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Making land management more sustainable: experience implementing a new methodological framework in Botswana

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Making land management more sustainable: experience implementing a new methodological framework in Botswana

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Abstract

It is increasingly recognized that tackling land degradation through more sustainable land management (SLM) depends on incorporating multiple perspectives using a variety of methods at multiple scales, including the perspectives of those who manage and/or use the land. This paper reports experience implementing a previously proposed methodological framework that is designed to facilitate knowledge sharing between researchers and stakeholders about land degradation severity and extent, and SLM options. Empirical findings are presented from the Botswana site of the EU-funded Desertification and Remediation of Land (DESIRE) project. The paper reflects upon the challenges and benefits of the proposed framework, and identifies a number of benefits, notably related to insights arising from the integration of local and scientific knowledge, and the ownership of the SLM strategies that emerged from the process. However, implementing the framework was not without challenges, and levels of poverty and formal education may limit the implementation of the framework in some developing world contexts.

1 Introduction

Global environmental problems demand interdisciplinary assessment. Although this is now widely recognised by academics (e.g. Kates et al., 2002; Lélé and Norgaard, 2005) and policy-makers (UNCBD, 1992; UNCCD, 1994), there is little consensus about how this can best be achieved. The challenge of marrying results about environmental change from different disciplines is further compounded by the difficulty of reconciling potentially conflicting perceptions among and between researchers and different stakeholders. This article will ask whether we can disentangle the complex arguments that characterise these complex relationships, to arrive at an assessment of environmental change that can effectively learn from these diverse forms of knowledge.

This challenge is particularly acute in the assessment of land degradation[1]. Land degradation is an anthropocentric concept that can only be defined in relation to the objectives of those who use and manage the land: "land degradation is contextual" (Warren, 2001:449). For land degradation assessment to be accurate and reliable, it must therefore incorporate multiple perspectives using a variety of methods at multiple scales, including the perspectives of those who manage and/or use the land (Reed *et al*., in press).

To address this challenge, Reed *et al*. (2011) present a methodological framework for land degradation and sustainable land management (SLM) monitoring and assessment (Figure 1). The framework integrates approaches used by the Desertification Mitigation and Remediation of Land (DESIRE) project, the World Overview of Conservation Approaches and Technologies (WOCAT), the Dryland Development Paradigm (DDP), and the UN Food & Agriculture Organisation's UNEP/GEF-funded Land Degradation Assessment in Drylands (LADA) project. It groups methodological steps under four broad themes:

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[1] Land degradation: i) is a human-induced phenomenon that cannot be caused by natural processes alone; ii) decreases the capacity of the land system as managed to meet its user demands; and iii) threatens the long-term biological and/or economic resilience and adaptive capacity of the ecosystem. This definition is based on a synthesis of: Holling, 1986; Abel and Blaikie, 1989; UNEP, 1992; Turner & Benjamin, 1993; UNCCD, 1994; Dean et al., 1995; Kasperson et al., 1995; UNEP, 1997; Holling, 2001; and IPCC, 2001.

i) Establishing land degradation and SLM context and sustainability goals;
ii) Identifying, evaluating and selecting SLM strategies;
iii) Selecting land degradation and SLM indicators; and
iv) Applying SLM options and monitoring land degradation and progress towards SLM goals.

This methodological framework is now being applied and evaluated through the DESIRE project in 16 of the most degraded drylands of the world, representing a wide range of land degradation processes and environmental, socio-cultural, economic and policy contexts. One of these sites is Botswana, which has been described as “one of the most desertified countries in sub-Saharan Africa” (Barrow, 1991: 191).

This paper for the first time reports experience implementing the DESIRE/WOCAT/LADA methodological framework proposed by Reed *et al*. (2011), using the DESIRE study site in Botswana to critically evaluate its application. Elements of the framework have been tested elsewhere (e.g. Reed et al., 2007, 2008; Schwilch et al., 2009, 2011), but this is the first time that all the elements brought together by Reed et al. (2011) have been applied and evaluated. It starts by exploring the case study context, including an assessment of key constraints to sustainable land management. It goes on to describe the SLM strategies selected by local stakeholders for field trials, and the indicators chosen to monitor progress in their efforts to tackle land degradation. The paper ends by reflecting upon the practical challenges of applying the framework, in particular reconciling multiple perceptions of environmental change.

[Figure 1 here]

2 Case study context

The Boteti study site is situated in the Central District of Botswana. Within Boteti, the focus is on the villages of Mopipi, Mokoboxane (Figure 2) and Rakops (not in Figure 2) with an estimated combined area of 3,000 sq km. This study site is regarded as a ‘desertification’ hotspot and was the focus of Botswana's 1993 case study for the Intergovernmental Convention to Combat Desertification (INCD), and is identified on the GLASOD map as an area of extreme human induced wind erosion (Government of Botswana, 1994). The Boteti area has consequently been a foci of efforts to “combat desertification” and from 2002 was one of the sites for the Indigenous Vegetation Project (IVP), a five-year Botswana Government-GEF-funded pilot project for “community-driven rehabilitation of degraded rangelands”[2]. DESIRE builds on these past and on-going efforts, which are all in line with the recently adopted National Action Programme to Combat Desertification (Department of Environmental Affairs, 2006).

[Figure 2 here]

The climate is semi-arid and the rains are concentrated in the summer season (October to April). The average rainfall is about 350 mm/yr and has a variability of about 38%. The rate of evapotranspiration for the area is taken to fall within the Botswana average of 2000 mm/yr. The drought cycle in the area is estimated at 9-15 years recurrence interval (Ministry of Agriculture, 1994).

The Boteti River spans two major ecosystems, the Makgadikgadi to the north east and the Kalahari System to the south-west and has undergone pronounced change over the last thirty years. Water from rains in the Angolan highlands pass through the Okavango Delta and reach the lower Boteti in the dry season, providing essential surface water and access to the surrounding forage (plains grasslands and riparian zones) for wild ungulates and domestic animals. As part of wildlife seasonal migration, zebra move from the Pans in the wet season to the Boteti River in the dry. About 80-90% mortality of the Makgadikgadi zebra population in the 1982-86 resulted from drought, partly exacerbated by competition with livestock (over 80,000 animals died). Other wildlife (e.g. wildebeest and hartebeest) and livestock suffered a similar fate.

A major grievance of the communities in the area is that they do not benefit from wildlife related tourism, but endure crop and livestock losses from wild predators.

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[2] http://www.indigenousvegetation.net

Consequently, an electrified game-proof fence was erected along the Boteti in 2004 to try and reduce predation. Seasonally intense grazing by mobile populations of wildebeest and zebra on the western plains area, including Lake Xau, has today been replaced by permanent grazing by livestock facilitated by intensified borehole and shallow well drilling.

The study site is located on tribal land and falls under the responsibility of the Ngwato Land Board. Tribal land in Botswana is communally owned; hence its use is also communal except where individuals or groups of people have been granted exclusive rights to use a particular piece of land. Most livestock are kept at cattle posts, located away from villages to avoid conflict with other land uses such as crop production. Indeed, in the 1970s and part of the 1980s, Mopipi was a fishing and "molapo" farming village, according to the villagers. With the loss of flow along the Boteti River since the late 1980s, the people converted the productive flood recession "molapo" agricultural system along the fluvisols of the Boteti river to the inherently more risky rain-fed production. Since then arable agriculture has also expanded into grazing land to the west of Rakops and north of Mokoboxane slightly reducing land available for livestock and wildlife grazing.

