Working Paper

# Probabilistic Decision Modelling to Determine Impacts on Natural Resource Management and Livelihood Resilience in Marsabit County, Kenya

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## Abstract

Decision makers, from the household to state level, are frequently faced with decisions that need to be made within a context of risks, uncertainties, multiple possible outcomes and stakeholder groups with varied interests. Business decision analysis methods offer a promising solution because they have been designed to aid businesses in making decisions on risky projects with limited research budgets. The decision analysis approach applied at ICRAF supports decision-making by evaluating business cases and simulating the impact of proposed investments using participatory and probabilistic tools to quantify the potential costs, benefits and associated risks of interventions while accounting for uncertainty in order to realistically forecast the range of plausible project outcomes. A decision analysis exercise was commissioned by the International Union for Conservation of Nature (IUCN) under the "Integrated plan to enhance socioeconomic and ecological resilience of the wider Huri Hills and Shurr Plains landscapes, Marsabit Kenya" project. The purpose was to evaluate the business case for selected investments to improve water availability and access in each landscape. To build comprehensive quantitative models for the proposed investments, the analysts simulated the impact pathways of interventions identified by the local communities that would enhance their resilience. From this information, the analysts conceptualized the models, seeking confirmation on the models' logic from community discussions and implementing partners. The analyses provided initial approximations of the overall net benefits of three interventions in Huri Hills and Shurr. It also revealed trade-offs, especially between environmental and socioeconomic effects, that would require careful consideration by local decision makers. These reflections could be supported by targeted measurements to narrow the identified critical knowledge gaps. Such additional measurements were recommended as the next step to reducing uncertainty, not only on the highlighted key input variables, but also on the projected outcomes. This would improve decision makers' ability to decide on whether tank construction is desirable from an overall impacts point of view in Shurr, and which, if any, of the investment alternatives at Huri Hills is likely to achieve the goals of the programme. As illustrated in this case study, the decision analysis approach is valuable as a tool for monitoring and learning, allowing the community and project implementers to study the actual performance of the investments against the projected performance during their implementation.

**Keywords**: Decision analysis, ex-ante impact assessment, natural resource management, Marsabit County

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Dr. Keith Shepherd leads the Research & Development Theme on Land Health Evaluation, Restoration and Investment Decisions and serves as a Principal Soil Scientist at the World Agroforestry Centre. His research focuses on (i) land and soil health surveillance – an evidence-based approach to measuring and monitoring land and soil health and associated risk factors, and (ii) decision analysis in data-limited environments using Bayesian approaches and value-of-information analysis to improve stakeholder decision-making. Shepherd has pioneered a Soil-Plant Spectral Diagnostics Laboratory at the Centre for high throughput analysis of soils, plants, fertilizers and manures using only light (infrared, x-ray and laser spectroscopy). The lab is supporting the Africa Soil Information Service and a network of spectral laboratories in national and development institutions across the tropics. Shepherd co-leads flagships on Restoring Degraded Landscapes and Enhancing Sustainability across Agricultural Systems in the CGIAR Program on Water, Land and Ecosystems.

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## Abbreviations and Acronyms

| | |
|---|---|
| AIE | Applied Information Economics |
| CV | Coefficient of Variation |
| EOL | Expected Opportunity Loss |
| EVPI | Expected Value of Perfect Information |
| HH | Household |
| ICRAF | World Agroforestry Centre |
| IUCN | International Union for Conservation of Nature |
| KES | Kenya shillings |
| NPV | Net Present Value |
| PLS | Projection-to-Latent Structures |
| SIE | Stochastic Impact Evaluation |
| TEV | Total Economic Value |
| TLU | Tropical Livestock Unit |
| USD | United States Dollar |
| VIP | Variable Importance in the Projection |
| WASH | Water and Sanitation Hygiene |
| ZEF | The Centre for Development Research |

## Introduction

Decision makers from the household to state level frequently have to make decisions within a context of risks, uncertainties, multiple possible outcomes and stakeholder groups with varied interests. It is therefore reasonable for them to be concerned about the risk that an investment or intervention could fail to achieve its objectives. This happens because the uncertainties surrounding the impacts of a proposed development intervention during project assessment are usually not addressed. These uncertainties can be high where information on the parameters of interest and how they will evolve under future change is scarce. For instance, there is a severe lack of data on the ecological, socioeconomic, cultural and political parameters that would influence the complex dynamics of environmental systems.

Decision analysis aims to assist decision makers arrive at rational resolutions in situations where they are faced with imperfect information. It is concerned with identifying the most promising course of action, while recognizing risks and uncertainties. Initially, analyses are based on the current state of knowledge about particular variables of interest, before any measurements are taken. This knowledge is used for probabilistic simulations of the full range of plausible system outcomes of particular interventions, which aid in prioritizing decision options based on their likely outcomes or impacts. This is achieved by including decision makers, various stakeholders and end-users in conducting ex-ante impact assessments using quantitative impact pathways and probabilistic estimates of all relevant benefits, costs, risks and uncertain variables.

Business decision analysis methods offer a promising way forward, because they have been designed to aid businesses in making decisions on risky projects with limited research budgets. To achieve this, a key objective of decision analysis is to capture the current state of uncertainty.

## Background Information

The two study landscapes, located in the arid and semi-arid lands of Marsabit County (Figure 1), are extremely water scarce, with limited availability and accessibility of fresh water resources. The most common water sources in Huri and Shurr are boreholes, low-yielding springs, water pans, dams and shallow wells, as well as roof and rock catchments. Surface water facilities are often faced with problems such as low storage capacity, sedimentation, evaporation and seepage, and therefore, rarely last for more than three months. Underground facilities are often poorly constructed and maintained. Since they are home to an increasing population of numerous communities and a large number of livestock, competition for this natural resource can easily spark conflict. They are thus, among the top priorities of the Marsabit County government in terms of environmental rehabilitation and livelihood enhancement planning and intervention (IUCN, 2016).

The decision analysis assignment was commissioned by the International Union for Conservation of Nature (IUCN) under the "Integrated plan to enhance socioeconomic and ecological resilience of the wider Huri Hills and Shurr Plains landscapes, Marsabit Kenya" project. It aimed to evaluate the business case for selected investments to improve water availability and access in each landscape.

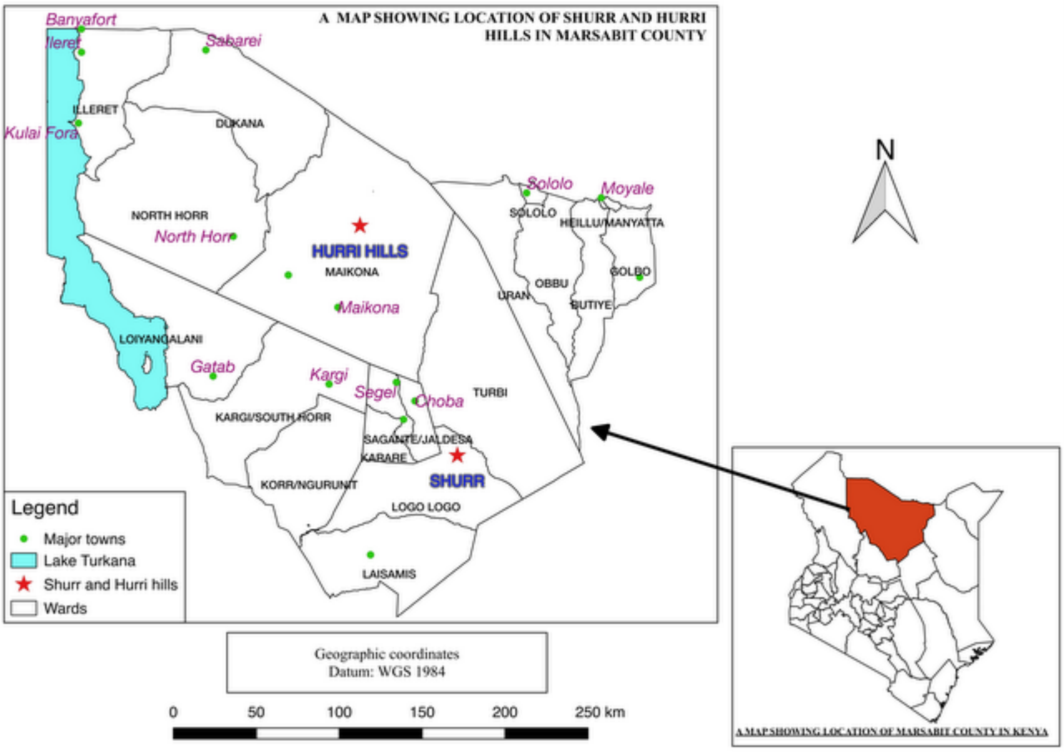


*Figure 1: Location of Huri Hills and Shurr plains in Marsabit County*

From the onset of this pilot analysis, there was no specific decision under consideration regarding particular interventions for the management of natural resources. However, to arrive at well-defined decision options, IUCN convened a gendered community consultation process while ICRAF facilitated a GIS resource mapping exercise. Both activities were carried out in both landscapes to aid decision-making in prioritizing interventions for sustainable resource management, use and access. This process yielded a wide-ranging list of strategic interventions for sectors that touched on the user groups' natural resource base. These interventions were envisioned to help them enhance their resilience to the adverse effects of climate change, such as increased frequency of drought and other related shocks and stresses, thereby enhancing sustainable livelihoods and ecosystems.

Involving the local community, the decision makers, who in this project would also be the project implementers, and the ICRAF decision analysis team in these consultation exercises provided a more holistic understanding of the current degradation status and its trend over time. This would not have been possible without local stakeholder involvement. It also helped to address the community's priorities by gender (men, women and the youth) and establish their trust, buy-in and support for the resource management plans formulated in the process.

Initially, it had been planned that the prioritization process would select a few interventions to model the wider list of strategic interventions. In addition, IUCN would facilitate the stakeholder consultations in order to assist local communities select their most important investment alternatives and thereby create ownership, mobilize resources and foster sustainability. However, this was not possible due to facilitation and time constraints. For this reason, IUCN from a project implementer's perspective, identified those intervention options that appeared to have the widest reaching impact and with the greatest uncertainties. The key constraint arising from inadequate time and resources was a limited ability to engage with stakeholders, which resulted in scarce and unreliable data, as well as incomplete insight into the consequences of making certain decisions pertaining to these particular investments. The challenge was to develop a conceptual framework that acknowledges uncertainties around the outcomes of the proposed investments in the prevailing data-scarce environment. To do this, the decision analysis process used tools to build decision models that assess the level of uncertainty and value of information of the relevant parameters along the entire impact pathway for those investments. This means that all the social, economic, political and environmental impacts, the uncertainties and risks around outcomes are included, in order to improve the accuracy of decision impact projections.

## Proposed Investments in Huri Hills

### Constructing a community underground water conservation tank

The construction of underground water tanks in Huri Hills is considered a rain water harvesting technology that could facilitate longer term collection and storage of water for use during the dry season (Figure 2). Over the years, residents of Huri Hills have been relying on rain and mist harvesting to sustain their subsistence farming and livestock keeping. However, due to the impacts of prolonged drought, several wells and underground water tanks (both communal and private) are also drying up. Large holes (100-500$m^3$) are excavated, and underground stone tanks built in these holes. The tanks are covered with stone slabs, and a series of filter wells developed in the entry channel to facilitate de-silting of runoff. Tanks are fenced off and grass is grown in the catchment area to facilitate further natural filtration (Concern Kenya, 2012).

These tanks serve as reservoirs for rainwater or for water bought and transported by water bowsers from neighbouring wards, Maikona and Kalacha. When the rains fail, the frequency of refilling depends on the demand and financial resources mobilized from residents. Each household receives two to five 20-litre jerricans of water to serve them for three days, water that is hardly sufficient for their own needs and those of their livestock. Sometimes, individuals who own the private underground tanks sell to other community members or give them water on credit.


*Figure 2: An underground water tank in Huri Hills (Source: Nation Media Group, 2015)*

Considering that there are periodic influxes of users from neighbouring areas, including Ethiopia, pressure on water resources is very high in this area. Therefore, access to water from these tanks is controlled by selected community members who act in a managerial capacity and are paid by the community, to only allow access to households living within Huri Hills and not outsiders. They also maintain them and keep them locked to preserve the water for use only during critical periods.

