A CASE STUDY:

BUILDING RESILIENCE IN RANGELANDS THROUGH A NATURAL RESOURCE MANAGEMENT MODEL

Ecosystem-based approaches to adaptation: strengthening the evidence and informing policy

CONSERVATION SOUTH AFRICA

Member of the CI Network

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Contents

Acronyms

BACIP	Before-After-Controlled-Impact-Paired study design
CSA	Conservation South Africa
DEA	Department of Environmental Affairs
EbA	Ecosystem-based Adaptation
EPWP	Expanded Public Works Programme
IIED	International Institute for Environment and Development
IUCN	International Union for Conservation of Nature
SANParks	South African National Parks
UNEP-WCMC	United Nations Environment Programme - World Conservation Monitoring Centre
WfWet	Working for Wetlands programme

Introduction

The Succulent Karoo, including Namaqualand is globally recognized as a semi-arid biodiversity hotspot (Myers et al 2000) and is particularly vulnerable to climate variability. Temperatures as well as hot extremes have increased over the last century, specifically minimum and maximum temperatures have increased by 1.4°C and 1.1°C respectively, with an increase of 30 mm evapotranspiration per decade in coastal regions (Davis et al 2016). While there is no evidence of changed mean annual rainfall, changes in spatial variability and increased temperatures present challenges for water security in the area (Davis et al 2016; Reid et al 2018). Arid rangelands are vulnerable to land degradation, e.g. loss of vegetation and soil (Bourne et al 2017a). This is presently exacerbated by anthropogenic threats to habitat and biodiversity, such as overgrazing of livestock that is linked to poverty, resulting in a climate-resources-poverty nexus.

Anthropogenic threats to diversity in the biome are not likely to reduce under present climate scenarios (Driver et al 2003) because local capacity to adapt to climate change is very low (Bourne et al 2015). Adaptation could take the form of fodder subsidies for livestock or alternative livelihoods but because the Northern Cape is one of South Africa's poorest provinces, many households in the rural areas rely on livestock farming as a major source of income beside social grants, leaving the communities extremely vulnerable should farming fail (Gardiner 2017; Jansen 2017). Since the area is arid, very large areas of land are needed to sustain relatively few animals (Bourne et al 2015). This means that farming is on the margins of economic viability and the continuous use of rangelands (overgrazing) and overstocking by resource-poor farmers to extract more income is common, causing increasing loss of plant diversity and cover (Todd and Hoffman 1999) and ultimately soil erosion. Pastoralists opportunistically use ephemeral wetlands to provide their livestock with water and fodder during the dry summer months (Bourne et al 2017b) and this may also lead to loss of wetlands and soil if there is uncontrolled and unmanaged grazing. Sheet erosion is the progressive removal of very thin layers of soil across extensive areas by wind and water. Gully erosion is where channels are cut when water flows down livestock paths, roads or areas affected by sheet erosion. The presence of erosion gullies is a clear sign of rapid water flows, plus soil and organic matter from an area.

Rangelands and wetlands provide crucial water, soil and grazing services (Ziervogel et al 2014; De Villiers 2013) to the same rural communities that threaten their provision, and this problem is further exacerbated by climate change, i.e. this is a 'wicked problem'. It is possible that Ecosystem-based Adaptation (EbA) can overcome this problem by helping sustain agricultural production while maintaining the ecological infrastructure that supports this production.

EbA is the use of biodiversity ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change. EbA approaches or strategies consider ways to manage ecosystems so that they can provide the services that reduce vulnerability and increase the resilience of socio-ecological systems to both climatic and non-climatic risks, while at the same time providing multiple benefits to society. EbA uses sustainable management, conservation and restoration of ecosystems. It considers the anticipated climate change impact trends, in order to reduce vulnerability and improve the resilience of ecosystems and communities. It is important to develop the resilience of farming communities to climate change, by restoring the capacity of ecosystems to retain soil, provide fodder, replenish aquifers, store water, and reduce the impacts of flooding. At a broader scale, EbA is not being sufficiently mainstreamed into some international and national policy processes and programmes (Reid et al 2019). This is partially due to a lack of robust quantitative data on the effectiveness of EbA, despite information or guidance on methodologies for mainstreaming EbA into new and existing programmes of work, and metrics to monitor this effectiveness.

Nationally, ecological restoration and rehabilitation projects focused on clearing alien vegetation from river courses and restoring degraded wetland ecosystems have been active for over two decades. These have been implemented largely through government funded Natural Resource Management (NRM) programmes, as part of the Expanded Public Works Programme (EPWP) led by the Department of Environmental Affairs (DEA). More recently, restoration activities in Namakwa District focus on reversing sheet and gulley erosion of soil. These interventions comprise low-cost, low-technology soil stabilization measures such as un-caged gabions and micro-catchments or ponds (soft options). They are expected to reduce water run-off and increase sediment capture, water infiltration into the soil, soil moisture content, and ultimately vegetation cover. Conventionally, wetlands and rangeland restoration in the Namakwa District is accomplished using engineered options such as caged gabions, concrete water culverts and earth works (hard options) estimated to cost ca. ZAR143 354 per hectare (Black & Turpie 2016), while soft options were estimated to cost ZAR10 350 per hectare (Marais 2018).

Until recently, monitoring of the NRM programme has focused mainly on activities such as cubic meters of gabions constructed and jobs created. The outcomes and impacts of these activities, including the co-benefits, are not being considered. Although there is presently an effort to develop socio-ecological metrics for the NRM programmes (Marais 2018), which is a move towards an EbA approach, we need to quantify the efficacy of these soft options of erosion control, before DEA NRM can invest and implement these options at scale.