Provision of water is by drilling boreholes, and farmers do not have exclusive rights to either water or grazing resources. However, farmers can apply for exclusive rights, and a block of leasehold farms are located south of Mopipi. These farms were allocated under the Tribal Grazing Land Policy of (1975) and the revised/new Policy on Agricultural Development of 1991 whose aim was to primarily reduce grazing pressure from the communal areas, improve grazing management and increase livestock production. According to the Botswana Poverty Map, the Boteti District population falls within the 40-50% headcount poverty level making it the third poorest region after Ngamiland west and Kgalagadi South Sub-Districts (CSO, 2008). Livelihood sources in the area include livestock rearing, arable farming, casual employment, government support, formal employment, and gathering of veld products. Although hunting and gathering was an important source of protein and food for many households in the recent past, due to the drastic decline of wildlife populations at the end of the last century, pastoralism is now by far the most important source of livelihoods in the study area. The agropastoral system and practice in Botswana separates crop fields and livestock completely during cropping season (October-June) and at night for almost the whole year. Arable farmers who use cow dung to improve soil fertility let the cows graze in the fields for about six months after harvest. Even these however would still kraal their cattle at night to be able to get milk and protect them from stock theft and predators. Cow dung for bio-gas will be mainly collected from watering points and kraals. For these reasons there is no competition for cow dung.

Fishing, as indicated earlier, ceased to be an important source of livelihood in the late 1980s when the Boteti River stopped receiving water from the Okavango delta system. Although the floods have returned to the system today, fishing has been slow to re-establish. Livelihoods are supplemented by harvesting a variety of rangeland products, including building poles, thatching grass, firewood, wild fruits and vegetables, medicine and Mopane worms[3]. Although these products are used mainly for subsistence, Reed (2005) found that some families derived significant income, for example from the sale of traditional beer brewed from wild fruits. Reed (2005) found that thatching grass was increasingly hard to find in the study area and that firewood was a problem for families without access to transport. It was found in some workshops conducted under the DESIRE project that all other rangeland products have been commercialized to some extent.

Until the 1930s, the study area was sparsely populated and Basarwa (San) were the predominant ethnic group. The Bakalanga, who migrated into the area in the 1930s, are now the largest ethnic group in the area. Population density is still low (estimated at about 1 person per square kilometer). However, the population in the study sites grew significantly during the 1991-2001 decade. The population of Rakops grew from 3122 inhabitants in 1991 to 4555 in 2001. Mopipi village population grew from 2264 to 3066 inhabitants during the same period. Mokoboxane registered the highest growth rate from 614 inhabitants in 1991 to 1290 by 2001. Around 40% of the population of the study area is under the age of 15. Furthermore the area has a high proportion of adults above the age of 20 who have never been to school, with significantly more illiterate women than men.

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[3] The caterpillar of the Mopane Moth, *Imbrasia belina.*

For instance, in Mopipi 41% of women compared to 34% of men in this age bracket had never been to school (Republic of Botswana, 2004).

3 Methods

The following text will describe the methods used to apply the framework described in Figure 1, structured by each of the steps in the framework.

3.1 Establishing land degradation and SLM context and sustainability goals

Identifying system boundaries, stakeholders and their goals (Figure 1, step 1): A detailed account of the environmental, socio-economic and policy context in which land degradation and SLM occur in this area are provided in section 2 (see also Atlhopheng et al., 2009 on DESIRE website: http://www.desire-his.eu). System boundaries, stakeholders and their goals were determined through Workshop 1 with land users, conducted following the WOCAT approach described in Bachman et al. (2007a&b). The participatory exercises established not only sustainability goals, but also the influence of various stakeholders and institutions on local land management (cf. Magole et al. 2008).

Describing the socio-cultural, economic, technological, political and environmental context and identifying key drivers of change (Figure 1, step 2): This was also done during Workshop 1 through an exercise that elicited from land users land degradation cause-effect linkages or impact chains (cf. Magole et al., 2008). This information was supplemented through literature (cf. Atlhopheng et al., 2009 on DESIRE website: http://www.desire-his.eu) and policy reviews (cf. Chanda et al., 2009a; Atlhopheng, et al. 2009a; Mulale and Chanda, 2009).

Determining current land degradation status, future land degradation risk and existing SLM measures using existing indicators (Figure 1, step 3): This was done in two ways. First, participatory methods were used to identify indicators that could measure progress towards sustainability goals, and that could be used easily by communities themselves.

This was done through Workshop 1, reflecting on land degradation indicators participants had observed during a transect walk, which took place prior to the workshop. This built on previous participatory indicator development by Reed et al., (2008). Second, a more standardised procedure adopted across the DESIRE project (which had previously been used to determine land degradation indicators in the Mediterranean region by the DESERTLINKS project) was used to survey indicators in the most important land use types in Boteti (agriculture, pasture, woodland/forest, settlement, pan/dam). A structured indicator questionnaire was completed for each process deemed significant in a land use type using appropriate weighing indices (cf. Chanda et al., 2009b). The weighing indices provided the quantitative data for subsequent statistical analysis and determination of significant degradation indicators in land use types.

3.2 Identifying, evaluating and selecting SLM strategies

Identifying, assessing and prioritising possible SLM options (Figure 1, steps 4 and 5): Potential SLM options were listed by participants during Workshop 1, and evaluated using WOCAT standard questionnaires and then during structured small group discussions about the strengths and weaknesses of each option (cf. Magole et al., 2008). SLM options deemed appropriate by participants in Workshop 1 were further investigated by the research team (e.g. cost, current use in Botswana, etc), and then further evaluated during Workshop 2 using Multi-Criteria Evaluation. After reviewing the top-ranked remediation options from Workshop 1, participants discussed and agreed on evaluation criteria and scored each SLM option using 'facilitator software' (see Magole et al., 2009).

Trial SLM options at field scale (Figure 1, step 6): Although the most preferred SLM strategy was community game ranching, on account of affordability the land users settled for biogas production and use, with local cow dung as the main input to the gas production process (see section 4 for more details). The plan for implementing SLM options in Boteti therefore centres on piloting the impact of household biogas use on household fuelwood consumption and woody biomass conservation. This entails monitoring the rate of fuel wood consumption by a family utilizing biogas as the primary energy source compared to a control family of similar characteristics still dependent on firewood as the primary energy source. It will also be necessary to establish baseline information on current (i.e. pre-biogas) household energy options, fuel wood consumption rates, estimates of current (pre-biomass) standing woody biomass, as well as estimates of available feedstock (cow dung) for the biogas plant. Current household energy options were captured through 42 household surveys using a structured questionnaire, conducted during winter (July to September) of 2009. Fuelwood consumption rates were estimated from a 2-week monitoring and measurement of firewood supply and use using a spring scale for a subsample of surveyed families in Mopipi village. With regard to estimating feedstock for biogas production, two kraals (cattle-posts) were chosen to estimate dung produced by cattle over-night. Each morning, farmers usually allow their cattle to go out to graze leaving their calves behind. In the evening, when they return to the water point they are kraaled – although in good rainfall seasons many animals do not return to the water point but stay out to graze. With the consent of two kraal owners ten 'standard' fresh dung pats were weighed after night time kraaling over a period of three days. Assessment of woody biomass was made within a radius of 12 km from Mopipi using stepwise sampling points at distances of 2, 4, 6, 8, 10 and 12 km from the village. At each sampling point, a cluster of three quadrats of 50m x 10m each were located with the aid of tapes and ranging poles. Coordinates of each quadrat were recorded. A boundary of 100m between quadrats was allowed. Individual rooted woody species within the quadrat were identified at species level; their stem diameters (at ankle height) and woody biomass estimated via the related regression equations developed by Tietema (1993).

