Supplementary material for Sibiya *et al.*:

Drivers of degradation of croplands and abandoned lands: a case study of Machubeni communal land in the Eastern Cape, South Africa

v.3.4 [28 Feb. 23]

Overview

Supporting material is provided here in two parts: Part I details the Spatial Analysis, providing methodological details and results; Part II details the multi-criteria analysis (MCA).

Part I: Spatial Analysis, is presented in the following sub-sections:

Section S.1: Level of degradation mapping (further detail on method)

Section S.2: Overview of Macubeni crop fields

Section S.3: Status of crop fields

Section S.4: Degradation level in the crop fields

Section S.5: Vulnerability level in the crop fields

Section S.6: The condition of crop fields

Part II: Multi-Criteria Analysis, is presented in the following sub-sections:

Section S.7: Additional MCA methodological detail

Section S.8: Data, calculations, and associated references for Criterion 1 (cost)

Section S.9: Summary of stakeholder input, used in Criterion 2 (reliance on external funding) and Criterion 3 (perceived efficacy of interventions)

Section S.10: Multi-criteria analysis performance matrix

Part I: Spatial Analysis

S.1 Level of degradation mapping (further details on methods)

The first objective was to map and classify the extent of land degradation on currently cultivated and previously cultivated crop fields in Machubeni. To achieve this objective, the researchers used methods that were adapted from Schlegel et al. (2018) and Huchzermeyer et al. (2018) studies, which were conducted in a different location in the Eastern Cape called the Upper Tsitsa river catchment but has similar topographical, biological, and socio-cultural characteristics as Machubeni.

The 2019 digital aerial photographs of Ward 13 used here were sourced from National Geo-Spatial Information, Pretoria. These photographs are captured at a scale of 1:10 000 with 0.5 m resolution. The crop fields of Ward 13 were identified from the digital aerial photographs and mapped using GIS digitising tool on ArcMap© v.10.6. Since this study was conducted on a ward level and wards are institutional boundaries, the researchers acknowledge that cultivated fields do not conform to such boundaries. Therefore, a clipping tool was utilised on ArcMap to overlay municipal and biophysical boundaries. It is to be noted that unlike the "used" fields, some abandoned fields have a faint margin, therefore the accuracy of digitising them can be somewhat limited. Furthermore, smaller fields (< 10 ha) close to each other in the villages and falling under the same status and degradation level, were merged into one polygon.

The crop fields were assigned codes 1, 2 or 3 through an attribute table created in ArcMap© and classified according to status, degradation, and encroachment. Microsoft Excel© was used for calculations of values such as the total percentage of different classes in terms of the area they each cover, and to display the results on graphs.

S.1.1 Crop field classification

A. <u>Status</u>
   Status refers to the usage of the crop field (displayed in Figure S.1(A)-(C) where;
   1 = used (currently/ recently ploughed)
   2 = partly used (a portion of a crop field still ploughed)
   3 = Abandoned (old/ unused)

Figure S.1:Examples of crop fields: (A) a clearly used crop field (status 1); (B) a partly used crop field (status 2); (C). an abandoned crop field (status 3).

B. Degradation

This indicates the current condition of a crop field with respect to visible erosional features such as rills, gullies and lack of vegetation cover as indicated in Table S.1. Moreover, each degradation class is subdivided into three vulnerability codes. These refer to the probability of future degradation of the land through erosion or bush encroachment in the absence of any mitigation measures. Examples of crop fields with the different degradation levels can be found in Figure S.2(a)-(c).

Table S.1: Degradation and vulnerability codes for crop fields. Adapted from (Schlegel et al., 2018).

Degradation Code	Description		Vulnerability Code	Description
1	Low degradation: *No rills/gullies*		**1**	Unlikely to degrade (low)
			2	Erosion encroaching on cultivated land (moderate)
			3	n/a
2	Moderate degradation: *Rills, small gullies, lack of vegetation and/or sheet erosion*		**1**	Low erosion risk (erosion stable, low)
			2	Moderate erosion risk (moderate)
			3	High erosion risk (formation of larger gullies visible, high)
3	High degradation: *Abundant erosion*		**1**	n/a
			2	Moderate erosion risk (moderate)
			3	High erosion risk (high)

Figure S.2: Examples of crop fields with (A) little to no degradation (code 1); (B) moderate degradation (code 2); and (C) high-levels of degradation and vulnerability (code 3).

S.2. Overview of Macubeni crop fields

To determine the extent of land degradation on cultivated fields and investigate whether they were being used or had been abandoned, a total of 840 crop fields were mapped out, which covered an area of 3159.95 ha in total. The crop fields equate to 20.81% of the total ward area. It must, however, be noted (as mentioned earlier in the methods section above) that not all the crop fields were mapped out individually. Most of the small fields (<10 ha) were found within the village homes (Figure S.3) and had the same usage and degradation status, therefore a few were grouped together into one polygon

to make it into a slightly bigger one. In doing so, the total area of the crop fields remained undistorted, which in this case was found to be a total of 3159.95 ha. This makes 20.81% of the total area in ward 13 of the Macubeni catchment. The bigger crop fields (>10 ha) are mostly located away from the village houses and close to riverbanks.