Within this context and in collaboration with International Institute for Environment and Development (IIED), International Union for Conservation of Nature (IUCN) and United Nations Environment Programme - World Conservation Monitoring Centre (UNEP-WCMC), Conservation South Africa (CSA) aimed to test whether soft options of soil erosion control could provide both socio-economic and ecosystem benefits (as improved soil capture and hydrology) that support an EbA approach. At the same time, the study informs the development of a broader metrics process and tests whether EbA can be integrated into NRM programmes at scale.

The main hypothesis for the case study was that NRM programmes have restoration outcomes and socio-ecological benefits through direct ecological restoration of soil erosion, and social benefits via employment, training and community driven climate adaptation activities. Specific questions were:

1. Is there an improved understanding of climate change through the programme?
2. Is there an improved understanding of the programme among NRM workers in relation to climate adaptation?
3. What are the challenges and benefits of the programme in relation to adaptation?
4. Can low-cost, soft erosion control structures slow run-off of water during rainfall events in arid rangelands and thus increase soil retention and water infiltration?

Long-term, we expect that increased soil retention and infiltration will increase the net primary productivity of rangeland and thus the resilience of rangelands to extreme weather events.

Sheet erosion is the removal of thin layers of soil by wind and water
Gully erosion is the removal of soil in deep channels due to water flows over bare areas such as roads, livestock paths and sheet eroded areas

Photo I A Before-After-Control-Impact-Paired (BACIP) study site is prepared by employees of the Natural Resource Management (NRM) Land User Incentive programme.

Materials and methods

Climate and biophysical characteristics of the study area

The study site is in Namaqualand, specifically the Leliefontein commonage in the Kamiesberg Local Municipality, Namakwa District of Northern Cape, South Africa (Fig. 1). The climate of Namaqualand is determined mostly by the southern subtropical high-pressure system and circumpolar westerly airstream, with geographic and marine features (mountains and the cold Benguela current) influencing local climate (Tyson & Preston-Whyte 2000). Mean annual precipitation (MAP) for the Kamiesberg is 428 mm (Tyson & Preston-Whyte 2000) with an extremely low average of 138 mm in 2017 (measured in this study). More than 60% of MAP falls in antipodal winter between May and September as a result of cold westerly fronts from the southern oceans. Mountains receive more precipitation than the surrounding plains (Desmet 2007). The Orange River, with its origins over 2000 km away in the Lesotho Highlands, is the only perennial river in the District and supplies much of the fresh water for the towns in the northern parts, with the rest coming from groundwater. Temperatures range between -3°C and 36°C. Maximum temperatures vary between 1.8°C and 35°C in winter (from March to August) and 6°C and 36°C in summer (September to February). Minimum temperature varies between -3°C and 24°C in summer and -3°C and 23°C in winter (Tyson & Preston-Whyte 2000).

Namaqualand has a great diversity of soil types that can be broadly grouped into three categories (inland weakly structured grey, yellow or red medium grained sands from aeolian reworking of marine or fluvial deposits; coastal red, granite-derived colluvial soils rich in clay near the coastal plain; and shallow undifferentiated free-draining red and yellow sandy to loamy soils (Hengl et al 2017), upon which our study sites were situated. Soils at the site are shallow with ca. 70% of the soils comprising sand but also high percentages of clay (Table 1). The vegetation types comprise Namaqualand Klipkoppe Shrubland and Namaqualand Blomveld (Mucina & Rutherford 2006, Fig. 1).

Table 1 | Rainfall and soil characteristics (Hengl et al 2017) of the study site.

Erosion type	Rainfall (2017-2018)	Depth to bedrock	Bulk density	Soil pH	Clay	Silt	Sand	Course fraction	Soil organic matter
	(mm)	(mm)	(g m^{-3})				(%)		
Gully (n=6)	188	1013 ± 73	1.45 ± 0.01	7.2 ± 0.04	16 ± 1.2	13 ± 0.5	70 ± 2	11 ± 1	3 ± 0.3
Sheet (n=4)	207	1134 ± 10	1.44 ± 0.0	7.0 ± 0.0	14 ± 1.5	14 ± 0.4	69 ± 2	13 ± 0.2	4 ± 0.3

