al., 1999). Small development activities have been well studied. Phalla and Paradis (2011), Gomani et al. (2009), and Das et al. (2000) discuss hydrological research and local participation in interventions with the goal to improve decision-making about the options for interventions. In order to properly implement an intervention, theories and practices of adaptive management have been suggested as potential beneficial approaches (Fabricius and Cundill, 2014; Beratan, 2014; Von Korff et al., 2012). Furthermore, local participatory approaches in hydrological monitoring throughout the world have shown to be potentially effective – e.g. in South Africa, Zimbabwe, and India (Kongo et al., 2010; Vincent, 2003; Das, 2003; Das et al., 2000). However, the combination of the two – hydrological research management and local participation in the hydrological research – has been rather absent from the literature. Currently, a more systematic overview of issues on planning hydrological research within small-scale water intervention projects is lacking. This paper aims to fill this gap.

In developing our analysis, we focus on hydrological studies in three areas: Vietnam, Kenya and Indonesia. Some information on and understanding of the local hydrology is typically required for design, construction and management of small-scale water interventions. Even though such a hydrological study may be limited in scope – both in terms of time and detail – it still takes considerable effort performing the study and collecting the data. This holds especially for building and maintaining (informal) networks and relationships for successful local data collection (Mackenzie, 2012). Despite this, most studies on small hydrological studies related to interventions – if available at all – focus on negative events like theft and vandalism (see Kongo et al., 2010; Mul, 2009; Gomani et al., 2009). Even when these events are discussed, they seem to be perceived as simple bad luck, which could happen every time and everywhere during a research. As theft and vandalism usually result in less data, and data sets would have been relatively limited anyway, studies using such limited data are typically difficult to be accepted in the scientific research areas (Winsemius, 2009). We argue that human agency – both positive and negative – should be an integral aspect of designing, performing, and evaluating intervention-based hydrological research.

Many small-scale interventions are located in areas that have been studied less well. In 2003, the International Association of Hydrological Sciences (IAHS) initiated the Prediction in Ungauged Basins (PUB) initiative with the objective to promote the development and use of improved predictive approaches for a coherent understanding

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of the hydrological response of ungauged and poorly gauged basins (Sivapalan et al., 2003). This paper links to PUB as all catchments in our study areas were originally ungauged and were similarly approached. Available data came from stations far from the study area and satellite data providers. One of the topics in PUB that related to our case studies is investigating the dominant processes by using a multi-method approach (Mul et al., 2009; Hrachowitz et al., 2011). Our researches were primarily field campaigns, with the disadvantage of financial constraints (Mul et al., 2009; Hrachowitz et al., 2011); they were performed in short periods. Furthermore, as with the PUB challenges (Hrachowitz et al., 2013), the case studies were located in remote areas in three different developing countries. These conditions challenged us in setting up a proper field campaign. On-site measurements were much dependent on the support of the local communities.

Human changes the landscapes through interventions for many purposes due to human demands (Ehret et al., 2014). Hence, human agency is continuously changing future hydrology, which means we need to build deeper understanding of human–water dynamics (Sivapalan et al., 2014; Ertsen et al., 2014). As in our cases, it turns out to be highly relevant to look at the interactions between humans (as a proposer and/or stakeholder of intervention and/or research itself) and the complex hydrological system. Likewise, as the interventions influence society – beneficially or not – society needs to create an awareness and overall understanding of the interventions. Hydrological change usually occurs after a certain intervention has been implemented. On the other hand, society actually interacts before, during, and after the intervention as well, which are crucial phases in deciding the type of intervention to be implemented. Therefore, the potential interactions with possible feedbacks and changes not only show that humans play an important role in determining much of the behaviour of catchments, but also may already influence hydrology and society before the intervention takes place.

In tracing the social processes relevant for the development of research and intervention in our three cases, we looked for patterns. In the current context, as hydrologists who cannot be separated from the socio-hydrological world (Lane, 2014), we

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searched for a better way of conducting small-scale hydrological research in the future. How can hydrologists make better decisions when planning hydrological research realizing that humans make decisions on a daily basis that will affect the intervention development and hydrological research itself? Our objective is to propose a systematic process of performing hydrological research in small-scale water intervention projects. We propose two related steps: (1) being prepared for and respond to surprises, and (2) cost-benefit analysis.

In terms of planning for surprises, we have found the frameworks as developed by the RAND cooperation on how to be prepared when facing "surprises" in planning extremely useful. Dewar (2002) (see also Dewar et al., 1993) discusses such surprises and provides a tool for improving the adaptability and robustness of existing plans by making assumption-based planning (ABP). With ABP, one would double-check the planners' awareness of uncertainties associated to any plan, including assumptions that might have been overlooked. In terms of cost-benefit analysis, research budgets for small-scale interventions are usually constrained (e.g. Phalla and Paradis, 2011). What to do with such limited budget, how human action affects research activities and budget, and how to deal with possibly costly surprises are important questions to prepare oneself for. In terms of time constraints, a very useful example of how to optimize short-term data is offered by Hagen and Evju (2013). To understand a certain water intervention, ideally a hydrological researcher would prefer measurements being conducted at many locations, for a long time and with high frequency. However, within that general preference and given financial constraints, much remains to be chosen by the researcher (Hamilton, 2007; Soulsby et al., 2008). This suggests that different researchers would select different actions and measurement techniques, even when performing a similar type of hydrological research. As such, choices can be studied in terms of costs and benefits.

Despite this potential of looking at uncertainty in planning of small-scale hydrological research related to human actions, there is still a long way to go. The above-mentioned bias towards not publishing small-scale studies not only may limit understanding of

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the hydrology of small-scale water systems, but it also prevents understanding the nature and performance of the small-scale studies in relation to the intervention itself. Any intervention can be understood in terms of cooperation and negotiation between actors in the process (re)shaping its design (Ertsen and Hut, 2009). In other words, water planning and management are typically organised or "co-engineered" by several agencies or actors (Daniell et al., 2010). This co-engineering will also be the case in shaping the hydrological research itself – and thus principally the science of hydrology as well. In this paper, we evaluate co-engineering of the hydrological sciences in action. We scan for solutions, explicitly analyse the research management in the three cases, and define how it can be improved in practice (see Sutherland, 2014). Daily realities of performing small hydrological studies are our focus. Based on evidence of the effectiveness of our own learning, we contextualize our personal experiences to extrapolate general principles how to improve knowledge development for researchers and practitioners (Beratan, 2014).

We start with an overview of the three case studies, discussing the hydrological research and the social realities of the project. These hydrological overviews are not exhaustive, but meant to allow the discussion on scenario development in the second part of this paper. Finally, we propose how to plan hydrological research in a (surprisingly) surprise-rich context in a systematic way.

2 Three small hydrological research projects

2.1 Vietnam case: contour trenches for artificial recharge in Ninh Thuan province, Vietnam

2.1.1 Introduction

Contour trenching is one of the water harvesting techniques implemented to increase water availability in semi-arid and arid region. The Food and Agriculture Organization

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of the United Nations (FAO) defined it as contour furrowing. Its implementation differs in size, depending on its purpose. In agriculture, it is meant for effective crop production. A study on trenches in Chile by Verbist et al. (2009) suggested that few efforts were observed to quantify the effect of runoff water harvesting techniques on water retention. On the other hand, Doty (1972) found that there is almost no change in soil water between with and without trench.

In our Vietnam study, we investigated recharge processes of contour trenching after events by conducting a multi-method approach. One of the important aspects in modern approaches in understanding catchment dynamics, as Tetzlaff et al. (2010) pointed out is integration of field-process studies. Here, we applied a similar approach during a single wet year in 2009. Our field measurements explored physical parameters to be used in Hydrus (2-D/3-D) modelling. Moreover, we performed an isotope study; as such studies on recharge are known to allow improved understanding of catchment dynamics (Soulsby et al., 2003; Rodgers et al., 2005; McGuire and McDonnell, 2007).

2.1.2 Site description

The study area is located in the Phuoc Nam Commune, in the Ninh Phuoc district, with latitude 11°27′46.06′′ and longitude 108°55′44.39′′ E (Fig. 1). The landscape is a foothill with an average slope of about 3.5%. It is dominated by mountainous granite and downhill valley with mix of loamy sand, weathered granite, residual soils and alluvial deposits. Interpolating lithological logs resulted in Fig. 2, where loamy sand, weathered granite, and possibly fractured granite formed the subsurface. Initially, contour trenching was planned for an area of 97 ha. At the end of the project, only 22 ha were trenched. The research area itself focused on an area of about 8 ha. The climate is dominated by tropical monsoons. Generally, the wet season with heavy rainfall events occurs from September to December. However, from April to May there are sometimes light rainfall events. The dry seasons are from January to April and from June to August. The average rainfall and temperature are 810 mm yr^{-1} and 27 °C, respectively. In the current situation, local people mainly graze livestock and grow Neem trees. Much

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of the area could be seen as bare soil with erosion gullies, with some parts covered by cacti and grasses.

2.1.3 Material and methods

Field measurements; rainfall, surface water, and groundwater level

Only during one 6 month period (June to November 2009) data of rainfall, water levels and groundwater levels were simultaneously available. On 11 October 2007, before the construction of contour trenches, we installed two rain gauges (Casella tipping buckets, 0.2 mm, with HOBO data logger). Infiltrated ponding water in the trenches was monitored daily after rainfall events. The surface water was measured using a stick and two measuring scales in the trenches. The subsurface (geology and soil) survey was partially conducted three times, in October 2007, March 2008, and June 2009. In October 2007, we performed inverse auger tests (Porchet test) to obtain a range of hydraulic conductivity values. Six locations were selected from uphill to downhill at the proposed trench area. In March 2008, we drilled 3 m holes at eight locations for additional lithology investigations. We also took four soil samples at the trench plots and analyzed those using wet and dry methods at the laboratory of UNESCO-IHE Delft. In October 2007, we constructed three observation wells; Wells 1, 2, and 3, at the upstream and middle part of the planned project area. We measured the groundwater level with divers (Schlumberger Water Services). Because of the loss of two divers in two different observation wells, since February 2008 we measured groundwater level manually on a 3 to 4 day basis.

Isotope Oxygen-18 and dye tracer

From September 2009 to November 2009, 72 water samples were collected in 2 mL vials. ^{18}O variation of rainfall, surface water and groundwater were analyzed. Samples were collected on site at a random interval depending on rainfall events. The filled vials

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were then sealed and subsequently sent to the Netherlands. We utilized a spectrometer at the Isotope Laboratory of Delft University of Technology. The ^{18}O analysis used per mil units relative to Vienna Standard Mean Ocean Water (VSMOW) with an average standard deviation of 0.15 ‰.

The vertical flow paths at the bottom of the trench were checked using dye tracer. Dye tracer in forms of powder and low cost was available in the nearby market. Initially, we dug about 40 cm × 40 cm in area and 3 cm deep of the sediment surface in the middle of the trench and poured evenly the dye powder. Afterwards, we filled back the dug sediment.

Modelling Hydrus (2-D/3-D)

Hydrus (2-D/3-D) (Šimůnek et al., 2008) was chosen to simulate the process of infiltration and recharge. It is a physically-based model using finite-elements that solves numerically the Richards' equation for unsaturated and saturated flows in porous media:

$$K(\theta) = K_S S_e^{0.5}\left[1-\left(1-S_e^{\frac{1}{m}}\right)^m\right]^2$$

$$S_e = \frac{\theta-\theta_r}{\theta_s-\theta_r}$$

$$\theta(h) = (1+|\alpha h|^n)^{-m}$$

where K is the hydraulic conductivity function (m s^{-1}), h is the matric head (kPa), S_e is the effective water content (–), and m is empirically assumed $1-1/n$, n is the pore size distribution index, $n>1$ (van Genuchten, 1980). O is the water content (m^3 m^{-3}), "s" represents saturated and "r" residual, and α is a fitting parameter.

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2.1.4 Result and discussion

Rainfall–runoff processes to the trench area and potential evaporation

According to four nearby meteorological stations, the long-term average of annual rainfall is 810 mm yr^{-1}. In 2008 and 2009, rainfall measurements at the study area reached annually 1134 and 1303 mm respectively, suggesting two very wet years in a row. Observations showed that runoff entered the trench area through specific paths; it became concentrated in space. These flow paths occurred due to the nature of the local topography and the man-made road path surrounding the trench area. Trench 1 to trench 7 received water fluxes from the granite hills upstream. These fluxes produced the main ponding in the trenches. As the first trench originally obstructed an erosion gully, it received the maximum runoff. Every event resulted in specific runoff generation. As such, the contribution of runoff towards the trenches from a bigger catchment area uphill the trench area is much larger than the surface created by the spacing between trenches.

Compared to other trenches, ponding at the first uphill trench took a longer time to infiltrate because of sedimentation. Fine material was brought by runoff into the trench. Also during storms, sand from uphill was brought to the first trench, which filled up the trench about half full. Ponding in the smaller trenches showed lower water levels. The ponded water infiltrated quicker, because there was little fine sediment and the main soil type was grey sand. Thus, a high infiltration capacity was predicted. Additionally, the smaller trenches were not affected by external runoff such as in trench 1 to 7.

Geo-hydrological conditions and groundwater level response

The groundwater level responded in two ways to these inflows from rain and runoff: a slow annual increase and an instant increase after events (Fig. 3). From uphill to downhill of the observation wells, the gradient between Well 4 and Well 6 (100 m distance) is much lower than between Well 6 and Well 7 (200 m distance). This suggests that extrapolating subsurface layers may result in failure to identify the correct subsurface profile. Well logs data indicate granite bedrock, with assumed very low permeability, at 15 to 32 m below the soil surface. A possible explanation for the different groundwater fluctuations is the heterogeneity of geology. Even from two nearby locations of observation wells (100 to 200 m), groundwater level fluctuation was different.

Some references of the range of hydraulic conductivities of loamy sand and granite in semi-arid areas were used to compare our infiltration tests. At granite terrain in Hyderabad, India, the hydraulic conductivities were estimated by Chandra et al. (2008), at a maximum of 7.9 m day^{-1} and minimum of 7.9 cm day^{-1}. Katsura et al. (2009) characterizes the hydraulic properties in weathered granite as matrix flow with a moderate core-scale hydraulic conductivity of 8.6 m day^{-1} to 86 cm day^{-1}. Infiltration capacities of up to 2 m deep from the ground surface at six locations at the trench area show a range of 25 to 3 m day^{-1}. Our measurements lie between values found in these studies.