### De-silting and repairing a check dam (*haro*) at Add-Chuluqe

The check dam, otherwise referred to as *haro* in the local dialect, was first dug with a capacity to provide water to about 140 households for domestic use, roughly 140 herds of livestock from within Huri Hills and 360 from outside Huri. It is a temporary catchment with water usually available during the wet season, and can hold the commodity for at most two months, depending on the level of demand. At present, its capacity has radically decreased due to siltation and lack of adequate maintenance.

## Proposed Investments in Shurr Plains

### Above-ground concrete water tank with an underground steel water piping system

It was proposed that the tank be built in Kobadi village (approximately 10km from the Shurr borehole) using bricks and preferably sealed with concrete (Figure 3).

*Figure 3: A concrete water tank in Shurr (Source: IUCN 2016)*

The tank will be filled with water from the Shurr water point – a solar-/diesel-powered borehole that is used largely for livestock, domestic consumption and to supply the health centre and Shurr Primary School. There is a very large livestock population which depends on this water source and has contributed to environmental degradation (trampling and overgrazing) around the borehole. Construction of an underground steel pipeline has been proposed as a continuous strategy to refill the proposed reservoir tank, aiming to divert some livestock herds from the Shurr borehole and relieve environmental pressure and resource-based conflicts. Once the tank at Kobadi is operational, it will be used for livestock and for domestic use by the pastoralist community. Other similar tanks already exist in Badana – an operational concrete/brick water tank with insufficient water due to inflow pressure problems with its piping system, and in Ergmasa which is near the temporary Shurr settlement.

## Objectives of the Study

The objective of the pilot decision analysis within this project was to build a decision model aimed at evaluating the business case and overall impact for each of the proposed investments, while accounting for all the potential costs and benefits, and including all associated risks and uncertain variables in order to realistically forecast the full range of plausible project outcomes.

Results from the impact and risk assessment analysis for the selected interventions will inform the project implementers on the value of these investments and guide their monitoring and evaluation strategies, particularly by exposing the risks that might affect particular project benefits and should therefore be mitigated to increase the chances of success. They will also guide the development of the integrated community natural resource plan to enhance socioeconomic and ecological resilience.

## Methodology

The decision analysis approach applies the Stochastic Impact Evaluation (SIE) framework developed by the World Agroforestry Centre. The framework is based on the principles of Applied Information Economics (AIE), a business decision support methodology developed by Hubbard Decision Research (Hubbard, 2014), a consulting firm based in the United States. The approach incorporates risk and uncertainty in decision models by including calibrated estimates, quantifying risks, identifying knowledge gaps, computing the value of additional information and running Monte Carlo simulations (Luedeling et al*.,* 2015). These elements are discussed in more detail below.

SIE is also an iterative and participation-driven tool which necessitates frequent consultation with relevant stakeholders (Figure 4). To build comprehensive quantitative models for the proposed investments, the analysts began by studying the list of interventions identified by the local communities that would enhance their resilience and by integrating information drawn from many sources through a qualitative assessment. From this information, the analysts conceptualized the models, seeking confirmation on the models' logic from implementing partners whenever they were available.

*Elderly male participants in session*

*A group of male youth in session*

*Women participants in session*

*Figure 4: Group discussions with the community from Huri Hills*

## Quantitative Analysis – Monte Carlo Simulation

### Discounting future benefits and costs

In order to value future benefits and costs, the Net Present Value of all costs and benefits was calculated. This calculation assumed that future costs and benefits were discounted to reflect the preference of current over future profits that is an important consideration in most investment decisions. The discount rates expressed in this analysis are the rates used in common economic practice, though they are difficult to estimate. As a result, discount rates were explicitly stated as uncertain inputs to the model.

### Variable Importance in the Projection (VIP) analysis

To identify the variables which the model outputs are sensitive to, the decision model is set to generate a plot which relates the decision outcomes to input variables. This sensitivity analysis is implemented by statistically relating the values of all input variables to the respective outputs through 'Projection-to-Latent-Structures' (PLS) regression (Luedeling and Gassner, 2012; Wold 1995). The latent structures this name refers to are a type of principal components that are defined as linear combinations of the model's input variables. These components are then related to the model's outputs. This robust type of regression, which is frequently used in hyperspectral remote sensing (e.g. Luedeling et al., 2009) and other fields, can be effective in settings where independent variables are highly correlated and in situations where variation in a large number of predictor variables is to be explained by a relatively small number of observations.

This analysis produces two major outputs: 1) a set of model coefficients, which indicate the direction and strength of each independent variable's relationship with the output, and 2) the so-called Variable Importance in the Projection (VIP) statistic, which expresses the variables' importance in the PLS model, i.e., the variables the model is most sensitive to. As in many other analyses using PLS regression, we interpreted all VIP scores above 0.8 as indicating that the respective variable was an important determinant of the model output values.

### Expected Value of Perfect Information (EVPI)

Even if the VIP scores identify a variable as important, it may still have little effect on the recommendation about how to make the decision in question that emerges from the decision model. The reason for this could be, for instance, that the expected outputs of the model are guaranteed to be positive, regardless of the values assumed by a particular input variable. More information on any variable therefore has no value for the decision maker, because it would not change the recommended decision. For decision makers, the decisive question is not 'what variables determine the value of the model output?' but primarily 'what variables determine the sign of the model output?'. That is, whether the output is more likely to be positive or negative. The reason for this is that the sign determines whether the model results suggest higher returns from implementing or not implementing a project.

This weighing of options can be expressed by the desire to minimize the so-called Expected Opportunity Loss (EOL), which expresses the negative consequences of choosing a suboptimal decision option. The EVPI expresses the value of having perfect knowledge about a variable as the reduction in EOL caused by the additional information. While such perfect information is usually unattainable, knowledge of the EVPI for each variable provides information about which uncertain variables have the greatest potential to alter the emerging decision recommendation, and approximately how much money a rational decision maker should be willing to invest in obtaining more information about these critical variables.

## Model Results and Discussion

The decision analysis models for the earlier described interventions for Huri Hills and Shurr landscapes yielded three different categories of outcomes as shown below:

1. Community Net Present Value (NPV) – considering risk factors, this is the net present value of the direct monetary benefits that accrue to the community less the costs incurred by the community to sustain the structures.
2. Environmental NPV – considering risk factors, this is the net present value of the environmental impacts attributed to the structures.
3. Socioeconomic NPV – considering risk factors, this is the net present value of all direct and indirect benefits accruing to the community less the costs.

The simulation results for each outcome were also broken down into four sub-categories represented in a 4-panel diagram:

1. Outcome Distribution: this histogram presents the distribution of projected intervention returns for five years in each outcome category. The pink bars indicate the distribution of negative returns while the green bars indicate positive returns (See Figure 5).
2. Information Value: this bar graph indicates the EVPI for the simulated outcome.
3. Cash Flow: this displays the distribution of annual cash flows of the intervention's projected returns in that particular outcome category.
4. Variable Importance: this bar graph presents the most uncertain variables which the model outputs are sensitive to. The variables with pink bars have a negative relationship with the outcome variable, while those with green bars have a positive relationship with the outcome variable. The variables with purple bars have a VIP falling below the 0.8 threshold.

### Huri Hills Intervention I – Desilt and repair a check dam (*haro*) at Add-Chuluqe

All estimates for the Huri Hills models are provided in Annex A and the model itself in Annex B.

#### a) Projected Community NPV

Community NPV was calculated by determining the economic value of the *haro* (which earns revenue from the sale of water) and adjusting this value for risks associated with the rehabilitation of the *haro*, such as the risk of siltation, mechanical damage and drought. The costs incurred by the community to rehabilitate it are then subtracted from the resulting benefit values.

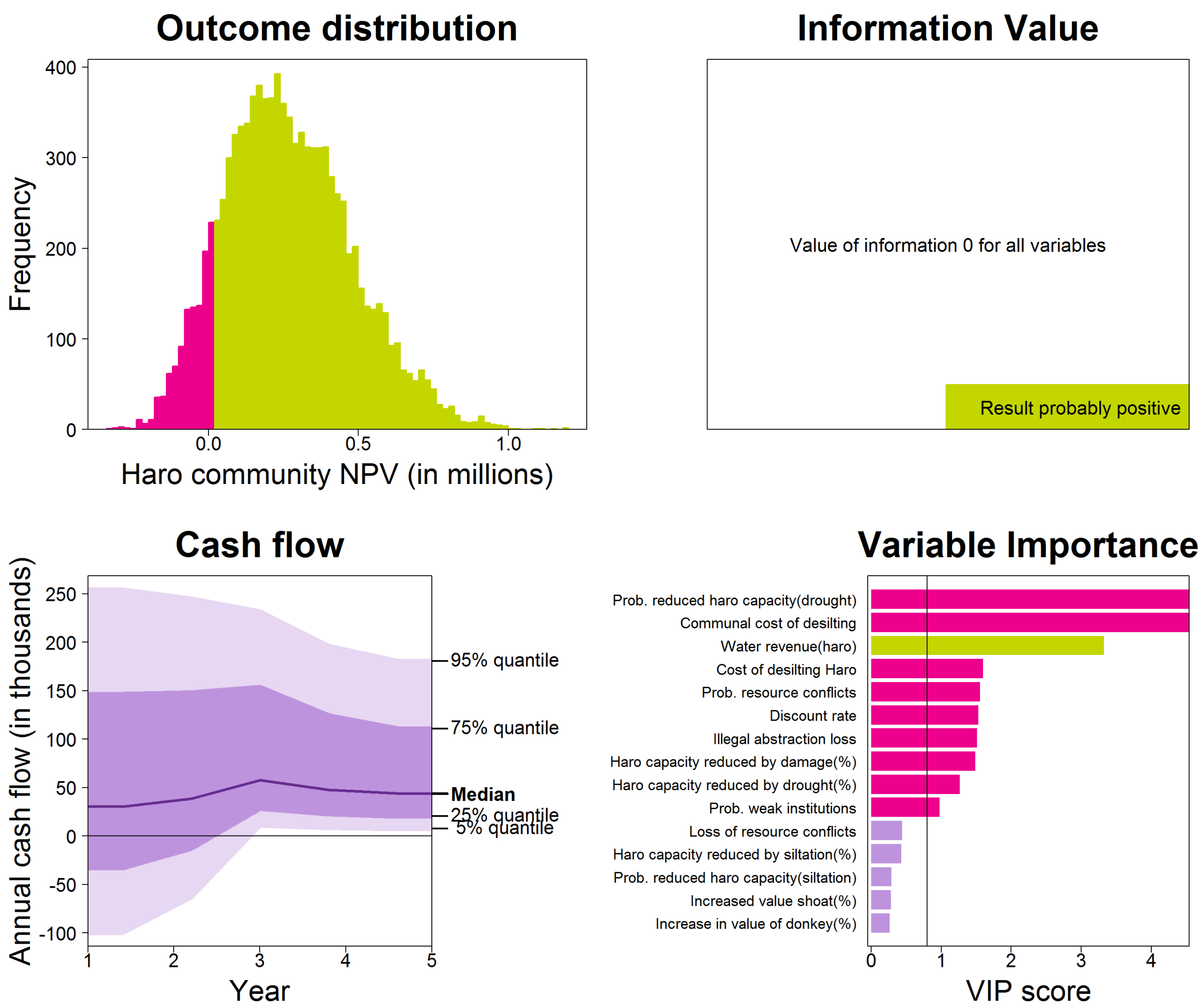


*Figure 5: Simulation results: Community NPV results for desilting the* haro *at Add-Chuluqe*

The projected monetary returns from the proposed rehabilitation of the *Haro* Add-Chuluqe (dam) have a 9% likelihood of being negative (Figure 5). The distribution's 90% confidence interval ranged from KES 4,800 to a positive return of about KES 555,067 for the 5-year simulation period. The distribution's median value stood at KES 270,000. The cash flow chart indicates that the likelihood of losses is highest in the first year due to the cost of investment that the community contributes. For subsequent years (year 2 to 5), the community's likelihood of making positive returns increases steadily up to year 3, when the distribution range is all positive. The variables affecting the expected returns from the *haro* are the risk variables of damage, drought and weak institutions (whose effects manifest themselves as illegal abstractions), the community's contributions to desilting activities and the water revenue earned from the *haro*.

### b) Projected Environmental NPV

Of particular concern to the implementers were the environmental impacts of the interventions and the risk to resilience of livelihoods within the community.

Environmental impact was quantified as the costs incurred as a result of the increased human activities following the interventions in the area. Examples of such impacts are land degradation and the loss of wildlife due to hunting.