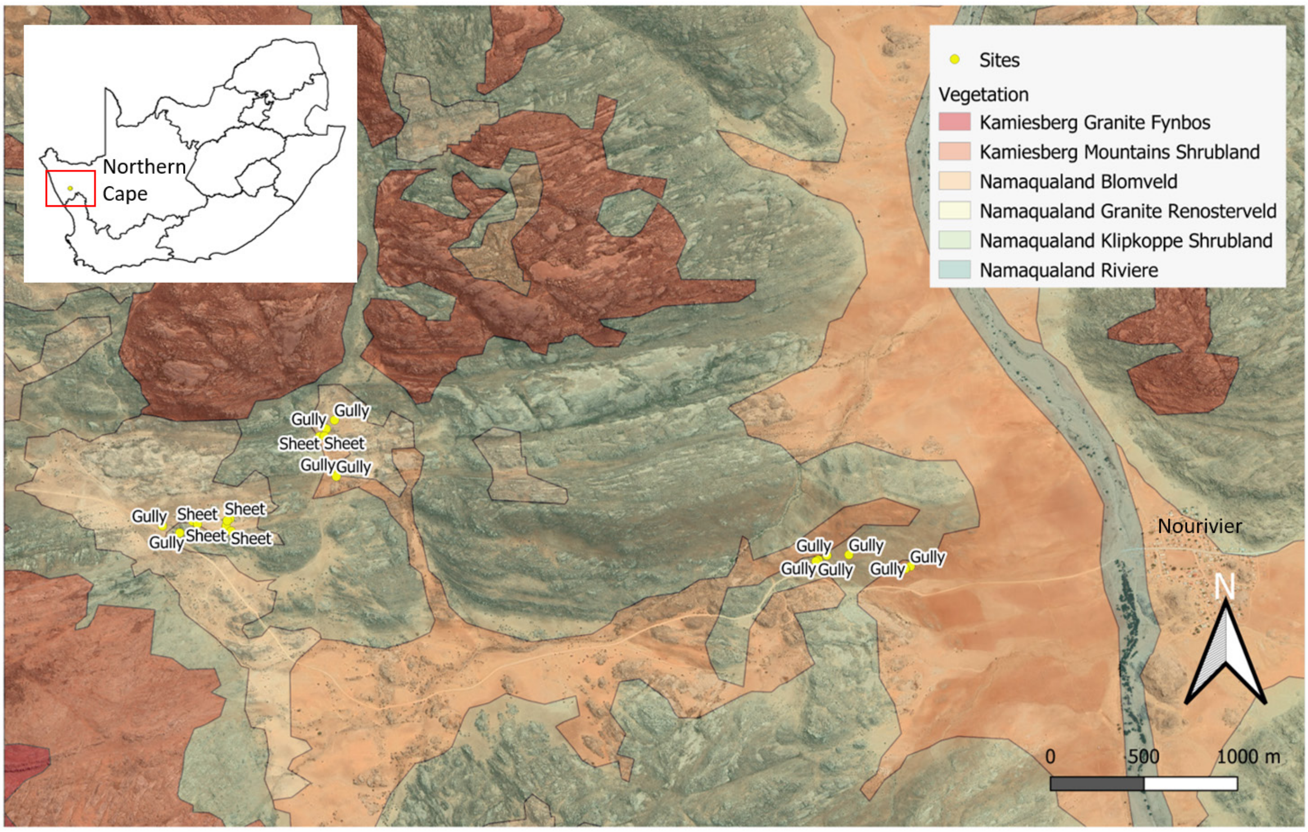


Figure 1 | Location of the paired experimental sites in the local vegetation and topography within the Leliefontein commonage, Kamiesberg Local Municipality, Northern Cape. One member of each paired site comprised low-cost erosion control structures on gully or sheet eroded areas while the other pair had no structures.

Socio-economic characteristics of the study area

Together with the aridity of the area, a dependence of the Namaqualand population on natural resources (e.g. grazing, fuelwood and medicines), livestock production and agriculture increases the vulnerability of people to climate change. Agriculture, mostly small stock (sheep and goats) production, is the primary land use amongst both communal and private land owners in Namaqualand, including the study area (Rohde et al 2001). There is some cultivation of arable allotments (oats, wheat, rye and barley) for growing additional feed for livestock, when conditions are suitable. Crop failures are frequent, and returns are highly variable. Consequently, crop farming constitutes a very small part of livelihoods. Herds comprise goats and sheep, which are herded by day and kraaled at night in stockposts. Boer goats and a hybrid mix of Karakul, Persian, Dorper and indigenous Afrikaner sheep are kept in a ratio of 55% goats and 45% sheep, though this may vary between herds. The mean size of a herds owned by each of the 42 farmers participating in the CSA stewardship programme is generally low: around 51 animals (based on recent stock counts). The stocking rate (hectares per large stock unit) of Leliefontein and Paulshoek has been as much as twice that recommended by the South African Department of Agriculture (Todd & Hoffman 1999; own stock counts 2014 to 2019). Regulations and mutual arrangements between communal livestock farmers do exist to control land use (May 1997). However, no formal written controls are in place with regards to stock numbers or movement (May 1997).

Animal production is mainly aimed at household consumption and exchange within families. It serves a savings function with few livestock owners selling animals on commercial markets (Anseeuw 2000). In the villages where the socio-economic surveys were conducted, only ca. 17% of the farmers in the Leliefontein commonage indicated that livestock production and dryland cultivation are their main source of income (Gardiner 2017) and ca. 11% of farmers in the Steinkopf commonage (Jansen 2017).

The unemployment rate among 15 to 64 year olds is highest (31%) in Kamiesberg Local Municipality, where NRM programmes are implemented, compared to the average of 20% for the District (Statistics South Africa 2016). Up to 64% of farmers in the Leliefontien and Steinkopf commonage rely directly on state grants as their main source of income (Gardiner 2017; Jansen 2017). Mines, commercial farms and larger towns such as Springbok, Vredendal and Cape Town, provide the main source of employment to people from the Leliefontein commonage (Simons 2005). Earnings from mining and commercial agriculture are unreliable, as much of this work is on a contract or seasonal basis and the future of these industries in the province is very uncertain (May 1997; Anseeuw 2000).

Socio-economic survey

Employees of the NRM Land User Incentive programme were deliberately targeted as participants for this survey (n = 106) since it was the programmes objective to inform its future practices. However, results should be interpreted in the context of non-random sampling open to bias, e.g. prone to overestimation of benefits and underestimation of challenges due to potential fear of retribution or desire to please the employer. Prior to the survey all NRM participants received accredited training on combatting soil erosion control (SAQA US ID – 252457, NQF Level 2, Credits 8). All participants were informed about the objectives of the study, assured of anonymity and given the option to opt out of the study at any time. Participants within three villages (Nourivier, Leliefontein, Steinkopf) from two communal farming areas (Leliefontein and Steinkopf) were interviewed in 2017 and again in 2018 in their home language, at a place convenient to them, during working hours. Interviews comprised semi-structured, face-to-face interviews including closed- and open-ended questions. Respondents in the two years were the same people as far as possible but some respondents were different between the two years. The survey was conducted by completing printed questionnaires and capturing the data using an online survey tool (Survey Monkey: https://www.surveymonkey.com/). Surveys were conducted in April 2017 and February 2018 in all three villages. Generally, questions aimed to understand whether the programme had increased understanding of climate change and natural resource management, and what challenges and benefits participants experienced during the programme. Scores of understanding of NRM or climate change were calculated by counting the occurrence of relevant phrases and expressing as a score between 0 and 1 after logit transformation. Social perceptions complemented the biophysical study, which tested efficacy of one aspect of the program (erosion control).

