International Water Management Institute

Vienna Doctoral Programme on Water Resource Systems

TECHNICAL BRIEF

The Potential Role of Socio-Hydrological Models for Participatory Water Governance in Burkina Faso

Gemma Carr[1], Marlies Barendrecht[1] and Liza Debevec[2]
1 TU Wien
2 IWMI, Addis Ababa, Ethiopia

photo: Manon Koningstein/IWMI

Participatory planning for more inclusive and sustainable water management in rural Burkina Faso

1. INTRODUCTION

Halting and reversing water quality degradation is a major global concern. The variety of needs and priorities placed on water resources make the issue of water pollution multifaceted and complex. Addressing water quality management requires an approach that can tackle the diversity of requirements and concerns to achieve effective strategies. In Burkina Faso, stakeholder participation plays an important role in effective catchment management. The Participatory Water Governance Project in Rural Burkina Faso has developed support strategies to strengthen the capacity of local-level Water User Committees. Research conducted by TU Wien (Technical University Vienna) and International Water Management Institute (IWMI) aims to support the project by exploring the potential role of socio-hydrological models in water management decision making. The areas around the River Kou and Bapla Reservoir were the focus for this part of the study. The specific question addressed by TU Wien was: can a socio-hydrological model be developed that accurately captures the relationships between people and water quality in the study area?

In the study area, the river, reservoir and riparian zone are intensely used. Fishing, recreation, farming and vegetable cultivation, and providing water for livestock are some of the principle water uses. Water pollution results from agricultural chemicals (pesticides and fertilizers) entering the river, sediment mobilization from cultivation close to the river or by animals in the riparian area, and pollution from commercial activities such as mining. Strategies to reduce pollution and sediment transfer from the riparian zone to the river have focussed on reducing cultivation close to the river, and replacing crops requiring much soil disturbance, such as vegetables, with tree crops that stabilize soil and sediment. For example, a 100-m zone beside the river and reservoir is designated as a "no cultivation zone." Water User Committees play an important role in promoting pollution reduction strategies through awareness raising campaigns, marking the 100-m zone with signs and shrubs, supporting farmers to replace vegetables and other plants in the 100-m zone with tree crops such as mango, and encouraging farmers not to release agrochemical waste into the river or reservoir. Additionally, Water Police have been established in some areas to monitor and enforce the 100-m zone, and farmers may be encouraged to leave the 100-m zone through the provision of alternative land or compensation.

photo: Marlies Barendrecht/TUW

2. BACKGROUND TO SOCIO-HYDROLOGY

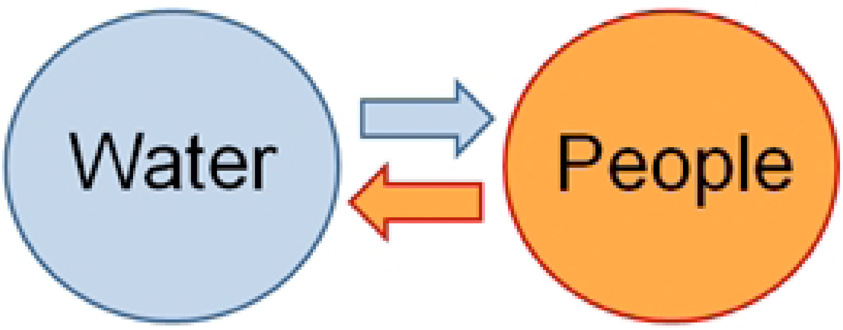
2.1 Overview of socio-hydrology

Socio-hydrology is the study of the dynamic interactions between water and people (Sivapalan et al. 2012; Figure 1). It is based on the premise that water and social systems develop in a highly interconnected way. As such, as changes in the water system take place (i.e., water becomes less available or more polluted), they trigger people to react (i.e., plant less water-intensive crops, develop alternative water sources such as groundwater, or build wastewater treatment plants to reduce water pollution). These human responses lead to further changes in the water system (i.e., reduce water consumption, increase water availability, or improve water quality). Such changes (especially when combined with unpredictable changes in rainfall amount, for example, entering a wetter or dryer period) trigger further reactions from people (i.e., either increasing or reducing the cropping area, and utilizing the cleaner and less-polluted water for fishing or recreation). These reactions further impact water availability and quality driving further changes in the human response and so on.