(i) Land degradation cost was quantified as:

$$Cost\ of\ land\ degradation = value\ of\ land\ * proportion\ of\ land\ degraded$$

*where the 'value of land' = carrying capacity (TLU/km$^2$) * value of livestock * Huri area (km$^2$)*

Note: The 'value of livestock' used was the market value of cattle.

(ii) The cost of wildlife losses as an environmental impact was quantified as:

$$Cost\ of\ wildlife\ losses = value\ wildlife * proportion\ of\ wildlife\ lost$$

Therefore:

$$Environmental\ costs = Cost\ of\ land\ degradation + Cost\ of\ wildlife\ losses$$

$$Environmental\ impact = -\ environmental\ costs$$

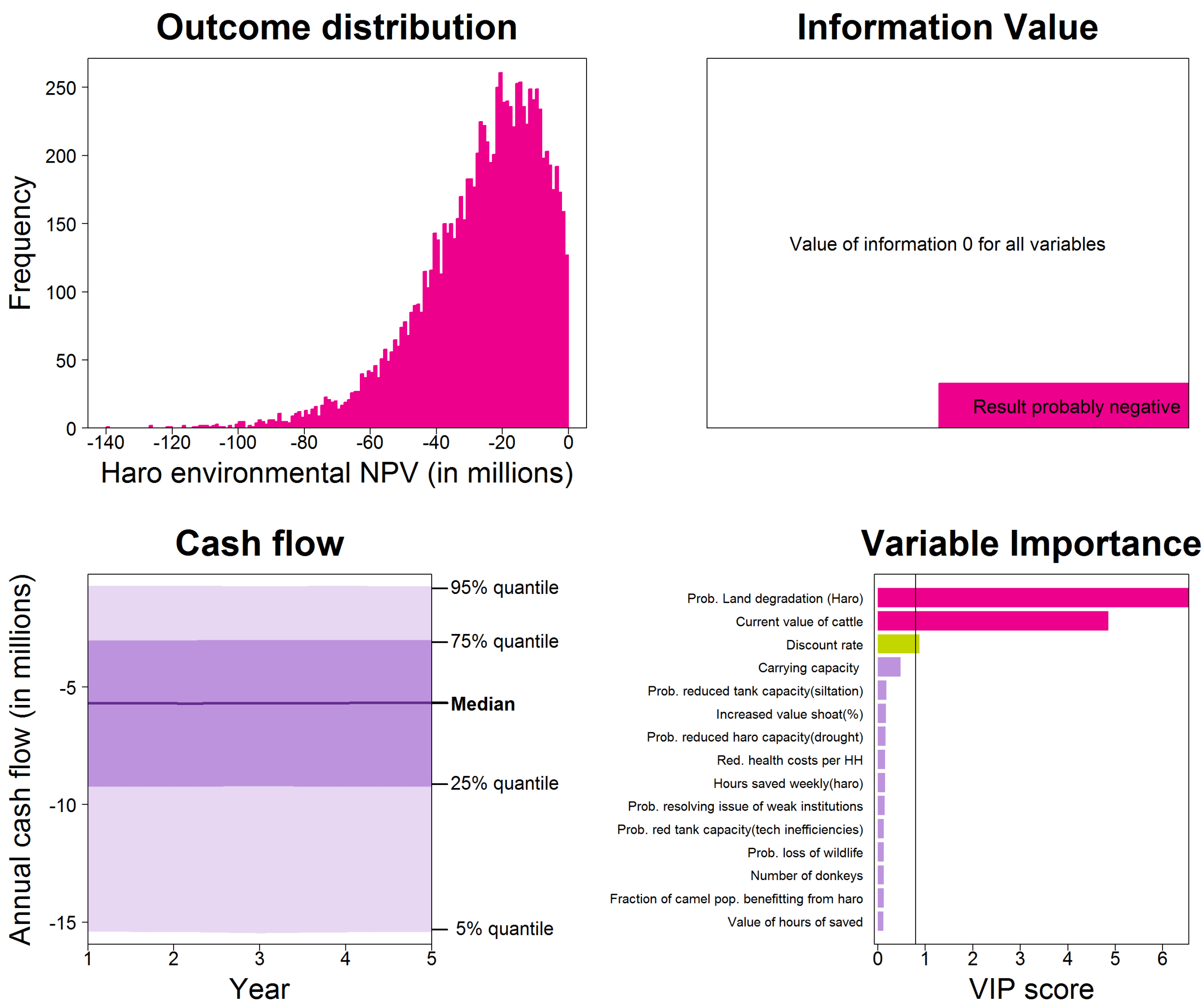


*Figure 6: Simulation results: Environmental NPV results for desilting the* haro *at Add-Chuluqe*

The environmental impact of the *haro* indicated a very high statistical chance of loss at 99.9% (Figure 6). The 90% confidence interval range of simulated environmental losses for the Huri Hills community ran from a loss of KES 52 million to a loss of about KES 6 million. The cash flow chart shows a uniform cash flow in all the five years while the most important variables for further measurement are the market value of cattle and the probability of land degradation, both of which are negatively related to the environmental impact outcome. The price of cattle in the market, determined by traders, is based on the size of the cow. These individually-based metrics presented themselves in the model as wide ranges for the value of cattle, hence the variable's appearance as being strongly related to the value of the environmental impact outcome. The implication for implementers is that they may need to implement strategies which would minimize the impact of degradation on healthy stock during the program design stage.

### c) Projected Socioeconomic NPV

The socioeconomic NPV is a composite of the direct monetary benefit of water revenue and the less direct non-monetary value of the time savings less the environmental and health costs of the *haro*. Time savings are expected for the community members who will no longer have to regularly travel long distances in search of water for their animals. The health costs arise from the probability of the populace contracting water-borne diseases from water in the check dam.

When all the monetary and non-monetary factors are considered, the probability of cumulative positive returns for the community over a 5-year period stands at 58% (Figure 7).

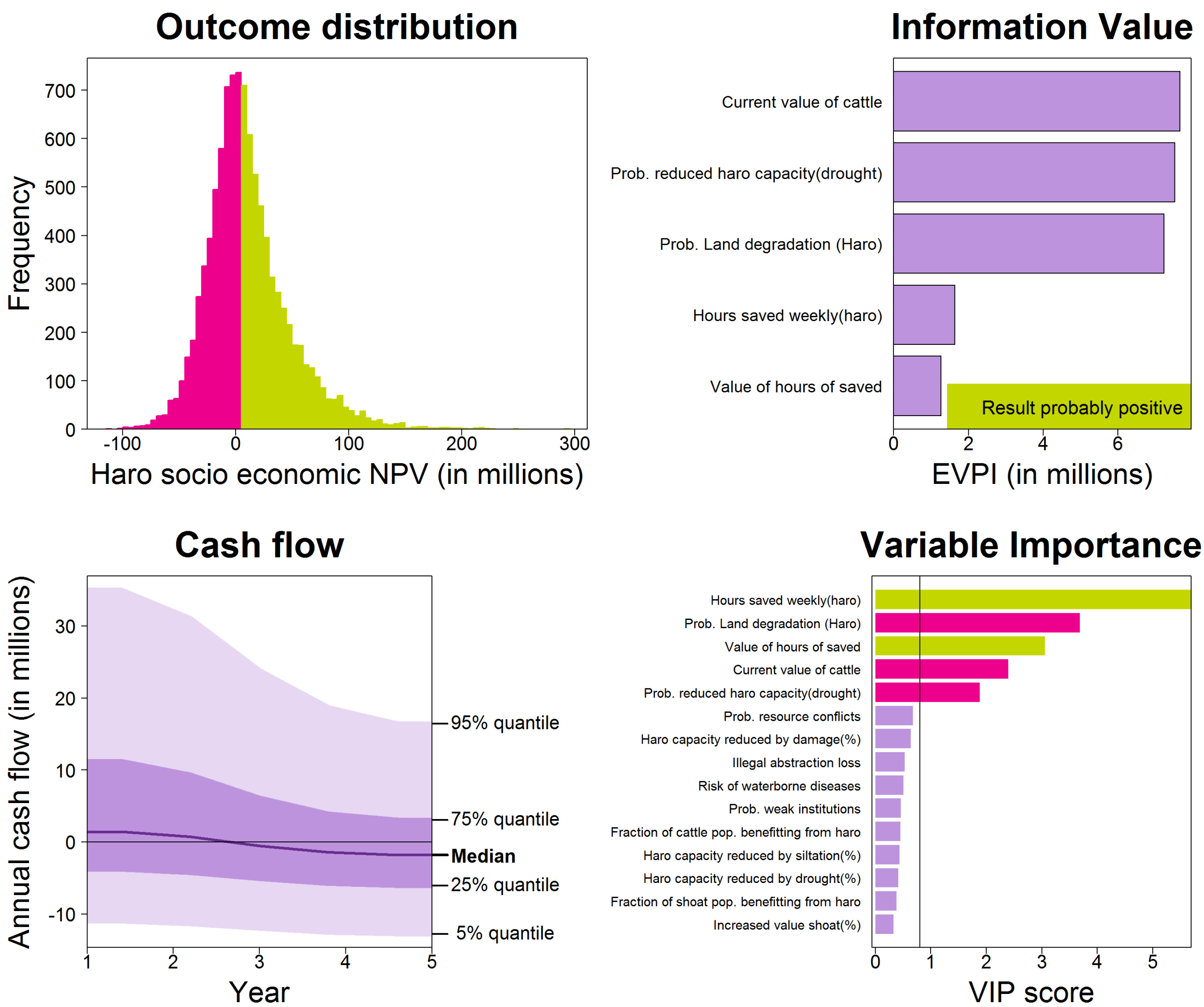


*Figure 7: Simulation results: Socioeconomic NPV of desilting the* haro *at Add-Chuluqe*

The final value after analysis was a distribution whose 90% confidence interval ranged from a loss of KES 29 million to a gain of nearly KES 59 million. This large range in simulated results could be attributed to uncertainty in a few important variables, i.e., the market value of cattle, the value and quantity of time saved, effect of technical inefficiencies on the *haro's* capacity and the probability of land degradation due to increased livestock and human population around the *haro*.

The EVPI for the outcome is also highest for the value of cattle, the probability that drought reduces the capacity of the *haro*, the probability of degradation due to the *haro* and the time saving implications of the *haro*. These are the variables whose measurement is most likely to enhance the precision of outcome projections, making them priorities for decision-supporting measurements. The cash flow values are highest in the first year and then decline in subsequent years as the risk factors remain unmitigated and grow each year.

## Huri Hills Intervention II – Construct a community underground water tank

### a) Projected Community NPV

The range of returns that the community could expect to receive from the construction of an underground tank (cumulatively over the simulation period of five years), taking into consideration the benefits accruing to them, the costs they would incur each year for the water tank, and the risks associated with the intervention has a 42% chance of being negative (Figure 8).