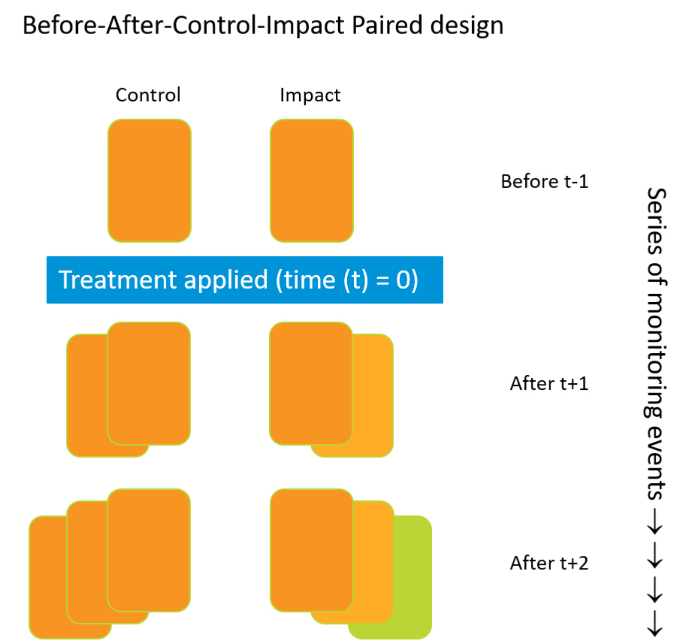
Biophysical study design

A Before-After-Control-Impact-Paired (BACIP, Fig. 2) study design was used to test the biophysical impacts of NRM interventions to control and reverse sheet and gulley erosion of soil. The BACIP design is recognized as being highly suitable for measuring change after a restoration activity has been implemented (Smith 2002). In more detail, each replicate in the study comprised paired sites that were similar in degree of erosion. Measures of sediment capture and water infiltration were taken after each rainfall event, both before the start of the experiment (November 2017 for sites 8 and 9, March 2018 for sites 1, 2, 3, 4, 5, 6, 7 and 10), and after low-cost structures were installed (gabions for gully eroded sites, micro-catchments and sloping for sheet eroded sites) then after each rainfall event up until October 2018. Only the 'Impact' member of the pair received treatments, while the other member in a pair did not, i.e. was a control. The use of measurements before treatments as well as the paired Control-Impact approach served to account as far as possible for variability from other independent variables besides the treatment, e.g. soil type, rainfall, land use (Control-Impact-Paired aspect of the study). This also allowed the calculation of a relative difference value (delta Δ) for each site, allowing the combination of diverse sites as replicates, e.g.

$$\Delta = I_{t=x} - C_{t=x}$$

Where Δ is the difference in sedimentation, runoff or infiltration, I is Impact, C is Control for any site and t indicates time, and x indicates a particular point in time.

Sediment capture was measured as the relative position of soil on numbered, graduated erosion pegs placed at all sites and geolocated before treatment (Fig. 3). A total of 25 1.2 m iron pegs were placed per pair and spaced 2 x 2 m apart (sheet eroded



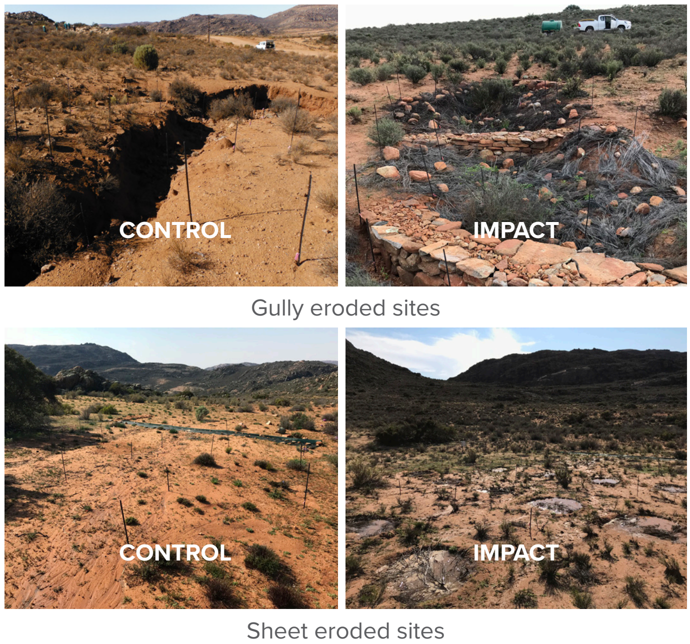


Figure 2 | Theoretical framework for comparing soil erosion structures using the Before-After-Control-Impact-Paired (BACIP) design. Paired sites are monitored both before and after applying treatments to account for variability from other variables besides the treatment.

Figure 3 | Placement of erosion pegs as part of the Before-After-Control-Impact-Paired (BACIP) design on sheet (bottom) and gully (top) eroded sites, where interventions were placed on Impact (right) but not Control (left) sites).

sites) or 1 m apart across a gully and 2 m apart along the length of the gully. At gullies, the third peg in each row was always placed so that it was in the middle of the gully floor. Pegs were installed to a depth of 0.6 m with a maximum depth of 0.9 m below or above the soil surface. Directly after installation, the height of the soil on the peg was recorded as the t=0 soil level, and subsequently measured after each rainfall event of more than 1 mm as a measure of sediment capture.