Up-scale/aggregate biophysical and socio-economic effects of SLM from field to regional and national scales to further prioritise SLM options (Figure 1, step 7): Experimental work as done in the previous step can give valuable information to evaluate a technology, but cannot easily be generalized to a larger scale, nor can scenario analyses be made to answer 'what-if' questions. In DESIRE, an integrated environmental modelling approach was adopted to address these issues (for details see Fleskens et al., 2009). For the case of biogas, modelling is focussing on the economic and environmental effects of widespread adoption of biogas in the Mopipi and Mokoboxane villages. In this paper, a simplified preliminary economic evaluation is presented. Investment costs for a biogas installation were estimated by participants in Workshop 2 (above). Potential collection sites for cow dung were assessed in relation to the demand for dung if all households would switch to biogas. The collection sites are assumed to be adjacent to boreholes, of which there are 378 in the study area. The price (transport and labour costs) for dung collection was explicitly taken into account. Moreover, a bi-annual maintenance of the biogas installation was assumed and estimated to be 5% of the investment costs. The economic life of the biogas installation was set at 20 years, and the discount rate for cost-benefit analysis was set at 10%, reflecting the local opportunity cost of capital. Importantly, biogas releases time (and perhaps financial resources) that would otherwise be spent collecting firewood. The cost of firewood is in the current analyses a model output, i.e. the daily average household firewood requirements are priced at break-even point (using 10% rate of internal return).

The biophysical effects will be simulated with the PESERA model (Kirkby et al., 2008). Biophysical models offer an opportunity to merge physical and social constraints on the production and availability of wood and grazing biomass. Once established, the model can be used to explore the spatial interaction between fuel demand, fuel production (biomass and dung) and land degradation under current and SLM practice. This modelling approach allows an assessment of the scale at which biogas offers resilience to the natural system with uncertainty in cattle numbers and rain fed biomass production. Monitoring and observation of current rates and patterns of biomass removal (fuel and grazing) provide essential data when considering modelling the bio-mass balance for the local area or region (Figure 3). Such data, combined with land use, vegetation data and climate are the primary input into bio-physical models. The biophysical component of the Pan-European Soil Erosion Assessment (PESERA) model. PESERA is a process-based model that is designed to estimate long term average erosion rates at 1 km resolution and has been applied in locations across Africa, Latin America and Asia through the DESIRE project. The model is built around a partition of precipitation into components for overland flow (infiltration excess, saturation excess and snowmelt), evapo-transpiration and changes in soil moisture storage. Transpiration is used to drive a generic plant growth model for biomass, constrained as necessary by land use decisions, primarily on a monthly time step. Leaf fall, with corrections for cropping, grazing etc, also drives a simple model for soil organic matter. The runoff threshold for infiltration excess overland flow depends dynamically on vegetation cover, organic matter and soil properties, varying over the year. The distribution of daily rainfall totals has been fitted to a Gamma distribution for each month, and drives overland flow and sediment transport (proportional to the sum of overland flow squared) by summing over this distribution. Total erosion is driven by erodibility, derived from soil properties, squared overland flow discharge and gradient; it is assessed at the slope base to estimate total loss from the land, and delivered to stream channels. The combined biophysical and biomass offer the potential to consider resource management options under future scenarios and inform further discussions between the study site researchers and stakeholders.

[Figures 3 & 4 here]

3.3 Selecting land degradation and SLM indicators

Finalise selection of indicators (in collaboration with likely users) to represent relevant system components for ongoing monitoring by land managers (Figure 1, step 8): Indicators identified during Workshop 1 (see section step 3, section 3.1) were evaluated and selected on the basis of their ease of use (i.e. the ability of land managers to measure them) and capacity to represent land degradation processes or the long-term sustainability of land management (cf. Magole et al., 2008 and Bachman et al., 2007a&b). This built on previous work by the team where indicators that had been identified in interviews were evaluated and shortlisted in workshops using Multi-Criteria Evaluation and further evaluated using field methods (Reed et al., 2008).

3.4 Promoting the application of SLM options and monitoring land degradation and progress towards SLM goals

Disseminate strategies and indicators for extension and national and international policy (Figure 1, step 9): Although literacy levels are relatively high in Botswana (average 81% according to Central Statistics Office (2004)), Boteti land users have no easy access to computers and the internet. Consequently, the most appropriate means of disseminating information to them would be through workshops, translated leaflets, manuals and posters. Participatory workshops have already proven to be an effective means of local stakeholder engagement. However, for national policy development and implementation, web-based dissemination would be possible. SLM options from this project and previous work (Reed and Dougill, 2010) were integrated, and linked to relevant indicators of land degradation and SLM in a manual, targeted at land managers and extension workers. In addition to biogas and game ranching, the manual includes a range of other SLM options deemed relevant to the study area through previous work (Reed and Dougill, 2010), such as changing livestock breeds, shifting grazing, managing bushes and various soil management techniques. These materials and other more detailed results from the project are also available via the DESIRE project's "Harmonised Information System", available at: http://www.desire-his.eu/.

Apply SLM strategies, monitor degradation and progress towards SLM goals, upscaling or aggregating to district and national levels (Figure 1, step 10): The results of the biogas project with respect to the environmental and socio-economic objectives for which it was adopted will be reviewed with land managers as soon as results become available. Depending on its impact on woody vegetation conservation and socio-economic welfare, the strategy could be implemented more broadly within the study village and in areas within the region and beyond with similar circumstances. Ongoing monitoring using indicators by land managers is facilitated through the dissemination of manuals linking indicators to SLM options (see previous step). These manuals are being used as part of the wider Government of Botswana's implementation of its UNCCD National Action Plan, under which it is hoped that these activities can be up-scaled to district and national scales, and progress towards SLM goals can be monitored nationally.

Adjust strategies to ensure goals are met (Figure 1, step 11): Finally, it should be noted that as goals are met and contexts change, it may be necessary to develop or prioritise new SLM strategies and indicators in future. Consequently, this framework is iterative, represented by the dashed arrow between steps 11 and 4.

4 Results

4.1 Establishing land degradation and SLM context and sustainability goals

Figure 5 shows land degradation drivers and desertification risk according to structured indicator questionnaires that were completed for each process deemed significant in each of the land use types found in the study area (Figure 1, step 3, section 3.1 above). Boteti stakeholders identified sustainability goals that addressed ecological (environmental) integrity (as suggested by the objective of reducing the depletion of trees), economic (livelihood) security (as suggested by the objective of minimizing the impact of drought on arable production) and social equity (as indicated by the objective of reducing poverty). These sustainability goals were a response to problems that are well documented in the literature in this study area. For instance, the Boteti area has had the highest proportion of permanent destitutes among the 5 sub-regions of the Central District of Botswana (Central District Council, 2003). However, despite the many studies that have identified rangeland degradation as a problem in this area (e.g. Ministry of Agriculture, 1993; Ringrose et al., 1996; Perkins, 2007; Chanda, et al., 2007), environmental sustainability goals focussed on the arable system and the availability of water and fuel-wood.

[Table 1 here]

This may reflect a number of potential problems with the research that initially identified rangeland degradation. In particular, Ringrose et al. (1996) inferred land degradation from the presence of three indicators: (1) increased wind erosion and dust storms; (2) *localised* permanent damage to vegetation around villages and along the river; (3) die-back of riverine forest (it is assumed due to lowering of water table or salinisation due to unsustainable water extraction). It is clear that the riverine system has been degraded in Boteti, due mainly to the loss of the Boteti flows, with losses in fishing and flood plain agriculture. However there is less evidence to support the claim that grassland resources in this area are degraded, and not simply responding to drought. Although increased wind erosion may be a degradation indicator, it is also an indicator of drought. Evidence of wind erosion features from remotely sensed data may simply indicate drought conditions. Ringrose *et al*. (1996) detected wind erosion features from remote sensing data collected in 1984, 1989 and 1993. Two of the three years were drought years.