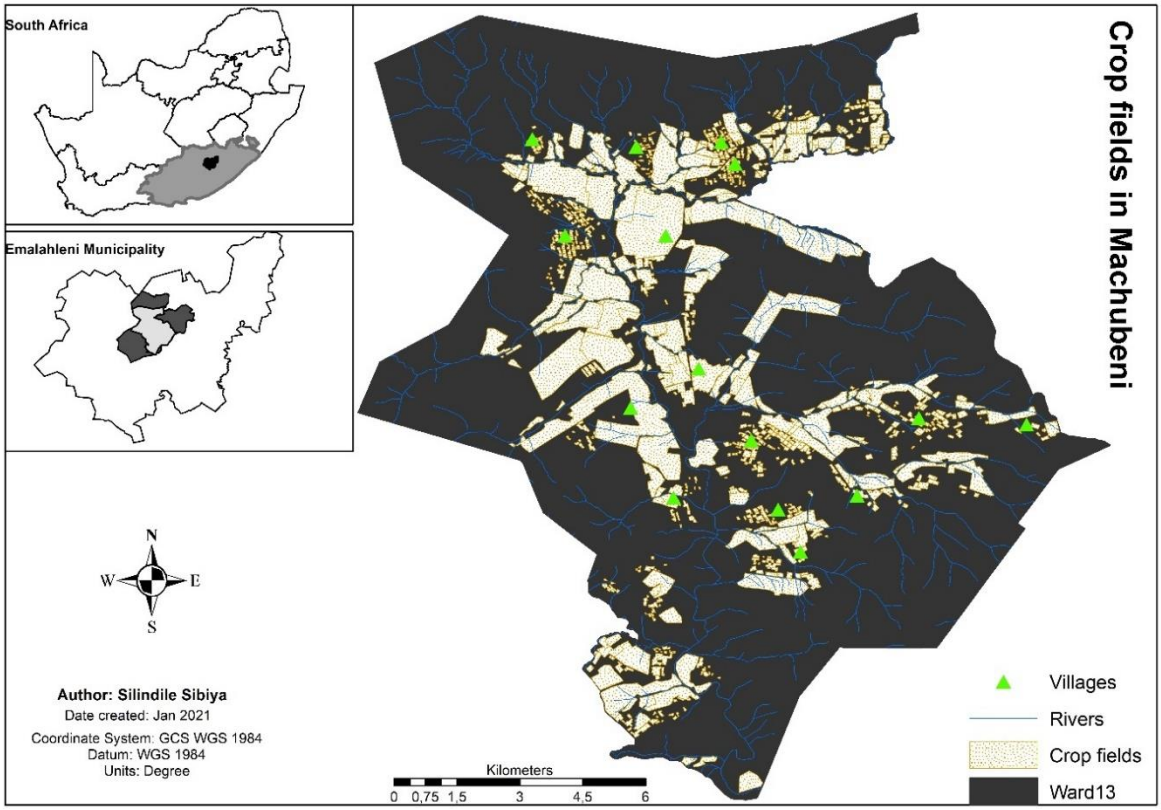

Figure S.3: Crop fields locality in Macubeni.

S.3 Status of crop fields

All the mapped cultivated fields in the study area were classified according to the usage status (Table S.2) as the first step in determining the state that each crop field is in. Almost half of the number of mapped fields (47%) were partly used, followed by abandoned fields at 30% and the lowest being used fields, which were a total of 23%. The same trend is seen on the percentage area covered by the fields from each of these classes (Figure S.4), which is a more important factor than the count of the fields. The biggest area coverage of 1666.07 ha (52.72%) was attributed to partly used fields and the lowest being the used fields with only 10% out of all the crop fields in the area.

Table S.2: Status of crop fields in Macubeni.

Status	Total no. of fields	Total area (ha)	Average crop field size (ha)	Area out of all fields (%)	Total area in the Ward (%)
Used	197	309.97	1.57	10.00%	2.04%
Partly used	394	1666.07	4.23	52.72%	10.97%
Abandoned	249	1183.92	4.75	37.47%	7.80%
Total	**840**	**3159.96**	-	**100%**	**20.81%**

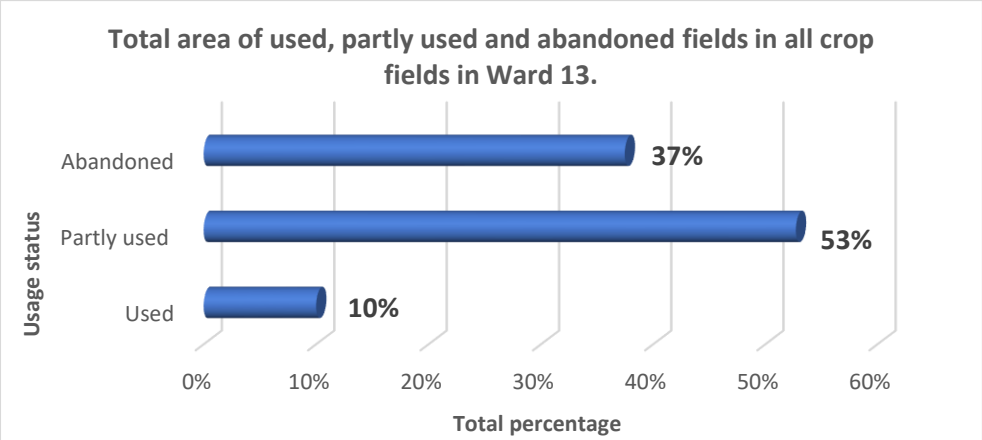

Figure S.4: The percentage of area covered by the different status categories in Macubeni.