Run-off data was collected using a gutter system installed at the down-slope extent of each site. The gutter system channelled run off water to a water meter which was logged in real time by a CR200 series datalogger using LoggerNet v. 2.1 Software. A 12V DC 12 Ah sealed rechargeable battery powered the dataloggers. Unfortunately, waterflow between the gutter and the soil surface resulted in small rills eventually diverting all run-off water underneath the PVC gutter, making these measurements unusable. An alternative rainfall simulation and infiltration experiment was conducted 18 months after treatment implementation for sites that could be reached with a vehicle, specifically three gully paired sites (sites 3, 8 and 10) and four sheet paired sites (sites 4, 5, 6 and 9, Fig. 4). A petrol pump was used to pump water from a water bowser to a network of pipes with sprayer heads to simulate rainfall at each site. The volume of water required to initiate run-off was recorded. This volume was used as a proxy for volume of water infiltrated into the soil.

Rainfall was collected continuously and recorded after each rainfall event using a conventional rain gauge at three sites and in the nearby Nourivier village (Fig. 1). As a result of the low number in rainfall events, the study extended over an 18 month period (April 2017 to October 2018). Rainfall events were small, between 1 mm and 27 mm.

Statistics

All data was inspected for normal distribution and assumptions of linearity before resorting to logit (proportional data) or log (continuous data) transformation as a corrective measure. Analysis of variance on drivers of response variables (social perceptions, sediment capture, infiltration) were performed on both transformed and untransformed data with similar results, using ANOVA or Kruskal-Wallis tests, or paired t-test/ Mann Whitney test, respectively after selecting potential explanatory variables from matrices of Pearson product-moment correlations. Predictors of response variables were tested using linear mixed-effects models (Harrison et al 2018) with the 'lme4' package (Bates et al 2014) in R (RCoreTeam 2016). Briefly, significance of the overall best-fit linear mixed-effects models used the maximum likelihood test and t-tests to determine the significance of terms within the model using the Satterthwaite's method ['lmerModLmerTest'] with an ANOVA-like table produced for random effects. Erosion control treatments, and social aspects such as gender were considered fixed effects while variables designating nonindependence of replicates (i.e. repeated measures in years 2017 and 2018, respondents) were considered random effects.

Figure 4 | Rainfall simulation and infiltration experiment using a series of water pipes connected to spray heads (top), which received water from a water bowser via a petrol pump and sprayed over the paired sites until run-off occurred (bottom).

Results

Socio-economic survey

The demographics of respondents was fairly balanced with 55% females and most (79%) respondents being between 18 and 50 years old and the rest between 50 and 70 years old. Over half (63%) of respondents had some high school education, while only 27% had completed high school and only 2% had tertiary education. Each household comprised about 4.6 ± 0.2 people with 1.5 ± 0.1 of those being employed. Much of the income per household (38% ± 2) came from government grants (pension, child support, disability, youth and other) while 20% were previously employed through other EPWP programmes.

Most participants displayed a basic understanding of climate change using phrases such as 'temperature', 'rainfall', and 'seasonal changes' while some included the phrases 'greenhouse gases' and 'climate patterns' (Fig. 5). Participants could also provide examples of natural resource management where phrases such as 'restoration', 'increased plant cover', and 'ground water recharge' were commonly mentioned while a smaller number of people mentioned the less visible potential impacts of NRM such as 'healthy wetlands', 'healthy crops' 'healthy animals' and 'withstand shocks' (Fig. 6). More people recognized that NRM could result in increased plant cover in 2018 compared to 2017 (Fig. 6). Related to the understanding of climate change and interventions through NRM were benefits perceived from NRM (Fig. 7). Respondents focused on training, employment and the confidence that this provided rather than socioecological benefits such as water and food provision or resilience to climate change. Overall the scores for understanding climate change ranged between 0 and 5 and did not differ with year, age, gender or previous employment (data not show) while scores for NRM ranged between 0 and 10. While NRM scores did not differ with age, gender or previous employment, scores were higher in 2017 versus 2018 ($p = 0.04$, 2-way ANOVA, Fig. 8).

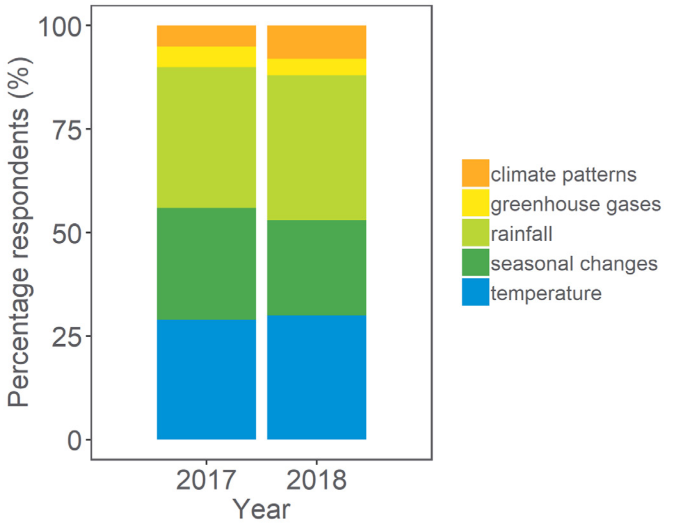


Figure 5 | Phrases mentioned in response to a question about respondents understanding of climate change.

Over half of respondents (58%) said that the NRM programme could improve on how it is delivered, and experienced challenges mainly relating to environmental stressors (heat, cold, wind) and transport, while lesser challenges were a lack of tools and problems with co-workers. Most felt that communication to workers and the employment period were not a challenge (Fig. 9). Importantly, many felt that fetching rocks for gabions at a place distant from the sites (to not erode adjacent areas by removing rocks) was a challenge in 2017 but by 2018 only 3 respondents saw this as a challenge (Fig. 9). The top three recommendations that respondents made to the programme was that the quality of erosion control structures should be improved (accounting for 30% of recommendations), more indigenous plants should be planted (16%) and that the project timescale should be increased (ca. 16%). Other comments accounting for a collective 20% were more information sharing between co-workers, efforts to maintain the erosion control structures, and specific training about climate change. Levels of education, gender, age, previous employment or location did not influence the number of challenges or recommendations reported.