Modelling – Hydrus (2-D/3-D)

Three parameters were sensitive to fit the measurements of infiltration (surface water drawdown) and groundwater level fluctuation. The three parameters were the subsurface (the main Ks in the domain), Ks at BC, and the porosity. We set first the Ks values according to the point measurements. In reality, it would be hard to obtain all Ks of the subsurface, especially in depths of more than 3 m to the saturated zone. The measured Ks in this case study was only up to 2 m below the soil surface. However, this parameter was simulated through different scenarios of values.

The simulation results provide visualization of the infiltration mechanism to the subsurface. Sedimentation at the bottom of the trench retains water for longer periods but water infiltrated merely in a downward direction with very little horizontal flow to the side of the trench walls.

Comparing the simulation and measurements (Fig. 4), it appears that the selected subsurface properties in the modelling to allow similar infiltration as observed were lower than the range of the measured ones. The minimum infiltration measurement found was 25 cm day^{-1}, whereas in the simulation the lowest value was approximately

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7 cm day^{-1}. The porosity measured was about 33 %, whereas in the simulation it was better set to 11 %. The parameter decrease with depth were observed by several researchers; Neuzil (1986), Manning and Ingebritsen (1999), Saar and Manga (2004), Wang et al. (2009a), Jiang et al. (2010) found the decrease of Ks and Athy (1930), Screaton et al. (2002) found the decrease of porosity. However, for simplification the assumption of the model was set to be homogeneous.

Isotope technique and dye tracer

The rainfall analysis produced a local meteoric water line. For our short period of observations MLWL is δ^2H = 7.965 × δ^{18}O + 11.406, corresponding to measurements by IAEA at Kings Park, Hong Kong. Average isotope composition of δ^{18}O and δ^2H are −7.8 and −50.6 ‰ for rainfall and −8.1 and −56.1 ‰ for groundwater.

Initial groundwater composition at Well 4 before the events was −8.3 ‰ in δ^{18}O and −61.1 ‰ in δ^2H (Fig. 5). After about two weeks, a signal of mixed small events with the one on 9 October could be found. Recharge is first indicated as the composition turns to −9.9 ‰ in δ^{18}O and −70.7 ‰ in δ^2H, decreased by 1.6 ‰ in δ^{18}O and 9.6 ‰ from the initial values. Subsequently, its isotope composition increased due to the following events that had heavier isotope composition. In the end, the isotope composition returned back close to the average value with little increase due to the last rainfall, a mixture of heavy isotope composition.

The signal of dye was searched by digging into the sediment about tens of centimetres. It was found to be about 30 cm from the sediment surface. Initially, dye was poured about 3 cm from the previous sediment surface. Then, a 10 cm sedimentation was estimated during the current wet season (with 4 times of ponding), which means that dye moved about 17 cm downward. This suggests a very slow infiltration process.

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2.1.5 Conclusion

The combination of field measurements, the isotope technique, and modelling over a 6 month period has given us the understanding of the recharge process at contour trenching plots in Vietnam. Based on the groundwater level measurements, we conclude that artificial recharge took place in the trench area. It seems reasonable to explain this with the recharge in the trenches, although it is hard to simulate the measured groundwater level based on the obtained isotope signature. Isotope analysis suggests that one out of four wells (Well 4) responded to the signal of a mixed rainfall with groundwater. Because the flow path from the trench to the observation well screen would need more time, recharge processes may have been influenced by a short cut (macro pore).

From the modelling in Hydrus (2-D/3-D), the estimated values of parameters used were focused on matching the true scenarios of possible hydraulic conductivities and porosities. Even though the geology of observation wells was available, those data cannot be simply interpolated. Also between Wells 6 and 7 the groundwater system is disconnected. Infiltration requires a few days to two weeks. Sedimentation occurs after events and reduces the infiltration capacity. During the dry season the artificial recharge that yields subsurface water storage can be maintained up to 2 months.

On the long term, infiltration in the trenches will increase the groundwater levels based on the events during the wet season. The quick groundwater level increase is followed by gradual drawdown during the dry season. For the time being, the trenches seem to benefit short-term subsurface storage.

2.2 Kenya Case: the impacts of contour trenches in Amboseli, Kenya

2.2.1 Introduction

In Amboseli, a semi arid area in Kenya, contour trenching started in 2002. Until recently, the hydrological long-term impacts of this construction were not well documented. Previous studies showed impacts of similar water harvesting techniques in different dimensions and semi-arid areas. For example, Makurira et al. (2010) concluded that fanya juus (infiltration trenches with bunds) increased soil moisture in the root zone. Singh (2012) stated that rainwater-harvesting structures enhanced vegetation growth and biomass production. Mhizha and Ndiritu (2013) showed that depending on the soil type conditions, modified contour ridges resulted in crop yield benefits. Three studies indicated that those techniques reduced soil erosion.

An attempt was made to answer two research questions on the impacts of contour trenching eight years after construction. First, what is impact of trenching to the vegetation growth? With the absence of ground data from the past, an effort by using satellite imagery analysis for this period was conducted. In the absence of rain gauges, satellite images can be source of data (Nesbitt et al., 2004; Su et al., 2008). Tropical Rainfall Measuring Mission (TRMM) quantified rainfall "best" between 50° N and 50° S (Huffman et al., 2007). Normalized Difference of Vegetation Index (NDVI) was used to investigate the greenness of an area. Second, what is the impact of trenching to the soil redistribution in the trench area? Erosion and sedimentation investigation using cesium-137 analysis (Ritchie and McHenry, 1990; Zapata, 2003) was performed to qualitatively understand the sources of sediment, both in trenches and surrounding area.

2.2.2 Site description

The contour trenching area is located about 30 km downstream of Kilimanjaro Mountain (altitude 5895 m). See Fig. 6. It lies on the altitude of 1245 m, with latitude 2°46′57.46′′ S and longitude 37°16′45.93′′ E. From visual observation, the study area was eroded and has an average slope of about 2 %. Additionally, it is situated next to an erosion gully originated from Kilimanjaro Mountain.

There were two types of trenches. The first are small trenches (1 m wide, 0.8 m deep), which were constructed in 2002. The larger ones (4 m wide, 1 m deep) were started in 2003. From 2002 until recently, a temporary diversion structure from stones was made to divert upstream rainwater to the whole trenched area.

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2.2.3 Material and methods

Vegetation growth

For vegetation growth, two types of satellite images were used; Tropical Rainfall Measuring Mission (TRMM) and Moderate Resolution Imaging Spectroradiometer (MODIS) time series were downloaded freely from https://reverb.echo.nasa.gov in January 2011. Those satellite images were processed using ERDAS Imagine 9.1.

TRMM is a joint project by NASA and the Japanese Space Agency (JAXA) launched in November 1997 to study tropical and sub-tropical rain systems (Kummerow et al., 2000). The images have a spatial resolution of 25 km and temporal resolutions of 3 hourly, daily, and monthly. In this study, monthly temporal resolution data were used. Data were available from beginning 1998 onward, but we used only from January 2002 to December 2010. TRMM images were corrected by using WGS84.

MODIS-NDVI is a readily satellite image of cloud-free vegetation activity available in three spatial resolutions (250, 500, and 1000 m) and temporal resolutions of 8, 16 day, monthly, quarterly and yearly composite. In this study, MODIS in 250 m and monthly resolution were used. In total, 102 MODIS images, from 2002 to 2010, were used for this analysis. The coordinates of MODIS images used WGS84 as well.

The analysis was based on NDVI values by investigating its increase after the construction of the trenches. In case of success, vegetation growth should not only increase NDVI values, but also remains high throughout the year. An independent two samples t test was used to evaluate the impact of contour trenching to vegetation growth. NDVI of areas with trench was compared with NDVI without trench.

Erosion-sedimentation; cesium-137

Fallout Cesium-137 (^{137}Cs) is a tracer used for erosion (Zapata, 2003) and sedimentation studies in different environments around the world. ^{137}Cs originated from the nuclear tests in the 1960s, was absorbed in soil particles, and has a half-life of about

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30.2 years. In this study, the ^{137}Cs concentration is assumed to be evenly distributed throughout the catchment of the study area. By measuring the concentration of ^{137}Cs in the vertical distribution, sources of sediment can be identified (Walling and Quine, 1991; Wallbrink et al., 1999).

For soil redistribution or the impact to erosion-sedimentation in the trench area, soil samples (using split tube sampler, Eijkelkamp Agrisearch Equipment) with a depth of 40 cm from the soil surface were collected. Figure 7 shows the sample locations, which are divided into four parts of samples; two undisturbed samples for references, six samples in areas which were not influenced by trenching, four samples in areas which were influenced by trenching, and four samples at the bottom of the trenches. Each point was sampled three times in a radius of 1 m, yielded to one composite sample (Sutherland, 1994).

In total 16 soil samples were oven-dried at temperature of 1050 °C for 24 h, sieved in 2 mm, and weighed at Moi University, Eldoret, Kenya. A minimum of 100 g samples were packed into small polyethylene bags, sealed, and sent to ISOLAB, Georg-August-Universitaet Goettingen, Germany, for cesium concentration measurement. The concentration was measured in Bq kg^{-1} using a HP Germanium detector. Due to low activity concentration, the measurement time per sample was maximum 250 000 s.

2.2.4 Result and discussion

NDVI with and without trench, TRMM vs. NDVI

NDVI values of areas with trenches (WT1 refers to small trenches and WT2 refers to large trenches) were compared to areas without trenches (WOT1, WOT2, and WOT3) using a fixed area size; for the small trenches 2 ha and for the large trenches 4 ha. The results are summarized in Fig. 8.

The average of NDVI with trench throughout 2002 to 2010 was 0.3 and without trench 0.27. The t test resulted to $t(102) = 1.76$, df (degree of freedom) = 196.5, and $p = 0.08$

or 8 %. Since the probability is 8 %, there is a weak significant difference between with and without trench.

An attempt to correlate TRMM with NDVI values of the trench area was performed. Martiny et al. (2006) showed a lag of 1 month in western Africa and 1.5 month in southern Africa between rainfall and NDVI peaks. Also, the relation between soil moisture and the greenness index may lie in the order of a few weeks (Cheema et al., 2011). Thus, by shifting TRMM values up to 2 month earlier to its actual month, it is expected that a lag correlation could be obtained. However, results show low values of correlation (1 month lag $R = 0.44$, 2 month lag $R = 0.16$).

Overall, it has been possible to study monthly NDVI values between 2002 and 2010. The results of MODIS images indicate that NDVI values fluctuate in time because of alternating dry and wet seasons. Thus, there is no clear signal that contour trenching increases the NDVI (or “greenness”) throughout the year, but it does show short-term effects.

Cesium-137 analysis

Comparisons of 128 ^{137}Cs concentrations at the small trench area (see Table 1) are analyzed:

- between the reference (R1 and R2) and the area that is not affected by trenches (U1 to U3);
- between the reference (R1 and R2) and the area assumed to be affected by trenches (D1 to D4, and U4 to U6);
- amongst the samples in the trenches (T1 to T4).

The trench area is an eroded area that has a low concentration of ^{137}Cs at the top 20 cm soil surface. Based on the two reference samples, ^{137}Cs concentrations are lower than 2 Bq kg^{-1}. Below 15 cm, there is almost no ^{137}Cs concentration found. From the trench area to the West, erosion and sedimentation were much heavier. Comparing

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the vertical soil profiles, low ^{137}Cs concentrations are found unevenly distributed up to a depth of 20 cm.

Inside the trench area that is surrounded by stone walls, sediments show layering of high and low ^{137}Cs concentrations. It is presumed that early deposition originated from local sediment within the trench area. In the first 30 cm in trenches (T1 to T4), ^{137}Cs concentrations show values below 2 Bq kg^{-1}. In the upper part, ^{137}Cs concentrations are above 2 Bq kg^{-1}. This mechanism can possibly be due to ponding and/or grazing activity. The upper sediment is found with enriched ^{137}Cs concentration. This is most likely to originate from outside the trench area; the sediment was brought to the trench area through the erosion gully and settled in the trench area. Furthermore, it suggests mix sources of sediment between the trench area and external source upstream during different time of events.

This ^{137}Cs analysis could be limited due to the condition of the two reference samples that might be eroded samples. The external sources with higher ^{137}Cs concentration seems to be the concentrations at the first few centimeters soil surface, where the values lie between 2 and 9 Bq kg^{-1}. UNSCEAR (1972, 1977) estimated the ^{137}Cs concentration at latitude 0 to 10° S of 5.2 Bq kg^{-1} in the first 5 cm below soil surface. In addition, deGraffenried (2009) detected ^{137}Cs concentration in non-eroded topsoil in Western Kenya up to 9.49 Bq kg^{-1}. In practice it is difficult to find a reference place (Poreba, 2006; deGraffenried, 2009).

2.2.5 Conclusion

The signal of greenness found was most likely due to alternating dry and wet seasons, but does show short-term effect. Furthermore, TRMM is correlated to NDVI where results show low correlation between TRMM and NDVI. The results of the erosion and sedimentation analysis show the study area is previously an eroded area. Sediments found in the trench area are a combination of local and external sources; early deposition originates from local sources and followed after about 30 cm thickness of sedi-

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ments from external sources. As sedimentation still occurs in the trench area, the stone wall still allows sediment to enter the trench area.

2.3 Indonesia Case: the potential of micro-hydro power plants on Maluku islands, Indonesia

2.3.1 Introduction

The province of Maluku, Indonesia, consists of many scattered small to big islands that demand a high investment to build up its energy infrastructure. On the other hand, sustainable and qualitative growth for developing economics and habitat requires increased energy input (Dudhani et al., 2006). One of the important elements to support economic growth is providing local communities with a reliable electricity supply. Currently, the state electricity company of Indonesia (Perusahaan Listrik Negara) provides electricity that dominantly uses diesel generators. However, Indonesia has abundance of water resources that can be used to create hydropower as a valuable source of energy. Most of large capacities of micro hydro were installed in North Sumatra, Central Java, West Java and Bengkulu (Suroso, 2002; Hasan et al., 2012).

For hydropower to be useful and effective, a potential location has to meet demands on technical and economic feasibility. An example of an economic feasibility study of potential hydropower using GIS approach has been conducted for the La Plata basin (Popescu et al., 2012). Also, Kosnik (2010) carried out research on construction cost-effectiveness of micro-hydro in the US.

This study is particularly focusing on Aboru village on Haruku Island, where the project intended to build a micro-hydro power plant that could improve the socio-economic situation of the local community (Balakrishnan, 2006; Anyi et al., 2010). The main objective of the research was to map locations with high-energy heads and assess the minimum available annual discharges for potential micro-hydro in Aboru. The second research effort is aiming at finding potential locations for micro-hydro power plants on the Maluku islands.