The bigger fields as displayed on the map in Figure S.5 are mostly located on the outskirts of the area compared to the smaller fields which are in the settlement area. These fields are also located right next to rivers.

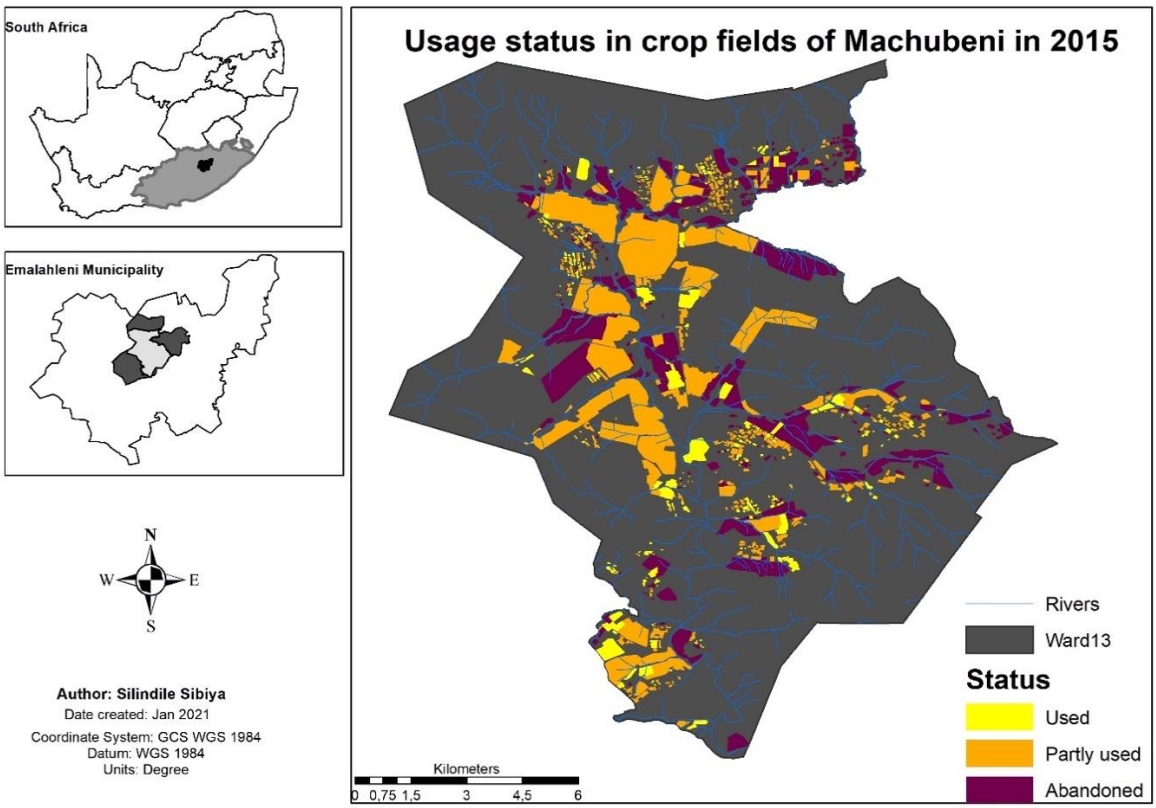

Figure S.5: The spatial distribution of used, partly used and abandoned crop fields in Macubeni

S.4 Degradation level in the crop fields

As described in the methods chapter, the levels of degradation in this study were defined using three codes. Code 1 classified low degradation (no rills/gullies and low vulnerabilty to future erosion), code

2 classified moderate degradation (presence of rills, small gullies, lack of vegetation and/or sheet erosion), and code 3 classified high degradation (abundant erosion and big gullies).

An area of 1498.19 ha (out of the total 3159.96 ha) which is the largest portion (47.41%) of the total mapped crop fields area as displayed in Figure S.6, was found to be highly degraded, despite the number of fields in this class being the smallest (Table S.3). This is due to the fact that the highly degraded fields are mostly the big crop fields (Figure S.7) which cover a large area. Moderately degraded fields covered the second largest area of 1138.03 ha (36.01% of all the crop fields), while those that displayed signs of low degradation covered the smallest area 523.73ha (16.57% of all the crop fields). The maximum area coverage out of the whole Ward is 9.87% from the highly degraded, 7.49% from moderately degraded, and 3.45% by the fields with little to no degradation.

Most of the highly degraded fields are those that are partly used and those which have been abandoned, with a total of 26.01% and 20.02%, respectively. A much lower area of only 1.38% from used fields is highly degraded. The levels of degradation are shown spatially in Figure S.7.