Socio-hydrological modelling aims to capture these interactions and feedbacks using mathematically based models (based on linked differential equations) (Di Baldassarre et al. 2013). Such models can be used to explore how the interconnected system evolves and may continue to develop into the future. As such, socio-hydrological models can be used to simulate a variety of different trajectories that could be anticipated in the future. They can also be used to explore how the system interacts and what might happen if, for example, a policy change to provide subsidies for less water-intensive crops, or regulations that forbid releasing untreated wastewater into the river are implemented.

As such, socio-hydrological models are different to hydrological models that aim to show how people impact water systems. While hydrological models may aim to develop predictions, of, for example, future water availability based on a plausible scenario for human water demand, socio-hydrological models integrate the human responses to water changes within their structure. While they cannot, therefore, make predictions about the future, they can produce a range of different scenarios that might be expected.

Figure 1: The premise of socio-hydrology - that water and people co-evolve



2.2 Socio-hydrology in this project

In this project, the research focus is on water quality changes through time. The assumption is made that human actions increase water pollution and reduce water quality. The subsequent change in the water quality leads to changing land and water use strategies by people. These actions further lead to changes in water quality (e.g., reduced water pollution).

Socio-hydrological modelling has been selected as an approach in this project for two reasons. First, from a research perspective, the study sites provide a valuable opportunity to explore if and how socio-hydrological models can be successfully developed and applied for situations where water quality is the primary concern. Very little research has been completed on this to date. Second, in an applied context, the development of the model and trajectories produced are anticipated to be of interest and value to the water user committees and other stakeholders for exploring the possible impacts of different policy decisions on water quality.

photo: Anuša Pisanec/IWMI


photo : Marlies Barendrecht/TUW

3. A SOCIO-HYDROLOGICAL MODEL FOR WATER QUALITY MANAGEMENT IN THE STUDY AREA

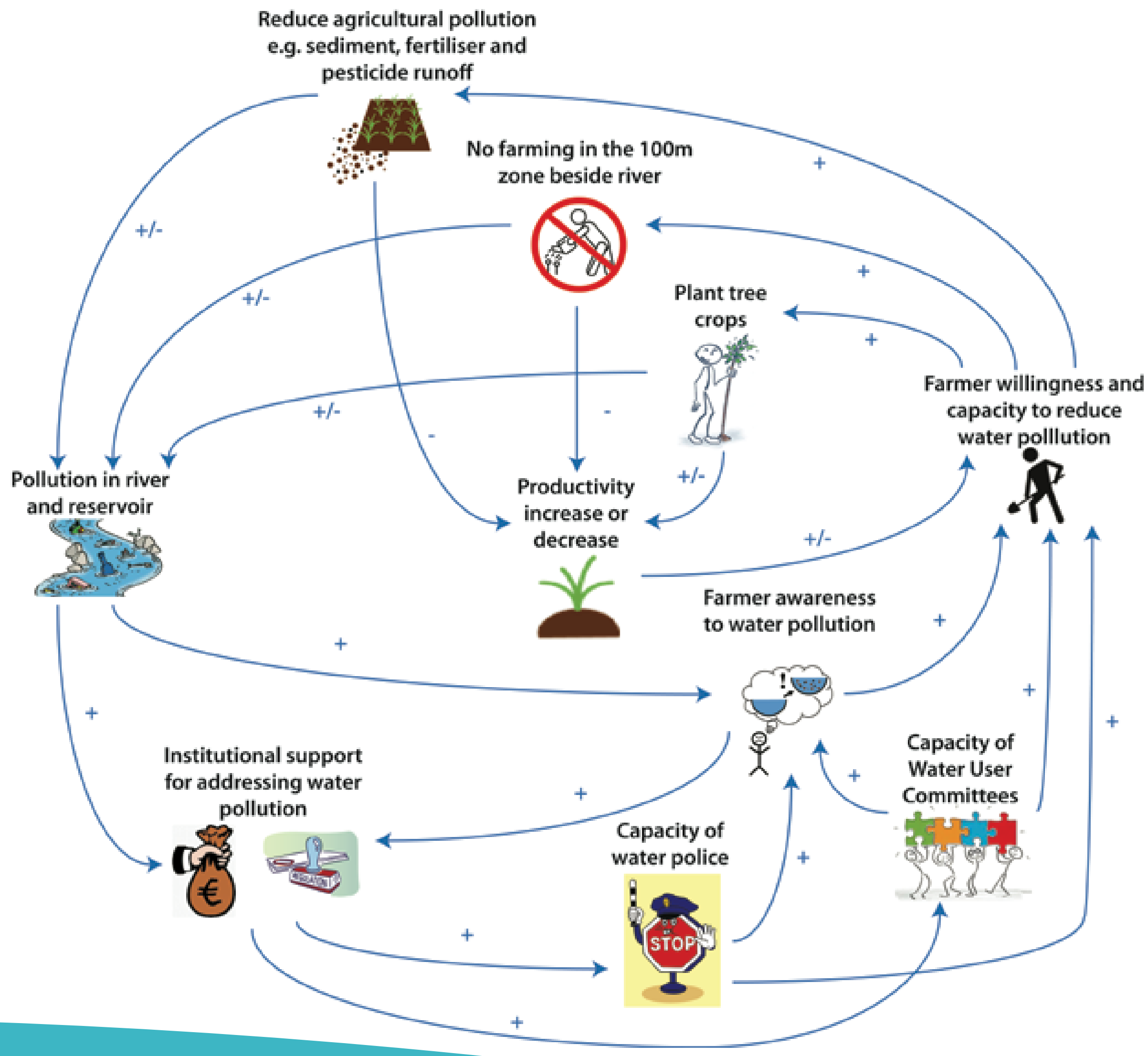
3.1 Development of the socio-hydrological model