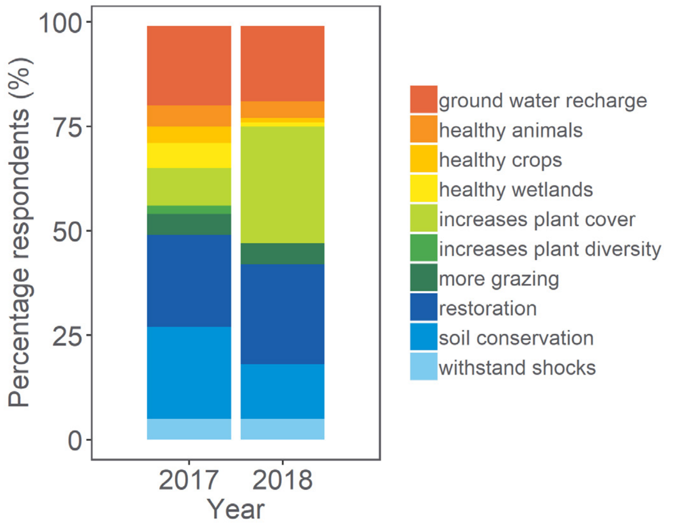


Figure 6 | Phrases mentioned in response to a question about respondents understanding of natural resource management (NRM).

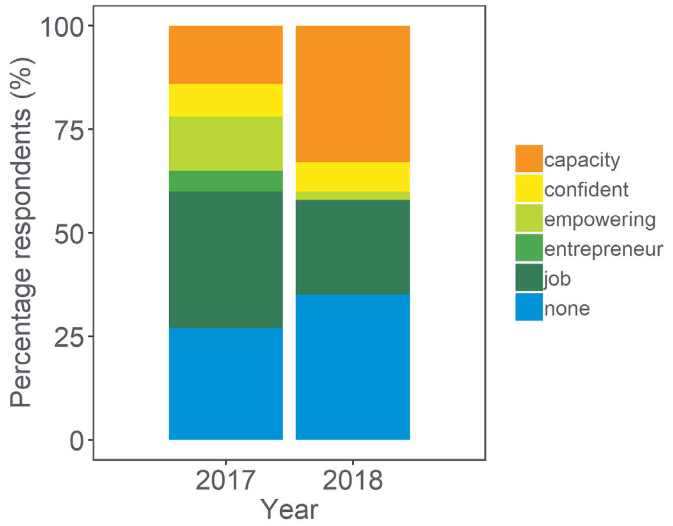


Figure 7 | Phrases mentioned in response to a question about benefits that respondents experienced as part of the natural resource management (NRM) programme.

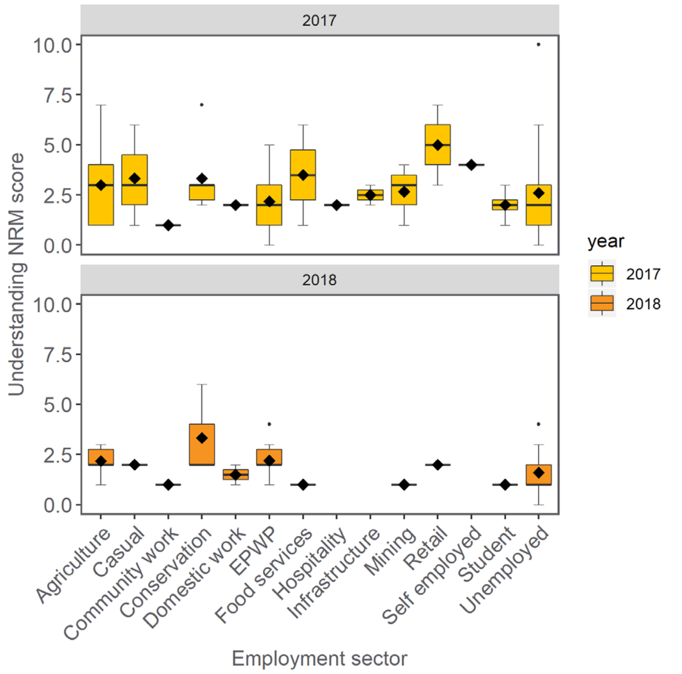


Figure 8 | Scores for understanding of natural resource management (NRM) amongst respondents in communal areas between 2017 and 2018. Boxes indicate where half of the data is distributed while whiskers indicate 25th and 75th percentiles.

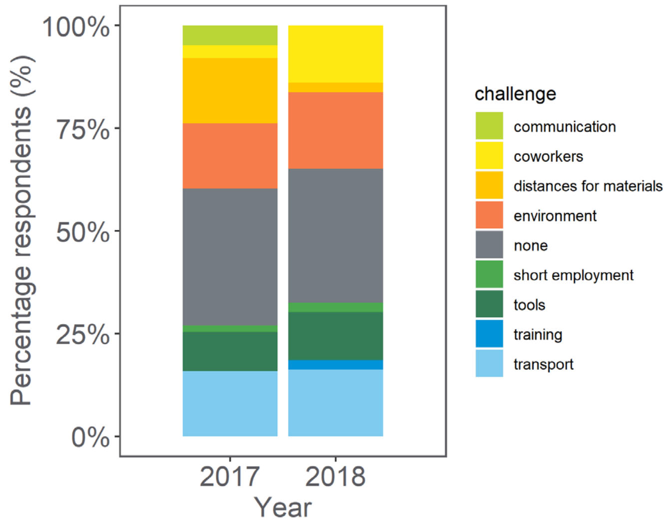


Figure 9 | Phrases mentioned in response to a question about challenges that respondents experienced as part of the natural resource management (NRM) programme.

