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Full Length Research Paper

Land degradation evaluation in a game reserve in Eastern Cape of South Africa: soil properties and vegetation cover

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Land degradation in the agricultural domains of South Africa has attained a scale that requires scientific intervention. To devise an appropriate control measure, we investigated the contribution of vegetation condition and soil properties to observed land degradation conditions. Twenty three degraded sites were identified and classified using a land degradation index derived from six physical degradation indicators, using multidimensional analysis techniques. A veldt condition assessment was also conducted on the sites. Soil samples from the sites were analyzed for soil degradation indicators viz., particle size fractions, aggregate stability, organic C, pH, EC, total and exchangeable Na, Mg, K and Ca. The veldt condition score ranged from 26.3 – 50%, which implied that the veldt condition has diminished by up to 50 - 77% of its standard condition. Most of the degraded sites are poorly covered; the percentage basal cover ranged from 12 – 39% with average distance of 0.8 – 30.7cm between plants. The degraded lands consisted of high (69 - 100%) proportion of increaser's species which was caused by selective grazing of palatable species by wildlife herbivores. The stable soil aggregate size ranged from 0.8 – 1.4 mm across the mechanical disaggregation, fast wetting and slow wetting tests. Soils of the degraded sites (poorly, moderately and highly degraded) have low organic carbon content < 13.0 mgkg^{-1}. Higher quantities of Na and Ca were observed in the highly degraded sites, indicating the effects of increased solidification and calcification on the breakdown and erosion of soil aggregates. Soil erosion was the major end occurrence in land degradation episodes at Tsolwana game reserve, which was a result of the integrated effects of the vegetation and soil variables. It is recommended that land degradation control measures should be focused on the alteration of cause-variables rather than the effects variable (soil erosion).

Key words: Land degradation, land degradation index, nature game reserve, Soil erosion and vegetation.

INTRODUCTION

Land degradation is a widespread environmental problem in South Africa (Hoffman and Todd, 2000). It has been defined differently by authors (Thomas and Middleton, 1994), but all definitions encompass the reduction of the current or future capacity of land to produce. Most definitions covered the subject of plant species composition, biological productivity and soil health (Reynolds and Stafford Smith, 2002). In rangelands, overgrazing is often considered as the major cause of land degradation. It was reported to result in extensive decrease in population of palatable species, and encroachment of undesired forbs and shrubs (Snyman, 2004). It further leads to decline in soil quality variables such as aggregate stability, water infiltration rate, soil organic matter content and microbial activities (Russel et al., 2001; Du Preez and Snyman, 2003; Snyman and du Preez, 2005).

In a natural game reserve; where human activities are limited, land degradation could be due to a number of

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natural factors, such as excessive proliferation of game animals leading to overgrazing of the natural vegetation, soil innate properties and climatic variables. The control and prevention of land degradation in this instance should be a natural process, being an undisturbed eco-system, but an imbalance in the components could result in land degradation. This is because the components of nature depend on one another to function appropriately; torrential rainfall could lead to eroded topsoil, destroyed vegetation and degraded water resources could endanger biodiversity; induce climate change and disturb hydrologic cycles. It is therefore important, to arrest land degradation on time before it assumes a threshold that may defy reasonable remediation techniques.

Available information is not adequate for detailed understanding of the different process that leads to land degradation. This could be due to the multi-dimensional nature of land degradation and the large numbers of variables involved. Thus, managers are not provided with the much needed guidance about the intervention points that will be most effective in promoting positive outcomes or the most appropriate sequencing of intervention for the best result. Most activities aimed at ameliorating de-gradation on fragile lands are focused on the main com-ponents conditions that only respond to pressures. Yet, it may be more effective to influence pressure points since these may largely determine other components response. However, there is very little empirical evidence that clarifies the relationship between these different levels of actions and their actual effects on key outcome variables. Finding such empirical evidence is one of the main objectives of this study.

There are a number of possible methods for assessing the nature, extent and rate of land degradation. But an important factor in the choice of method is whether or not the changes are brought about by human activities or natural factors (O'Connor, 1994). Many past land degradation assessments focused on vegetation and cli-matic considerations especially on communal range-lands while there is dearth of information on degradation assessment of natural game reserve where the effect of natural factor sequences can be ascertained. Our study examined land degradation in a game reserve using variables from vegetation, landscape, soil properties, historical land use and climatic modification, to explain factors responsible for land degradation and their inter-relationships.