The researchers created the socio-hydrological model by first developing a schematic conceptual model of how river and reservoir water quality might change as a result of agricultural activities in the area close to the river or reservoir. This first model was based on information provided by numerous research reports from the study region. A field trip was then undertaken in October 2018 with the aim of exploring whether the model was considered to reflect reality through 19 interviews conducted with members of Water User Committees and other stakeholders. The interviews and field observations in the study areas led to the identification of several necessary changes to the model. These were implemented to create a refined model, shown schematically in Figure 2 and described below.

3.2 Description of the socio-hydrological model

In the socio-hydrological model (Figure 2), changes to water quality in the river and reservoir are driven by awareness creation and provision of support that encourage and enable the farmers to implement different management strategies designed to reduce water pollution. The model hypothesizes that as awareness of water pollution increases, the institutional support to address it increases. This support puts in place, or strengthens, the Water Police (institutions that raise awareness, monitor and enforce the rule that farming is forbidden in the 100-m zone next to the river) and Water User Committees (institutions that aim to develop and implement strategies to improve catchment management). These regional and local-level institutions raise farmer awareness of water pollution and provide support to implement management strategies. In this model, three different management strategies are available to farmers that are expected to lead to a reduction in water pollution: (i) agricultural activities do not take place close to the river/reservoir; (ii) vegetable crops are replaced with tree crops; and (iii) measures are taken to reduce the runoff of sediment, fertilizer and pesticides from farm plots (e.g., reducing their use, reducing tillage, etc.). Implementing these strategies has an impact on the productivity of the farmer. For example, growing vegetable crops in a different place far away from the river may have a lower productivity than cultivating close to the river, or tree crops may not produce fruits for five years. These "productivity costs" may reduce farmer willingness to continue implementing the strategy and need to be effectively "offset" by compensation, support provided by the Water User Committees, or fines enforced by the Water Police, coupled with a high personal awareness by the farmer to the issue of water pollution that further drives their willingness.

Figure 2: Graphical schematic of the socio-hydrological model



A series of equations were developed to describe the relationships shown in Figure 2. They were programmed using the software "R" (an example is shown in Figure 3). The equations described institutional awareness, whereby a parameter for the influence of water pollution on awareness drives institutional awareness and another parameter leads awareness to decline through time because it is assumed that as pollution decreases, the awareness of pollution also decreases. Similarly, the equation for farmer awareness is driven by actual water pollution combined with a parameter for decline in awareness and a parameter for awareness-raising activities (which reduce the decline in awareness).