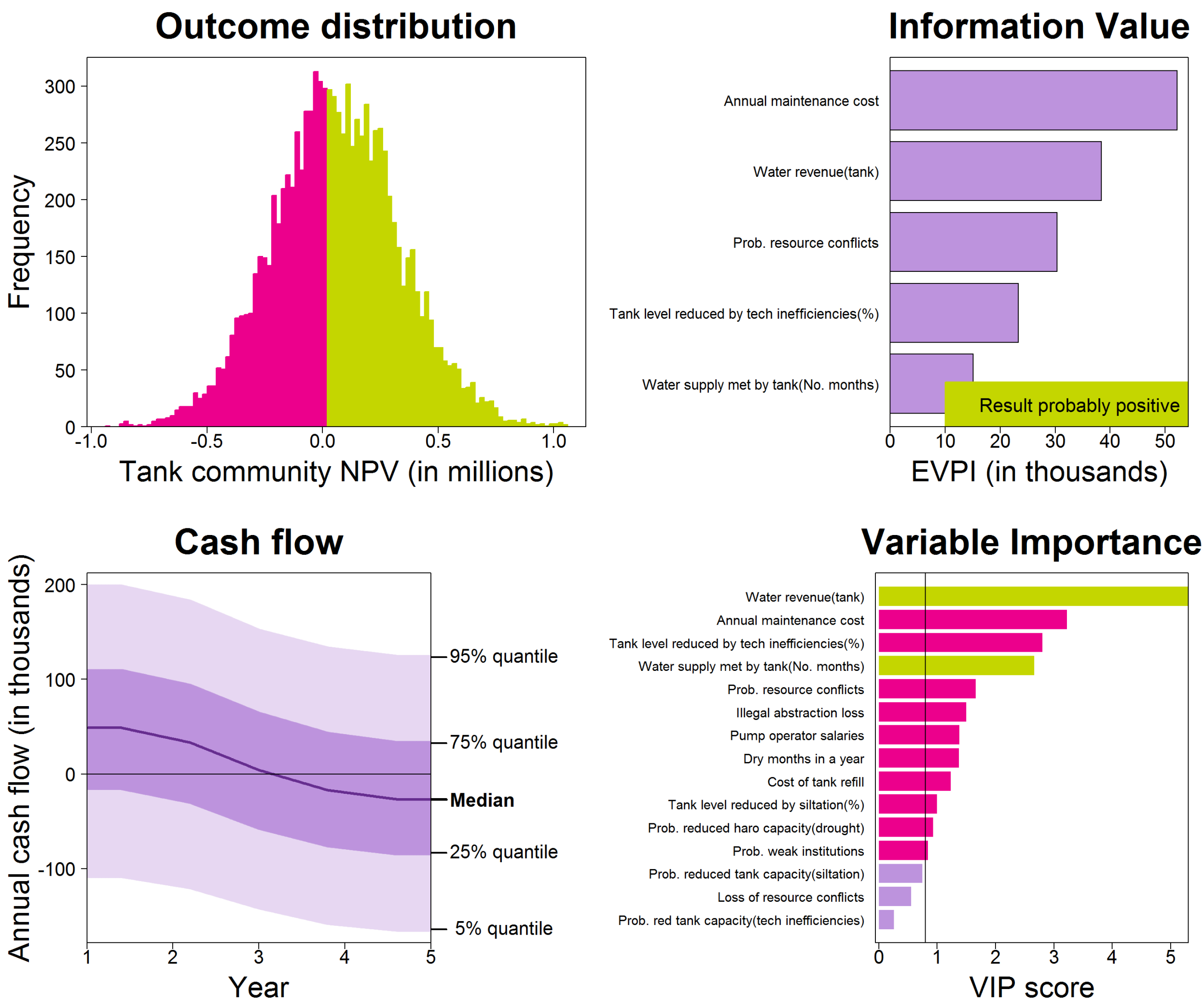


*Figure 8: Simulation results: Community NPV of constructing the underground water tank*

The 90% confidence interval distribution ranged from a loss of KES -1.1 million to a gain of KES 1.3 million with a median value of KES 61,000. The variables affecting clarity of the model's results were the cost of refilling the tank, revenue from the sale of water, the period in a year during which the water demand was met by the tank, the number of dry months in a year, the annual tank maintenance cost and the effect of technical inefficiencies on the capacity of the tank. While the water revenue variable had the greatest uncertainty, the variable with the highest value of information was the annual cost of tank maintenance. Water revenue from the tank, the probability of resource conflicts and reduced water level in the tank due to technical inefficiencies also have an information value for the intervention

## b) Projected Environmental NPV

The tank's environmental impact was computed using the same approach as in the *haro's* environmental analysis. The community cited water scarcity as the main economically-limiting factor, which also hindered mass settlement in the area. If enough underground water tanks were constructed, the problem of water scarcity would be alleviated. The community members expect that the result would be both human and livestock immigration and the expansion of permanent settlements, which would have grave environmental consequences in the medium- to long-term. The analysis therefore looked at the degrading effect of mass immigration into Huri Hills.

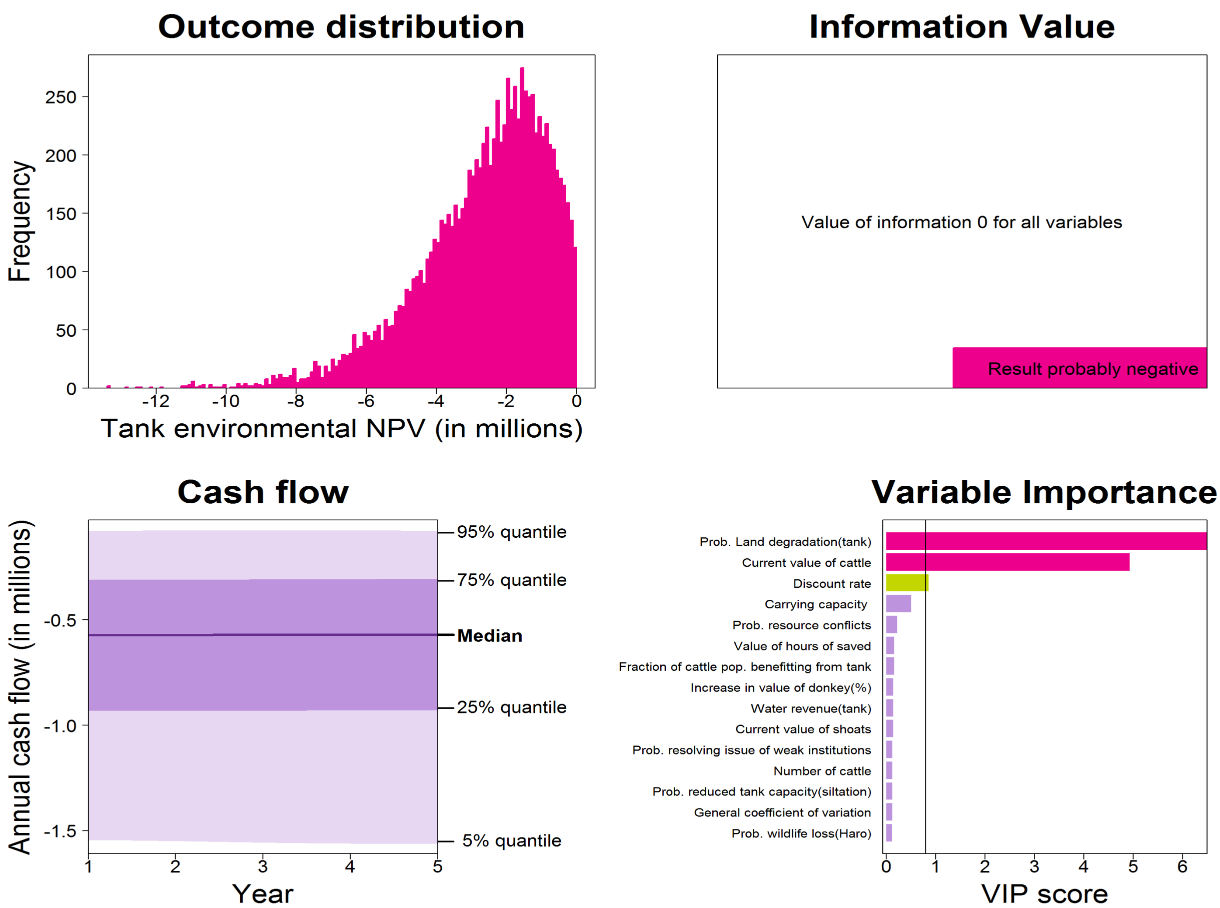


*Figure 9: Simulation results: Environmental NPV of constructing the underground water tank*

The 90% confidence interval of the environmental cost of putting up the tank stands at a loss of KES 5.2 million to a loss of about KES 620,000 (Figure 9). The variables which the analysis flagged as causing uncertainty were the likelihood of land degradation and the market price of cattle. Both variables were negatively correlated with the outcome variable. The EVPI analysis, on the other hand, revealed no variables with information value, since the environmental impact is virtually certain to be negative. The cash flow values are constant in all years, as was the case for the environmental cost of the *haro.*

### c) Projected Socioeconomic NPV

Looking at the socioeconomic returns of the tank, the chance of loss is very low at 0.41%. Expected returns to the community are high (Figure 10). The socioeconomic outcome took into account and quantified both the direct and indirect benefits of the tank. These included every household's time savings as a result of having nearby water sources and the health implications in the community. In this case, health costs for each household might decrease due to improved sanitation expected to result from increasing water availability. On the other hand, if the quality of water stored in the tank is poor and the water remains untreated, the health costs of each household consuming the water could increase.

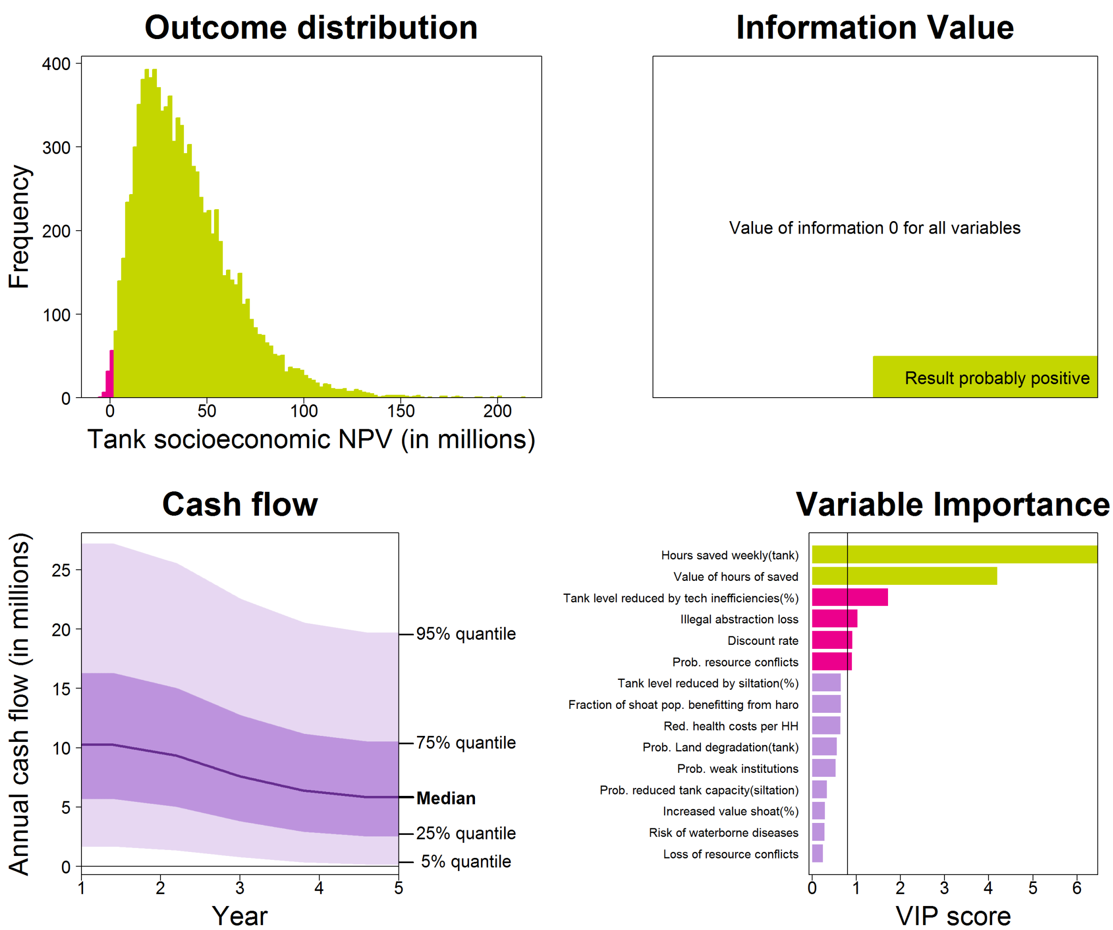


*Figure 10: Simulation results: Socioeconomic NPV of constructing the underground water tank*

The 90% confidence interval distribution ranges from a gain of KES 12 million to one of nearly KES 74 million. The cash flow returns are highest in the first year but decline steadily in subsequent years. The uncertain variables which are positively related to the socioeconomic return variable are the time saved every week from having to travel long distances in search of water and the economic value of this time. The negatively related variables are the impact of technical inefficiencies on the tank's water levels, the losses due to illegal abstraction and the probability of resource-based conflicts. None of the variables seem to have information value to justify further measurements.

### Shurr Plains Intervention – Constructing an above-ground concrete water tank with an underground steel water piping system

All estimates for the Shurr model are provided in Annex C and the model itself in Annex D.

#### 1. Projected Community NPV

The community at Shurr requested a tank at Kobadi to decongest the Shurr borehole. The implications this has for the community present themselves as monetary gains from water revenue – water sold to the community at Kobadi. The community itself, however, has to spend money on the maintenance of the underground steel pipeline. Once the costs are subtracted from the benefits and risk factors used to adjust the value of the benefits, the community's range of returns runs from a loss of KES 2.5 million to a gain of KES 4.1 million with a median value of KES 810,000. The likelihood of a negative outcome stands at 43% (Figure 11).