Table S.3: summary of the degradation levels of crop fields in Macubeni

Degradation status	Total no. of fields	Total area (ha)	Average crop field size (ha)	Area out of all fields (%)	Total area in the Ward (%)
Low	464	523.73	1.13	16.57%	3.45%
Moderate	301	1138.03	3.78	36.01%	7.49%
High	75	1498.19	19.98	47.41%	9.87%
Total	**840**	**3159.95**	-	**100%**	**20.81%**

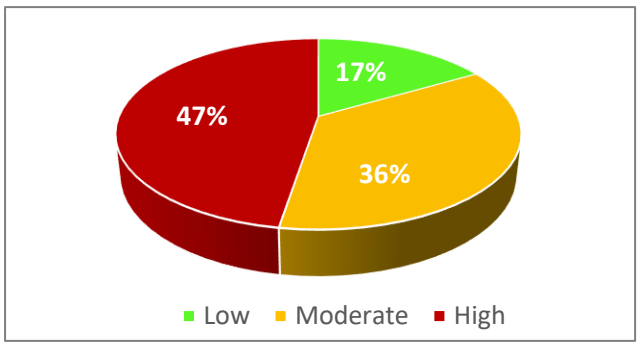

Figure S.6. The percentage of area covered by the different levels of degradation.

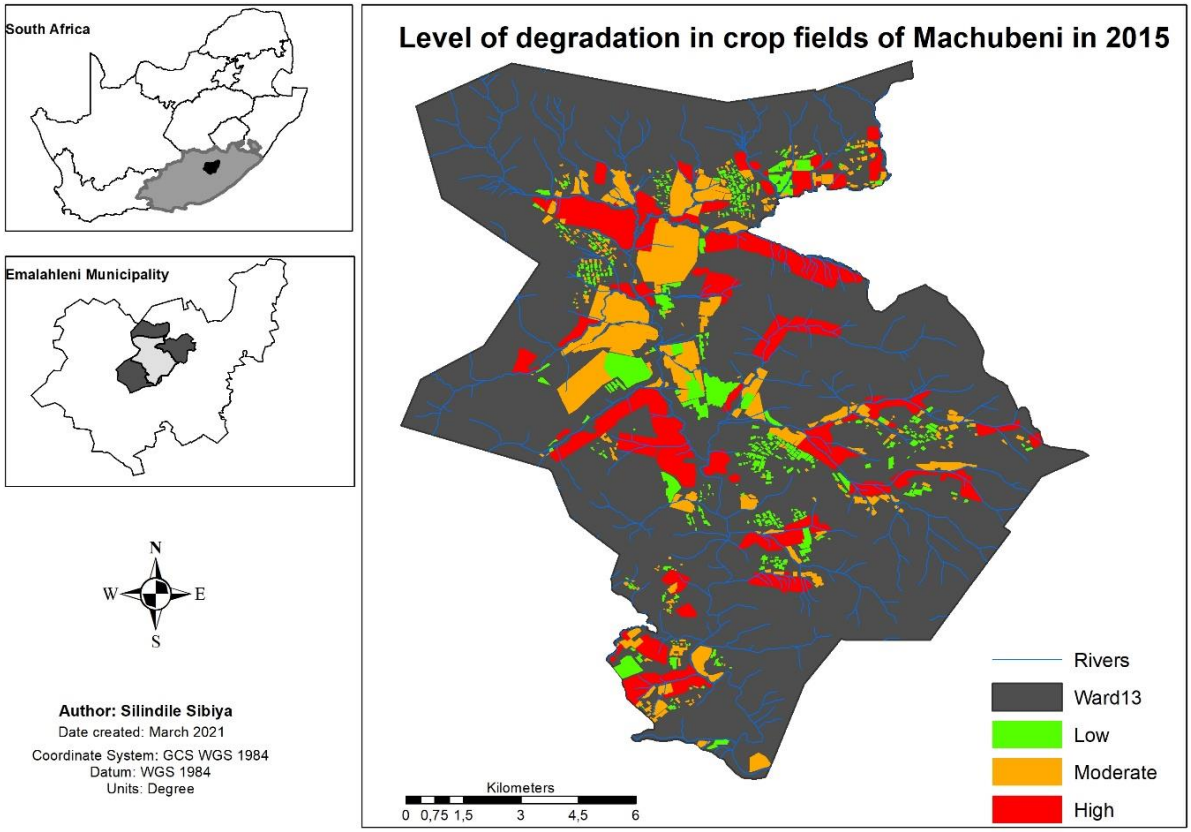

Figure S.7. The levels of degradation identified on crop fields

S.5 Vulnerability level in the crop fields

The vulnerability level of crop fields speaks to the potential risk that the area will be degraded in the future, judging by the features already exhibited by the crop field itself or characteristics of the surrounding area. Table S.4 shows that the moderately vulnerable fields are the largest in quantity, with 577 fields in total. However, these do not make up most of the total area.

Table S.4: Vulnerability levels of crop fields in Macubeni.