The capacity of water policy and water user committees is driven by institutional awareness combined with a parameter for institutional support. Farmer willingness and capacity to implement measures is a factor of the farmer's awareness of pollution together with the reduced or increased productivity as a result of implementing the measure (cultivating crops far away from the river is estimated to be 60% less productive than cultivating directly beside the river; planting fruit trees is estimated to be 50% less productive in the first five years and then 200% more productive; reducing agricultural pollution is estimated to be 40% less productive). Furthermore, parameters are included to encourage each measure (provision of subsidies for cultivating away from the river, planting trees or engaging in less-polluting activities, or fines for farming in the 100-m zone).

Figure 3: Screen shot example showing how the model is programmed using the software "R"

```r
eq1 <- function (t, state, parameters) {

 with(as.list(c(state, parameters)),{

   beta_IGL <- fbeta_IGL(t)
   alpha_WP <- falpha_WP(t)
   alpha_WUC <- falpha_WUC(t)
   alpha_IGT <- falpha_IGT(t)
   alpha_IGL <- falpha_IGL(t)
   alpha_IGP <- falpha_IGP(t)

   Qin <- 0.5
   Qout <- 0.4*Sr
   C0 <- 0.08

   if (theta>5){
     IG <- (0.4+0.6*L)*(0.6+0.4*P)^(1+0.5*T)
   }else{
     IG <- (0.4+0.6*L)^(0.6+0.4*P)^(0.5+0.5*(1-T))
   }

   WT <- IG-(1-0.01*AG)*1+alpha_IGT*WUC   #willingness/ability to plant trees
   WL <- IG-(1-0.01*AG)*1+beta_IGL*WPO+alpha_IGL*WUC   #willingness/ability to move away
   WP <- IG-(1-0.01*AG)*1+alpha_IGP*WUC   #willingness/ability to be less polluting

   CinA <- (0.6+0.4*(1-T))*L*(0.6+0.4*P)
   Cin <- 0.001

   dSrdt <- Qin - Qout #storage in reservoir
   dCdt <- ((CinA*0.4)+Cin*Qin-C*Qout)/Sr #water quality in reservoir

   dAIdt <- alpha_AI*(C-C0)*AG*(0.5+0.5*tanh(1000*(C-C0)))*(1-AI)*AI -mu_AI*AI # Awareness of the water quality of institutions
   dAGdt <- alpha_AG*(C-C0)*beta_AG*WPO*(0.5+0.5*tanh(1000*(C-C0)))*(1-AG)*AG -mu_AG*AG # Awareness of the water quality of Gardeners

   # Three kinds of measures: plant trees, move away or use less polluting practices
   dTdt <- WT*T*(1-T)
   dLdt <- -WL*L*(1-L)
   dPdt <- -WP*P*(1-P)
   dWPOdt <- alpha_WP*AI*WPO*(1-WPO)-WPO*mu_WPO
   dWUCdt <- alpha_WUC*AI*WUC*(1-WUC) -WUC*mu_WUC

   dthetadt <- ifelse(T<0.1,-theta,1)


  list(c(dSrdt, dCdt, dAIdt, dAGdt,dLdt,dPdt,dTdt,dWPOdt,dWUCdt,dthetadt), Qin=Qin,Qout=Qout,Cin=Cin, WT=WT, WL=WL,WP=WP, IG=IG, CinA=CinA)
  }) # end with(as.list ...
  }

sol1<- ode(y=c(Sr=Sr0, C=C0, AI=AI0,AG=AG0,L=L0,P=P0,T=T0,WPO=WPO0,WUC=WUC0,theta=theta0), times=time, func=eq1,
           parms=c(alpha_AG= alpha_AG,mu_AG=mu_AG,alpha_AI= alpha_AI,mu_AI=mu_AI,mu_WPO=mu_WPO,mu_WUC=mu_WUC,beta_AG=beta_AG))

solution1 <- as.data.frame(sol1)
```

The implementation of each of the three strategies in the model (cultivating away from the river, planting trees or engaging in less-polluting activities) is, therefore, a result of the farmer's willingness to implement the measure, combined with their experience of the strategy so far (i.e., costs incurred). Their willingness to implement the strategies can be increased by creating a higher awareness of water pollution, provision of support from Water User Committees and/or fines enforced by the Water Police.