The important variables for the Shurr community are the number of small livestock (shoats) that will get their water from Kobadi. The fees paid for these animals to access water and the length of the dry period are positively related to the outcome variable (Figure 11). The risk and effect of conflicts over water resources, as well as the amount of money spent on diesel fuel for piping water to Kobadi, have a negative effect on the value of intervention outcomes. These variables also appeared in the EVPI analysis as those whose measurement is critical for decision makers.

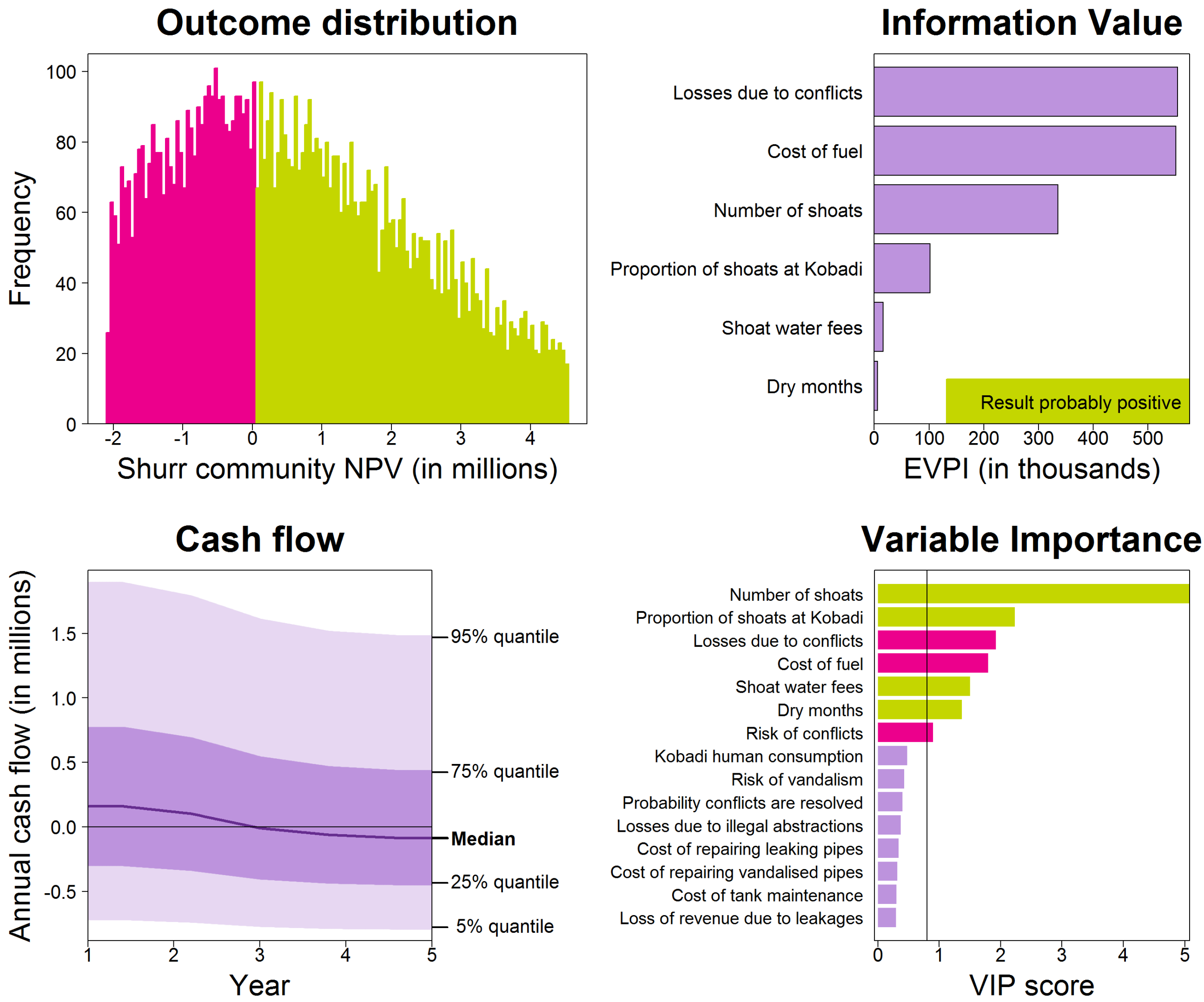


*Figure 11: Simulation results: Community NPV of constructing an above-ground concrete water tank with a steel water piping system*

## 2. Projected Environmental NPV

The environmental impact of the intervention is expected to differ between Shurr centre and Kobadi, which is 10 km away. Due to the resulting decongestion of Shurr centre, the area gains a positive environmental effect, as the intensity of degradation is reduced. However, Kobadi, a pasture area, will experience increased degradation because of increased human and livestock traffic within the area. The analysis used the Total Economic Value (TEV) framework for land ecosystems to quantify degradation (Mulinge et al., 2016). If this project is implemented, the simulation results indicate that the likelihood of the Shurr community incurring losses is 97% (Figure 12).

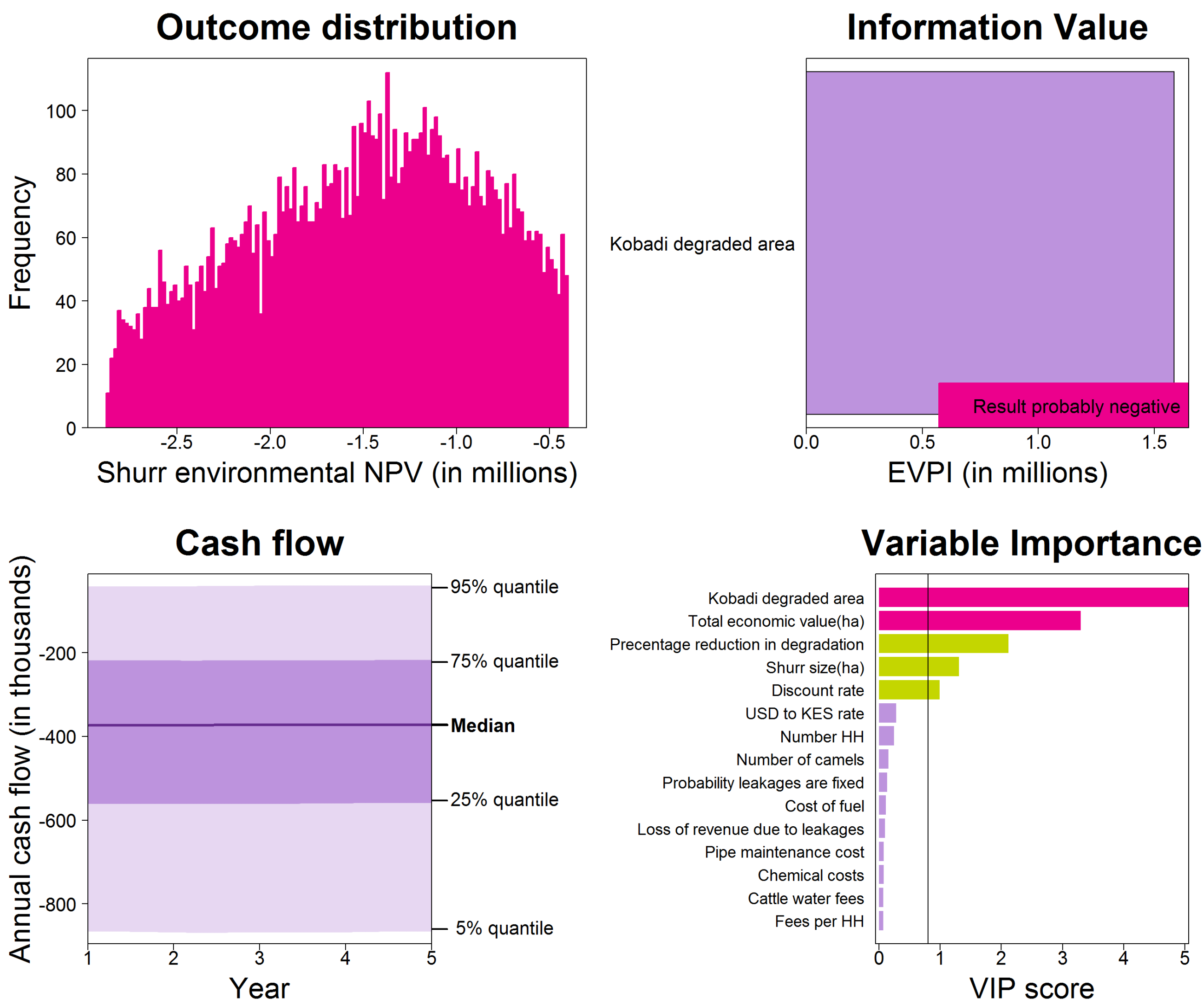


*Figure 12: Simulation results Environmental NPV of constructing an above-ground concrete water tank with a steel water piping system*

The distribution's 90% confidence interval went from a loss of KES 2.9 million to a loss of KES 440,000. The median value of environmental cost was KES 1.7 million.

The size of the area in Kobadi expected to be degraded and the total economic value per hectare are negatively correlated to the outcome variable. The level of reduced degradation in Shurr and the affected section of Shurr are positively related to the environmental NPV. From the EVPI analysis, only one variable appears to have considerable information value, i.e., the area in Kobadi expected to experience degradation.

## 3. Projected Socioeconomic NPV

The socioeconomic NPV for the Shurr community was arrived at by calculating its worth from the risk-adjusted benefits and the costs. The benefits considered here are the direct and indirect gains from water revenue earned at Kobadi and the reduced waiting times at the Shurr borehole. The costs covered the running costs that the community is expected to incur (given that the initial costs will be taken up by the implementing agency) as well as the cost of environmental degradation. With all these factors, the probability of the community making a loss from the investment was quite high at 68% (Figure 13).

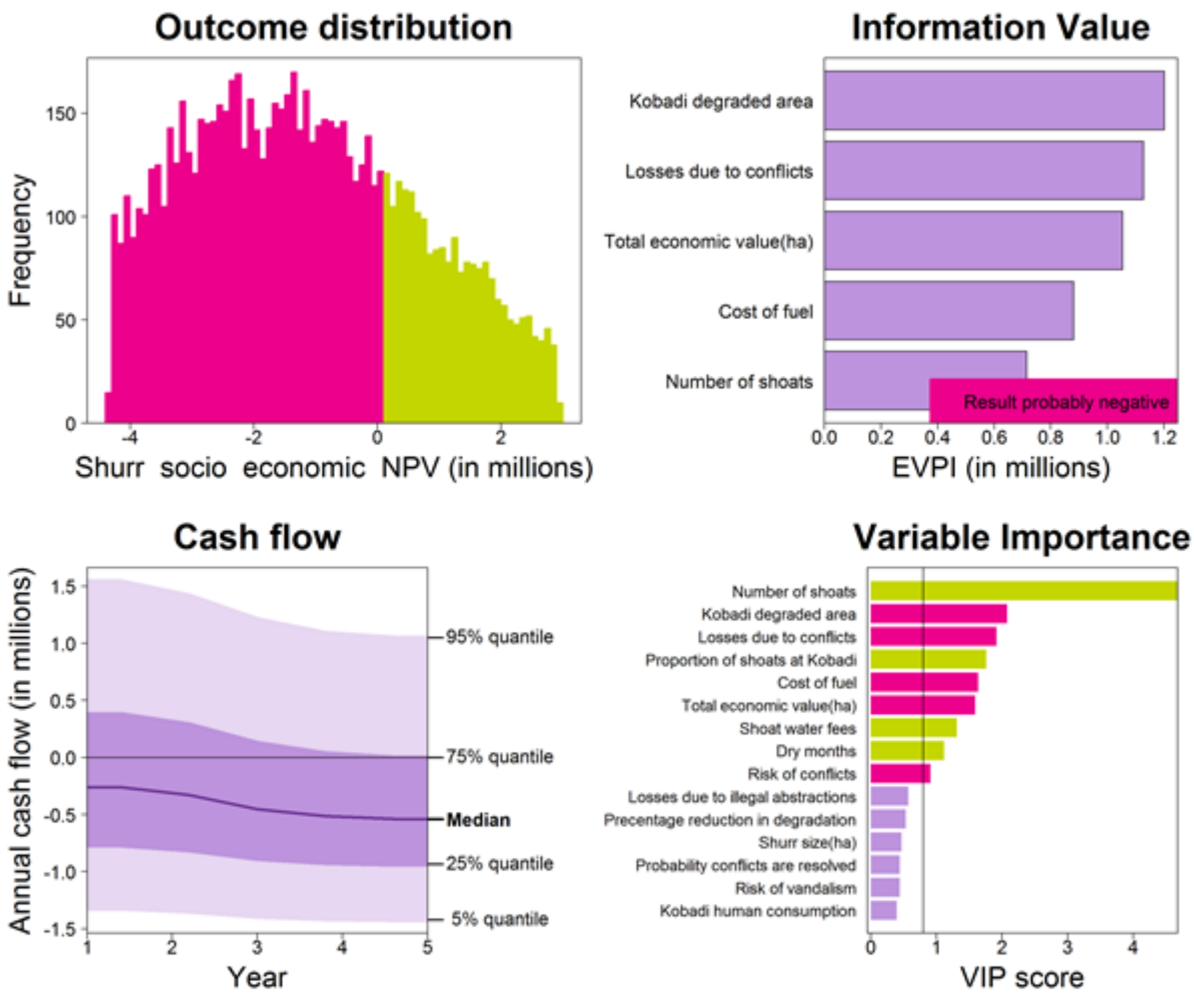


*Figure 13: Simulation results: Socioeconomic NPV of constructing an above-ground concrete water tank with a steel water piping system*

A 90% confidence interval for the NPV ranged from a loss of 4.3 million to a gain of 2.7 million. The important variables were revenue variables (number of shoats, water fees paid for watering shoats, proportion of shoats watered at Kobadi), the risk of conflicts over resources (risk of occurrence, losses should the risk occur), land degradation (TEV per ha, size of Kobadi affected by degradation), the cost of fuel and the length of the dry period during which the tank would be used.