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2.3.2 Site description

The Maluku islands are located in the eastern part of the Indonesia archipelago. In total, there are 1027 islands. Most Maluku islands are mountainous (about 57 %). The climate is humid, affected by monsoons, with an average annual temperature of 26 °C. High rainfall, annually from 1000 to 5000 mm, occurs from May to August and the remaining months are the dry season. The Maluku islands are mainly covered by rainforests, in which local people cultivate sago and rice. In 2009, the population of the Maluku Islands was estimated at about two million. The study area is located in Aboru, a small village on Haruku island (latitude 3°35′33″ S and longitude 128°31′0.7″ E). The catchment area is roughly 3 km^2. Aboru has about 1000 inhabitants.

2.3.3 Material and methods

The general equation to estimate the potential of micro-hydro is

$$P = \rho \times g \times H \times Q \times \eta$$

where P is the potential capacity (W), ρ is density (1000 $kg\,m^{-3}$), g is the gravitational acceleration ($m^{-1}\,s^2$), H is the head (m), Q is the river discharge ($m^3\,s^{-1}$), and η is the efficiency (%) with assumption of 60 to 80 % (Paish, 2002; Purohit, 2008).

The potential of micro-hydro depends on the main two parameters; the river discharge and the energy head. The river discharge was measured uphill of the planned micro-hydro plant. Two divers (Schlumberger Water Services Delft, the Netherlands, measurements at 30 min intervals) were installed in the river to measure the pressure of surface water levels. To compare the discharge results, a test using the dilution gauging method (Calkins and Dunne, 1970) was also performed several times at different locations.

Similar to a study by Mosier et al. (2012), a Digital Elevation Model (DEM) was used. Data was downloaded from http://srtm.csi.cgiar.org, which was provided by the Con-

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sortium for Spatial Information of the Consultative Group for International Agricultural Research (CGIAR).

2.3.4 Result and discussion

Field measurements; rainfall and surface water level

The estimated monthly discharge during one wet year resulted to about 0.2 $m^3 s^{-1}$ in a 5 month consecutive period. During the dry season, low water levels were recorded, that corresponded with ranges from 0.015 to 0.06 $m^3 s^{-1}$. A big difference in discharges between wet and dry season can be seen. However, this could be included in the final decision on the capacity of a proposed micro-hydro plant. For example, facilitating only five months of hydropower (during the wet season) and a shutdown of seven months might result in a higher micro-hydro capacity. Another option is using a low micro-hydro capacity the entire year. From these two possible scenarios, the latter one is preferred.

DEM analysis

Most of the potential locations are found on Buru and Seram Island (Fig. 9). The two islands are mountainous and are the two largest islands compared to others in the Maluku region. On Buru Island, high heads are located on the western part, very close to the western coast. On Seram Island, high heads are found along the northern and southern coasts, at the middle of the island. Halmahera Island also has some hills, however, the available heads in the river on this island are considered low and thus no potential was identified.

Potential capacity of micro-hydro power

At the proposed location for micro-hydro, in Aboru village, the rainfall–runoff process is determined by a quick response. The discharge observed ceased within days after a rainfall event. This suggests that a higher potential of micro-hydro will most likely be

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limited to the wet season, which is 5 months. One usually designs the installation with the average monthly discharge. However, a daily discharge would not represent the monthly discharge that is taken as the design capacity of a micro-hydro power plant. For a continuous annual operation of micro-hydro, it is suggested to take the minimum discharge during the dry season (see Table 2 and Fig. 10). At this area, it is safe to take a low capacity of about 3.5 kW, in accordance to the local head (35 m) and discharge ($0.02\,m^3\,s^{-1}$). This means that Aboru village suits better to a very small hydropower (pico-hydro) schemes.

2.3.5 Conclusion

Maluku islands have a small potential for micro-hydro power plants. Extrapolated discharges that can be used range from $0.03\,m^3\,s^{-1}$ to almost $0.2\,m^3\,s^{-1}$. As a result, available streams with head conditions between 20 to 35 m can produce a minimum of 6 kW and maximum of 40 kW. Other related factors were not taken into account such as socio-economic ones. However, this approach provides a step forward for follow up survey on related factors, to ensure that micro-hydro plants could be build to benefit local communities at the estimated potential locations.

3 Human actions towards intervention and hydrological research

In the Kenyan case two rain gauges were installed close to the study area. One rain gauge in front of the manyatta was destroyed by elephants and afterward removed by local people. The other one had a data logger that could not be retrieved. Soil moisture analysis would have indicated correlations with rainfall events and the impact of trenching. However, it could not be performed due to disappearance of tubes and difficulties getting labour. Local people seemed to prefer other work (easier to be conducted without the need for a long trip to the study area).

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In an attempt to look at these anecdotal experiences more systematically, we started first by identifying participative actions from local people during the process of intervention and hydrological research. The time periods of three hydrological intervention-based research projects can be seen in Table 3. In each of the three interventions – in Vietnam, Kenya and Indonesia – local people were engaged (see Tables 4–6). This included the hydrological research, especially where it was part of the intervention itself. Our analysis will focus on community participation, including what went differently in the hydrological studies than expected and the issue whether in the future such developments could be anticipated upon. Based on the results, we develop suggestions how hydrological researchers can include considerations on human agency when planning and performing field research. As already mentioned, for this we incorporated results from RAND studies on being prepared for uncertainties.

Human agency in intervention and research can be related to existing theories on community participation. There are many participation theories; Arnstein (1969) introduced the ladder of participation for urban development where the scale was from non-participation to being able to make decision (citizen empowerment). The scale influenced other fields and was further developed, for example by Choguill (1996). Her ladder of participation was based on the scale of willingness of government in community projects. One recent participatory spectrum is IAP2 (2007), where along the spectrum the impact of public participation increases. Another participation framework during intervention phase was proposed by Srinivasan (1990), where this was meant for training trainers in participatory technique. We found this last approach useful in analysing our case studies, as the community participation scale from Srinivasan (1990) allows for differentiating attitudes towards change, by sorting them along a scale showing varying degrees of resistance or openness (see Fig. 11). Therefore, we found this potential to "measure" attitude even more interesting because our results suggest that these attitudes of stakeholders change over time, during the intervention and research itself.

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As an example, we use the Vietnam case to gain an overview how the local community participated in the intervention phase and how this altered over time. The implemented scale of community participation (Srinivasan, 1990) is shown in Fig. 12.

- 0 to 6; at the start of the project, none of the landowners agreed with the intervention, especially because they had not yet seen a successful example in their particular area. After negotiations, a monk organization was willing to provide their land as an example case [#6A].
- 6 to 3; after construction of large trenches, the monk organization did not like the design. The rejection of the large trenches enforced the proposer to reconsider the trench dimensions. Thus, the proposer provided a smaller design of contour trenches. Despite the smaller design, the monk organization still refused to continue implementing the new design on its remaining land.
- 3 to 6; consequently, the proposer introduced the smaller design to other farmers and fortunately one farmer accepted it. The smaller trenches were then implemented in one farmers' area.
- '6 to 7; the acceptance of the smaller design by other farmers continued. Farmers living nearby requested also the small trenches to be constructed on their land. After the monks' organization saw the results at several farmers' land, the monk organization eventually requested the proposer to construct small trenches on their remaining land. The decision of local people who wanted to have contour trenches occurred after seeing an example of a smaller design.

Within the context where intervention was done simultaneously with hydrological research – the Vietnam case [#6] – the actual shape of the final intervention was decided upon within several rounds of discussions between project team and the local communities. Agreement was obtained through a negotiation process. The actual shape of the hydrological research was heavily dependent upon knowing the definitive location of the intervention. As the decision process went, however, measurements were

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conducted in the vicinity of the possible locations of the intervention. On-site measurements had to be re-evaluated from time to time due to changes of intervention locations. The intervention period and financial support for research were both limited and limiting as well. Most likely, in conditions of simultaneous intervention and research, changes require adjustments to a new setup, which often means increasing financial expenditure for measurements. Therefore, any decision to start either intervention or hydrological research is troublesome and needs careful thought.

In general, we find different processes of involvement and different human actions related to the three hydrological research projects (see Table 4a, on events labelled with [#]). The implementation of the hydrological research was strongly correlated to social relations and aspects. For example, in Vietnam and Kenya, access tubes [#3, #9A] were stolen. Also, in Vietnam the divers were stolen [#4]. In Kenya, one rain gauge was damaged by elephants, and thus, removed by the local people [#7]. Next to human agency affecting the hydrological research, other events affected the research activities. In Vietnam, one rain gauge clogged [#1] because of fine sands from strong winds, and the screen of the observation wells [#5] proved to be not suitable for local conditions. Obviously, these events could have been avoided. Rain gauges could have been checked and maintained on regular basis, especially when realizing that local conditions and climate might affect the measurement. When planning to conduct isotope analysis, observation well structures should have been constructed for a proper sampling. However, there were also problems that probably could not have been avoided, especially technical failures of data loggers [#2, #8, #10, #11] from tipping buckets and divers.

Table 2b also provides the detailed results in terms of timing and type of human actions during intervention processes. For example, the Vietnamese intervention could only be constructed after many negotiations between the proposer and the end user. Such a decision could change the final location of the intervention, which in turn affected directly the hydrological research. In the Vietnam case, intervention design and location were determined by the local people, who had the power to choose their pref-

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erence of intervention and decided whether it could be implemented on their land or not. In the Kenyan case, intervention design and location were simply accepted by the local Maasai and decisions were made by KWS. In this case, the intervention existed first and was evaluated later. In addition, negotiating about reasonable labour costs for the field study in 2010 resulted in lack of local assistance for soil moisture measurements. In the Indonesian case, the intervention was not, as was preferred before, an outcome as a recommendation from the hydrological research. The end user of the intervention shifted from a pilot at a village to a micro hydro model at a local university. The intervention was cancelled due to insufficient funding, even when the hydrological research went smoothly.

The Srinivasan scale allows for analysing the changes in attitudes and possible actions concerning an intervention over time. However, the scale seems to be less relevant for the hydrological research itself, which is actually interesting as it suggests that stakeholders may have different attitudes and ideas on interventions. Compared to the research, reflecting on human actions towards the three hydrological studies, motivation of stakeholders when deciding what action to take clearly plays an important role. To what extent this motivation is always directly linked to an attitude towards the intervention, however, remains an open question. Take the Vietnam case, where some measuring devices were stolen. Possible reasons behind the stolen access tubes and divers are that someone rejected the project, did not want any intervention to be constructed on the land, had negative impressions of the intervention or was not satisfied with the proposer's offer. On the other hand, the attractiveness of the device itself and/or curiosity could make people eager to have such devices. Therefore, the resulting human action to remove the device may not have been a rejection of the project at all, but just a desire to own a device with a unique appearance.

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4 Planning for surprises in hydrological research

In all our three case studies, we conducted different measurement techniques depending on the research objectives per case study. What all case studies had in common was that the projects had to be changed due to local negotiations. No matter the scale of neither stakeholders' participation in hydrological research nor their motivations, one will have to face human actions – disappearance of measurement devices, changes of locations, etcetera – when designing a field research. The events we experienced in our own field research could possibly have been anticipated upon – let alone (partially) avoided – but usually are treated as surprises or unforeseen side-effects. Learning from our own experience, we claim that they should at least be anticipated upon. For example in the Vietnam case, when the divers disappeared, a stronger cover for the observation wells might have been used. In the Kenya case, a more secure location for some devices could have been prepared to cope with communities outside the research area ("third party surprises"). The RAND studies provide guidance for an approach that anticipates on known surprises (Dewar, 2002). In planning for surprises, as outcomes of local negotiations are not known before, we envision that a hydrological field researcher prepares the study taking into account several scenarios. Thinking in scenarios for hydrological fieldwork instead of one single approach allows for making decisions based on expected implications of events on the hydrological results, and should minimize the costs of improvisation.

We developed three research budget scenarios for the three cases, where we defined effectiveness in terms of process understanding and important model input. First, we evaluated the technical approaches per case study (see Tables 7–9) in terms of performance (Blume et al., 2008), which is the effectiveness of measurements in understanding hydrological processes. Then, expenditures included in our (fictitious) budgets are labour and financial costs, which are shown in ranges of EUR; (+-) is between EUR 0 to 50, (+) EUR 50 to 250, (++) EUR 250 to 750, and (+ + +) above EUR 750. These ranges are given as examples to illustrate the expenditures.

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Either collecting more data and/or different data is usually the choice we have to make to confirm certain underlying dominant hydrological processes due to an intervention. We used cost-benefit analysis (Sassone, 1978) in research scenarios that were developed based on the Delphi method (Linstone and Turoff, 1975). Each scenario specifies a budget; the measurements that can be conducted within that budget and the dominant hydrological processes studied. In changing the budgets, we could explore changes in and differences between probable field campaigns, especially in gaining better understanding of dominant mechanisms of the intervention.

4.1 Scenarios

We tested the scenario approach with a group of experts. We offered three scenarios. Scenario 1 was approximately at the lowest budget, which was estimated by considering the experiences gained by the author during the hydrological research. As it was already known how the research went, the lowest cost scenario was drafted by eliminating the measurements that failed or were not used in the analysis. This combined at least a desk study with field measurement data. Also, this was a theoretical baseline scenario for good understanding of the intervention.

Scenario 2 and 3 covered a longer research period. Extension of measurement and performing other methods were proposed. There were several options related to parameters that were selected and added, with various spatial and temporal combinations. Those options were:

A. extension of the measurement period;

B. additional samplings;

C. additional measurement devices;

D. Additional analysis.

Option C and D are connected since having another type of measurement might use the same or require a new (commercial) software program or service.

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Interactive Discussion

Scenario 2 was set with a budget increase of about 20 %. Options for an extension of the measurement period and more samplings were preferred.

Scenario 3 used an approximately 80 % increased budget. It implies a condition with an expansion of the second scenario combined with much more room for additional parameters in the field campaign.

Some assumptions for the budgeting were set as follows:

- related research budget components like transportation to the site, meals, and accommodation were not considered;
- a researcher was categorized as a non-paid labour in the research area, since s/he receives salary from the researcher's institution. Thus, the researcher's expenses were ignored;
- shipping cost of devices and samples, taxes of research devices, and research permit costs were excluded;
- there were no subsidies from research institutions for measurements devices or models;
- none of the scenarios took into account decisions made for a particular intervention and its development.