MATERIALS AND METHODS

Site description

The study was conducted at Tsolwana nature reserve in Eastern Cape of South Africa. The reserve was established in the year 1978, to conserve the unique flora and fauna of the area and serve as a tourist attraction. It covers an area of 8,500 ha, with an altitude of 1350 m Asl at lowland and 1800 m Asl at the mountainous area. The climate of Tsolwana nature reserve is modified mainly by the topography. Rainfall varies from year to year with an annual average of 500 mm in the grassland and the thornveld, while an annual average of 800 mm is observed in the mountainous area. The soils of Tswolana have been described by Acocks (1988). They were formed from sandstone and shale which has led to the development of less fertile soils. The geology was part of the Tarkastad sub-group which includes the arenaceous Katberg formation that is about 1000 m thick. The formation overlays an agillaceous Burghersdorp formation with some intruding Karoo dolerite dykes.

Acocks (1988) describe the vegetation of Tsolwana nature reserve as a mixture of species groups modified by the soil properties and land use over time. Three categories were identified, (1) The dry *Cymbopogan themeda* veldt: This is found in the open field of the northern lowland part of the reserve, it was described as the sweet grassland made up of *Cymbopogon Themeda* veldt. (2) Invasion of grassveld by bush: There are several portion of the reserve sweet thornsveld with invasion of *Acacia karroo*. (3). The *karroid merxmeullera* mountain veld: these occur at high altitude and it ranged from the open sour grassland to shrubby sour fynbos communities dominated by *Euryops pyroides* (Harpuis) *Elytrap-appus rhinocerotis* (Renosterbos) and *Passerina montana* (Pakaan)

Data collection

Twenty three degraded sites including two non-degraded sites (control) were identified across the game reserve for evaluation.

Vegetation assessment

A veldt condition assessment was conducted on each site using the method described by Trollope (1990). This method measures the botanical composition of the grass sward and compares it with a reference benchmark site. A benchmark site should possess optimum vegetation condition for livestock production relative to the specific veldt type. The vegetation assessment was conducted on a sampling area of 50 x 100 m in each degraded sites. Two transect lines were established to pass through the center of the sampling area. On each transect, 50 points were taken at an interval of two meters, the presence and species name of plant at each point was recorded. The results were expressed as the percentage relative frequency of each species occurring in the sampled site. Basal cover (BC) was estimated as the proportion of strikes to the total number of points. Veld condition score (VCS) was determined by multiplying the percentage frequency of each species in the sampled site with a forage factor which is an index of the forage production potential of each species (Trollope, 1990). The sum score of all the species in the sampled site was expressed as percentage of the score for the benchmark site. The observed grass species were categorized into decreaser, increaser I and increaser II based on their reaction to grazing as defined by Trollope (1990). Decreaser species are the herbaceous species which decrease in population when a rangeland is mismanaged (over-grazed, under-grazed etc). Increaser I species increase in population when a rangeland is under-grazed, while increaser II species increase when a rangeland is over-grazed.

Standing herbage biomass was measured at an interval of two meters along the same transects with a disc pasture meter (Bransby and Tainton, 1977; Trollope and Potgieter, 1986). Mean disc heights were converted to estimate the herbage mass (kg ha^{-1}) using the generalized calibration equation developed for the area. Herbage biomass (kg ha^{-1}) = 340 + 388.3* (mean disc height in cm). Bush density was estimated by count of all the rooted trees within the sampling area, the count was then extrapolated to hectare basis.

Soil assessment

Soil samples were collected from each of the 23 sites. A composite

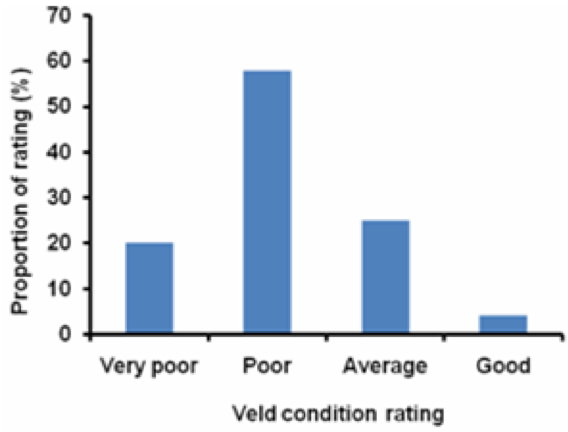

Figure 1. Quality categorization of veld condition assessment at Tsolwana game reserve. (n = 23).