These important variables also appeared after the EVPI analysis, which indicated information values of several hundred thousand Kenya shillings.

## Limitations of the Study

Ideally, the decision analysis process is participatory; where analysts continually elicit information as well as seek feedback from key informants throughout the model building and analysis stages. However, for this pilot analysis, this was not possible due to the inaccessibility of key informants and project staff based in the study area. Both Huri Hills and Shurr are remote areas without reliable cellular networks. Where electronic mail could be used, communication was often delayed, and this in turn delayed the analysis and deliverable timelines.

Language barriers between the analysis team and the local community were also a problem during the community stakeholders' discussion forums. Though most of the locals were able to communicate in Swahili, they preferred their local language, which the analysts couldn't understand. Intermittent and inconsistent interpretation limited the authenticity of information that was communicated.

Where the analysts could not obtain information directly, they supplemented it with data from secondary sources (literature reviews) which are usually not from exactly the same location and often not up-to-date. For Shurr in particular, there was hardly any site-specific information. As a result of this limitation, the analysts had to roll back the Shurr analysis to analyse only one intervention.

## Conclusion and Recommendations

The decision analysis for this project aimed at aiding decision makers in both Huri and Shurr in prioritizing specific interventions, which would improve the quality of livelihoods and resilience of the communities. The cost, benefit and risk assessment returned the net present value (NPV) of the interventions in different categories, monetary and non-monetary returns to the community, environmental impact and socio economic impact of the interventions.

### Huri Hills decision

The decision to be made is whether to desilt the check-dam at *Add-Chuluqe* or construct an underground concrete tank. Results indicate that the underground concrete tank has a smaller negative effect on the environment than the check dam. In terms of monetary returns to the community, the tank will earn more revenue for the community during the 5-year period under consideration. In addition, when the totality of effects of both structures is considered, the underground concrete tank appears to yield higher returns than the dam. There are, however, variables that the analysis recommends for further measurement to clarify on the outcomes of the interventions that would help decision makers settle on a final investment option.

The sustainability of each of these two structures is a key factor for decision makers as this could mean consistently high returns. It is important that further information be sought to gain more information on the financial sustainability of the structures, i.e., the expected benefits weighed against the costs that the communities would have to put into it. To minimize the possibility of losses from the concrete underground tank, it would be economically useful to gather more information on what amount of revenue the community could earn from the sale of water and the maintenance costs they would have to expend their earnings on. A careful consideration of the technical design of the tank during project design is also of high value since this factor has the potential to cause a reduction in the tank's capacity and lifespan.

The *haro's* environmental impact emerged from the analysis as a priority for measurement. While the level of returns from the *haro* are likely to be higher than those from the concrete underground tank, so are its associated environmental costs. This leaves it up to the implementer to decide which considerations are more important to achieving their goals and the community's needs. The second consideration for prioritization is the potential of the *haro* to save time for the community members. By desilting the *haro* so as to have one more option for accessing water, the need to travel long distances is eliminated. However, to improve the decision outcome, the implementers need to gain clarity on how much time is actually saved and the economic or social implications of such time savings for households.

If the decision to implement either of the selected interventions is made, there are some important variables that should be prioritized for close monitoring, as they determine whether the expected returns earned fall on the negative or positive end of the returns distribution. These are the variables that have been highlighted in the Variable Importance plot in the results figures. The monetary returns from the underground tank will be positive if the revenue earned from selling water is maximized and if its water supply is made to last as long as possible. Variables such as the annual maintenance costs and the effect of risk factors such as siltation and conflicts with neighbours over the shared resources contribute to negative returns. Another important factor, which should be addressed before implementation, is the risk of weak institutions and the associated problems of enforcing rules, particularly those related to the illegal abstraction of water. Where these institutions are weak and thus unable to enforce rules, the community is at risk of making significant losses.

The important variables for the *haro* that were highlighted by the PLS analysis are similar to those of the underground tank. Implementers should seek to maximize the revenue the community earns from sale of water. They should, however, monitor and minimize the costs the community incurs, as well as reduction in water levels or functional capacity of the *haro* through resource conflicts, physical damage, drought and illegal abstraction.

### Shurr plains decision

The analysis for the above-ground tank with steel piping intervention for Shurr indicated that, while it may have a modest chance of positive contributions to the community, high environmental costs may nullify these gains. The analysis recommends that while considering the high cost of pumping, the implementers should focus on what the community could do to sustain the pipeline operations. One possible remedy would be to utilize solar energy to pump the water as an alternative to diesel fuel. The investment in a tank appears to solve one problem but brings up another with a significant negative impact – environmental degradation. To fully understand the direct impact of degradation on the community's basic livelihood, the implementers should measure these effects further.

The goal of laying down the pipeline for the water tank is to divert the high livestock traffic from Shurr centre. From the analysis, before doing so, it would be useful for implementers to consider how much of this traffic will be diverted in terms of livestock numbers and how much revenue the community could earn from water sales at Kobadi. It appears that these variables should also be monitored closely to increase the possibility of positive returns. Should the implementers choose to go ahead with the investment without any further measurements, they should focus on the variables discussed above during the project design stage, in addition to the risk of losses from conflicts over resources. If possible, these variables should be carefully monitored all through the lifespan of the investment.

Our analyses provided first approximations of the overall net benefits of the three interventions. However, they also indicated trade-offs, especially between environmental and socioeconomic effects, that will require careful considerations by local decision makers. These reflections could be supported by targeted measurements to narrow the identified critical knowledge gaps. Such additional measurements are recommended as the next step to reducing uncertainty, not only on the highlighted key input variables but also on the projected outcomes. This will improve decision makers' ability to decide on whether tank construction is desirable from an overall impacts point of view in Shurr, and which, if any, of the investment alternatives at Huri Hills is likely to produce best results.

As illustrated in this case study, the decision analysis approach is of value as a tool for monitoring and learning, allowing the community and project implementers a chance to study the actual performance of the investments against the projected performance during their implementation.

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# Annexes

## Annex A: Huri Hills estimate sheet

| Variable name | Lower bound (5% quantile) | Upper bound (95% quantile) | Variable name in model |
|---|---|---|---|
| ***General variables: variable description*** | | | |
| Number of years for simulation | 5 | 5 | n_years |
| General coefficient of variation | 5 | 10 | general_CV |
| Number of households in the area | 1200 | 1200 | no_HH |
| Discount rate | 5 | 20 | discount_rate |
| ***Cost of constructing tanks: variable description*** | | | |
| Total cost of manual labour | 120,000 | 150,000 | labour_costs |
| Total cost of equipment | 500,000 | 1,000,000 | cost_of_equipment |
| Total cost of skilled labour | 50,000 | 100,000 | cost_of_skilled_labour |
| Cost of tools and materials (including transport) | 350,000 | 500,000 | cost_tools_materials |
| Cost of paying salaries for pump operators | 20,000 | 48,000 | pump_operator_salary |
| Probability that siltation reduces the tank's capacity | 0.5 | 0.9 | prob_reduced_capacity_due_siltation |
| Annual reduction in tank level as a result of siltation (%) | 0.01 | 0.35 | percentage_level_reduced_by_siltation |
| Probability that technical inefficiencies affect the tank's capacity | 0.3 | 0.5 | prob_reduced_capacity_due_technical_inefficiencies |
| Annual reduction in tank level as a result of technical inefficiencies | 0.01 | 0.4 | percentage_level_reduced_by_technical_inefficiencies |
| Number of dry months in a year (seasonal+off-season) | 6 | 9 | no_dry_months |
| Cost of tank refills (water boozer) | 20,000 | 30,000 | cost_tank_refills |
| Annual cost of maintaining the tank (cleaning etc.) | 20,000 | 90,000 | annual_maintenance_cost |
| No. of months in a year where water demand is met by the tanks | 4 | 6 | no_months_water_is_supplied_by_tank |
| ***Tank benefits: variable description*** | | | |
| Annual revenue earned from sale of water | 200,000 | 400,000 | tank_revenue |
| Reduction in annual health costs due to improved WASH (per household) | 500 | 3500 | reduced_health_costs_HH |
| Risk of poor water quality | 0.1 | 0.2 | risk_poor_water_quality |
| Increased annual health costs due to poor water quality (per household) | 1000 | 2000 | increased_health_costs_HH |
| Current market value of shoat | 3500 | 5000 | current_value_shoat |
| Percentage increase in market value of shoat due to improved livestock quality | 25 | 50 | percentage_increase_value_shoat |
| Fraction of total shoat population that benefit from the tank | 1 | 7 | percentage_benefit_tank_shoats |
| Number of shoats (total owned by the community) | 20,000 | 30,000 | number_shoat |
| Current market value of cattle | 7500 | 35,000 | current_value_cattle |
| Percentage increase in market value of cattle due to improved quality | 20 | 50 | percentage_increase_value_cattle |
| Number of cattle (total owned) | 10,000 | 15,000 | number_cattle |

| Variable name | Lower bound (5% quantile) | Upper bound (95% quantile) | Variable name in model |
|---|---|---|---|
| Fraction of total cattle population that benefit from the tank | 0.5 | 1 | percentage_benefit_tank_cattle |
| Current market value of camel | 40,000 | 70,000 | current_value_camel |
| Percentage increase in market value of camel due to improved quality | 1 | 10 | percentage_increase_value_camel |
| Number of camel (total owned) | 1000 | 2000 | number_camel |
| Fraction of total camel population that benefit from the tank | 0.1 | 0.1 | percentage_benefit_tank_camels |
| Current market value of donkey | 5000 | 10000 | current_value_donkey |
| Percentage increase in market value of donkeys | 1 | 5 | percentage_increase_value_donkey |
| Number of donkeys (total owned) | 100 | 300 | number_donkey |
| Fraction of total donkey population that benefit from the tank | 5 | 10 | percentage_benefit_tank_donkey |
| Time per week saved by reduced distance to tank | 1 | 10 | tank_hours_saved_per_week |
| Value of time saved | 20 | 70 | value_hours_saved |
| ***Risk variables:variable description*** | | | |
| Additional degradation as a result of increased human and livestock numbers | 0.1 | 0.5 | degrading_loss_increased_human_livestock_population |
| Annual loss of tree cover due to cutting down for charcoal | 0.01 | 0.1 | loss_of_cover_due_tree_cutting |
| Risk of weak institutions | 0.5 | 0.9 | p_weak_institutions |
| Possibility of the issue of weak institutions being resolved | 0.4 | 0.7 | p_weak_institutions_resolution |
| Loss through illegal abstractions because of weak institutions | 20 | 40 | loss_illegal_abstraction |
| Risk of resource conflicts | 0.01 | 0.25 | p_resource_conflicts |
| Possibility of the issue of conflicts being resolved | 0.3 | 0.8 | p_resource_conflicts_resolution |
| Losses due to conflicts | 50 | 80 | loss_resource_conflicts |
| Annual probability of loss of wildlife due to increased land pressure | 0.001 | 0.05 | p_loss_wildlife |
| Annual carrying capacity of Huri Hills (TLU) | 5500 | 6400 | carrying_capacity |
| Annual proportion of land degraded due to tank causing increased human and livestock population | 0.001 | 0.01 | tank_degrading_loss_increased_human_livestock_population |
| Probability of lack of management training | 0.001 | 0.01 | p_lack_training |
| Losses due to lack of training | 0.5 | 0.8 | percentage_loss_due_lack_training |
| ***Haro costs: variable description*** | | | |
| Annual revenue earned from sale of water of *haro* | 250,000 | 400,000 | haro_revenue |
| cost of desilting | 200,0000 | 3,500,000 | cost_desilting |
| Proportion of cost of desilting covered by the community | 0.01 | 0.1 | community_cost_contribution |
| ***Haro risks:Variable description*** | | | |
| Proportion of land degraded due to *haro* causing increased human and livestock population (0…1) | 0.01 | 0.1 | haro_degrading_loss_increased_human_livestock_population |
| Economic value of existing wildlife in Huri | 1000 | 5000 | value_wildlife |
| Loss of wildlife due to increased land pressure (0…1) | 0.01 | 0.1 | haro_loss_wildlife |