For Scenarios 2 and 3, the end result of possible field campaign and analysis were discussed with ten experts from different Dutch institutions, who were selected from the working environment of the author. Each scenario had its own specific hydrological objective that fits to an expertise (i.e. hydro-geology, hydrology, remote sensing), but the experts were expert from any hydrological background. The implemented research with the results and proposed scenarios of several field campaigns were explained to the experts to clarify the content and objective of the research. Subsequently, s/he had to grade the scenarios based on the level of additional understanding (if any) that would be achieved. The required budget itself was not mentioned to allow experts to

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objectively value the proposal without any economic consideration. The author picked the Dutch grading scale with set up of the 4-level of understanding as follows:

- 1–5.5 = little understanding of the relevant mechanism of intervention;
- 6–7.5 = good understanding of the dominant mechanism of intervention;
- 8–8.5 = better understanding of the dominant mechanism of intervention;
- 9–10 = complete (full process) understanding of the underneath mechanism of intervention.

In the last part of the interview, the experts were also given the opportunity to provide his/her own alternative approaches that could result in better understanding.

Even though this was a theoretical exercise and that it was not easy to provide clear-cut evidence for the scenarios to be realistic enough, results are useful. There may be many other options of optimization, such as cheaper measurement devices, modelling and different research institutions prefer different measurement devices, or software that are developed by certain institutions. Research institutions might already own measurement devices and software, thus do not want to spend money on others. This specific setup is merely an estimation in the context of the three case studies and may well vary from person to person due to people's preference. However, by asking ten experts for their input and analyze further their responses over the entire width of the scenarios, a good degree of objectivity, certainty and reality can be reached, if not in absolute, then at least in comparative terms. Our results are given in Fig. 13. We discuss the Vietnam case in more detail.

4.2 Vietnam case

The lowest budget for having sufficient understanding of groundwater recharge gained in the actual research is reduced to almost 70 % of the expenses during implementation (see Appendix A, Table A1). Rainfall measurement is a must for the input of the model.

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The hydraulic properties of soil and infiltration test are important as well. The water level measurement is required to get the ponding in the trench correctly. These costs are not much compared to other measurements. Soil moisture measurement is removed from the field campaign since it is not only expensive, but also the access tubes are prone to be stolen by the local people. Isotope tracers are excluded, because the constructed observation wells were not suitable for groundwater sampling. In addition, the cost for this analysis is considered to be expensive. On the other hand, isotope tracer is beneficial and will provide signals as long as the observation wells would be better constructed. A minimum of 3 observation wells are set, since it is the minimum or triangle layout to get an idea on the groundwater flow direction. A short but sufficient period of measurements would be during the wet season, where the trench may be filled with rain water.

Even though the cost reduction is high, the conditions to apply these methods could remain uncertain. For example, when a researcher made a plan for scheduling the starting point of measurement at the beginning of a wet season, no one would expect at first that negotiating with the local community was difficult, even though it decides whether or not the intervention can be built or continued. There has to be willingness from the community to provide land for the intervention. After several discussions and meetings, a local to local approach was needed to convince stakeholders that the intervention would be beneficial to the local community. However, no one could predict when and where it could be realized. If the decision to be made for construction was delayed, the plan for hydrological measurements would have to wait until the next wet season, which is after one year. And if there is a tension to install the measurement devices for a "with and without" analysis, and the location shifts in time, new measurement set ups have to be adjusted. These conditions will result in lost of data and time for the hydrological research. As such, the minimum budget is somewhat artificial. The other way around, the big difference between the minimum budget and the actual budget suggests that in the Vietnam case, negotiations on the intervention brought along high costs.

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When more budgets would be available, Scenario 2 (see Appendix A, Table A2) could expand the implemented program by constructing one new observation well and its groundwater level measurements. Also the sampling period for isotope tracer is added. The observation well should be placed in line with the existing wells and its screen should be along the pipe, from near soil surface to the bedrock. It would be expected that the recharge can be more apparent where the signal of infiltrated rainwater can directly infiltrate into the pipe. Thus, the groundwater fluctuation and sampling can confirm the result of the implemented research.

In Scenario 3 (see Appendix A, Table A3), an 80 % increased budget gives options for more applications and/or more advanced methods. Besides one new observation well and isotope samplings, three other wells should be constructed. The observation wells should be placed at the small trench area. A possible advanced measurement is by performing an Electrical Resistance Tomography (ERT) survey for subsurface imaging. Several cross sections of the subsurface could be obtained during the dry and wet period. By having these new wells combined with the analyzed ERT data, the hypotheses could be made more pronounced regarding the difference in groundwater behaviour with and without the intervention structure.

4.3 Interview with experts

The results of the interview with the experts can be seen from Appendix B, Tables B1–B3. Comparing the three cases, the Vietnam case had more options, due to better financial conditions than the other two cases. Considering Scenario 2, 70 % of the experts believe an additional well and a 1 year continuation of the groundwater level measurements, including isotope samplings and analysis, would result in similar data collection to the implemented research. One expert considered that extra data might even lead to confusion. Another period of 1 year data could be used for validation, thus might give more confidence. A very long data series, from two to about ten years of groundwater level measurement would be very beneficial for better understanding the mechanism of the recharge. In the Kenya case, 60 % of the experts value the out-

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comes of additional soil moisture measurement, extension of rainfall and NDVI images as similar to the implemented research. The remaining 40 % think that new soil moisture measurements could lead to additional understanding. For Indonesia, 90 % of the experts think that the result of extending discharge measurement will not increase understanding. However, one expert says new data matter, as measurements could have been made during a very dry or very wet year.

In Scenario 3, with 80 % increase in budget, the value of measurements directs to similar results as in Scenario 2, with some additional elements. For Vietnam, 80 % of the experts say that Electrical Resistivity Tomography (ERT) measurements could increase the understanding of mechanism of the recharge; provide more explanation of the disconnected groundwater system. Thus, it could potentially confirm the groundwater profile and the groundwater level during recharge. Performing ERT either during dry or wet seasons sometimes yields results hard to interpret, since ERT is a static measurement. In the Kenya case, 70 % of the experts say adding higher resolution of 10 m might be sufficient to capture the greenness of the trenches. The images could be of importance to see a hypothetically constant greenness signal. Finally, for the Indonesia case, as a micro-hydro installation usually requires a minimum annual discharge, a long-term discharge will be used for discharge statistics. 60 % of the experts believe that more discharge measurements at different locations with different soil types, geology, and land uses, could improve our understanding, especially the discharge response of different catchment on different islands.

In summary, a research plan with 20 % increased funding (Scenario 2) appears to obtain similar understanding as the reference result. On the other hand, an 80 % increase in funding may be capable of gaining a better understanding, but realizing the costly research plan for a small-scale intervention project may not be economic feasible and thus impossible to be implemented.

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5 Towards systematic planning

Despite all the problems we encountered in the three field research projects, we could develop a good understanding of the hydrological impacts of interventions in three different developing countries. In Vietnam, during the wet season, contour trenches contribute to recharge, but only for short-term impact, up to two months. In Kenya, vegetation growth in the trench area as reflected in the signal of greenness index was most likely due to the wet season, without a clear long-term effect from the trenches. In Indonesia, the potential of micro-hydro capacity on Maluku islands ranges from 6 to 40 kW. In the three cases local people participated during the implementation of the projects, both in the intervention and hydrological research. As a result, the field campaigns were not perfect in terms of hydrological standards. Measurement devices were damaged, removed, disappeared or not located at the final intervention. In the end, we ended up with less data of lower quality. Local participation and financial constraints forced us to deal with research and intervention as interacting with and affecting each other.

As this setting is not unique to our three small cases, balancing intervention and research is a general challenge. Tracing back the social reality and the way it shapes research and intervention with the associated budget allowed us to gain more insight into trade-offs between hydrological knowledge and hydrological research management. Based on our experiences, we propose that planning ahead is posisble and propose a new, systematic perspective on how to prepare hydrological research for a more effective way to implement small-scale water intervention research projects. Being prepared for surprises due to human actions can be achieved by developing scenarios that combine hydrological issues with cost-benefit analysis. Considering financial costs and specific research objectives of small-scale interventions, options for field campaigns and analysis that could answer the research questions can then be defined.

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Baiocchi and Fox (2013) suggest six key issues to be prepared for and respond to surprises, (1) learn from experience: attract and retain the most experienced people, (2) address the negative effects of surprise, (3) assess the level of chaos in the work environment, (4) prepare for "third-party surprises", (5) focus on building a network of trusted colleagues, and (6) conduct regular future-planning exercises. Their recommendations confirms our ideas: planning for surprise requires proper understanding of small interventions within their hydrological context and incorporating interdisciplinary knowledge, learning, and local participation (see Karjalainen et al., 2013; Rodela et al., 2012; Reed et al., 2010).

Similar to balancing development and conservation (Garnett et al., 2007), when financial constraints – and usually time as well – become important, a researcher should be able to balance what he/she can and cannot do. Since budgets and time for a small-scale intervention are usually limited, research should be well planned. In order to include the costs of performing hydrological studies and the efficiency (effectiveness) in planning for surprises, we discussed an approach applying cost-benefit analysis. Despite its simplicity, it appears to be a good way to quantify research efforts vs. the (probable) outcomes. The options or scenarios of research were developed based on the Delphi method.

The judgments on the outcomes were obtained from interviews with water experts. Sharing options with other experts adds value to the preparation. Each scholar has his/her own preferences, and thus there is no single solution. This was shown during the interviews with the experts, when they were forced to make a choice by pushing their preference in grading the available field campaign options. Eventually, even when incorporating experts' inputs, we as a researcher will still have to make decisions and will possibly select our own preferred choices. In the end, dealing with the local constraints is a decision to be made by the researcher. However, by doing the two analyses of scenarios and cost benefits continuously during planning and performing hydrological research, one will be better informed to make decisions.

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The notion that the effects of human actions to be expected in hydrological field campaign are basically unspecified does not imply that they could not adequately and fruitfully be translated in specific planning, as we have shown. Taking into account human actions in planning field campaign for something that is usually seen as a single-scientific activity implies that each field design should be tuned to the situation under consideration: a designer cannot come up with a standard solution. Paradoxically, introducing such a multifaceted approach asks for hydrological researchers with higher qualifications. Planned improvisation needs scientific expertise, as much as it requires a specific attitude.

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References

Anyi, M., Kirke, B., and Ali, S.: Remote community electrification in Sarawak, Malaysia, Renew. Energ., 35, 1609–1613, 2010.

Arnstein, S. R.: A ladder of citizen participation, J. Am. I. Planners, 35, 216–224, 1969.

Athy, L. F.: Density, porosity, and compaction of sedimentary rocks, AAPG Bull., 14, 1–22, 1930.

Baiocchi, D. and Fox, D. S.: Surprise! From CEOs to Navy SEALs: How a Select Group of Professionals Prepare for and Respond to the Unexpected, RAND Corporation, Santa Monica, CA, 2013.

Balakrishnan, B.: Women and Micro-Hydro Systems, Himalayan Small Hydropower Summit, New Delhi, 2006.

Beratan, K. K.: Summary: addressing the interactional challenges of moving collaborative adaptive management from theory to practice, Ecol. Soc., 19, 46, doi:10.5751/ES-06399-190146, 2014.
Blume, T., Zehe, E., Reusser, D. E., Iroume, A., and Bronstert, A.: Investigation of runoff generation in a pristine, poorly gauged catchment in the Chilean Andes I: a multi-method experimental study, Hydrol. Process., 22, 3661–3675, doi:10.1002/hyp.6971, 2008.
Calkins, D. and Dunne, T.: A salt tracing method for measuring channel velocities in small mountain streams, J. Hydrol., 11, 379–392, 1970.
Chandra, S., Ahmed, S., Ram, A., and Dewandel, B.: Estimation of hard rock aquifers hydraulic conductivity from geoelectrical measurements: a theoretical development with field application, J. Hydrol., 357, 218–227, 2008.
Cheema, M. J. M., Bastiaanssen, W. G. M., and Rutten, M. M.: Validation of surface soil moisture from AMSR-E using auxiliary spatial data in the transboundary Indus Basin, J. Hydrol., 405, 137–149, 2011.
Choguill, M. B. G.: A ladder of community participation for underdeveloped countries, Habitat Int., 20, 431–444, 1996.
Daniell, K. A., White, I., Ferrand, N., Ribarova, I. S., Coad, P., Rougier, J.-E., Hare, M., Jones, N. A., Popova, A., Rollin, D., Perez, P., and Burn, S.: Co-engineering participatory water management processes: theory and insights from Australian and Bulgarian interventions, Ecol. Soc., 15, 11, 2010.
Das, S. V. G.: Judicious Management of Groundwater through Participatory Hydrological Monitoring, A Manual, APWELL Project, Andhra Pradesh, India, 2003.
Das, S. V. G. and Rao, P. S.: Participatory Hydrological Monitoring (PHM) – An effective tool for community managed groundwater systems? Paper presented at the International Conference on Land Resource Management for Food, Employment and Environmental Security, 9–13 November 2000, Vigyan Bhavan, New Delhi, 2000.
deGraffenried Jr., J. B. and Shepherd, K. D.: Rapid erosion modeling in a Western Kenya watershed using visible near infrared reflectance, classification tree analysis and ^{137}cesium, Geoderma, 154, 93–100, 2009.
Dewar, J. A: Assumption-based Planning, A Tool for Reducing Avoidable Surprises, RAND, Cambridge University Press, 2002.
Dewar, J. A, Builder, C. H., Hix, W. M., and Levin, M. H.: Assumption-based Planning, A Planning Tool for Very Uncertain Times, RAND Corporation, Santa Monica, CA, 1993.