Finally, the amount of pollution coming from farmland and entering the river/reservoir is calculated using the resulting percentage of farmland in the 100-m zone (zero farmland means zero pollution), the percentage of trees in the 100-m zone (100% trees mean 60% reduction in pollution), and the percentage of farms in the 100-m zone not employing pollution reduction strategies (employing such strategies leads to a 60% reduction in pollution).

3.3. Selection of management strategy simulations

Based on the field trip observations and interviews conducted with stakeholders, three different approaches were identified that encourage farmers to adopt strategies to reduce water pollution. These could be categorized under regulation and enforcement, providing incentives, and awareness raising. For this study, the researchers chose to explore how the different approaches compared to each other in improving water quality over the long term. They were particularly interested in exploring what would happen to water quality if an approach was implemented and then, after a period of time, removed. For example, how effective the short-term provision of incentives for planting tree crops would be for improving water quality compared to an awareness-raising campaign. To do this, parameters were defined and the model was run for six different scenarios. For each scenario, the approaches (regulation, incentives or awareness raising) were active only during the first half of the modelled time period. The aim was, therefore, to see how the system would respond if an intervention was started and then withdrawn. The six scenarios were as follows:

SCENARIO 1: Baseline scenario - where no management strategies are employed and pollution from agriculture continually increases to a point where all available land beside the river is used for farming.

SCENARIO 2: Regulation and enforcement scenario - where the water police enforce the 100-m no cultivation zone through fines.

SCENARIO 3: Financial incentives and support given to farmers **to move from the 100-m zone** and cultivate further away from the river.

SCENARIO 4: Financial incentives and support given to farmers **to reduce pollution from sediment and agrochemicals.**

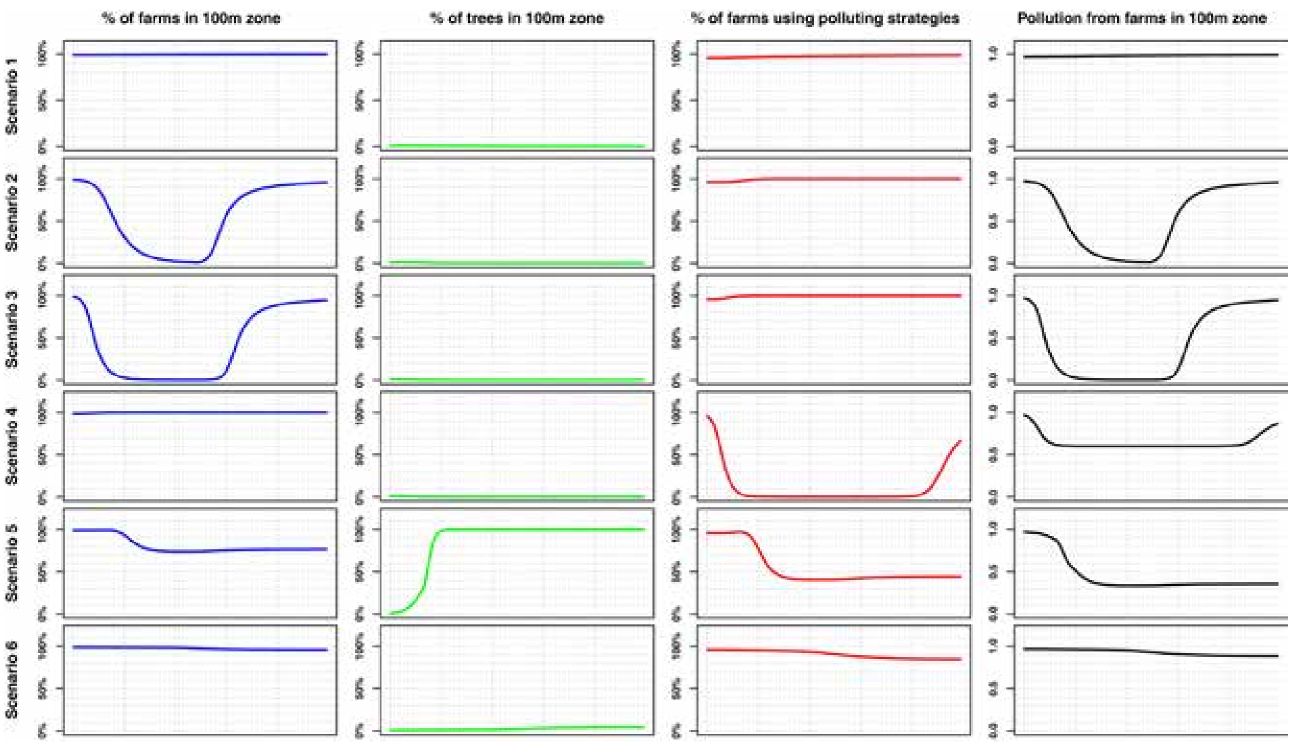
SCENARIO 5: Financial incentives and support to plant fruit trees in the 100-m zone rather than cultivating vegetables.