Permanent changes are evident around settlements, however these changes are highly localised in extent and do not suppress the productivity of the livestock system. Reed (2005) found that grass cover was high 2-4 km from villages in Boteti. The dominant grass species, *Cynodon dactylon* was classified as "high grazing value" by van Oudlshoorn's (1999). In common with Ringrose *et al*. (1996), community members cited a range of environmental problems, which they blamed predominantly on drought (Reed, 2005). When probed about the capacity of the land to recover after rain, the majority of respondents interviewed by Reed (2005) emphasised the resilience of the grassland zone, noting that rainfall produced sufficient fodder to maintain herds for at least two years. As such few land users were constrained by their natural capital. However, community members agreed that the mopane veld zone, which is less important for livestock production, had experienced a decline in productivity. This was due to increased dominance of *C. mopane* in response to grazing, leading to the suppression of grass. Elsewhere in the mopane region of Botswana, the species is highly valued for forage. However, elsewhere in Botswana it is usually valued in relation to available alternatives, which tend to comprise less palatable annual grasses (Ringrose, pers. comm.), and it is inferior to forage in the grassland zone in Boteti.

In conclusion, the riverine system in the study area is clearly degraded due to declining river water levels and heavy stocking pressure within the riparian woodland. The absence of flows along the Boteti from the late 1980s until recently has significantly constrained livelihood options for the local community, who once relied on fishing and flood plain agriculture. Localised rangeland degradation is occurring around villages and in the mopane veld zone. At present levels, this does not appear to threaten the sustainability of livestock production in Boteti, but there are major concerns over fuel-wood availability and water shortages. These concerns are reflected in the identification and selection of SLM options that emerged from the two workshops.

4.2 Identifying, evaluating and selecting SLM strategies

Altogether, land users identified 13 SLM strategies during Workshop 1, out of which they prioritized 4, viz: biogas as an alternative energy source, community wildlife (game) farming, irrigation and dam-building (water harvesting). The DESIRE team investigated three of these (biogas, water harvesting and game ranching) and another technology not mentioned by the land users (solar power via solar cooker). In order to help them make informed decisions about the technologies, the findings of the investigations were shared with land users during Workshop 2. The latter four technologies were evaluated as outlined under section 3.2 above. As Figures 6-8 below indicate, the technologies with the highest beneficial environmental (ecological), economic and socio-cultural impacts according to land users were community game ranching and biogas (cf. Magole et al, 2009). Figure 6 shows that there was considerable disagreement over the ecological benefits of game ranching (indicated by the length of the horizontal line) compared to biogas. Figures 7 and 8 show that there was considerable agreement however, over the economic and socio-cultural benefits of game ranching, and that these benefits were considered greater for game ranching than for other technologies.

The land users' prioritization of game ranching was based on a number of social and environmental considerations. Game ranching was perceived to have the potential to bring economic returns for poverty alleviation (Table 1) and also to be a more viable alternative to livestock farming which causes overgrazing. They reasoned that wildlife species are better adapted to the semi-arid environment which they utilize more optimally as grazers and browsers. On the other hand, biogas production and use was expected to reduce the need to collect firewood which is the main source of energy in the study area. The stakeholders reasoned that by using biogas one can save time, use less labour and save trees. Although it was marginally less popular than game ranching, the land users ultimately settled for the biogas production strategy because the initial set-up costs were lower, and hence could be implemented within the funding and time available within the DESIRE project.

[Figure 6-8 here]

4.3 Selecting land degradation and SLM indicators

During Workshop 1, land users identified a wide array of indicators of both land degradation and SLM (Table 2). Participants considered the positive indicators as depicting past environmental conditions, confirming findings from earlier studies that the people of Boteti perceive a long-term deterioration in their environment which, as observed earlier, they readily link to climate desiccation and failure of Boteti floods (cf. Chanda, 1996; Penning de Vries, 2007; Chanda and Darkoh, 2007).

[Table 2 here]

4.4 Applying SLM options and monitoring land degradation and progress towards SLM goals

Monitoring of environmental and socio-economic impacts of adopting biogas as an alternative domestic energy source is ongoing. However, the following baseline data has been generated using the methods described under section 3.2 above:

- There is indeed a very high dependency on firewood as a source of energy for cooking (100% - Mopipi; 98.4% Mokoboxane), space heating (77% - Mopipi; 96% - Mokoboxane), warming bath water (98.7% - Mopipi; 98.4% - Mokoboxane) and various family events or ceremonies (78.5% - Mopipi; 83% - Mokoboxane);

- There has been mounting scarcity of firewood within more accessible areas (86% of Mopipi and 90% of Mokoboxane respondents). This is supported by the increasing use of donkey cart and motor vehicles in firewood collection, especially in the larger village – Mopipi (88.9% of respondents);
- On average, families use 10kg of firewood per day;
- Most firewood is collected from communal land predominantly (not solely) lying in the easterly direction;
- There is enough cattle dung in the Mopipi area to support domestic biogas production on a sustainable basis without compromising it use as organic fertiliser in arable agriculture. The total dung output per animal per night was estimated at 5.4 kg wet weight; and
- Biomass of both live and dead fuel wood increases linearly with distance from the village. Biomass of live trees (25 989 kg per ha average) was far greater than that of dead wood (919 kg per ha average), suggesting depletion of the latter stock as people currently depend on dead, rather than live, wood for energy. *Colophospermum mopane* (the most preferred firewood species) contributed the most biomass of live tree species and, expectedly, the least biomass to dead tree species – underscoring its popularity as a firewood resource.

These results portray a situation of a decreasing stock of dead tree biomass for firewood within collection zones. Thus the land users' choice of biogas production as an alternative energy source could be viewed as a proactive move intended to pre-empt cutting of the now more accessible live trees for firewood.

Regional assessment of introducing biomass was elaborated based on the above indicators. Figure 9 shows the location of boreholes as potential dung collection sites. To simplify the analysis, we classified boreholes based on distance into 5 classes: less than 1 km (1.6%); 1-2km (0.5%); 2-5 km (4.0%); 5-11 km (18.8%); 11-20 km (41.5%); and more than 20 km (33.6%). Importantly, dung collection from these sites is assumed to be undertaken on foot (in the case of the first class), by cart (next two classes), or by van (the remaining classes).

The results from scenarios of introducing biogas are shown in Table 3. If we assume a uniform distribution of cattle over boreholes (potential collection sites), all dung required for operating biogas installations for the 872 households inhabiting Mopipi and Mokoboxane will be collected from within a range of 11 km from the villages; note that in this scenario (A) the six boreholes at less than a kilometre from the villages are disregarded as dung collection on foot is uneconomical. Biogas is financially attractive if firewood collection is about twice as costly as collecting dung. In view of less attractive rangelands close to the villages, it is more likely that cattle is kept away from the village.

If we assume all cattle is held beyond 11 km (scenario B), dung collection costs for operating all biogas installations will rise by about 24%. The cost of firewood collection at which biogas becomes a viable investment rises by about 12% relative to Scenario A. Similarly, if cattle is kept at more than 20 km (Scenario C), dung collection costs almost double (+81%) but firewood opportunity costs would need to rise 40% in order to make the investment viable. Neither of Scenarios A-C is likely to be correct; however these analyses show that cattle herding dynamics (e.g. in response to drought) do not have to form an obstacle to adopting biogas.

Scenario D addresses what happens if the biogas installations do not perform (or are not managed) efficiently and can only fulfil 75% of energy demand, with the remaining 25% continuing to be provided by firewood. This obviously renders the investment in biogas less attractive (i.e. a higher firewood opportunity cost is needed). Importantly, the assessment method employed requires the share of firewood energy substituted by biogas to be larger than 50% - any share lower than that means the technology will never be viable from an individual decision-making perspective.

Scenario E addresses the fact that firewood collection costs may not yet be as high as to push people to other alternatives, but may be on a rising trend. If we assume an annual increase of 10%, reflecting both increased scarcity (and thus time) and distance (transport and time) of firewood collection, adoption of biogas can anticipate these future changes and be viable even if the current cost of firewood collection is lower than dung collection costs.