Vulnerability status	Total no. of fields	Total area (ha)	Average crop field size (ha)	Area out of all fields (%)	Total area in the Ward (%)
Low	39	27.93	0.72	0.88%	0.18%
Moderate	577	1093.36	1.89	34.60%	7.20%
High	224	2038.66	9.10	64.52%	13.43%
Total	**840**	**3159.95**	-	**100%**	**20.81%**

The highly vulnerable fields amount to a total area of 2038.66 ha, which means 64.52% of all the mapped fields fall into this category, while the moderately vulnerable makes 34.60% and the low vulnerability with only 0.88%% (27.93 ha) of the total mapped fields area. In relation to the entire

catchment, as displayed geographically on the map in Figure S.8, the high vulnerability crop fields make-up 13.43% of the area.

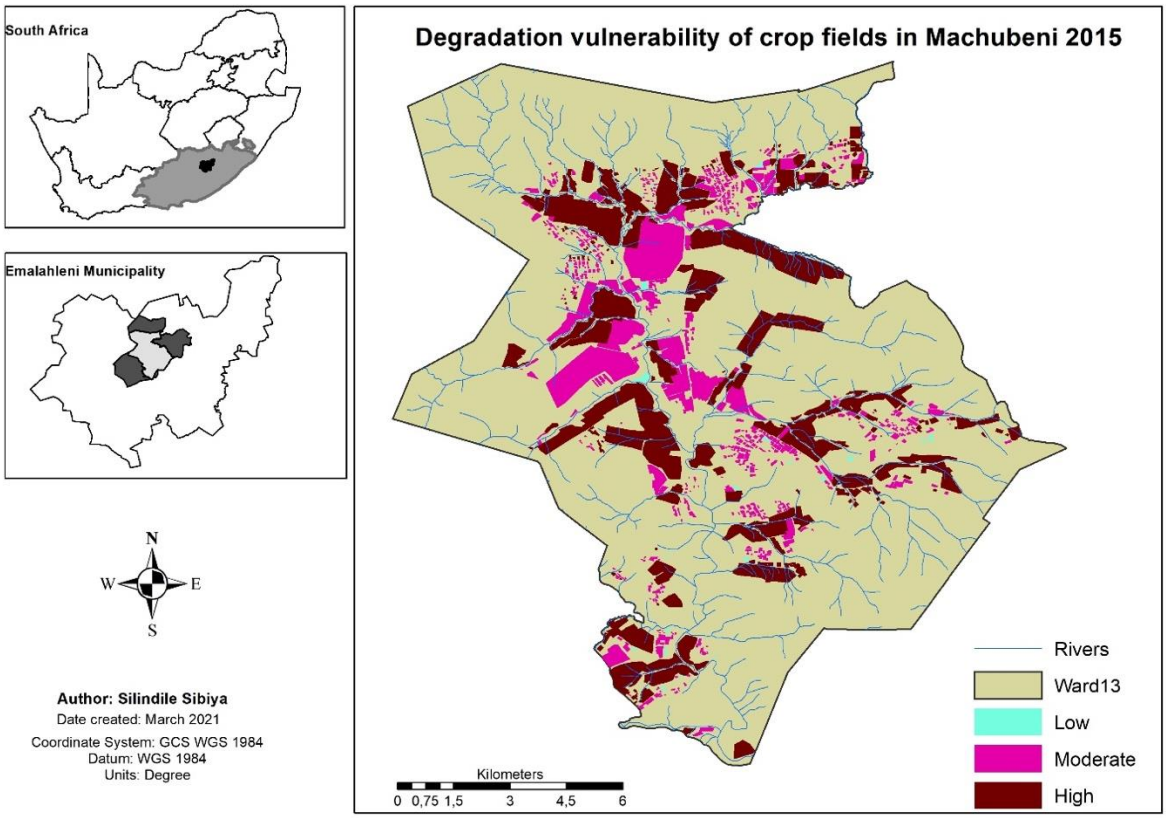

Figure S.8. The vulnerability to degradation in crop fields at Macubeni.

S.6 The condition of crop fields in Macubeni.

The previous sections (S.2 – S.5) summarised the usage status, degradation level and vulnerability levels, respectively. This section documents the details on all the different categories in relation to one another. That is, how degraded and vulnerable to future erosion are the used fields, partly used fields, and abandoned fields in the catchment (Table S.5-Table S.10).

S.6.1 Degradation in used fields

Table S.5 shows that out of the 309.97 ha of total land area identified as used crop fields, half (153.84 ha) of it is from fields with low degradation. Interestingly, even though used fields are usually the ones with the most exposed soil, there is only a small portion of 43.69 ha (14% of used fields) where used fields exhibit high degradation (score of 3). These are fields that have clearly visible large gullies and no vegetation cover.

Table S.5:Degradation levels in used crop fields

Degradation (Used)	No. of crop fields	Area (ha)	Percentage (%) area covered (all crop fields)	Percentage (%) of Ward
Low	143	153.84	4.87%	1.01%
Moderate	51	112.44	3.56%	0.74%
High	3	43.69	1.38%	0.29%
Total	**197**	**309.97**	**9.81%**	**2.04%**

Vulnerability codes were used to estimate the potential of crop fields to exhibit further erosion at different degradation levels (Table S.6). Most (98%) of the used fields with low degradation have moderate vulnerability to future erosion. This is because there are no erosion features exhibited by these fields, however, they still have a level of exposure to future erosion due to the exposed soil surface when it is cultivated.