| *Variable name* | *Lower bound (5% quantile)* | *Upper bound (95% quantile)* | *Variable name in model* |
|---|---|---|---|
| Probability of increasing incidences of waterborne diseases | 0.1 | 0.5 | p_risk_waterborne_diseases |
| Increased health costs due to increased incidence of waterborne diseases | 1500 | 3500 | haro_increased_health_costs |
| Probability of damage to the dam reducing capacity of the dam (0…1) | 0.1 | 0.3 | prob_reduced_capacity_due_damage |
| Annual reduction in water level as a result of damage | 0.1 | 0.25 | percentage_level_reduced_by_damage |
| Probability of siltation which will reduce capacity of the dam (0…1) | 0.5 | 0.8 | prob_reduced_capacity_haro_due_siltation |
| Annual reduction in water level as a result of siltation | 0.05 | 0.2 | percentage_level_haro_reduced_by_siltation |
| Probability of drought to the dam reducing capacity of the dam (0…1) | 0.25 | 0.7 | prob_reduced_capacity_due_drought |
| Annual reduction in water level as a result of drought | 0.7 | 0.9 | percentage_level_reduced_by_drought |
| ***Haro benefits:variable description*** | | | |
| Fraction of total shoat population that benefit from the dam | 5 | 15 | percentage_benefit_haro_shoats |
| Fraction of total cattle population that benefit from the dam | 0.5 | 5 | percentage_benefit_haro_cattle |
| Fraction of total camel population that benefit from the dam | 5 | 20 | percentage_benefit_haro_camels |
| Fraction of total donkey population that benefit from the dam | 1 | 5 | percentage_benefit_haro_donkey |
| Time per week saved by reduced distance to *haro* | 1 | 20 | haro_hours_saved_per_week |

## Annex B: Huri Hills decision model (R code)

Requires the decisionSupport and DAutilities packages.

```
Huri_underground_tank<-function(x, varnames)
    {
    #cost of investment Tanks
      initial_cost_construction_tank<-rep(0,n_years)
      initial_cost_construction_tank[1]<-
    labour_costs+cost_of_equipment+cost_of_skilled_labour+cost_tools_materials

    #calculate recurring costs-maintenance and cost of refilling the tank
      frequency_refilling_tanks<-
    (round(no_dry_months/vv(no_months_water_is_supplied_by_tank,general_CV,n_years)))
      cost_tank_refills<-frequency_refilling_tanks*vv(cost_tank_refills,general_CV,n_years)
      drought_frequency_refilling_tank<-
    round(12/vv(no_months_water_is_supplied_by_tank,general_CV,n_years))
      drought_cost_refills<-drought_frequency_refilling_tank*vv(cost_tank_refills,general_CV,n_years)
       annual_communal_cost_refilling_tanks<-
       chance_event(prob_reduced_capacity_due_drought,value_if=drought_cost_refills,
       value_if_not=cost_tank_refills,n=n_years,CV_if=general_CV,CV_if_not=0,one_draw=FALSE)
      recurring_tank_cost<-
    vv(annual_maintenance_cost,general_CV,n_years)+vv(pump_operator_salary,general_CV,n_years)+
                  annual_communal_cost_refilling_tanks
      tank_total_cost<-recurring_tank_cost+initial_cost_construction_tank
      value_land<-carrying_capacity*vv(current_value_cattle,general_CV,n_years)
      tank_environmental_cost<-vv(tank_degrading_loss_increased_human_livestock_population,
    general_CV,n_years)*value_land
      implementer_cost_tank<-initial_cost_construction_tank
      tank_communal_cost<-recurring_tank_cost+tank_environmental_cost

    #calculate cost of desilting and expanding haro
      cost_desilting_haro<-rep(0,n_years)
      cost_desilting_haro[1]<-cost_desilting

      haro_environmental_cost<-
    (haro_degrading_loss_increased_human_livestock_population*value_land)+(haro_loss_wildlife*value_wildl
    ife)
      haro_health_costs<-
    chance_event(p_risk_waterborne_diseases,value_if=haro_increased_health_costs,value_if_not=0,n=n_year
    s,CV_if=general_CV,
                      CV_if_not=0,one_draw=FALSE)
      haro_community_cost_desilting<-(community_cost_contribution*cost_desilting_haro)
      haro_communal_cost<-
    haro_community_cost_desilting+haro_environmental_cost+(haro_health_costs*no_HH)

    #Benefits of tanks
     #1
      good_water_quality<-
    chance_event(risk_poor_water_quality,value_if=0,value_if_not=1,n=n_years,CV_if=general_CV,CV_if_not=0
    ,one_draw=TRUE)
       if (good_water_quality[1]==1) health_impact_HH<-vv(reduced_health_costs_HH,general_CV,n_years)
    else
                        health_impact_HH<--(vv(increased_health_costs_HH,general_CV,n_years))


     #2
```

```
increased_livestock_value<-
function(current_value_livestock,percentage_increase_value_livestock,number_livestock,percentage_benef
it,general_CV,n_years)
    {increased_value<-
  vv(current_value_livestock,general_CV,n_years)*vv(percentage_increase_value_livestock,general_CV,
  n_years)/100
    increase_wealth<-increased_value*number_livestock*(percentage_benefit/100)
    return(increase_wealth)}

increased_value_shoats_tank<-
increased_livestock_value(current_value_shoat,percentage_increase_value_shoat,percentage_benefit_tank_shoat
s,                                number_shoat,general_CV,n_years)
increased_value_cattle_tank<-
increased_livestock_value(current_value_cattle,percentage_increase_value_cattle,number_cattle,
                                percentage_benefit_tank_cattle,general_CV,n_years)
increased_value_camels_tank<-
increased_livestock_value(current_value_camel,percentage_increase_value_camel,number_camel,
   percentage_benefit_tank_camels,general_CV,n_years)
increased_value_donkeys_tank<-
increased_livestock_value(current_value_donkey,percentage_increase_value_donkey,number_donkey,
   percentage_benefit_tank_donkey,general_CV,n_years)
tank_increase_combined_livestock_wealth<-
increased_value_shoats_tank+increased_value_cattle_tank+increased_value_camels_tank+
   increased_value_donkeys_tank
#3
   tank_time_saved<-
(vv(tank_hours_saved_per_week,general_CV,n_years)*vv(value_hours_saved,general_CV,n_years))*52*no_
HH
#4
   tank_revenue<-vv(tank_revenue,general_CV,n_years)

#total benefits from tanks
   health_impact<-health_impact_HH*no_HH
   tank_non_monetary_economic_benefits<-tank_time_saved+tank_increase_combined_livestock_wealth
   tank_economic_impact<-tank_revenue
   tank_total_community_benefits<-
health_impact+tank_economic_impact+tank_non_monetary_economic_benefits

#benefits from haro
  #1
   haro_economic_benefit<-vv(haro_revenue,general_CV,n_years)
  #2
increased_value_shoats_haro<-
increased_livestock_value(current_value_shoat,percentage_increase_value_shoat,percentage_benefit_haro
_shoats,     number_shoat,general_CV,n_years)
increased_value_cattle_haro<-
increased_livestock_value(current_value_cattle,percentage_increase_value_cattle,number_cattle,
   percentage_benefit_haro_cattle,general_CV,n_years)
increased_value_camels_haro<-
increased_livestock_value(current_value_camel,percentage_increase_value_camel,number_camel,
   percentage_benefit_haro_cattle,general_CV,n_years)
increased_value_donkeys_haro<-
increased_livestock_value(current_value_donkey,percentage_increase_value_donkey,number_donkey,
   percentage_benefit_haro_donkey,general_CV,n_years)
haro_increase_combined_livestock_wealth<-
increased_value_shoats_haro+increased_value_cattle_haro+increased_value_camels_haro+
   increased_value_donkeys_haro
   #3
```

```
   haro_time_saved<-
(vv(haro_hours_saved_per_week,general_CV,n_years)*vv(value_hours_saved,general_CV,n_years))*52*no_
HH

  #total benefits haro
   haro_non_monetary_economic_benefits<-haro_time_saved+haro_increase_combined_livestock_wealth
   haro_total_community_benefits<-haro_economic_benefit+haro_non_monetary_economic_benefits

  #Risk analysis
   risk_reduced_capacity_due_technical_inefficiencies<-
rbinom(n_years,1,prob_reduced_capacity_due_technical_inefficiencies)
   benefit_scaler_technical_inefficiencies<-rep(1,n_years)
    for (i in 1:(n_years-1))
     {if(risk_reduced_capacity_due_technical_inefficiencies[i]==0)
       for (j in (i+1):n_years)
              if (risk_reduced_capacity_due_technical_inefficiencies[i]==1)
                       benefit_scaler_technical_inefficiencies[j]<-benefit_scaler_technical_inefficiencies[i] else

benefit_scaler_technical_inefficiencies[j]<-(benefit_scaler_technical_inefficiencies[i])*
                                          (1-percentage_level_reduced_by_technical_inefficiencies)}

    risk_reduced_capacity_due_siltation<-rbinom(n_years,1,prob_reduced_capacity_due_siltation)
    benefit_scaler_siltation<-rep(1,n_years)
      for (i in (1:(n_years-1)))
              {if(risk_reduced_capacity_due_siltation[i]==0)
                       for (j in (i+1):n_years)
                                if(risk_reduced_capacity_due_siltation[i]==1) benefit_scaler_siltation[j]<-
benefit_scaler_siltation[i] else
                                          benefit_scaler_siltation[j]<-(benefit_scaler_siltation[i])*(1-
percentage_level_reduced_by_siltation)}

    risk_no_training<-rbinom(1,1,p_lack_training)
    if (risk_no_training==1)
              bs_tanks<-vv(1-percentage_loss_due_lack_training,general_CV,n_years) else
                       bs_tanks<-rep(1,n_years)
    bs_tanks<-bs_tanks*benefit_scaler_technical_inefficiencies*benefit_scaler_siltation

    bs_tanks<-bs_tanks*temp_situations(p_weak_institutions,
                              p_weak_institutions_resolution,
                              loss_illegal_abstraction,general_CV,n=n_years)

    bs_tanks<-bs_tanks*temp_situations(p_resource_conflicts,
                              p_resource_conflicts_resolution,
                              loss_resource_conflicts,general_CV,n=n_years)

#benefit_scaler haro
   reduced_capacity_due_damage<-rbinom(n_years,1,prob_reduced_capacity_due_damage)
   benefit_scaler_damage<-rep(1,n_years)
    for (i in 1:(n_years-1))
              {if(reduced_capacity_due_damage[i]==0)
                       for (j in (i+1):n_years)
                                if (reduced_capacity_due_damage[i]==1)
                                          benefit_scaler_damage[j]<-benefit_scaler_damage[i] else
                                                    benefit_scaler_damage[j]<-(benefit_scaler_damage[i])*(1-
percentage_level_reduced_by_damage)}

   reduced_capacity_haro_due_siltation<-rbinom(n_years,1,prob_reduced_capacity_haro_due_siltation)
   benefit_scaler_haro_siltation<-rep(1,n_years)
    for (i in (1:(n_years-1)))
```

```
		{if(reduced_capacity_haro_due_siltation[i]==0)
					for (j in (i+1):n_years)
					if(reduced_capacity_haro_due_siltation[i]==1)
benefit_scaler_haro_siltation[j]<-benefit_scaler_haro_siltation[i] else
							benefit_scaler_haro_siltation[j]<-
(benefit_scaler_haro_siltation[i])*(1-percentage_level_haro_reduced_by_siltation)}

   drought_effect<-chance_event(prob_reduced_capacity_due_drought,value_if=(1-
		percentage_level_reduced_by_drought),value_if_not=1,n=n_years,CV_if=general_CV,CV_if_not=
   0,one_draw=FALSE)

   bs_haro<-rep(1,n_years)
   bs_haro<-drought_effect*benefit_scaler_damage*benefit_scaler_haro_siltation

   bs_haro<-
bs_haro*temp_situations(p_weak_institutions,p_weak_institutions_resolution,loss_illegal_abstraction,gene
ral_CV,n=n_years)
   bs_haro<-
bs_haro*temp_situations(p_resource_conflicts,p_resource_conflicts_resolution,loss_resource_conflicts,gen
eral_CV,n=n_years)
```