SCENARIO 6: Awareness-raising campaigns to make farmers aware that their activities could lead to water pollution, and to encourage them to reduce the runoff of sediments, fertilizers and pesticides.

4. THE MODELLED SCENARIOS

The results of the modelling show that the different scenarios lead to very different situations in the catchments and different amounts of water pollution from farming (Figure 4). The baseline scenario (Scenario 1) shows a continual increase in farming in the 100-m zone that corresponds to an increase in pollution. The regulation and enforcement scenario (Scenario 2) shows that fines are effective in reducing the number of farm plots in the 100-m zone and results in a corresponding decrease in pollution. However, halfway through the modelled time period when the Water Police cease to regulate and enforce the 100-m no cultivation zone, there is a rapid increase in farms in the zone and an increase in pollution. A similar pattern is seen for the incentives scenarios, where financial incentives are given to farmers to cultivate away from the 100-m zone (Scenario 3) or to implement pollution reduction strategies (Scenario 4), which are effective at reducing water pollution as long as farmers continue to be supported. However, if the provision of incentives is stopped, the model suggests that farmers return to the 100-m zone and to more polluting agricultural activities. Short-term incentives (though importantly, of at least 5-year duration) to plant trees and support farmers seem to have a longer-term positive impact on water quality (Scenario 5). This is because it was estimated that, for this model, fruit trees provided 200% more income than vegetables after five years. Data to support this assumption would, therefore, be needed. Finally, awareness-raising campaigns (Scenario 6) interestingly show a positive long-term impact on water quality. This is because the model is designed so that awareness-raising activities increase the willingness and capacity of farmers to implement measures to reduce water pollution, and this leads to a very gradual decrease in cultivation in the 100-m zone, an increase in planting trees and in the adoption of pollution reduction strategies. While the literature does suggest that awareness of environmental issues raises motivation to address them (e.g., Nordlund and Garvill 2002), further supporting data would be needed to confirm this relationship in this setting.

Figure 4: Modelled results of change in percentage of agricultural land use in the 100-m zone close to the river or reservoir as a percentage of the total area, and the resulting impact on water pollution (1 = high pollution and 0 = low pollution). Six scenarios are shown: 1 = baseline - continual increase in farming in the 100-m zone that corresponds to an increase in pollution; 2 = regulation and enforcement with the imposing of fines for cultivating within the 100-m zone; 3 = incentives and support to cultivate away from the 100-m zone; 4 = incentives and support to reduce pollution from farming in the 100-m zone; 5 = incentives and support for planting fruit trees; and 6 = awareness-raising campaigns about how farming can lead to water pollution. For each scenario, the intervention (regulation, incentives or awareness raising) only took place during the first half of the modelled period, in order to explore how the system might respond if the intervention was applied and then withdrawn.



5. THE POTENTIAL VALUE OF THE MODEL TO STAKEHOLDERS

During the interviews conducted with stakeholders in 2018, interviewees were shown the draft version of the socio-hydrological model and some scenarios of water quality change, and asked whether they thought such a model could be of value for their work. The responses were very positive, primarily because stakeholders believed that the model could be useful for exploring the impacts of implementing different strategies to prevent water quality degradation. To make the model of value to stakeholders, further work would be needed to place it in a user-friendly interface that would enable the parameters to be adjusted to better reflect the system and to allow users to simulate different management settings. For models such as these, careful consideration of the graphics and explanations is essential to ensure the model structure and assumptions are transparent and can be accurately understood.