Biophysical study

We recorded 25 rainfall events ranging between 1 mm and 30 mm over an 18 month period between April 2017 and October 2018 amounting to a total of 188 mm in gully sites and 207 mm in sheet eroded sites (see Table 1). The low cost, low technology gabions captured significant amounts of sediment compared to controls over the study period whether calculated for all pegs (Fig. 10) or the middle pegs only ($p < 0.0001$, paired t-tests). The most parsimonious model to describe overall sediment capture at gully eroded sites was a linear mixed-effects model ($p < 0.0001$):

$$Sediment\ capture\ (mm) \sim treatment + depth\ to\ bedrock(m) + \frac{1}{site}$$

where ~ indicates dependence, and treatment and site were highly significant components of the model ($p < 0.0001$, ANOVA after lmerTest). The addition of soil texture properties and bulk densities of the sites did not improve the model. The middle of the Impact gullies captured ca. 100 mm more sediment than other areas of Impact gully sites, which captured ca. 22 mm. Some areas in gullies lost sediment so that the average sediment capture in gullies with structures was between 5 mm and 45 mm soil (Fig. 10). Control gully sites showed no change in sediment levels (Fig. 10). The amount of rain per event did not affect the ability of the low-cost gabions to capture sediment (data not shown). No significant sediment capture was observed for the sheet eroded sites with micro-catchments, after 18 months of collection (Fig. 10, $p > 0.05$, paired t-tests), although this may change over time.

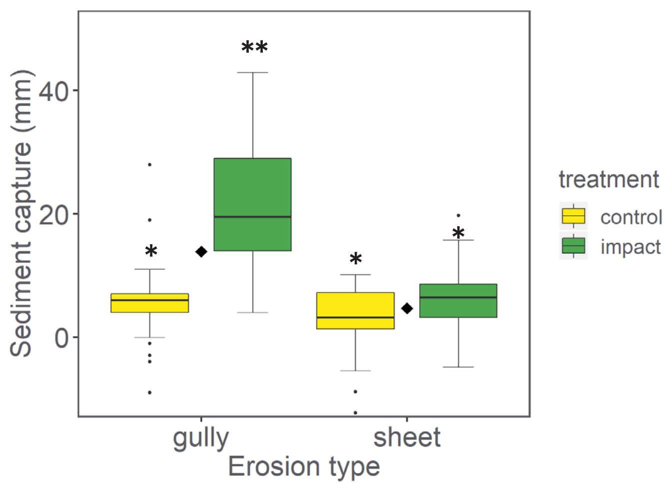


Figure 10 | Sediment capture at gully and sheet eroded sites with (impact) and without (control) the installation of low cost, low technology erosion control structures. Boxes indicate where half of the data is distributed while whiskers indicate 25th and 75th percentiles. Stars indicate significant difference at the $p < 0.05$ level after a one-way ANOVA and post-hoc Tukey test.

The placement of erosion control structures at either gully or sheet eroded sites significantly increased infiltration of water into soils ($p < 0.007$, paired t-test), presumably due to the structures reducing run-off. Infiltration was similar between gully and sheet eroded sites with erosion control structures, and in both cases was higher than the controls ($p = 0.0019$, ANOVA; Fig. 11). The most parsimonious model to describe overall infiltration at both types of eroded sites was a linear mixed-effects model ($p < 0.0002$):

$$Infiltration\ (L) \sim treatment + \frac{1}{site}$$

where ~ indicates dependence, and treatment was a highly significant component of the model (p < 0.0002, ANOVA after lmerTest). Specifically, the sheet erosion sites with structures had to be irrigated with between 1291 and 2822 L of water before run-off was recorded at the down slope end of the site. For control sites, run-off was recorded after the application of between 567 L and 891 L of water. The difference between application volumes for impact and control gully sites was less, where control sites received between 636 L and 861 L of water before run-off was recorded while sites with structures required between 887 L and 2180L of water.

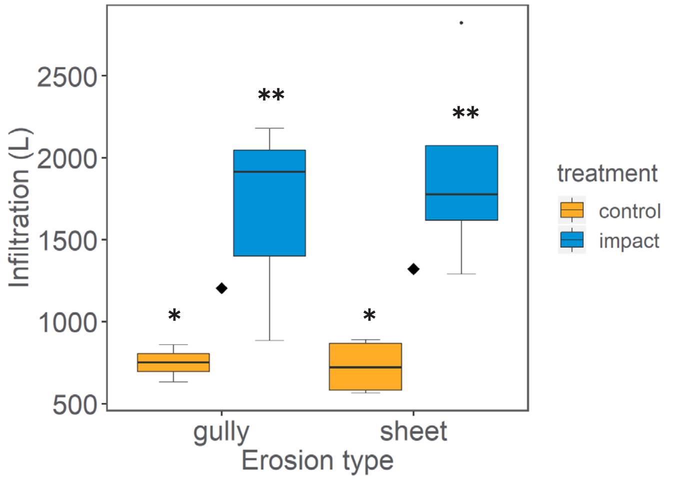


Figure 11 | Water infiltration into soil at gully and sheet eroded sites with (impact) and without (control) the installation of low cost, low technology erosion control structures. Boxes indicate where half of the data is distributed while whiskers indicate 25th and 75th percentiles. Stars indicate significant difference at the $p < 0.05$ level after a one-way ANOVA and post-hoc Tukey test.

Discussion

The socio-economic survey of NRM employees confirmed that most respondents were from low income households where the number of working people per household was low and government grants comprised much of the income. It is evident that the benefits of the NRM programme most valued by participants were a source of income, job creation, capacity building and the increased food security that this would bring. Co-benefits such as increased community involvement, healthier animals, more successful farming, and more water, were not considered direct benefits from the programme, although respondents were aware that these aspects are part of NRM.