**#calculate scaled NPV for underground tanks**

```
   tank_economic_returns<-(tank_economic_impact*bs_tanks)-recurring_tank_cost
   tank_environmental_impact<--tank_environmental_cost
   tank_socio_economic_impact<-(tank_total_community_benefits*bs_tanks)-tank_communal_cost
```

**#calculate scaled NPV for haro. Cost of desilting not included because it's not incurred by the community**

```
   haro_economic_returns<-(haro_economic_benefit*bs_haro)-haro_community_cost_desilting
   haro_environmental_impact<--haro_environmental_cost
   haro_socio_economic_impact<-(haro_total_community_benefits*bs_haro)-haro_communal_cost

   return (list(Tank_community_NPV=sum(NPV(tank_economic_returns,discount_rate,TRUE)),
		Cashflow_Tank_community_NPV=tank_economic_returns,
		Cashflow_Tank_environmental_NPV=tank_environmental_impact,
		Tank_environmental_NPV=sum(NPV(tank_environmental_impact,discount_rate,TRUE)),
		Cashflow_Tank_socio_economic_NPV=tank_socio_economic_impact,
		Tank_socio_economic_NPV=sum(NPV(tank_socio_economic_impact,discount_rate,TRUE)),
		Cashflow_Haro_community_NPV=haro_economic_returns,
		Haro_community_NPV=sum(NPV(haro_economic_returns,discount_rate,TRUE)),
		Cashflow_Haro_environmental_NPV=haro_environmental_impact,
		Haro_environmental_NPV=sum(NPV(haro_environmental_impact,discount_rate,TRUE)),
		Cashflow_Haro_socio_economic_NPV=haro_socio_economic_impact,
		Haro_socio_economic_NPV=sum(NPV(haro_socio_economic_impact,discount_rate,TRUE))
		))}
```

## Annex C: Shurr estimate sheet

| *Variable name* | *Lower bound (5% quantile)* | *Upper bound (95% quantile)* | *Variable name in model* |
|---|---|---|---|
| ***General variables: variable description*** | | | |
| Number of years for simulation | 5 | 5 | n_years |
| General coefficient of variation | 5 | 10 | general_CV |
| Number of households in the area | 300 | 300 | no_HH |
| Discount rate | 5 | 20 | discount_rate |
| ***Cost variables: Variable description*** | | | |
| Annual maintenance cost of solar equipment | 10,000 | 50,000 | tank_maintenance_cost |
| Cost of laying pipes per km | 1,500,000 | 1,650,000 | cost_laying_pipes_km |
| Distance between Shurr and Kobadi in km | 10 | 10 | distance_shurr_kobadi |
| Initial cost of tank construction | 1,900,000 | 2,000,000 | initial_tank_cost |
| Annual cost of fuel | 500,000 | 1,000,000 | cost_fuel |
| Annual cost of personnel | 25,000 | 50,000 | personnel_costs |
| Annual cost of chemicals | 10,000 | 11,000 | chemical_costs |
| Annual cost of maintenance | 60,000 | 70,000 | maintenance_costs |
| ***Benefit variables: variable description*** | | | |
| Total economic value of land ecosystems in Northeastern_Kenya ($/ha) | 7000 | 20,000 | TEV_ha |
| New degraded area around Kobadi (ha) | 0.3 | 1 | new_degraded_area |
| Shurr area (ha) | 1.5 | 5 | area_Shurr |
| Conversion rate USD to KES (2007 base) | 60 | 65 | USD_KES |
| Percentage reduction in the effects of degradation in Shurr | 0.01 | 0.1 | percentage_reduction_effects_degradation |
| How much water is expected to be sold daily for human consumption at Kobadi? (please identify units of water e.g. litres or 20 litres | 5 | 40 | human_consumption_qtty |
| Price per 20 L unit of water consumed by human | 20 | 50 | value_water |
| Shoat traffic in shurr | 10000 | 50000 | number_shoats |
| Proportion of shoat whose water demand will be met at Kobadi every 2 days | 0.2 | 0.35 | proportion_shoat |
| Water fees per shoat | 2 | 3 | shoats_water_fees |
| Length of dry season when pastoralists come to Shurr (days) | 150 | 200 | dry_period_length |
| Cattle traffic in Shurr | 500 | 1200 | number_cattle |
| Proportion of cattle whose water demand will be met at Kobadi every 3 days | 0.05 | 0.15 | proportion_cattle |
| Water fees per cow | 3 | 5 | cattle_water_fees |
| Camel traffic in Shurr | 500 | 1000 | number_camel |
| Proportion of camels whose water demand will be met at Kobadi every 14 days | 0.005 | 0.05 | proportion_camel |
| Water fees per camel | 7 | 12 | camel_water_fees |
| Annual fees paid by households for water | 1000 | 1500 | hh_fee |
| Number of households receiving water | 2000 | 4000 | no_households |
| Reduced wait times in a week (hours) | 8 | 10 | weekly_reduced_wait_times |
| Value of man-hours | 20 | 50 | value_hr |

| *Variable name* | *Lower bound (5% quantile)* | *Upper bound (95% quantile)* | *Variable name in model* |
|---|---|---|---|
| ***Risk variables: variable description*** | | | |
| Risk of damages as a result of vandalism | 0.05 | 0.2 | risk_vandalism |
| Probability that the pipe is repaired after vandalism | 0.01 | 0.1 | p_resolution_vandalism |
| Cost of repairs as a fraction of c0st of piping installation | 2 | 20 | repairs_vandalism |
| Revenue lost due to vandalism | 15 | 30 | revenue_loss_due_vandalism |
| Risk of leakages | 0.1 | 0.3 | risk_leakages |
| Probability that the pipe leakage is repaired | 0.1 | 0.3 | p_resolution_leakages |
| Cost of repairs due to leakage as a proportion of piping installation | 2 | 20 | repairs_leakages |
| Revenue lost due to leakage as a proportion of total revenue | 2 | 10 | revenue_loss_due_leakages |
| Risk of conflicts | 0.3 | 0.6 | risk_conflicts |
| Possibility of resolution of conflicts | 0.2 | 0.8 | p_resolution_conflicts |
| Losses due to conflicts | 20 | 80 | loss_conflicts |
| Risk of mismanagement of water resources | 0.2 | 0.4 | risk_mismanagement |
| Probability of resolution of mismanagement risk | 0.25 | 0.5 | p_resolution_mismanagement |
| Losses resulting from illegal abstraction due to mismanagement | 10 | 30 | loss_due_illegal_abstraction |

## Annex D: Shurr model (R code)

Requires the decisionSupport and DAutilities packages.

```
Shurr_water<-function(x, varnames)
        {
        #cost of piping water to tank at Kobadi
        initial_cost_pumping<-rep(0,n_years)
        initial_cost_pumping[1]<-cost_laying_pipes_km*distance_shurr_kobadi
        pumping_recurrent_cost<-vv(personnel_costs,general_CV,n_years)+vv(cost_fuel,general_CV,n_years)+
          vv(chemical_costs,general_CV,n_years)+vv(maintenance_costs,general_CV,n_years)
        initial_cost_construction_tank<-rep(0,n_years)
        initial_cost_construction_tank[1]<-initial_tank_cost
        tank_recurrent_cost<-vv(tank_maintenance_cost,general_CV,n_years)
        cost_degradation<-vv(TEV_ha,general_CV,n_years)*vv(new_degraded_area,general_CV,n_years)*
          vv(USD_KES,general_CV,n_years)
        total_costs<-initial_cost_pumping+pumping_recurrent_cost+initial_cost_construction_tank+
          tank_recurrent_cost
        community_costs<-pumping_recurrent_cost+tank_recurrent_cost

        #Benefits of piping water
        dry_period_length<-vv(dry_period_length,general_CV,n_years)
        monetary_value_degradation<-vv(TEV_ha,general_CV,n_years)*vv(area_Shurr,general_CV,n_years)*
          vv(USD_KES,general_CV,n_years)
        value_reduced_effects_degradation<-monetary_value_degradation*
          vv(percentage_reduction_effects_degradation,general_CV,n_years)
        value_reduced_wait_times<-vv(weekly_reduced_wait_times,general_CV,n_years)*
          vv(value_hr,general_CV,n_years)*round(dry_period_length/7)

        #revenue from sale of water
        human_consumption_revenue<-vv(human_consumption_qtty,general_CV,n_years)*
          vv(value_water,general_CV,n_years)*round(dry_period_length)
        shoats_water_revenue<-
        vv(number_shoats,general_CV,n_years)*vv(proportion_shoat,general_CV,n_years)*
                    vv(shoats_water_fees,general_CV,n_years)*round(dry_period_length/2)
        cattle_water_revenue<-vv(number_cattle,general_CV,n_years)*vv(proportion_cattle,general_CV,n_years)*
                    vv(cattle_water_fees,general_CV,n_years)*round(dry_period_length/3)
        camel_water_revenue<-
        vv(number_camel,general_CV,n_years)*vv(proportion_camel,general_CV,n_years)*
                   vv(camel_water_fees,general_CV,n_years)*round(dry_period_length/14)
        total_water_revenue<-shoats_water_revenue+cattle_water_revenue+camel_water_revenue+
          human_consumption_revenue

        #function to simulate the occurrence of a problem (conflict, interference, security issues) over a certain
        number
        #of years. This is simulated with 3 parameters: the annual chance of the problem occurring (scale 0..1),
        the
        #annual chance of the problem being resolved (scale 0..1), and the losses it causes (percent: 0..100).
        #the function also needs a coefficient of variation for introducing variability in annual losses.
        loss_vandalism<-vv(repairs_vandalism,general_CV,n_years)+
          vv(revenue_loss_due_vandalism,general_CV,n_years)
        bs<-rep(1,n_years) #benefit_scaler
        bs<-bs*temp_situations(risk_vandalism,p_resolution_vandalism,loss_vandalism,general_CV,n=n_years)

        loss_leakages<-
        vv(repairs_leakages,general_CV,n_years)+vv(revenue_loss_due_leakages,general_CV,n_years)
        bs<-bs*temp_situations(risk_leakages,p_resolution_leakages,loss_leakages,general_CV,n=n_years)

        bs<-bs*temp_situations(risk_conflicts,p_resolution_conflicts,loss_conflicts,general_CV,n=n_years)
```

```
bs<-bs*temp_situations(risk_mismanagement,p_resolution_mismanagement,
  loss_due_illegal_abstraction,general_CV,n=n_years)

#calculate impact of infrastructure on community
community_economic_returns<-(total_water_revenue*bs)-community_costs
investment_NPV<-
((total_water_revenue+value_reduced_effects_degradation+value_reduced_wait_times)* bs)-total_costs
environmental_NPV<-value_reduced_effects_degradation-cost_degradation
socioeconomic_NPV<-((total_water_revenue+value_reduced_effects_degradation+
  value_reduced_wait_times)*bs)-community_costs

return (list(Shurr_community_NPV=sum(NPV(community_economic_returns,discount_rate,TRUE)),
        Cashflow_Shurr_community_NPV=community_economic_returns,
        Cashflow_Kobadi_investment_NPV=investment_NPV,
        Kobadi_investment_NPV=sum(NPV(investment_NPV,discount_rate,TRUE)),
        Cashflow_Shurr_environmental_NPV=environmental_NPV,
        Shurr_environmental_NPV=sum(NPV(environmental_NPV,discount_rate,TRUE)),
        Cashflow_Shurr_socio_economic_NPV=socioeconomic_NPV,
        Shurr_socio_economic_NPV=sum(NPV(socioeconomic_NPV,discount_rate,TRUE))))
```

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