Furthermore, Table S.6 shows that used fields which display moderate degradation are mostly highly vulnerable, with 39 fields out of 50 (78%) being classified as such. Most importantly, the total area of fields in the moderately degraded category with high vulnerability is also the largest with 101.32 ha. These fields have small gullies running through them, which have a high potential of incising further or there are bigger gullies in the immediate surrounding area.

Lastly, the entire 43.69 ha of all used fields area that displayed high degradation also present high vulnerability.

Table S.6: Vulnerability of used crop fields within different degradation levels.

Degradation	Vulnerability	No. of crop fields	Area (ha)	Percentage (%) area covered (all crop fields)	Percentage (%) of Ward
Low	Low	3	2.22	0.07%	0.01%
	Moderate	140	151.61	4.80%	1.00%
Moderate	Low	2	0.38	0.01%	0.003%
	Moderate	10	10.74	0.34%	0.07%
	High	39	101.32	3.21%	0.67%
High	Moderate	0	0.00	0.00%	0.00%
	High	3	43.69	1.38%	0.29%
Total		**197**	**309.97**	**9.81%**	**2.04%**

S.6.2 Degradation in partly used fields

Partly used fields were found to be the category that holds the largest total area of 1666.07 ha (52.72%) amongst all the identified crop fields (3159.96 ha). Further into this status, it is revealed in Table S.7 that the fields showing low degradation are the smallest group (331.24 ha). This is followed

by the moderately degraded fields, which make a total area of 512.86 ha from the total 1 666.07 ha of partly used fields. Lastly, the results in Table S.7 also indicate that the majority of partly used fields (821.97 ha of 1 666.07 ha) are highly degraded.

Table S.7: Degradation levels in partly used crop fields.

Degradation (Partly used)	No. of crop fields	Area (ha)	Percentage (%) area covered (all crop fields)	Percentage (%) of Ward
Low	272	331.24	10.48%	2.18%
Moderate	107	512.86	16.23%	3.38%
High	15	821.97	26.01%	5.41%
Total	**394**	**1666.07**	**52.72%**	**10.97%**

Table S.8 indicates that the fields showing low degradation are the smallest group but are almost all moderately vulnerable to future erosion (328.85 ha out of 331.24 ha). A majority of the moderately degraded fields are moderately vulnerable (274 ha out of 512.85 ha), which is 8.67% of all the mapped crop fields. The second biggest area in the moderately degraded category was classified as highly vulnerable fields covering 226.68 ha.

Additionally, as anticipated, none of the highly degraded fields exhibited low or moderate vulnerability (Table S.8). Since they are already currently highly degraded, that automatically puts them at a high risk for further degradation. Therefore, all 821.97 ha of highly degraded fields are highly vulnerable. This of course is dependent on whether any rehabilitation measures are taken to minimise further degradation (i.e., stabilising gullies).

Table S.8: Vulnerability of partly used crop fields in different degradation levels.

Degradation	Vulnerability	No. of crop fields	Area (ha)	Percentage (%) area covered (all crop fields)	Percentage (%) of Ward
Low	Low	4	2.39	0.08%	0.02%
	Moderate	268	328.85	10.41%	2.17%
Moderate	Low	15	12.18	0.39%	0.08%
	Moderate	43	274.00	8.67%	1.80%
	High	49	226.68	7.17%	1.49%
High	Moderate	0	0.00	0.00%	0.00%
	High	15	821.97	26.01%	5.41%
Total		**394**	**1666.07**	**52.72%**	**10.97%**

S.6.3 Degradation in abandoned fields

The third and last class in usage status is the abandoned fields, which contitutes 37.47% (1183.92 ha) of the total mapped cropped fields area. Table S.9 shows that a combination of abandoned fileds and low degradation is rare. Indicative of this, only 1.22% of the abandoned fields exhibited signs of low degradation (38.66 ha).

As seen in Table S.9, the gap between total area of abandoned fields that show moderate and high degradation is relatively small; 512.74 ha and 632.52 ha respectively (43% are moderately degraded and 53% highly degraded). Overall, the majority (632.52 ha) of abandoned fields (1183.92 ha) in the study area are highly degraded.

Table S.9: Degradation levels in abandoned crop fields.

Degradation (Abandoned)	No. of crop fields	Area (ha)	Percentage (%) area covered (all crop fields)	Percentage (%) of Ward
Low	49	38.66	1.22%	0.25%
Moderate	143	512.74	16.23%	3.38%
High	57	632.52	20.02%	4.17%
Total	**249**	**1183.92**	**37.47%**	**7.80%**

Table S.10 shows that most (36.62 ha out of 38.66 ha) of abandoned fields that exhibited signs of low degradation have moderate vulnerabilty.

Although it is a small portion of 8.72 ha (1.7% of 512.73 ha), some of the moderately degraded abandoned fields do show a low risk of further erosion. The high risk fields within moderately degraded abandoned fields are however the more dominant with 278.33 ha (54.28%).

The most detrimental combination of the different categories in the crop fields is the “abandoned, highly degraded and highly vulnerable”. Overall, the majority (632.52 ha) of abandoned fields (1183.92 ha) in the study area are highly degraded and 90% of those are highly vulnerable to future erosion (566.67 ha).

Table S.10: Vulnerability of abandoned crop fields in different degradation levels.