HESSD
12, 9489–9569, 2015

Doty, R. D.: Soil water distribution on a contour-trenched area, Research Note INT-163, US Department of Agriculture Forest Service, Ogden, UT, p. 6, 1972.
Dudhani, S., Sinha, A. K., and Inamdar, S. S.: Assessment of small hydropower potential using remote sensing data for sustainable development in India, Energ. Policy, 34, 3195–3205, 2006.
ECSP: Water Stories: Expanding Opportunities in Small-scale water and sanitation projects, Report from the Navigating Peace Initiative of the Environmental Change and Security Program, Woodrow Wilson International Center for Scholars, Washington, 2006.
Ehret, U., Gupta, H. V., Sivapalan, M., Weijs, S. V., Schymanski, S. J., Blöschl, G., Gelfan, A. N., Harman, C., Kleidon, A., Bogaard, T. A., Wang, D., Wagener, T., Scherer, U., Zehe, E., Bierkens, M. F. P., Di Baldassarre, G., Parajka, J., van Beek, L. P. H., van Griensven, A., Westhoff, M. C., and Winsemius, H. C.: Advancing catchment hydrology to deal with predictions under change, Hydrol. Earth Syst. Sci., 18, 649–671, doi:10.5194/hess-18-649-2014, 2014.
Ertsen, M. W. and Hut, R.: Two waterfalls do not hear each other. Sand-storage dams, science and sustainable development in Kenya, Phys. Chem. Earth, 34, 14–22, 2009.
Ertsen, M. W., Biesbrouck, B., Postma, L., and van Westerop, M.: Participatory design of sand storage dams, in: 2005 Coalitions and Collisions, edited by: Goessling, T., Jansen, R. J. G., and Oerlemans, L. A. G., Wolf Publishers, Nijmegen, 175–185, 2005.
Ertsen, M. W., Murphy, J. T., Purdue, L. E., and Zhu, T.: A journey of a thousand miles begins with one small step – human agency, hydrological processes and time in socio-hydrology, Hydrol. Earth Syst. Sci., 18, 1369–1382, doi:10.5194/hess-18-1369-2014, 2014.
Fabricius, C. and Cundill, G.:. Learning in adaptive management: insights from published practice, Ecol. Soc., 19, 29, doi:10.5751/ES-06263-190129, 2014.
Falkenmark, M., Fox, P., Persson, G., and Rockström, J.: Water Harvesting for Upgrading of Rainfed Agriculture, Problem Analysis and Research Needs, Stockholm International Water Institute, Stockholm, 2001.
Farrington, J, Turton, C., and James, A. J.: Participatory Watershed Development, Challenges for the Twenty-First Century, Oxford University Press, Oxford, 1999.
Garnett, S. T., Sayer, J., and Du Toit, J.: Improving the effectiveness of interventions to balance conservation and development: a conceptual framework, Ecol. Soc., 12, 2, 2007.
Gomani. M. C., Mahay, F., Mbilinyi, B., Dietrich, O., and Lischeid, G.: Establishment of a hydrological monitoring system through a participatory approach in a small tropical catchment

in Tanzania: learning hydrology from the local people, Proceedings of the Conference on International Research on Food Security, Natural Resource Management and Rural Development, 6–8 October 2009, University of Hamburg, Hamburg, 2009.

Gurung, T. R., Bousquet, F., and Trébuil, G.: Companion modeling, conflict resolution, and institution building: sharing irrigation water in the Lingmuteychu Watershed, Bhutan, Ecol. Soc., 11, 36, 2006.

Hagen, D. and Evju, M.: Using short-term monitoring data to achieve goals in a large-scale restoration, Ecol. Soc., 18, 29, doi:10.5751/ES-05769-180329, 2013.

Hamilton, S.: Completing the loop: from data to decisions and back to data, Hydrol. Process., 21, 3105–3106, 2007.

Hasan, M. H., Mahlia, T. M. I., and Nur, H.: A review on energy scenario and sustainable energy in Indonesia, Renew. Sust. Energ. Rev., 16, 2316–2328, 2012.

Hrachowitz, M., Bohte, R., Mul, M. L., Bogaard, T. A., Savenije, H. H. G., and Uhlenbrook, S.: On the value of combined event runoff and tracer analysis to improve understanding of catchment functioning in a data-scarce semi-arid area, Hydrol. Earth Syst. Sci., 15, 2007–2024, doi:10.5194/hess-15-2007-2011, 2011.

Hrachowitz, M., Savenije, H. H. G., Blöschl, G., McDonnell, J. J., Sivapalan, M., Pomeroy, J. W., Arheimer, B., Blume, T., Clark, M. P., Ehret, U., Fenicia, F., Freer, J. E., Gelfan, A., Gupta, H. V., Hughes, D. A., Hut, R. W., Montanari, A., Pande, S., Tetzlaff, D., Troch, P. A., Uhlenbrook, S., Wagener, T., Winsemius, H. C., Woods, R. A., Zehe, E., and Cudennec, C.: A decade of Predictions in Ungauged Basins (PUB) – a review, Hydrolog. Sci. J., 58, 1198–1255, doi:10.1080/02626667.2013.803183, 2013.

Huffman, G. J., Adler, R. F., Bolvin, D. T., Gu, G., Nelkin, E. J., Bowman, K. P., Hong, Y., Stocker, E. F., and Wolff, D. B.: The TRMM Multisatellite Precipitation Analysis (TMPA): quasi-global, multiyear, combined-sensor precipitation estimates at fine scales, J. Hydrometeorol., 8, 38–55, doi:10.1175/JHM560.1, 2007.

IAP2 – International Association for Public Participation: IAP2 home page, http://www.iap2.org (last access: 25 March 2015), 2007.

Jiang, X.-W., Wan, L., Cardenas, M. B., Ge, S., and Wang. X.-S.: Simultaneous rejuvenation and aging of groundwater in basins due to depth-decaying hydraulic conductivity and porosity, Geophys. Res. Lett., 37, L05403, doi:10.1029/2010GL042387, 2010.

Karjalainen, T. P., Rossi, P. M., Ala-aho, P., Eskelinen, R., Reinikainen, K., Kløve, B., Pulido-Velazquez, M., and Yang, H.: A decision analysis framework for stakeholder involvement and learning in groundwater management, Hydrol. Earth Syst. Sci., 17, 5141–5153, doi:10.5194/hess-17-5141-2013, 2013.

Katsura, S., Kosugi, K., Mizutani, T., and Mizuyama, T.: Hydraulic properties of variously weathered granitic bedrock in headwater catchments, Vadose Zone J. 8, 557–573, 2009.

Kongo, V. M., Kosgei, J. R., Jewitt, G. P. W., and Lorentz, S. A.: Establishment of a catchment monitoring network through a participatory approach in a rural community in South Africa, Hydrol. Earth Syst. Sci., 14, 2507–2525, doi:10.5194/hess-14-2507-2010, 2010.

Kosnik, L.: The potential for small scale hydropower development in the US, Energ. Policy, 38, 5512–5519, 2010.

Kummerow, C., Simpson, J., Thiele, O., Barnes, W., Chang, A. T. C., Stocker, E., Adler, R. F., Hou, A., Kakar, R., Wentz, F., Ashcroft, P., Kozu, T., Hong, Y., Okamoto, K., Iguchi, T., Kuroiwa, H., Im, E., Haddad, Z., Huffman, G., Ferrier, B., Olson, W. S., Zipser, E., Smith, E. A., Wilheit, T. T., North, G., Krishnamurti, T., and Nakamura, K.: The status of the Tropical Rainfall Measuring Mission (TRMM) after two years in orbit, J. Appl. Meteorol., 39, 1965–1982, doi:10.1175/1520-0450(2001)040<1965:TSOTTR>2.0.CO;2, 2000.

Lane, S. N.: Acting, predicting and intervening in a socio-hydrological world, Hydrol. Earth Syst. Sci., 18, 927–952, doi:10.5194/hess-18-927-2014, 2014.

Lasage, R., Aerts, J., Mutiso, G.-C., and De Vries, A.: Potential for community based adaptations to droughts: sand dams in Kitui, Kenya, Phys. Chem. Earth, 33, 67–73, 2008.

Linstone, H. A. and Turoff, M. (Eds.): The Delphi Method: Techniques and Applications, Addison-Wesley, Reading, Massachusetts, 1975.

Mackenzie, J., Tan, P.-L., Hoverman, S., and Baldwin, C.: The value and limitations of participatory action research methodology, J. Hydrol., 474, 11–12, 2012.

Makurira, H., Savenije, H. H. G., and Uhlenbrook, S.: Modelling field scale water partitioning using on-site observations in sub-Saharan rainfed agriculture, Hydrol. Earth Syst. Sci., 14, 627–638, doi:10.5194/hess-14-627-2010, 2010.

Manning, C. E. and Ingebritsen, S. E.: Permeability of the continental crust: implications of geothermal data and metamorphic systems, Rev. Geophys., 37, 127–150, 1999.

Martiny, N., Camberlin, P., Richard, Y., and Philippon, N.: Compared regimes of NDVI and rainfall in semi-arid regions of Africa, Int. J. Remote Sens., 27, 5201–5223, 2006.

McGuire, K. and McDonnell, J.: Stable Isotope Tracers in Watershed Hydrology, Blackwell Publishing, Oxford, 2007.

HESSD

12, 9489–9569, 2015

Systematic planning of small-scale hydrological intervention-based research

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Mhizha, A. and Ndiritu, J. G.: Assessing crop yield benefits from in situ rainwater harvesting through contour ridges in semi-arid Zimbabwe, Phys. Chem. Earth, 66, 123–130, 2013.
Mul, M. L., Savenije, H. H. G., and Uhlenbrook, S.: Spatial rainfall variability and runoff response during an extreme event in a semi-arid catchment in the South Pare Mountains, Tanzania, Hydrol. Earth Syst. Sci., 13, 1659–1670, doi:10.5194/hess-13-1659-2009, 2009.
Neuzil, C. E.: Groundwater flow in low-permeability environments, Water Resour. Res., 22, 1163–1195, 1986.
Paish, O.: Small hydro power: technology and current status, Renew. Sust. Energ. Rev., 6, 537–556, 2002.
Phalla, C. and Paradis, S.: Use of Hydrological Knowledge and Community Participation for Improving Decision-making on Irrigation Water Allocation, Working Paper Series No. 49, ACDRI Publication blackboxPlease provide place of publication., 2011.
Popescu, I., Brandimarte, L., Perera, M. S. U., and Peviani, M.: Assessing residual hydropower potential of the La Plata Basin accounting for future user demands, Hydrol. Earth Syst. Sci., 16, 2813–2823, doi:10.5194/hess-16-2813-2012, 2012.
Poręba, G. J.: Caesium-137 as a soil erosion tracer: a review, Geochronometria, 25, www.geochronometria.pl (last access: September 2015), 2006.
Purohit, P.: Small hydro power projects under clean development mechanism in India: a preliminary assessment, Energ. Policy, 36, 2000–2015, 2008.
Reed, M. S., Evely, A. C., Cundill, G., Fazey, I., Glass, J., Laing, A., Newig, J., Parrish, B., Prell, C., Raymond, C., and Stringer, L. C.: What is social learning?, Ecol. Soc., 15, 4, 2010.
Ritchie, J. C. and McHenry, J. R.: Application of radioactive fallout cesium-137 for measuring soil erosion and sediment accumulation rates and patterns: a review, J. Environ. Qual., 19, 215–233, 1990.
Rodela, R., Cundill, G., and Wals, A. E. J.: An analysis of the methodological underpinnings of social learning research in natural resource management, Ecol. Econ., 77, 16–26, 2012.
Rodgers, P., Soulsby, C., Waldron, S., and Tetzlaff, D.: Using stable isotope tracers to assess hydrological flow paths, residence times and landscape influences in a nested mesoscale catchment, Hydrol. Earth Syst. Sci., 9, 139–155, doi:10.5194/hess-9-139-2005, 2005.
Saar, M. O. and Manga, M.: Depth dependence of permeability in the Oregon Cascades inferred from hydrogeologic, thermal, seismic, and magmatic modeling constraints, J. Geophys. Res., 109, B04204, doi:10.1029/2003JB002855, 2004.
Sassone, P. G.: Cost-Benefit Analysis – a Handbook, Academic Press, New York, USA, 1978.

HESSD
12, 9489–9569, 2015

Screaton, E., Saffer, D., Henry, P., and Hunze, S.: Porosity loss within the underthrust sediments of the Nankai accretionary complex: implications for overpressures, Geology, 30, 19–22, 2002.
Šimůnek, J., van Genuchten, M. T., and Šejna, M.: Development and Applications of the HYDRUS and STANMOD Software Packages and Related Codes, Vadose Zone J., 7, 587–600, 2008.
Singh, G.: Enhancing growth and biomass production of plantation and associated vegetation through rainwater harvesting in degraded hills in southern Rajasthan, India, Springer Netherlands, 2012.
Sivapalan, M., Takeuchi, K., Franks, S. W., Gupta, V. K., Karambiri, H., Lakshmi, V., Liang, X., McDonnell, J. J., Mendiondo, E. M., O'Connell, P. E., Oki, T., Pomeroy, J. W., Schertzer, D., Uhlenbrook, S., and Zehe, E.: IAHS Decade on predictions in ungauged basins (PUB), 2003–2012: Shaping an exciting future for the hydrological sciences, Hydrolog. Sci. J., 48, 857–880, 2003.
Sivapalan, M., Konar, M., Srinivasan, V., Chhatre, A., Wutich, A., Scott, C. A., Wescoat, J. L., and Rodríguez-Iturbe, I.: Socio-hydrology: use-inspired water sustainability science for the Anthropocene, Earth's Future, 2, 225–230, doi:10.1002/2013EF000164, 2014.
Soulsby, C., Neal, C., Laudon, H., Burns, D. A., Merot, P., Bonell, M., Dunn, S. M., and Tetzlaff, D.: Catchment data for process conceptualization: simply not enough?, Hydrol. Process., 22, 2057–2061, 2008.
Srinivasan, L.: Tools for Communication Participation: A Manual for Training Trainers in Participatory Techniques: PROWWESS/UNDP-World Bank Water and Sanitation Program Washington, D.C., produced and distributed by PACT Inc., New York, 1990.
Suroso: The prospect of small hydro power development in Indonesia, available at: http://www.hcshp.org/en/world/db/Country_Report_Indonesia.pdf (last access: 8 October 2013), 2002.
Sutherland, R.: Spatial variability of ^{137}Cs and the influence of sampling on estimates of sediment redistribution, Catena, 21, 57–71, 1994.
Sutherland, W. J., Gardner, T., Bogich, T. L., Bradbury, R. B., Clothier, B., Jonsson, M., Kapos, V., Lane, S. N., Möller, I., Schroeder, M., Spalding, M., Spencer, T., White, P. C. L., and Dicks, L. V.: Solution scanning as a key policy tool: identifying management interventions to help maintain and enhance regulating ecosystem services, Ecol. Soc., 19, 3, doi:10.5751/ES-06082-190203, 2014.