In this technical brief, we have detailed one possible type of scenario analysis (the impact of implementing and then withdrawing support for different types of pollution reduction strategies). There are many alternative analyses that could be conducted, such as to explore the level of subsidies required to achieve land management changes, to explore how different levels of support for Water User Committees lead to changes in water quality, and how different relative financial impacts of land use change alter water quality. We anticipate that the model could be used by stakeholders to better understand the interconnections in the system and explore how certain actions (e.g., strong regulation versus weak regulation; incentives versus awareness raising) can positively or negatively affect water quality.

It must be emphasised that the model and its scenarios are purely exploratory and not predictive. Many of the assumptions made by the model are subjective assessments, based on field visits and other studies in the region, of how the system may work rather than facts on how it does work. Future work that captures the perspectives of a wide range of stakeholders is, therefore, essential in order to ground the model more firmly in the reality of land use and water quality management in the case of the study area, or further afield.

photo: Manon Koningstein/IWMI

CONCLUSIONS

This research has revealed that it is possible to develop a socio-hydrological model that describes water quality changes as a response to awareness of water pollution. This unique model is able to graphically illustrate a possible relationship between institutional support for Water User Committees and Water Police, and the willingness and capacity of farmers to implement pollution reduction strategies.

The modelled scenarios suggest that awareness raising has a mild but long-term positive impact on improving water quality by raising the willingness of farmers to implement pollution reduction strategies. Tree planting may also lead to long-term water quality benefits, if sufficient long-term support is provided to establish fruit trees. Continual support appears to be required for strategies that encourage farmers to leave the 100-m zone or adopt less-polluting approaches.

While models like the socio-hydrological model developed in this project are not able to predict the future, they may be able to help stakeholders to explore how different strategies might affect water quality in the future.

References

Di Baldassarre, G., Viglione, A., Carr, G., Kuil, L., Salinas, J.L. and Blöschl, G. (2013) Socio-hydrology: conceptualising human-flood interactions. Hydrology and Earth System Sciences. 17 (8), 3295–3303.

Nordlund, A.M. and Garvill, J. (2002): Value structures behind proenvironmental behavior. Environment and Behavior. 34 (6), 740-756.

Sivapalan, M., Savenije, H.H.G. and Blöschl, G. (2012) Socio-hydrology: A new science of people and water. Hydrological Processes. 26 (8), 1270–1276.

Contact

Gemma Carr, TU Wien:
carr@waterresources.at

Partners

International Water Management Institute (IWMI) - in charge of the coordination of the project and the scientific research

Mouhoun Water Agency (Agence de l'Eau du Mouhoun [AEM]) - main partner and intermediary between the project, the government, various integrated water resources management institutions and the researchers

AGRINOVIA Master's Program at the Pr. Joseph Ki-Zerbo University - in charge of providing support to the research component and capacity building of the national researchers

Vienna Doctoral Programme on Water Resource Systems at the Technical University Vienna (TU Wien) in Austria - in charge of the scientific research and providing advisory support for coordination

INTERNATIONAL WATER MANAGEMENT INSTITUTE (IWMI)

Headquarters: 127 Sunil Mawatha, Pelawatte, Battaramulla, Sri Lanka
Mailing address: P. O. Box 2075, Colombo, Sri Lanka
Telephone: +94 11 2880000, 2784080
Fax: +94 11 2786854 - **E-mail:** iwmi@cgiar.org - **Website:** www.iwmi.org

In West Africa: IWMI Accra Office
IWMI c/o CSIR Main Campus, Airport Residential Area (opposite Chinese Embassy), Accra, Ghana
Telephone: +233 302 784 752 - **E-mail:** iwmi-ghana@cgiar.org

This work was made possible through funding provided by the Austrian Development Cooperation, the Austrian Ministry of Finance and the CGIAR Research Program on Water, Land and Ecosystems (WLE).

Graphic design: Laura Delhommeau