Degradation	Vulnerability	No. of crop fields	Area (ha)	Percentage (%) area covered (all crop fields)	Percentage (%) of Ward
Low	Low	4	2.04	0.06%	0.01%
	Moderate	45	36.62	1.16%	0.24%
Moderate	Low	11	8.72	0.28%	0.06%
	Moderate	62	225.68	7.14%	1.49%
	High	70	278.33	8.81%	1.83%

Degradation	Vulnerability	No. of crop fields	Area (ha)	Percentage (%) area covered (all crop fields)	Percentage (%) of Ward
High	Moderate	9	65.85	2.08%	0.43%
	High	48	566.67	17.93%	3.73%
Total		**249**	**1183.92**	**37.47%**	**7.80%**

Part II: Multi-Criteria Analysis

Supporting information for the multi-criteria analysis (MCA) is presented here as follows:

Section S.7: Additional methodological detail on the MCA is provided

Section S.8: Data, calculations, and associated references for Criterion 1 (cost) – see Table S.11, which provides high-level cost data with cross-references to the associated breakdowns for the cost of each intervention (detailed in

Table S.12-**Error! Reference source not found.** and Figure S.9).

Section S.9: Summary of stakeholder input, used in Criterion 2 (reliance on external funding) and Criterion 3 (perceived efficacy of interventions) (see Table S.16).

Section S.10: multi-criteria analysis performance matrix (Table S.17).

Section S.7: Additional MCA methodological detail

The below text expands on the MCA overview provided in Section 2.4 of the manuscript.

MCAs can be used to (1) identify a preferred option; (2) rank alternatives against each other; (3) short-list a set of alternatives for further, more detailed analysis; (4) group alternatives; and (5) distinguish acceptable from unacceptable options (Brinkhoff, 2011; Communities and Local Government [CLG], 2009).

Within the broader family of MCA approaches, a subset focus on providing tools that explicitly and rigorously support decision-making. These techniques are usually grouped under the category of Multi-Criteria Decision Analysis (MCDA) but are also known as Multi-Attribute Decision Analysis (MADA). These approaches are suitable when the analysis entails a high level of detail and is more computationally complicated, requiring specialised software and usually including additional steps, such as sensitivity analyses and pairwise comparisons. In these situations, MCDA's that synthesise criteria and sub-criteria (e.g. Analytic Hierarchy Process) can be used, with other options including techniques that focus on outranking (e.g. ELECTRE and PROMETHEE) (Wang et al., 2009). In this study, a simple form of MCA was applied as part of the multi-method approach, complementing the spatial analysis and the systems diagramming methods (i.e. an MCDA was deemed unnecessary).

Section S.8: Data, calculations, and associated references for Criteria 1 (cost)

Table S.11: High-level cost data (for Criteria 1 (C.1)). All costs in South African Rand (ZAR).

Intervention	Total cost (ZAR)	Normalised cost	Reference	Comments
A. Sediment trapping structures	526,500.00	0.30	GEF5 Project	See Table S.12
B. Climate Smart Agriculture	305,500.00	0.17	GEF5 Project	See Table S.13
C. Agrograssing	1,782,240.00	1	GEF5 Project	See Table S.14 and Figure S.9
D. Grazing management	518,000.00	0.29	GEF5 Project	See Table S.15

Table S.12: Intervention A: sediment trapping structures, focusing on soil erosion control.

Sediment trapping structures (focus on soil erosion control)				
Item	**Unit cost**	**Quantity**	**Cost**	**Comments**
Uniforms	1,400.00	50	70,000.00	Two uniforms are bought per LCA each year (hence 25*2 = 50)
Wages	820.00	300	246,000.00	25 LCA's, each paid R820/month, for 12 months
Tools	1,420.00	25	35,500.00	Tools include wheelbarrows, spades, and picks
Tanks and installation	7,000.00	25	175,000.00	Tank = R5,000; installation = R2,000, total = R7,000
Total			**526,500.00**	

Table S.13: Intervention B: climate smart agriculture (CSA).

Climate smart agriculture				
Item	**Unit cost**	**Quantity**	**Cost**	**Comments**
Uniforms	1,400.00	50	70,000.00	Two uniforms are bought per LCA each year (hence 25*2 = 50)
Seeds	15,000	1	15,000.00	
Seedlings	10,000	1	10,000.00	
Tools	1,420.00	25	35,500.00	Tools include wheelbarrows, spades, and picks
Tanks and installation	7,000.00	25	175,000.00	Tank = R5,000; installation = R2,000, total = R7,000
Total			**305,500.00**	

Table S.14: Intervention C: agrograssing

Agrograssing		
Variable	**Quantity**	**Unit**
Cultivated lands hectares (Ward 13)	3160	ha
percentage crop fields heavily degraded	47	%
heavily degraded	1485.2	ha
required per degraded hectare	400	slips/ha (*see Figure S.1*)
total slips required	594080	slips
cost/slip	3.00	ZAR/slip
total costs	1,782,240.00	ZAR