HESSD
12, 9489–9569, 2015

Tetzlaff, D., Carey, S. K., Laudon, H., and McGuire, K.: Catchment processes and heterogeneity at multiple scales – benchmarking observations, conceptualization and prediction, Hydrol. Process., 24, 2203–2208, 2010.
UNSCEAR: Ionizing Radiation: Levels and Effects, A report of the United Nations Scientific Committee on the Effects of the Atomic Radiation to the General Assembly, United Nations, New York, 1972.
UNSCEAR: Sources and Effects of Ionizing Radiation, A report of the United Nations Scientific Committee on the Effects of the Atomic Radiation to the General Assembly, United Nations, New York, 1977.
Van Koppen, B.: Large-Scale and Small-Scale Infrastructure for Growth and Development, International Water Management Institute, Southern Africa Regional Program, Pretoria, South Africa, 2009.
Verbist, K., Cornelis, W. M., Gabriels, D., Alaerts, K., and Soto, G.: Using an inverse modelling approach to evaluate the water retention in a simple water harvesting technique, Hydrol. Earth Syst. Sci., 13, 1979–1992, doi:10.5194/hess-13-1979-2009, 2009.
Vincent, L. F.: Towards a smallholder hydrology for equitable and sustainable water management, Nat. Resour. Forum, 27, 108–116, doi:10.1111/1477-8947.00046, 2003.
Von Korff, Y., Daniell, K. A., Moellenkamp, S., Bots, P., and Bijlsma, R. M.: Implementing participatory water management: recent advances in theory, practice, and evaluation, Ecol. Soc., 17, 30, doi:10.5751/ES-04733-170130, 2012.
Walling, D. E. and Quine, T. A.: Use of ^{137}Cs measurements to investigate soil erosion on arable fields in the UK: potential applications and limitations, J. Soil Sci., 42, 147–165, 1991.
Wallbrink, P. J., Olley, J. M., and Murray, A. S.: Relating suspended sediment to its original soil depth using fallout radionuclides, Soil Sci. Soc. Am. J., 63, 369–378, 1999.
Wang, X.-S., Jiang, X.-W., Wan, L., Song, G., and Xia, Q.: Evaluation of depth-dependent porosity and bulk modulus of a shear using permeability–depth trends, Rock Mech. Min. Sci., 46, 1175–1181, 2009.
Warner, D. B. and Abate, C. G.: Guidelines for the Development of Small-Scale Rural Water Supply and Sanitation Projects in East Africa, Catholic Relief Services, Nairobi, Kenya, 2005.
Winsemius, H.: Interactive comment on “HESS Opinions “Urgent water challenges are not sufficiently researched”” by P. van der Zaag et al., Hydrol. Earth Syst. Sci. Discuss., 6, C342–C345, 2009.

HESSD
12, 9489–9569, 2015

Zapata, F.: The use of environmental radionuclides as tracers in soil erosion and sedimentation investigations: recent advances and future developments, Soil Till. Res., 69, 3–13, 2003.

HESSD
12, 9489–9569, 2015

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Table 1. Cesium-137 analysis at the small (1 m wide) Trench Area.

Depth	Cs ($\mathrm{Bq\,kg^{-1}}$)		Cs ($\mathrm{Bq\,kg^{-1}}$)			Cs ($\mathrm{Bq\,kg^{-1}}$)				Cs ($\mathrm{Bq\,kg^{-1}}$)			Cs ($\mathrm{Bq\,kg^{-1}}$)			
(cm)	R1	R2	U1	U2	U3	D3	T3	T4	D4	U4	U6	U5	D1	T1	T2	D2
5	1.98	1.87	<	<	<	<			0.73	4.70	6.65	9.37	1.78			1.58
10	1.70	1.05	<	<	0.74	<			<	6.33	4.11	5.73	0.77	2.94		3.60
15	0.34	<	<	<	<	<			<	2.82	2.38	<	0.37	3.40		<
20	<	<	<	0.61	0.56	<			<	2.03	1.10	<	<	3.44		<
25	<	<	<	<	<	<		3.89	<	0.75	<	<	<	4.66		<
30	<	<	<	<	<	<	7.69	6.48	<	<	<	<	0.38	4.89		<
35	<	<	<	<	<	<	8.89	6.48	0.64	<	<	<	<	3.43	2.17	<
40	<	<	<	<	<	<	5.84	8.31	0.64	<	<	<	<	3.26	1.50	0.79
45							2.37	5.60						4.74	0.48	
50							<	3.00							1.00	
55							0.37	1.07							1.05	
60							0.52	<							<	
65							<								<	
70															1.30	
75																
80																

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Table 2. The top 10 potential capacity in Maluku Islands.

No.	Catchment area (ha)	Discharge ($m^3 s^{-1}$)	Head (m)	Potential capacity (kW)
1	2798	0.18	27	30-40
2	1811	0.12	22	16–21
3	1200	0.08	25	12–15
4	1445	0.10	20	11–15
5	760	0.05	31	9–12
6	779	0.05	28	8–11
7	978	0.06	21	8–11
8	544	0.04	35	7–10
9	912	0.06	20	7–9
10	483	0.03	33	6–8

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Table 3. Time periods of three hydrological intervention-based research projects.

Case study	Intervention		Hydrological research	
	Start	End	Start	End
Vietnam	Oct 2007	Sep 2008	Oct 2007	Mar 2011
Kenya	2002	2003	Sep 2010	Mar 2012
Indonesia	Sep 2012	Sep 2013	Jul 2010	Oct 2011

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Table 4. (a) Vietnam case; hydrological research. **(b)** Vietnam case; intervention.

(a)				
Procedure (the official way of conducting hydrological research)	Event or observation (an indisputable happening)	Action (the process towards an event)	Interpretation (giving a meaning of the event and/or action to research)	Period
Install two rain gauges	Intermittent rainfall data	–	–	Oct 2007–Mar 2011
	Clogged rain gauges [#1]	Need of checks and maintenance	Loss of rainfall data series	Oct 2008
	Logger failed to record events [#2]	Tried to retrieved data from manufacture company and manual measurement	Loss of rainfall data series	Dec 2009–Mar 2011
Install access tubes for soil moisture measurements	Loss of access tubes [#3]	Substituted with new access tubes	Loss of soil moisture data series, extra costs for new tubes	Sep 2008–Mar 2011
Check infiltration at the bottom of the trench	–	–	–	Sep 2009–Nov 2009
Measure soil porosity and bulk density	–	–	–	Oct 2007–Jun 2009
Measure infiltration capacity	–	–	–	Oct 2007 and Apr 2009
Measure surface water level in the trenches during wet season	–	–	–	Oct 2007–Nov 2009
Construct observation wells	Loss of divers [#4]	Perform manual measurement	Loss in groundwater level data series	Dec 2007
	Improper screen instalment for isotope sampling [#5]	Nothing	Possible misinterpretation of isotope signal	Oct 2007 and Apr 2009
	Construction before intervention [#6]	Extra costs for constructing new wells	A shift in location of intervention requires more measurements, thus more cost	Oct 2007–Apr 2009

Table 4. Continued.

(b)

Procedure (the common way of intervention)	Event or observation (an indisputable happening)	Action (the process towards an event)	Interpretation (giving a meaning of the event and/or action to intervention)	Period
Introducing the concept of intervention to local authority and community	Meetings	Presentations and discussions to obtain support	Needed an agreement from local community	May 2006–Sep 2007
Constructing contour trenches [#6A]	A monks' organization provided their land in a size of 12 ha for intervention	Larger trenches were constructed on 8 ha area	Needed an agreement on someone's land to be interfered	Oct 2007
	After large contour trenching, the monks' organization refused to continue construction on their remaining land	Meetings and discussions to convince the intervention would be beneficial for the community	Although the monks gave permission for large contour trenching, they did not like the design	Nov 2007–Mar 2008
	The proposer approached other land owners	The proposer offered a smaller contour trench design	Negotiated on the design	Mar 2008
	A local farmer excepted the smaller trench design	Construction of smaller contour trenches on 1 ha area	The smaller design was tested	Apr 2008–May 2008
	Other local farmers requested smaller contour trenching.	Construction of smaller contour trenches on other farmers' land (10 ha)	The smaller design was preferred	Jun 2008–Aug 2008
	The monks' organization also provided their remaining land for smaller contour trenching	Construction of smaller contour trenches on the remaining 4 ha area.	Overall in this particular local community, a larger design was not accepted.	Jun 2008–Aug 2008

Table 5. (a) Kenya case; hydrological research. **(b)** Kenya case; intervention.

(a)				
Procedure (the official way of conducting hydrological research)	Event or observation (an indisputable happening)	Action (the process towards an event)	Interpretation (giving a meaning or impact of the event to research)	Period
Install two rain gauges	One rain gauge was damaged by elephants and thus removed by local people [#7]	Information came very late, thus arrangement for reset up of the rain gauge could not be performed	Loss of rainfall data series	Sep 2010–Mar 2012
	One logger failed to record events [#8]	Tried to retrieve data without success	Loss of rainfall data series	Sep 2010–Mar 2012
Soil moisture measurements to be conducted by a local person	A long negotiation to start measurement was not successful [#9]	Established new connection with other local people was not successful too	Loss of soil moisture data series	Sep 2010–Mar 2013
	Loss of access tubes [#9A]	Installed two remaining tubes	Loss of soil moisture data series	Sep 2010–Mar 2012
Used TRMM and NDVI analysis	–	–	–	Jan 2011–Mar 2011
Measure soil porosity and bulk density	–	–	–	Sep 2010
Soil sampling for Cesium analysis	–	–	–	Sep 2010

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Table 5. Continued.

(b)				
Procedure (the common way of intervention)	Event or observation (an indisputable happening)	Action (the process towards an event)	Interpretation (giving a meaning of the event and/or action to intervention)	Period
Introducing the concept of intervention to local authority and community	Meetings	Convincing local people with success	Local people accepted the design	2001–2002
Constructing contour trenches	The majority of Maasai supported contour trenches	Trenches were first constructed in smaller dimension and furthermore in larger ones	Easy to implement different dimension of contour trenching in this particular area	2002–2006
After construction of large contour trenches	–	–	–	2002–present

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Table 6. (a) Indonesia case; hydrological research. **(b)** Indonesia case; intervention.

(a)				
Procedure (the official way of conducting hydrological research)	Event or observation (an indisputable happening)	Action (the process towards an event)	Interpretation (giving a meaning or impact of the event to research)	Period
Install two rain gauges	One logger failed to record events [#10]	Only counted on one logger	Loss of rainfall data series	Jul 2010–Jul 2011
Install two divers	One logger failed to record events [#11]	Only count on one diver	Loss of water level data series	Jul 2010–Jul 2011
Measure discharge using dilution method and velocity area	–	–	–	Feb 2011–Mar 2011
Used DEM analysis	–	–	–	Apr 2011–Jun 2011

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Table 6. Continued.

(b)				
Procedure (the common way of intervention)	Event or observation (an indisputable happening)	Action (the process towards an event)	Interpretation (giving a meaning of the event and/or action to intervention)	Period
Proposed intervention to local authority and community	Meetings, permit issue, estimation of micro hydro budget and research on its potential	–	–	Mar 2010–Jun 2011
Design suitable micro hydro installation	Two plans were agreed; first an installation of about 80 kW and second small kW was estimated after the research	Search for extra funding to meet the construction cost	A decision had to be made based on the availability of funding	Jul 2010–Jan 2012
Pilot result	Research result suggests little potential for micro-hydro installation in a village, but funding was still not enough	Constructed micro-hydro model for a local university	The final intervention shifted from a pilot to a model	Sep 2012–Sep 2013

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Table 7. Evaluation of technical approaches: gain vs. expenditure in Vietnam case.

Parameter	Method	Gain		Expenditure		Problems
		Process	Model	Labour	Cost	
Rainfall	Tipping bucket	++	+	+−	+ + +	Clogging due to fine sand and logger
Soil moisture	TDR (with 8 access tubes)	+−	+−	++	+ + +	Prone to vandalism
Vertical flow path	Dye tracer	++	++	+−	+−	Destructive sampling
Soil physics	Lab analysis	++	++	+−	+	Point data, lack of deeper samples
Infiltration capacity	Inverse auger test	++	++	+−	+	Point data
Water level	Meter height reading	+ + +	+ + +	+−	+−	Point data
Groundwater level	Observation well (reached bedrock depth)	+ + +	+ + +	+	+ + +	Point data and divers prone to vandalism
Isotope tracer	Lab analysis	+ + +	++	+	+ + +	Short period of sampling

Notes: (+) positive rating = greater gain.

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Table 8. Evaluation of the technical approaches: gain vs. expenditure in Kenya case.

Parameter	Method	Gain		Expenditure		Problems
		Process	Model	Labour	Cost	
Rainfall	Tipping bucket	++	+	+	+++	Logger and removal
	TRMM (remote sensing)	++	++	–	–	Low resolution
Soil moisture	TDR (with 6 access tubes)	+–	+–	+++	+++	Point data and prone to vandalism
Soil physics	Lab analysis	++	++	+	+–	Sample composition
Greenness index	NDVI (remote sensing)	++	++	–	–	Low resolution
Erosion and sedimentation	Cs analysis	++	++	+	+++	Reference point

Notes: (+) positive rating = greater gain.

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Table 9. Evaluation of the technical approaches: gain vs. expenditure in Indonesia case.

Parameter	Method	Gain		Expenditure		Problems
		Process	Model	Labour	Cost	
Rainfall	Tipping bucket	++	++	+−	+++	Logger
Discharge	Velocity area	++	++	+−	+++	Logger
	Dilution gauging	++	++	+−	+−	Short measurement
Head	DEM (remote sensing)	++	++	−	−	Low resolution

Notes: (+) positive rating = greater gain.

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Table A1. Scenario 1: to measure rainfall and groundwater level for a short period.

Parameter	Method	Amount/ Samples	In EUR Labour		In EUR Cost	
Rainfall	Tipping bucket	2	+−	40	+ + +	2015
Soil physics	Lab analysis	6	+−		+	238
Infiltration capacity	Inversed auger test	8	+−		+	75
Water level	Meter height reading	13	+	720	+−	15
Groundwater level	Observation well and diver (reached bedrock)	3	++		+ + +	5533
			Total I	760	Total II	7876

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Table A2. Scenario 2: to recheck the signal of recharge.

Parameter	Method	Amount/ Samples	In EUR Labour		In EUR Cost	
Rainfall	Tipping bucket	2	+−	40	+ + +	2015
Soil moisture	TDR (with access tubes)	8	+ + +	2160	+ + +	4717
Vertical flow path	Dye tracer	3	+−		+−	10
Soil physics	Lab analysis	6	+−		+	238
Infiltration capacity	Inversed auger test	8	+−		+	75
Water level	Meter height reading	13	+−		+−	15
Groundwater level	Observation well and diver (reached bedrock)	7 + 1	++		+ + +	13 893
Isotope tracer	Lab analysis	116 + 116	+		+ + +	1856
			Total I	2200	Total II	22 819

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Table A3. Scenario 3: to map the subsurface.