Participants had a basic understanding of climate change and the meaning of NRM. The amount of time that participants spent with the programme or had spent in previous EPWP employment, i.e. were trained, did not increase their understanding of climate change, nor did any other demographic variable. However, many respondents have participated in conservation orientated training events in the last decade (H Muller, pers comm) so understanding was relatively high before entering EPWP/NRM programmes. Whether the higher 'NRM understanding' score obtained in 2017 versus 2018 is meaningful is uncertain considering that a few of the respondents were different between the two years, i.e. data was somewhat confounded, but this may reflect inconsistency in training between years. Possibly training scores could increase over time if engagement or training around climate change is consistent (Acker 2018).

The potential for the permanent incorporation of low cost, low technology erosion control structures into NRM programmes was demonstrated in this study based on reduced erosion (measured as increased sediment capture) and water run-off (measured as increased infiltration), despite the small rainfall events during the study. Continued monitoring, including monitoring of vegetation cover of sites, would further contribute to the evidence base for NRM as EbA. In addition the cost-effectiveness and overall implications for climate resilience (e.g. ground water level, soil retention) of this EbA should be compared to gold standard 'hard' options such as gabions in cages and concrete culverts.

Monitoring will also improve programme management, e.g. maintenance requirements of erosion control structures, availability of materials (rocks, brush), and personal protective clothing. Outside the programme, monitoring will enable the government to raise awareness about erosion management for increased ecosystem services amongst implementers, land users and management authorities. Monitoring can take the form of low-cost, low-input erosion pegs, fixed point photographs as well as rainfall measurements, groundwater measurement in wetlands using simple and easily constructible dip wells. A pilot Working for Wetland (WfWet) monitoring team has been operational in the Kamiesberg uplands since 2013 as part of South African National Parks (SANParks) Biodiversity and social programme. This successful pilot project illustrates the effort of DEA to develop monitoring approaches within the NRM programme and lessons learned from this initiative can be used to develop a broad monitoring protocol at scale, which aims to monitor NRM as EbA through biophysical, social and economic indicators. The WfWet monitoring team uses a monitoring protocol developed by wetland experts, WfWet officials and implementers, which includes the above listed indicators (sediment capture, fixed point photographs, rainfall and groundwater).

It was interesting to observe an increased response from the 2017 survey to the 2018 survey that the quality of erosion control structures should be improved and that more of the structures need to be built for the NRM programme to better assist them in dealing with climate change, which indicates genuine understanding of EbA, despite no difference in 'understanding' scores. We also note that incorrect design, placement, construction and the lack of follow up inspections and repairs of these structures, results in further erosion. Although the construction of low-cost, low-technology structures are easy to implement by unskilled but carefully supervised workers, it is advisable that workers and officials should complete a course or demonstration to enable more effective application of the erosion control structures.

The study showed that by implementing soft options to control soil erosion in arid rangelands, the DEA NRM programme is contributing to soil retention, sediment capture and increased water infiltration into a climate vulnerable ecosystem. This retention of soil and water supports restoration of the rangeland, helping to establish a rangeland that is more resilient to extreme weather events. Natural resource management is also providing socio-economic benefits to those engaged in the programme and surrounding communities who depend directly on the rangeland, further supporting an EbA approach.

Recommendations

CLIMATE CHANGE TRAINING

Climate change understanding was extant at the beginning of the programme but there is no formal engagement around climate change. **It is recommended that dedicated climate change training and ongoing engagement around this, forms part of the NRM programme**, especially considering that employees requested this. This training would support workers' understanding of the impact of their interventions in terms of adaptation, including the co-benefits of their work.

MONITORING

Monitoring the impacts of the NRM interventions is critical so that the actual climate adaptation outcomes can be tested and demonstrated.

Socio-economic monitoring

This monitoring should include socio-economic impacts of the NRM interventions in terms of specific adaptation benefits and linked to the biophysical monitoring to show the ecosystem benefits. These indicators need to align with the DEA NRM reporting processes. Quite a few challenges were noted by NRM workers and these need to be considered in terms of their ability to work and provide effective interventions. Continued assessment of the challenges experienced by workers is recommended so that this can be fed back into NRM programmes, and resources can be made available to try to address these challenges. There were notable direct benefits perceived by workers from the NRM but no significant co-benefits. It is recommended that these co-benefits be assessed so that workers are aware of them and the link to adaptation can be made.

Biophysical monitoring

Monitoring short and long-term biophysical impacts (erosion control, plant growth) of NRM interventions is essential, if we are to demonstrate EbA- and cost-effectiveness. Erosion pegs for sediment capture, fixed point photography for vegetation cover, dip-wells for ground-water and rain gauges to measure rainfall as a measure of environmental variation, are all cost-effective monitoring options.

DESIGN ITERATIONS

The design concerns of workers and officials should be considered, and an iterative process of redesign conducted. In this way structures will be able to withstand even high rainfall events and provide more effectiveness in terms of resilience.

LOW COST INTERVENTIONS

The study shows that low cost gabions do increase sediment capture and water infiltration and it is recommended that these interventions be used more within the NRM programme going forward, as part of an EbA approach. **These low cost (softer) options can also be used in conjunction with harder, constructed interventions to support restoration and resilience.**

COST-EFFECTIVENESS

Engineering (hard) options have been shown to be extremely costly as part of an EbA approach (Black & Turpie 2016). **The cost-effectiveness as well as cost-benefit of using softer options should be tested at scale to determine their feasibility as part of EbA in arid environments, especially where communities are directly dependent on ecosystem services.**

Conclusion

Perceived socio-economic benefits of the NRM programme related mainly to income through job creation but respondents were aware of concepts about climate change, NRM and some of the benefits thereof. The study demonstrated that NRM programmes using soft options for soil erosion control have the potential to be implemented as part of an EbA and rangeland restoration approach. We recommend that the programme includes climate change training, and that there is monitoring and reporting on biophysical and socio-economic elements that support climate adaptation. These recommendations, coupled with an increase in the application of soft options for restoration may enable NRM programmes to demonstrate and report more effectively as an EbA modality.

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