Scenario F represents Scenario A but assuming cattle dung from collection areas close to the village would not involve opportunity costs of labour. This drops the cost of dung collection and the minimum required opportunity cost of firewood collection to 67% and 60% of Scenario A respectively. In fact, taking the perspective of a pioneering adopter of biogas who would exclusively collect dung from a nearby collection area (from his/her own kraal for instance), the tipping point for opportunity cost of firewood collection would go down further to P6.98 (36%).

Finally, scenario G reflects the extremely high cost and tipping point when dung collection needs to be done on foot – taking into account labour opportunity costs. Although this situation may be highly theoretical (a biogas adopter who is not in a position to source dung using more economical means of transport would probably not invest in the installation in the first place), it does show that there is considerable scope for some entrepreneurs to create a local dung market and organize supply of dung to biogas installations, or to develop a biogas market. The latter does however require additional investment for pressure filling equipment and suitable cylinders to transport biogas.

[Table 3 here]

5 Discussion

This paper builds upon a number of previous studies conducted in this area, and through the integration of local and scientific knowledge, has provided a number of novel insights that contrast with these previous studies. Most notably, the present study challenges the nature and causes of land degradation identified previously, and hence suggests quite different options for tackling land degradation in the study area. The study started by identifying types and causes of land degradation with local communities, rather than inferring this via natural science assessments of land degradation indicators. In contrast to previous research based primarily on remote sensing (e.g. Ministry of Agriculture, 1993; Ringrose et al., 1996), and studies by Reed et al. (2007, 2008) which focussed on rangeland degradation, participants in this study emphasised problems associated with poverty, and degradation processes related to the depletion of fuel wood and water shortages. In contrast to previous studies, which had a strong environmental and rangeland focus, the present study considered land degradation and SLM in the broadest possible context. In this way, although localised rangeland degradation issues were identified (with associated indicators) they were not given undue importance, and other issues were prioritised, leading to the selection of SLM options for trial that were focussed on tackling poverty and fuel wood shortages.

In particular, the scenario analyses demonstrate considerable scope for biogas production. The currently felt scarcity of firewood seems to indicate that the resource is being overexploited. With 10 kg of firewood needed for each household each day, and using the average of 919 kg/ha of dead wood biomass observed, annually at least an area the size of 3460 ha is needed to satisfy the demand. This involves a 3.3 km search radius from the villages. However, the current level of availability of firewood is already much lower than average close to the village, and the harvesting of all dead wood is unlikely to be sustainable. Therefore, it seems safe to assume the real search radius for firewood is already much larger. Unlike dung, which is collected from kraals, firewood needs to be collected from highly disperse areas, so that time and transport requirements are likely much higher than for dung.

Simulations with the biophysical PESERA model will provide valuable insight in the environmental effects of both firewood and dung collection dynamics. However, ultimately an important social aspect is involved. As firewood is collected by women and girls, perhaps at a perceived opportunity cost of zero, whether biogas will be taken up depends on community recognition of the importance of freeing them of an onerous task. Even when this is recognized, investment in biogas is expensive and beyond the individual capacity to sustain; institutional arrangements are therefore needed, which may be most effective if embedded in national level policy. Apart from financial viability and environmental benefits, the rationale for supporting biogas development can be considerably broadened, including potential industry development when scaling up, energy saving, energy security, and health benefits by reducing smoke-related respiratory diseases.

The use of Multi-Criteria Evaluation makes the reasons why participants selected particular SLM options transparent, and it is interesting to note that despite considerable disagreement over the ecological benefits of game ranching, it was prioritised by participants primarily for socio-cultural and economic reasons. Again, this emphasises the need to consider the socio-cultural and economic aspects of land degradation and sustainable land management alongside environmental dimensions. The contrast between the results of this research and previous research in the area may therefore reflect a difference in the relative priority that researchers and local stakeholders give to these different dimensions of sustainability.

This further emphasises the need for methodological approaches such as those proposed by Reed et al. (2011) and used in this research, which can integrate local and scientific knowledge of land degradation and SLM. Rather than pitching local knowledge (as collected in this research) against scientific knowledge (as per previous publications in this study area), this research combines local and scientific knowledge of land degradation problems and SLM options. Scientific knowledge contributed to the understanding of these issues via land degradation indicators that were developed by researchers and evaluating and applying SLM options (such as biogas) suggested by researchers. Local knowledge then ensured that relevant SLM options were considered, based on a local appreciation of land degradation problems (which differed to the perceptions of most researchers), and only those that could best meet local needs and priorities were implemented.

Although for some these different priorities may represent a conflict of interests between researchers and local stakeholders, the participatory approach facilitated a close working relationship between the research team and local communities, which translated into strong local ownership of the adopted SLM strategies. The adopted SLM strategies addressed an environmental problem with a strong link to priority livelihood issues. Thus, environmental conservation has a concrete rather than theoretical or abstract meaning to the lives of the land users. There was a very high land user appreciation of what they referred to as the “DESIRE project process” of solving land use and management problems. Land users unequivocally observed that DESIRE made them realize that they possessed the ability to analyze their socio-economic circumstances and ultimately identify expert validated strategies to address locally genuine livelihood and environmental problems. They further applauded the process for promoting cooperation among various stakeholders and for affording them the opportunity to learn about the various remediation strategies from DESIRE experts (see online supplementary material). However, the Boteti experience also exposed a number of challenges to the operationalization of the approach, which may be relevant to other developing country contexts:

i) The high illiteracy rate among land users constrained progress with some of the more technical exercises in the WOCAT process (e.g. impact chain analysis and scoring of the strategies);

ii) High poverty levels among land users meant some remediation strategies were beyond most people's reach, requiring capital outlays (e.g. biogas production), which delayed the piloting of agreed strategies. Indeed, it is on this account that the most preferred (and arguably the most effective) remediation strategy (community-based game ranching) could not be adopted for piloting. The approach assumes that there will be a number of SLM options that are not already being used by land users, that will not require significant capital investment or be associated with significant opportunity costs, and this assumption may not be valid in some of the poorest communities of the world

iii) WOCAT workshop 2 requires access to electricity to run the 'facilitator software'. While this was not a problem in the Boteti case, it would surely be an obstacle in more remote areas with no or unreliable power supply

6. Conclusion

The dynamic, context-specific and value-laden nature of land degradation makes it hard to address mechanistically. There can be no simple, universal system for assessing land degradation or identifying relevant SLM options to prevent or tackle the problems it causes. Instead, land degradation assessment must recognise a multiplicity of perspectives, and cannot be judged in isolation from those who face its consequences

(Warren, 2002; Reed et al., 2011) propose a methodological framework for land degradation and SLM monitoring and assessment (Figure 1) that attempts to marry information about environmental change from different research disciplines and stakeholders. This paper shows how this framework has been applied in the Boteti District of Botswana, one of the study sites for the DESIRE project.

The paper illustrates methods that may be used to operationalise Reed et al.'s (2011) methodological framework, which could be applied in a variety of contexts internationally. It identifies a number of benefits associated with the proposed framework, notably related to insights arising from the integration of local and scientific knowledge, and the ownership of the SLM strategies that emerged from the process. However, implementing the framework was not without challenges. In some developing country situations, the operationalization of the methodology might be restrained by various challenges related to general underdevelopment or, as Penning de Vries (2007) puts it, "capability" problems. As the framework is applied in different contexts through the DESIRE project and elsewhere internationally (e.g. Ravera et al., in press), it will be possible to learn more about how researchers and stakeholders can work more effectively together to monitor and respond to land degradation.