Parameter	Method	Amount/ Samples	In EUR Labour		In EUR Cost	
Rainfall	Tipping bucket	2	+−	40	+ + +	2015
Soil moisture	TDR (with access tubes)	8	+ + +	2160	+ + +	4717
Vertical flow path	Dye tracer	3	+−		+−	10
Soil physics	Lab analysis	6	+−		+	238
Infiltration capacity	Inversed auger test	8	+−		+	75
Water level	Meter height reading	13	+−		+−	15
Groundwater level	Observation well and diver (reached bedrock)	7 + 4	+		+ + +	18 909
Isotope tracer	Lab analysis	116 + 116	+		+ + +	928
Subsurface mapping	ERT	4		2000	+ + +	10 000
			Total I	4200	Total II	36 907

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Table A4. Scenario 1: to use remote sensing data.

Parameter	Method	Amount/ Samples	In EUR Labour		In EUR Cost	
Rainfall	Tipping bucket	2	+	120	+ + +	1305
	Remote sensing analyis		–		–	
Greenness index	Remote sensing analysis		–		–	
			Total I	120	Total II	1305

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Table A5. Scenario 2: to retry one year soil moisture measurement.

Parameter	Method	Amount/ Samples	In EUR Labour		In EUR Cost	
Rainfall	Tipping bucket	2	+	120	+ + +	1305
	Remote sensing analysis		–		–	
Soil moisture	TDR (with access tubes)	6	+ + +	2880	+ + +	4990
Soil physics	Lab analysis	8	+–	40	+–	
Greenness index	Remote sensing analysis		–		–	
Erosion and sedimentation	Cs analysis	128	+	100	+ + +	1699
			Total I	3140	Total II	7994

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Table A6. Scenario 3: to maximize remote sensing analysis.

Parameter	Method	Amount/ Samples	In EUR Labour		In EUR Cost	
Rainfall	Tipping bucket	2	+	120	+ + +	1305
	Remote sensing analysis		–		–	
Soil moisture	TDR (with access tubes)	6	+ + +	2880	+ + +	4990
Soil physics	Lab analysis	8	+	40	+–	
Greenness index	Remote sensing analysis		–		–	
Erosion and sedimentation	Cs analysis	128	+	100	+ + +	1699
High resolution greenness index	Remote sensing analysis		–		+ + +	8400
			Total I	3140	Total II	16 394

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Table A7. Scenario 1: to measure discharge of one river for one year.

Parameter	Method	Amount/ Samples	In EUR Labour		In EUR Cost	
Discharge	Velocity area (diver)	3	+−		+++	1500
	Dilution gauging		+−		+−	25
Head	Remote sensing analysis		−		−	
			Total I	50	Total II	1525

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Table A8. Scenario 2: to investigate discharge of another river.

Parameter	Method	Amount/ Samples	In EUR Labour		In EUR Cost	
Rainfall	Tipping bucket	2	+−	50	+ + +	1990
Discharge	Velocity area (diver)	3 + 2	+−		+ + +	2500
	Dilution gauging		+−		+−	25
Head	Remote sensing analysis		–		–	
			Total I	50	Total II	4515

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Table A9. Scenario 3: to investigate discharges of four other rivers.

Parameter	Method	Amount/ Samples	In EUR Labour		In EUR Cost	
Rainfall	Tipping bucket	2	+−	50	+ + +	1990
Discharge	Velocity area (diver)	3 + 8	+−		+ + +	5500
	Dilution gauging		+−		+−	25
Head	Remote sensing analysis		−		−	
			Total I	50	Total II	7515

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Table B1. Vietnam case; the experts' opinions.

No	Title	Institution	Scenario 2		Scenario 3		Other suggestions
			Grade	Remarks	Grade	Remarks	Remarks
1	PhD	Utrecht University	7	Seasonality is already included	7	Disadvantage: profiles measured only one time	Require 10 year groundwater level data
2	MSc	Delft University	8	Measure for at least 2 years	8.5	Model only tests hypothesis. Measurements already answered the research question	–
3	MSc	Delft University	7	Isotope is an advance method with good result	7	One time measurement equals to nothing	To study the unsaturated zone, to measure rate of recharge using SM sensors etc
4	PhD	Delft University	8	Need validation and try to get more confidence or to decrease uncertainty. But it could even lead to confusing results	8	Hard to interpret	Depending on Ks and soil moisture. Challenging (qualitative result): infiltration test and surface water measurements
5	PhD	Delft University	7	Sceptic	8	–	–
6	Prof	UNESCO-IHE	7.5	–	8	–	–
7	PhD	UNESCO-IHE	7.5	–	8	Increase resistivity of water by injecting sodium chloride	More artificial tracer, (yellow dye), soil moisture measurement below the trench (use cheap sensors like Decagon). A need of timely scale measurements or time laps measurements
8	PhD	Delft University	8	–	8	–	Previous measurements were already sufficient
9	MSc	Eindhoven-Deltares	7	–	8	–	It would be an advantage to have 3-D
10	PhD	Delft University	7.5	–	8	Expensive (cost magnitude about EUR 10 000 to 30 000 for a 5 m interval)	Geophysical approach for spatial information. Soil type analysis, ground radar method, and 1–2 points tracer (pollution)

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Table B2. Kenyan case; the experts‘ opinions.

No	Title	Institution	Scenario 2		Scenario 3		Other suggestions
			Grade	Remarks	Grade	Remarks	Remarks
1	PhD	Utrecht University	7	NDVI related to temperature, LAI, but does not correlate to soil moisture	7	–	Try FPAR (Fractional Photosynthetically Active Radiation)
2	MSc	Delft University	7.5	–	8.5	–	Soil temperature measurement to estimate evaporation.
3	MSc	Delft University	7	Enough	7	Enough	–
4	PhD	Delft University	8	–	8	–	Aerial photos, LAI (although it is difficult)
5	PhD	Delft University	8	–	8	–	Try to measure discharge, modelling the impact of soil moisture and transpiration
6	Prof	UNESCO-IHE	8	–	8	–	Discharge measurements (notches) to close the detail water balance, micro station especially evaporation
7	PhD	UNESCO-IHE	7	–	7.5	–	Plant's physiological effects like water stress.
8	MSc	Delft University	7	–	8	–	A higher resolution is usually better.
9	MSc	Eindhoven-Deltares	8	–	8.5	–	–
10	PhD	Delft University	7.5	–	8	Try to see sub pixel	Pixel variability (to minimize the interval of images). Sensors for spectrometer through cable trolley/station and aerial photos (for more detail images)

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Table B3. Indonesian case; the experts' opinions.

No	Title	Institution	Scenario 2		Scenario 3		Other suggestions
			Grade	Remarks	Grade	Remarks	Remarks
1	PhD	Utrecht University	7	Absolut value is enough	7	–	–
2	MSc	Delft University	7.5	Reach a statistical information of regime	7.5	Reach a statistical information of regime	–
3	MSc	Delft University	7	–	7	–	–
4	PhD	Delft University	8	With more data we can get new or not increased understanding	8	Spatial information is important	Integrate geology and other point measurements at other rivers
5	PhD	Delft University	7	Hydrology engineering	8	Measure at more various areas. Start by investigating maps of the different factors; geological, topographical, vegetation, and boundary condition.	More variability means more recommendation to result in a catchment classification with certain discharges, but maybe diverse catchments are depended only on landscape and geology
6	Prof	UNESCO-IHE	7	–	8	–	Higher resolution of DEM.
7	PhD	UNESCO-IHE	7.5	–	8	–	Maps or information on internet: meteorological data (rainfall and temperature) DEM, soil, geology, and land use. Multiple regression (Q)
8	PhD	Delft University	7	–	8	–	Map of the basin. Field survey on all potential places based on the distance from the village etc. Socio-economic studies to answer where to build a MHPP.
9	MSc	Eindhoven-Deltares	7	–	8	–	Geology and land use map.
10	PhD	Delft University	7	–	7	–	Not important in hydrological science, but just as hydrological measurement. If one goes for uncertainty, then a long time series is needed. A flume (which will be costly) is an option to measure the Q.

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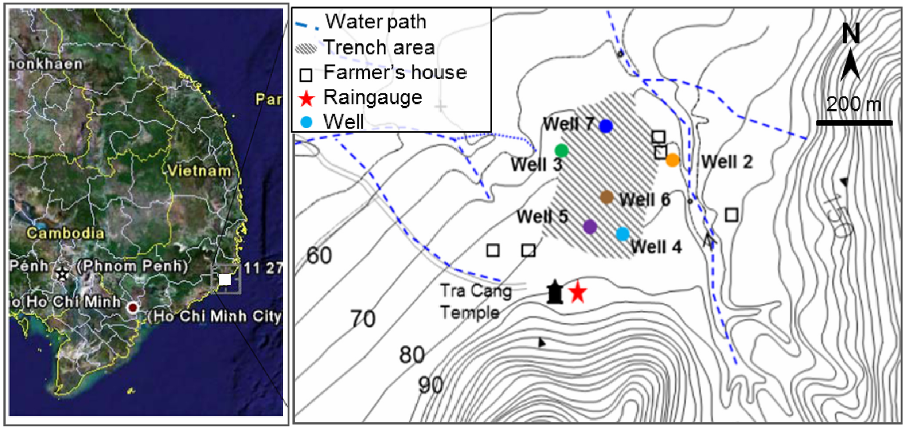

Figure 1. The location of the trenched area, rain gauge, and constructed wells. The study area is the shaded area on the lower map. Source: local produced map and Google Earth.

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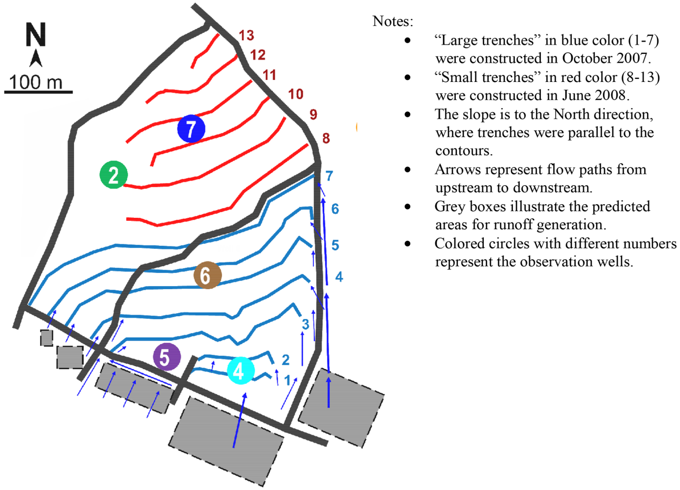

Figure 2. Schematization of the runoff entering the trench area.

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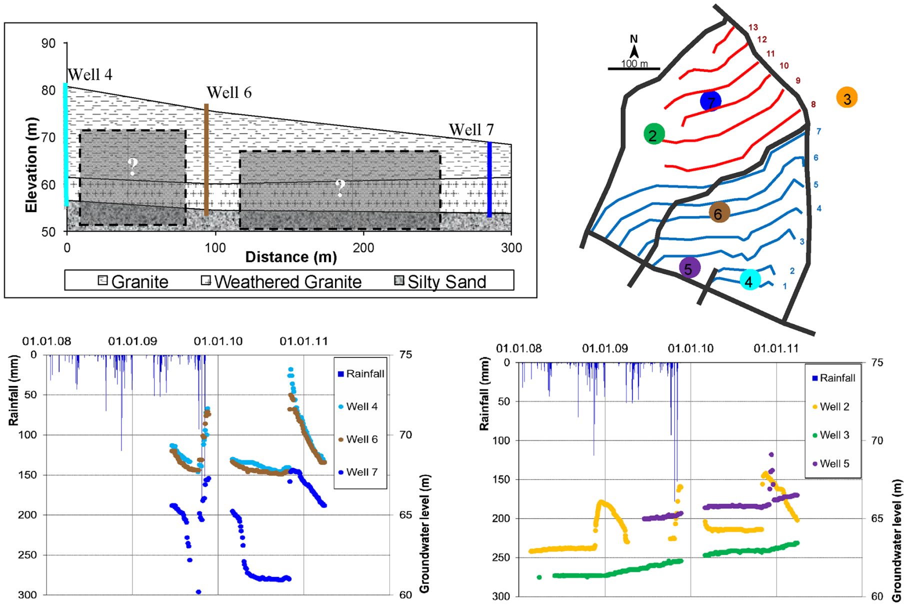

Figure 3. The ground surface, interpolated subsurface layer, and groundwater levels.

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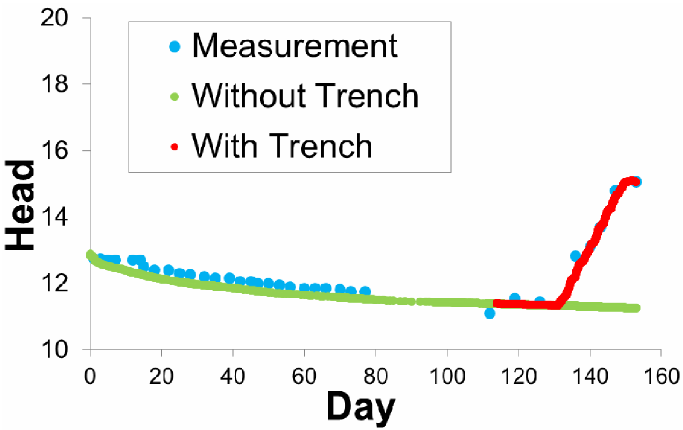

Figure 4. Simulation result with main Ks 7 cm day^{-1}, porosity 11 %, BC Ks 1 cm day^{-1}, and threshold 11 m.

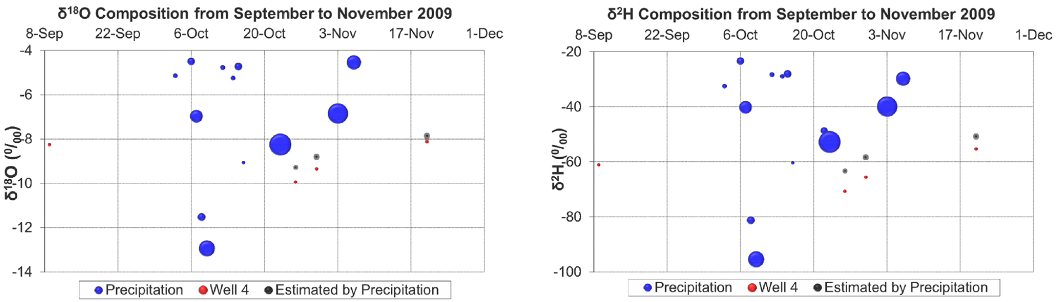

Figure 5. The δ^{18}O and δ^2H composition in groundwater at Well 4.