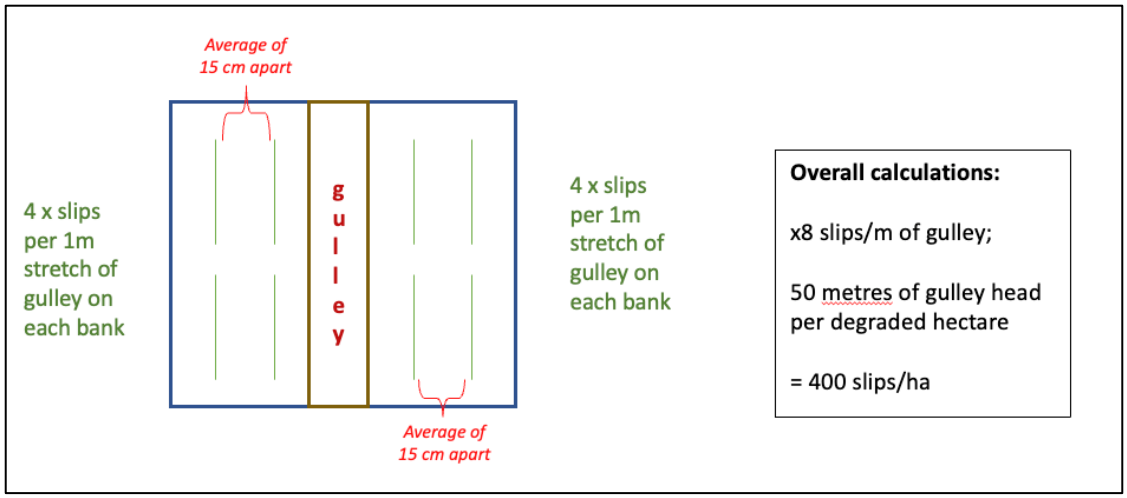

Figure S.9: Calculations for the required number of grass slips per metre of gulley for agrogassing purposes.

Table S.15: Intervention D: Grazing management.

Grazing management				
Item	**Unit cost**	**Quantity**	**Cost**	**Comments**
Uniforms	1,400.00	50	70,000.00	Two uniforms are bought per LCA each year (hence 25*2 = 50)
Wages	30,000	12	360,000.00	2x Eco-rangers per village at R3,000/month = R3,000*10 = R30,000/month for 12 months
Auction	50,000	1	50,000.00	
Vets	38,000.00	1	38,000.00	
Total			**518,000.00**	

Section S.9: Summary of stakeholder input, used in Criteria 2 (reliance on external funding) and Criteria 3 (perceived efficacy)

Table S.16: Stakeholder input to Criteria 2 (C.2) and Criteria 3 (C.3). Norm. score = normalised score.

			Stakeholder (SH)							Scores		
Criteria		**Intervention options**	**SH #1**	**SH #2**	**SH #3**	**SH #4**	**SH #5**	**SH #6**	**SH #7**	**Avg. score**	**Top score**	**Norm. score**
How reliant on external funding is this intervention? (5 = no reliance; 1 = completely reliant)	**Reliance on external funding**	A. Sediment trapping structures	1	1	2	3	3	3	1	2.0	5	**0.40**
		B. Climate Smart Agric.	2	3	3	3	2	2	3	2.6	5	**0.52**
		C. Agrograssing	2	2	2	2	3	2	2	2.1	5	**0.42**
		D. Grazing management	2	2	2	4	1	1	2	2.0	5	**0.40**
How effective do you think this intervention will be? (10 = very effective; 0 = completely ineffective)	**Perceived efficacy**	A. Sediment trapping structures	5	5	5	5	2.5	5	5	4.6	10	**0.46**
		B. Climate Smart Agric.	5	5	5	7.5	5	7.5	5	5.7	10	**0.57**
		C. Agrograssing	5	5	5	5	5	7.5	5	5.4	10	**0.54**
		D. Grazing management	5	7.5	5	7.5	5	7.5	7.5	6.4	10	**0.64**

Section S.10: multi-criteria analysis performance matrix

Note that weightings are rationalised as follows:

- The two criteria most heavily weighted are the 'cost' estimates (C.1). and the perceived 'efficacy' (C.3);
- The 'external funding reliance', while deemed important, was conceptualised as being half as important as each of the other two criteria.
- Hence, C.1 and C3 were *each* weighted as 40% (i.e. 0.4), for a total of 80%, and C.2 was weighted at 20% (i.e. 0.2).

Table S.17: Performance matrix. Perf. = performance; Wt'd perf = weighted performance.

Input matrix			Intervention options							
			A. Sediment trapping structures		B. Climate smart agriculture		C. Agro-grassing		D. Grazing management	
Criteria (Cn)	Weight (Wt)	Direct-ion	Perf.	Wt'd perf.	Perf.	Wt'd perf.	Perf.	Wt'd perf.	Perf.	Wt'd perf.
C1. Cost (annual)	0.4	-1	0.3	-0.120	0.17	***-0.068***	1	-0.400	0.29	*-0.116*
C2. External funding reliance	0.2	1	0.4	0.080	0.52	***0.104***	0.42	*0.084*	0.4	0.080
C3. Efficacy	0.4	1	0.46	0.184	0.57	*0.228*	0.54	0.216	0.64	***0.256***
Total	1			0.144		***0.264***		-0.100		*0.220*