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Table 1: Boteti land users' objectives for sustainable land management (source: Workshop 1)

Objective	**Appropriate technology**	**Adequate approaches**	**Responsible stakeholders**
To address the issue of shortage of water	Building dams	- Submit application for land. - Submit application for financial assistance.	- Land Board - Farmers - Agricultural extension workers - Financial assistance agencies
To reduce the impact of drought on harvests	Irrigation farming	- Submit application for land. -Produce a management plan. - Submit application for financial assistance -Produce a training plan for farmers.	- Village leaders (Village Development Committee). - Land Board - Agricultural extension workers and soil specialists - Arable farmers
To reduce depletion of trees	Use bio-gas as energy for cooking	-Submit application for land. - Submit application for financial assistance -Produce a training plan for implementers and or users.	- Village leaders (Village Development Committee). - Land Board - Local community - Rural Industry Innovation Centre (RIIC)
To reduce poverty	Divert to wildlife ranching	- Submit application for land. -Produce a management plan. - Submit application for financial assistance -Produce a training plan on wildlife ranching.	-Department of Wildlife and national parks (DWNP) and wildlife ranching experts - Village leaders (Village Development Committee). - Land Board - Local community

Source: Magole et al. (2008), p.10.

Table 2: Land user identified indicators

Negative or degradation indicators – Degradation	**The positive attributes or indicators – Conservation**
Lack of vegetation, no regeneration and germination	The river starts flowing again
Uncontrollable winds	Good rains
High temperatures	Good harvests (high crop yields)
Wild fires	Acceptable levels of soil and water salinity
Depletion of underground water	Soil fertility increases
No dew (due to dry atmospheric conditions)	Improved (raised) underground water table
High mortality rate of livestock	Dams, ponds, pans and lakes fill up with water.
Low weight and weak livestock	More food for both animals and people
Trees and other vegetation (e.g. weeds) die	Good vegetation cover
Browning (as opposed to greening) of the land	Animals recover and start to reproduce
Pans, dams and lakes dry up	Increased and improved quality of wild fruits
Extinction of certain plants	Wild animals re-appear
Poor soil conditions, crusting	Food becomes abundant
Some grasses disappear	Greening of the land
Low yields	Birds and other wildlife begin to sing
Shortage of water for both animals and people	
Some of the soils become disturbed (loose, poor)	
High water salinity	
High soil salinity	
Wildlife disappears e.g. animals, butterflies, etc	
Drying of the river (Boteti R.)	
Too much dust	
Poverty and hunger	
Cattle tracks expose soil leading to erosion and sand mounds	
Increasing and spreading of certain vegetation species	

Source: Magole et al. (2008), p.7

Table 3. Financial performance of biogas expressed in firewood collection opportunity costs under various scenarios.

	Daily household dung collection costs		Daily household firewood collection opportunity costs	
	Pula	%[a]	Pula	%[a]
Cattle distribution				
Scenario A: Cattle uniformly distributed[a]	6.84	100	13.82	100
Scenario B: Cattle herds from 11 km	8.51	124	15.46	112
Scenario C: Cattle herds beyond 20km	12.37	181	19.35	140
Efficiency and socio-economic dynamics				
Scenario D: Biogass covers 75% of demand	11.09	162	18.06	131
Scenario E: Firewood price rise trend 10%	6.84	100	6.45-18.47	47-134
Scenario F: No cost dung collection <1km	4.59	67	11.58	60
Scenario G: On foot dung collection only	95.93	1402	102.92	745

[a] Scenario A is used as baseline; percentages are relative to this scenario.

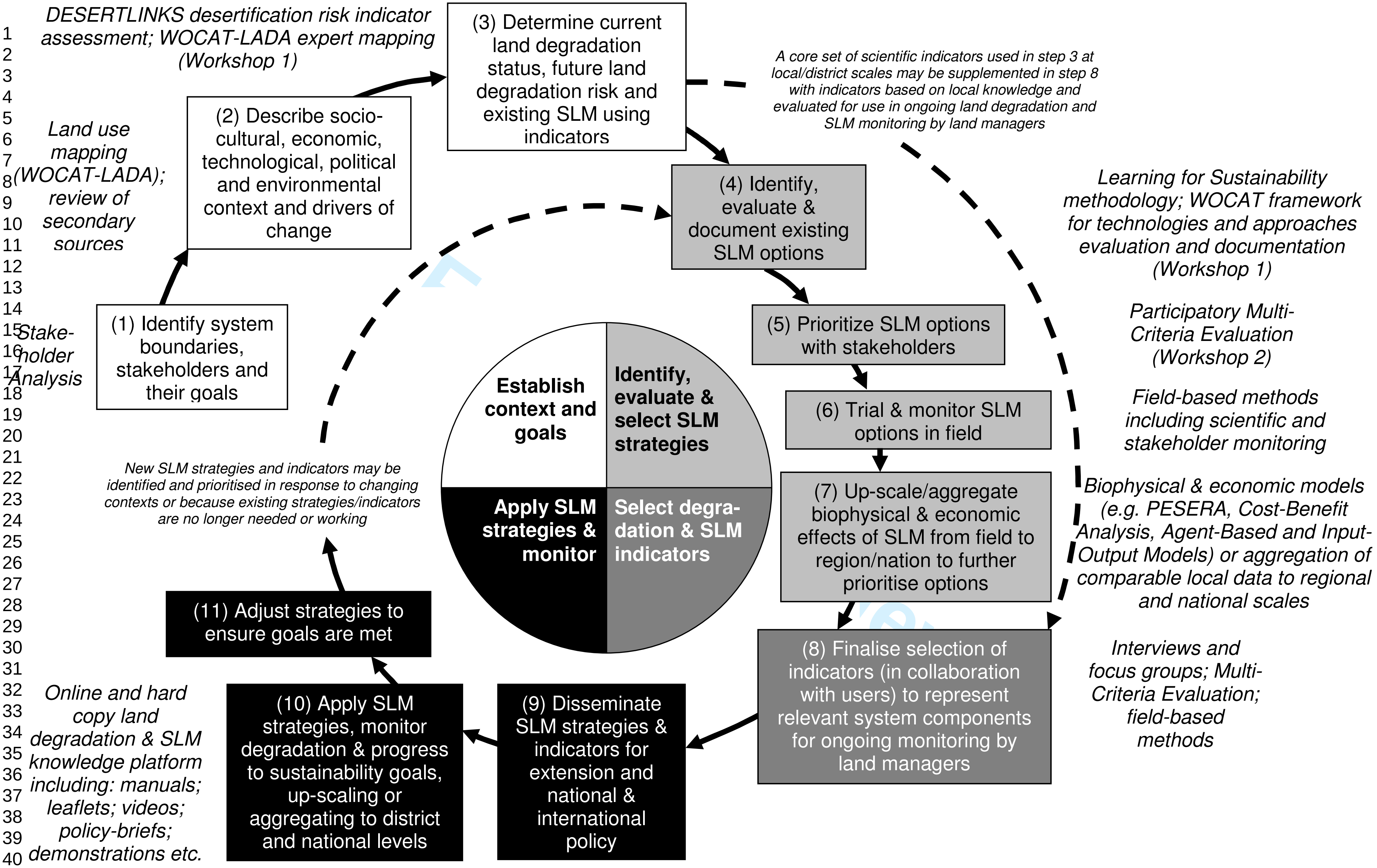

Figure 1: Integrated methodological framework for land degradation and SLM monitoring and assessment, building on the DESIRE, WOCAT, LADA and DDP approaches, providing examples in italics around the outside of the figure that show how each step may be operationalised (drawing mainly on experience from the DESIRE project). Dashed arrows represent potential links that may not always be realised (adapted from Reed *et al.*, 2011).