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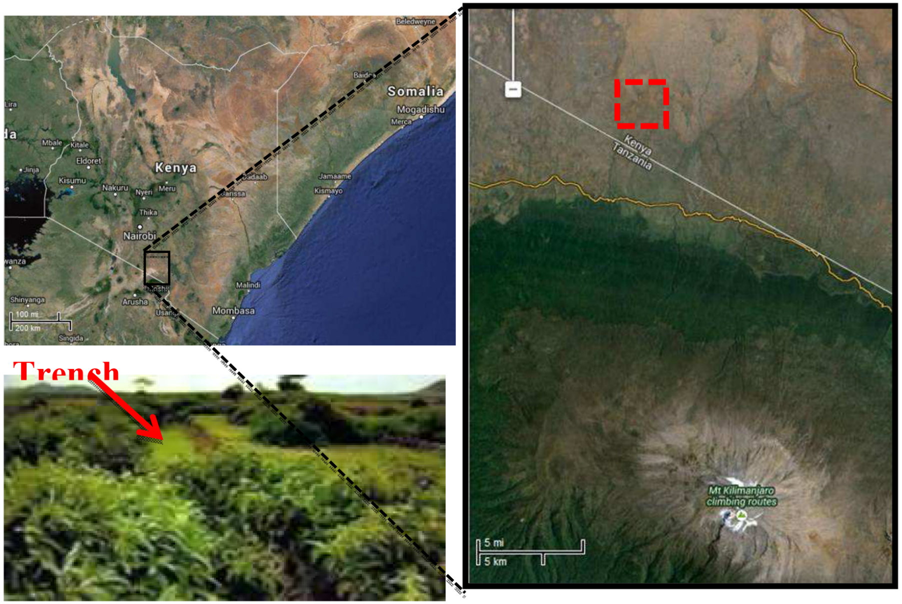

Figure 6. Location of studied contour trenching in Amboseli, Kenya (red dashed line). Source: Google Maps. Left bottom picture: an impression of greenness in the trench area during wet season.

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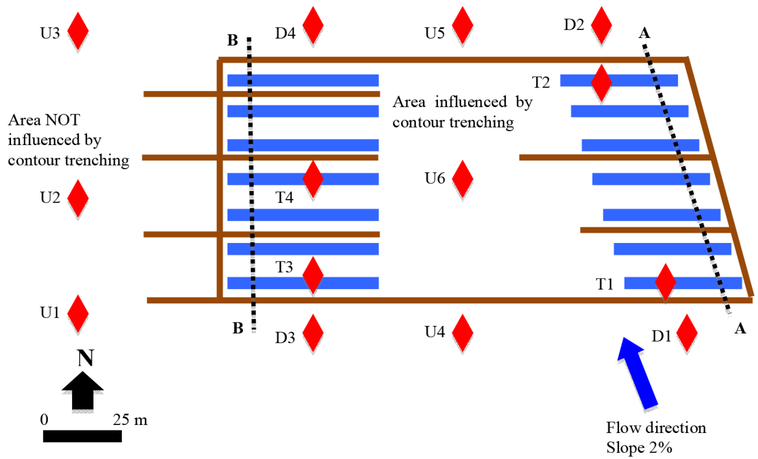

Figure 7. The "small" contour trenches (about 2 ha) in Amboseli. Blue squares are the trenches, brown lines are the stone walls, and red diamonds are the soil sample locations. The thicknesses of sedimentation in the trenches are measured from cross sections A-A and B-B.

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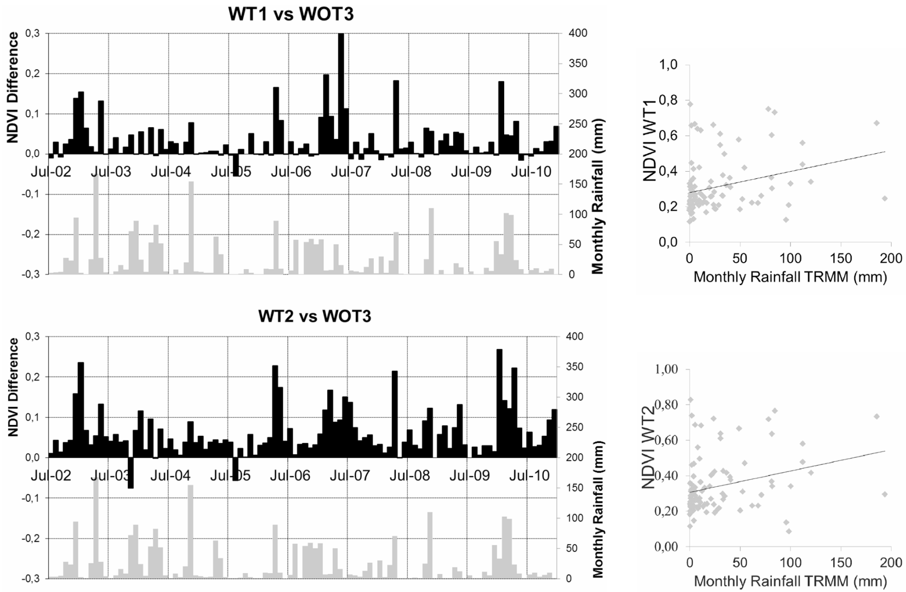

Figure 8. The difference of NDVI values of with (WT) and without trenches (WOT) compared to monthly rainfall. The correlation between TRMM and NDVI of WT1 and WT2 are correlated at the right side.

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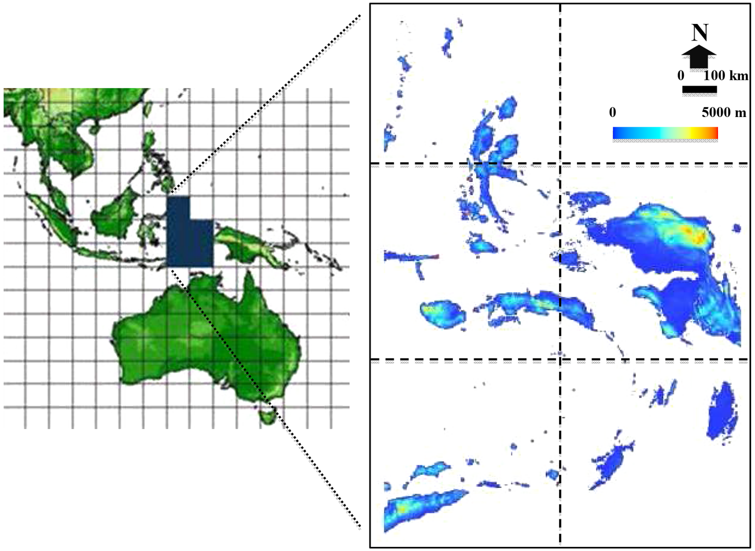

Figure 9. The result of merged and processed DEM tiles on Maluku islands.

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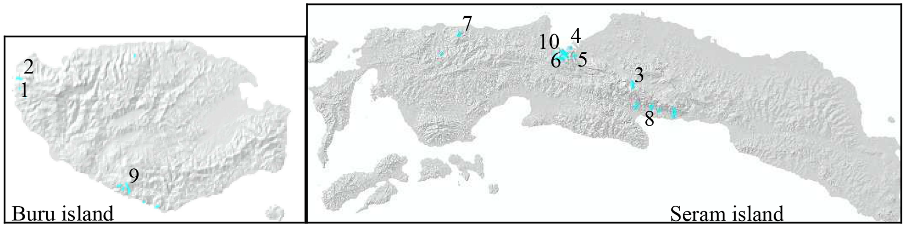

Figure 10. The locations of potential micro-hydro in Buru and Seram island.

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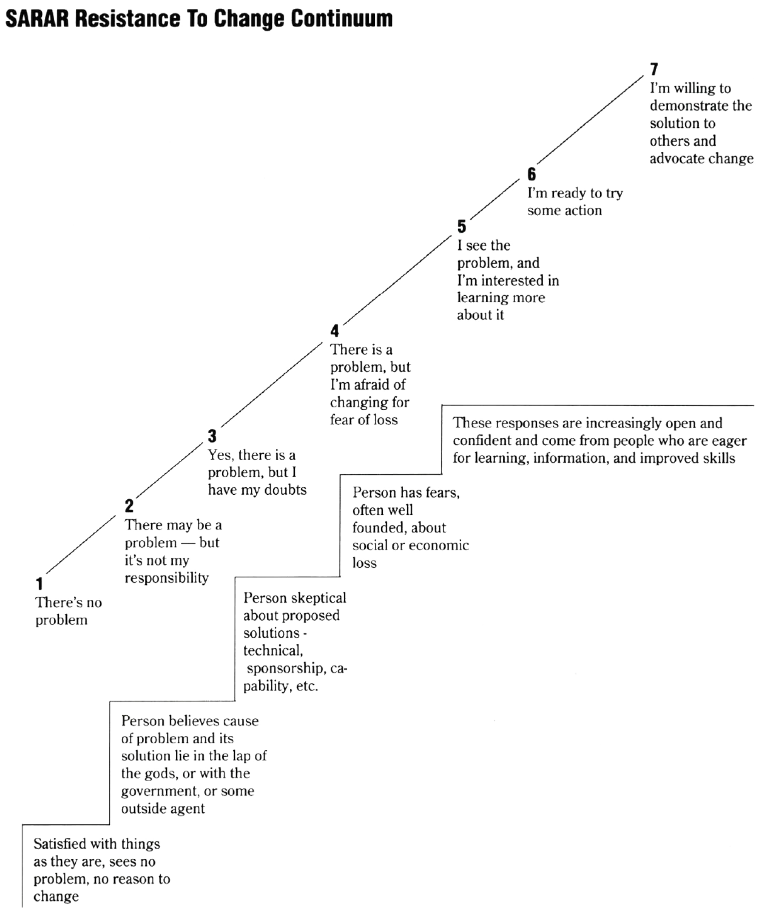

Figure 11. The scale of community participation. Source: Srinivasan (1990, p. 162).

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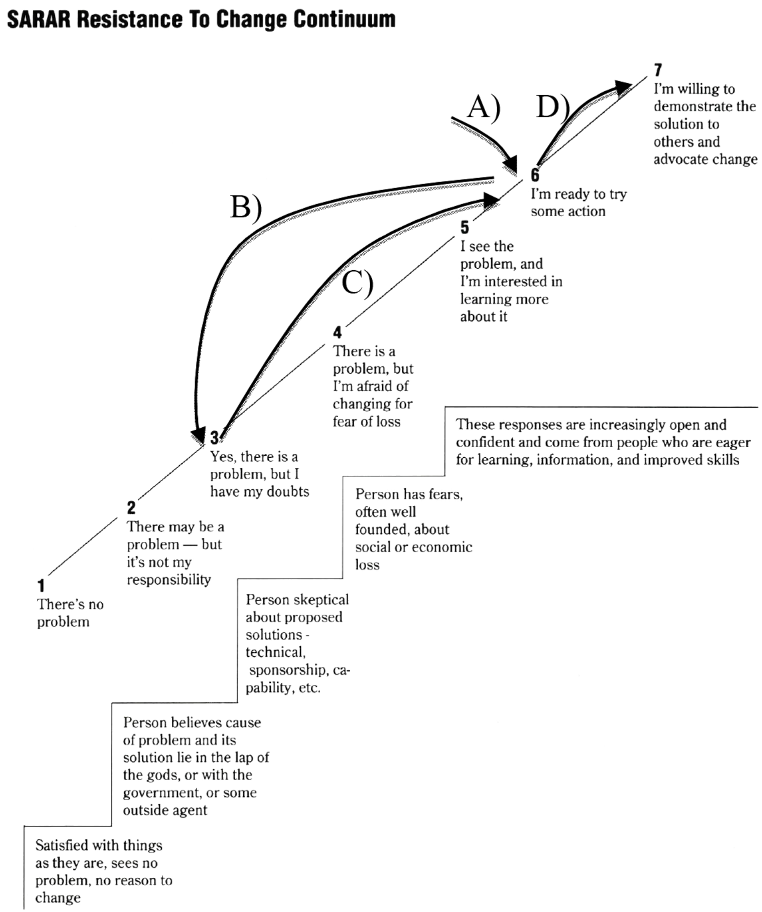

Figure 12. The implemented intervention based on the scale of community participation of Srinivasan (1990).

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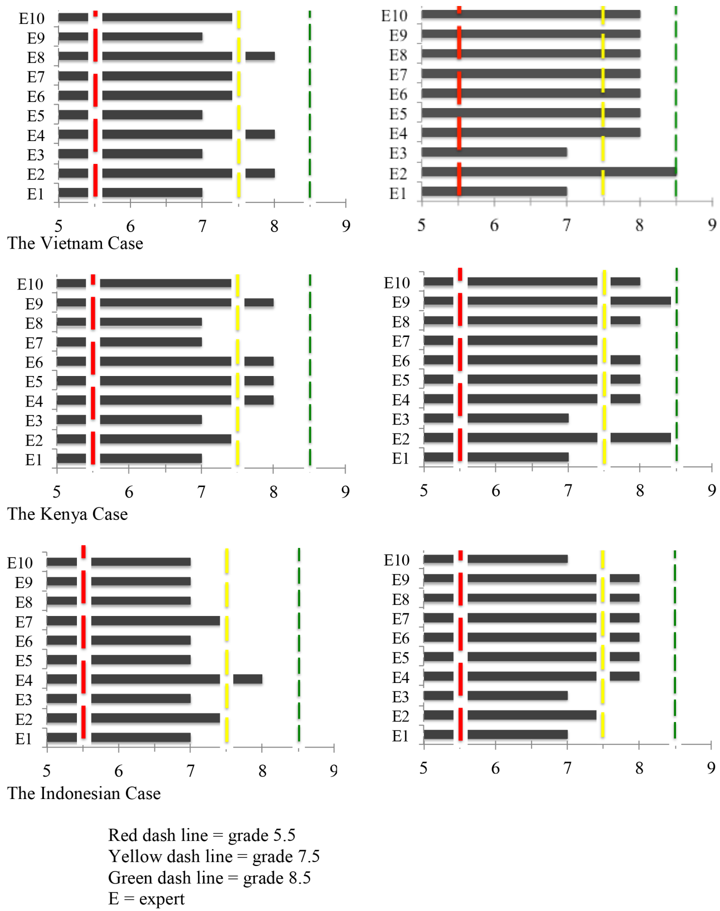

Figure 13. Summary of three cases; left panels: Scenario 2, right panels: Scenario 3.

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