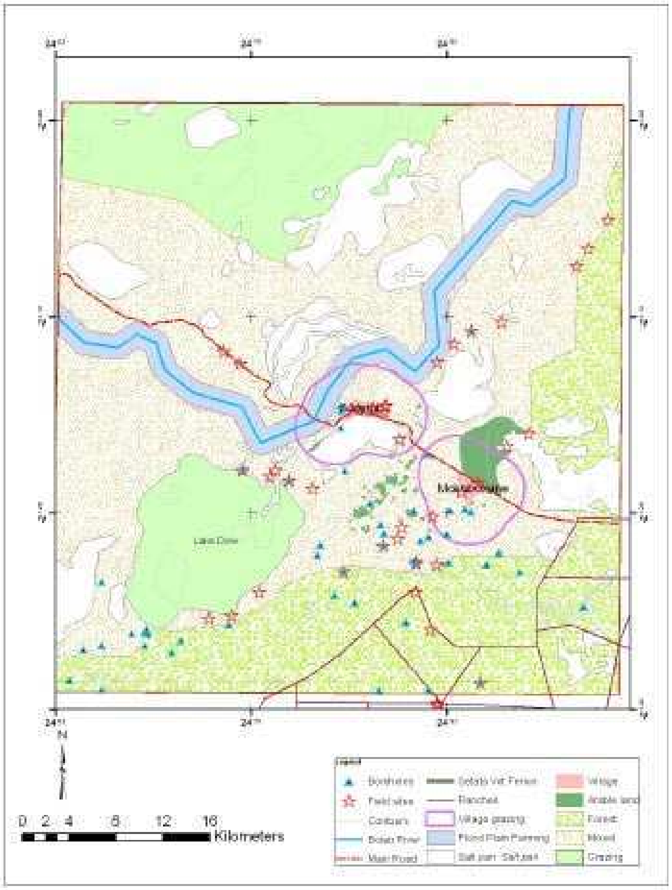

Figure 2: The Botswana DESIRE study site (Source: Sebego, RJ, Botswana DESIRE team)

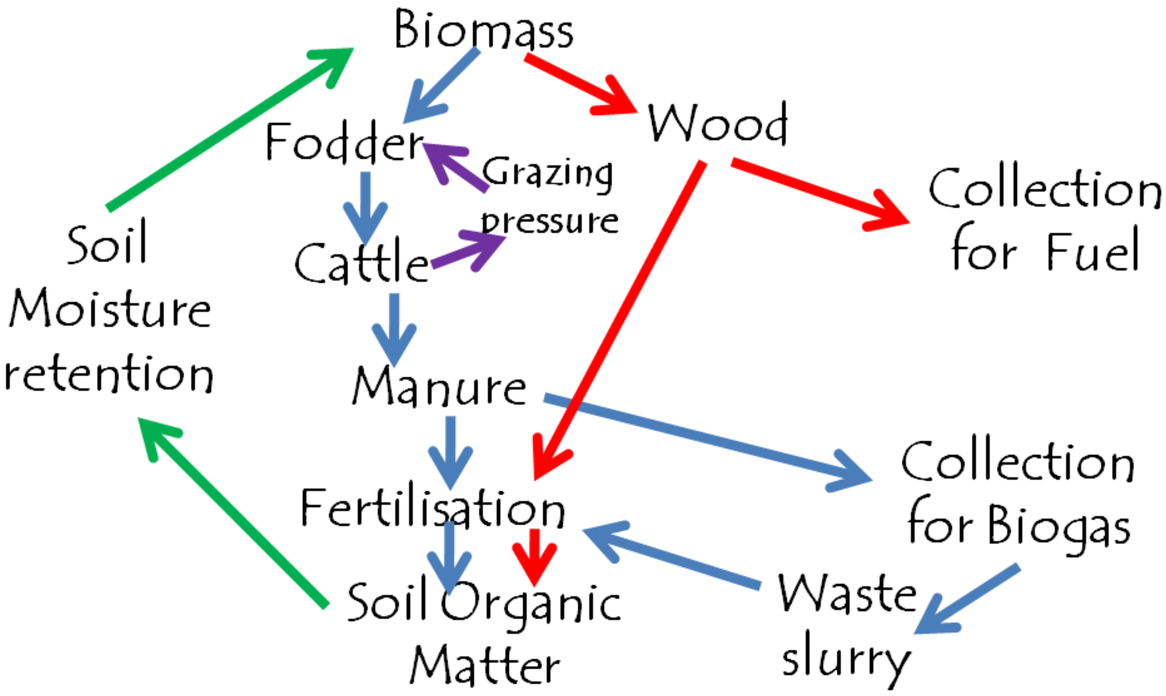

Figure 3: Modelling alternative uses of biomass resource

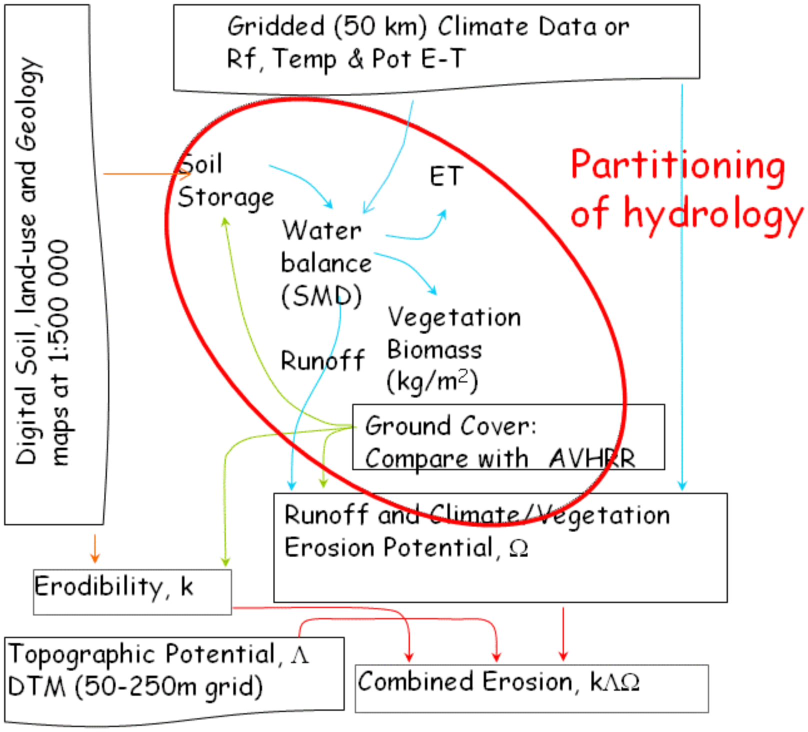

Figure 4: Schematic diagram showing how the Pan-European Erosion Assessment (PESERA) model partitions rainfall into components for overland flow, evapotranspiration and changes in soil moisture storage .

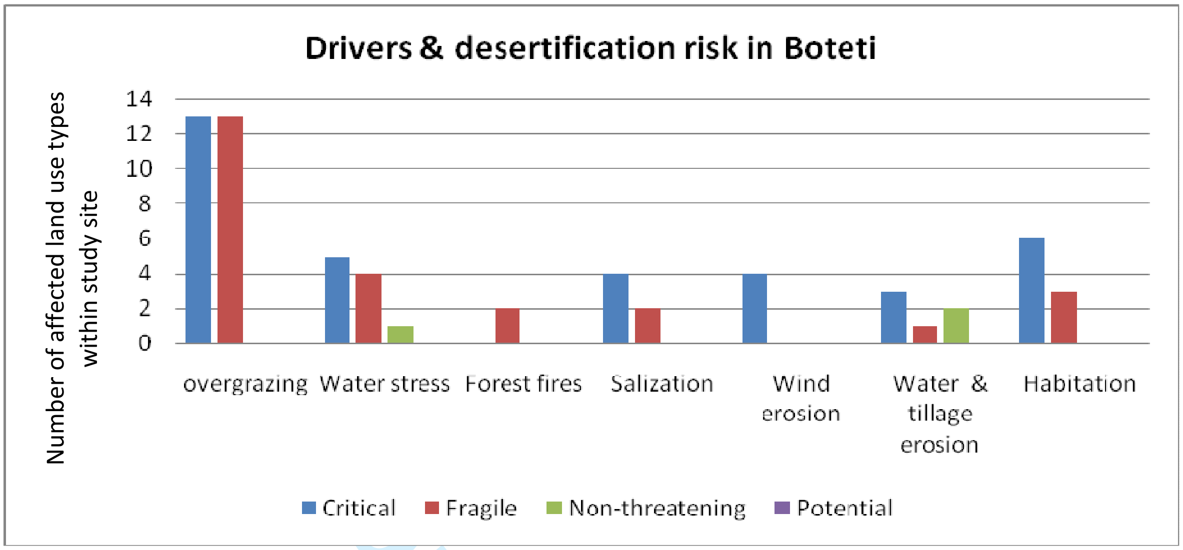

Figure 5: Land degradation drivers and desertification risk in Boteti, showing the number of land use types within the study site where different drivers of land degradation were deemed to be occurring, according an expert assessment of indicators by researchers and land managers (Source: Chanda et al., 2009a)

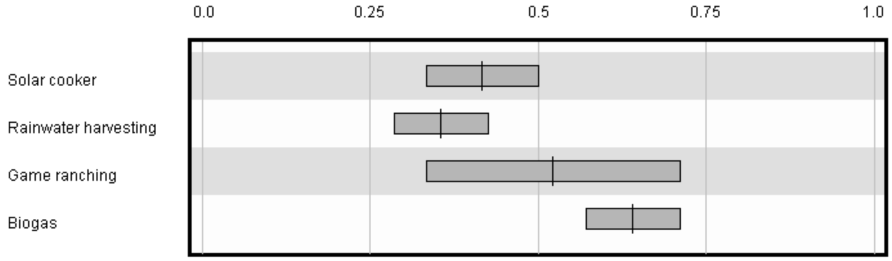

Figure 6: Perceived ecological impact of solar cooker, rainwater harvesting, game ranching and biogas, where 1.0 is a beneficial ecological impact an 0.0 is a negative ecological impact, and width of bar represents the breadth of responses received and hence the level of agreement or disagreement between stakeholders (narrow bar represents high levels of agreement and wide bar represents a wide range of different answers) (Source: Workshop 2 report; Magole et al., 2009, p. 11)

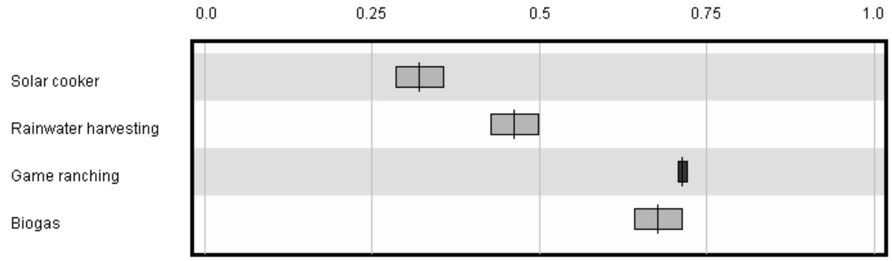

Figure 7: Perceived economic impact of solar cooker, rainwater harvesting, game ranching and biogas, where 1.0 is a beneficial economic impact an 0.0 is a negative economic impact, and width of bar represents the breadth of responses received and hence the level of agreement or disagreement between stakeholders (narrow bar represents high levels of agreement and wide bar represents a wide range of different answers) (Source: Workshop 2 report; Magole et al., 2009, p. 11)

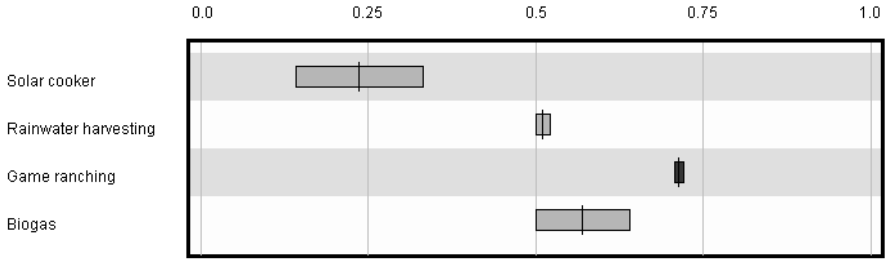

Figure 8: Perceived socio-cultural impact of solar cooker, rainwater harvesting, game ranching and biogas, where 1.0 is a beneficial socio-cultural impact an 0.0 is a negative socio-cultural impact, and width of bar represents the breadth of responses received and hence the level of agreement or disagreement between stakeholders (narrow bar represents high levels of agreement and wide bar represents a wide range of different answers) (Source: Workshop 2 report; Magole et al., 2009, p. 12)

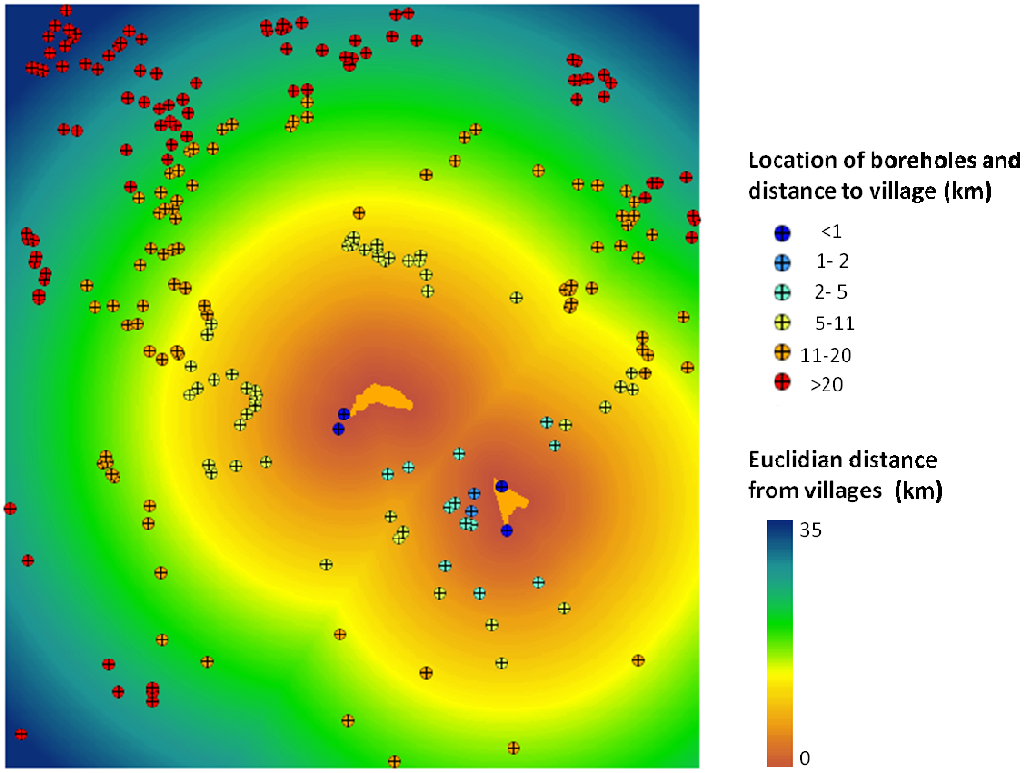

Figure 9: Location of the 378 boreholes (potential dung collection sites) in the study site relative to the villages Mopipi (centre) and Mokoboxane (south-east of Mopipi)

Online supplementary material

Video of local residents from the villages of Rakops, Mopipi and Mokoboxane talking about the environmental problems they are currently facing and their hopes for how the DESIRE project will help them:

http://www.desire-his.eu/index.php?option=com_content&view=article&id=388:interviews-with-local-people&catid=228:boteti-botswana&Itemid=155&lang=en