was made from a minimum of 10 representative cores collected at the depth of 0 -15 cm. The samples were air-dried and sieved through 2 mm mesh. Particle size analysis was conducted using the hydrometer method described by Okalebo et al. (2002); Soil pH and EC were measured in 1:2.5 water extract as described by Okalebo et al. (2002). Total N was measured colorimetrically in a digest of concentrated sulphuric acid with selenium powder and hydrogen peroxide (Okalebo et al., 2002). Total P, K, Ca, Mg and Na were determined in the digest, using an atomic absorption spectrophotometer. Available P, exchangeable K, Ca, Mg and Na were measured in AMBIC-2 extract (Soil Science Society of South Africa, 1990). Available P was determined colorimetrically using the modified molybdate blue method. Exchangeable cations were determined using the atomic absorption spectrophotometer. Organic carbon was determined using the wet dichromate digestion followed by titration with acidified ferrous sulphate (Okalebo et al., 2002). Soil aggregate stability was determined using the method reported by Le Bissonnais (1996). Top soil samples were carefully collected without breaking the aggregates, the samples were transported in a rigid box to prevent breakdown of aggregate. The samples were oven dried at 40^0C for 24 h to unify the samples moisture condition, thereafter, sub samples were subjected to (a) fast wetting by immersion in water, (b) mechanical disaggregation by shaking and (c) slow wetting by capillary action. The aggregates were then oven dried after ethanol treatment and sieved through six mesh sizes viz., 2000, 1000, 500, 200, 100 and 50 *u*m. The mean weight diameter was generated for each sampled soil and interpreted based on classification table described by Le Bissonnais (1996).

Land degradation index

Land Degradation Index (LDI) was generated using the multidimensional analysis technique reported by Sharma et al. (2005). Four major steps were outlined, (i) define the goal, (ii) select a minimum data set (MDS) of indicators that best represent the land degradation function (iii) score the MDS indicators based on their importance to the land degradation function and (iv) integrate the indicator scores into a comparative index of land degradation. The goal was to derive a representative index that best describe the observed degradation scenario. Often, land assessment variables, as increased soil looseness, increased sand deposition on road and paths, incidence of animal tracks, erosion severity (evidenced by rill, pedestals and gullies), degree of landscape slope and presence of gully are used as indicators of degradation. In our study, these variables were estimated as scores on a scale of 1 - 5 where 1 stands for least observed and 5 the highest.

After the determination of the minimum data set, the variables were then transformed based on theoretical contribution relative to magnitude of measurement; weather a high value was considered good or bad for land degradation function. For variables where "higher values were considered better", each observation was divided by the highest observed value, while for "less is better" variables, the lowest observed value was used as the numerator. This yield a set of transformed values where the best data point under each variable will be one and others will be a fraction of one. However, all the variables in our study fall in the "Less is better" category. Observations under each variable were weighted by multiplication with a weight of importance, which was allocated to each variable depending on their empirical and/or theoretical contribution to land degradation. We then sum up the weighted variables score for each site using this equation.

$$LDI = \sum_{i=1}^{n} WiSi$$

Si = Score of variable; *Wi* = weight of importance for the variable. The land degradation index was further categorized into four degradation classes 1= Non degraded; 2= moderately degraded; 3= poorly degraded and 4 = extremely degraded.

Statistical analysis

All data sett were subjected to summary statistics, using Statistical Analysis System version 8 (SAS 1999). Correlation and regression analysis were also conducted using the proc Corr and Proc Reg program of SAS (SAS, 1999).

The coefficient of relative contribution (CRC) of the variable was generated from the *F* values of the linear regression analysis. The *F* values were preferred since the intercept of the regression lines is not zero, then the CRC is better expressed with the *F* values rather than with the regression coefficients. CRC is the *F* value of the variable divided by sum of the *F* values of the six variables.

RESULTS AND DISCUSSION

Vegetation of degraded land

Vegetation cover plays an important role in landscape conservation; it protects the soil by preventing the direct impact of weather elements as rainfall, temperature and wind. Table 1 shows the vegetation assessment of degraded land at Tsolwana game reserve. The VCS (expressed as a percentage of a predetermined benchmark site) across 23 degraded sites ranged from 26.3 to 50%, with mild variation (CV = 17%) among the observed veld condition categories. Further categorization of these scores showed that 19% of the sampled site were categorized as very poor, 57% as poor, while 24% as moderate (Figure 1). These results indicated that the general veld condition had diminished by 50 – 77% from its potential condition. These types of changes could be attributed to the grazing pattern which is a variable that is

Table 1. Vegetation assessment of the degraded land area in Tsolwana game reserve.

Site No	Veld condition score	Basal cover	Decreasers	Increasers I	Increasers II	Grass biomass	Grass height	Bush	TE / HA
	%	%	%	%	%	Kg ha^{-1}	cm	Plant ha^{-1}	
1	35.9	14.9	3	1	96	1388	2.7	950	11
2	26.3	20.3	1	4	95	1660	3.4	650	14
3	34.5	17.3	0	0	100	1117	2	450	10
4	36.1	16.4	0	0	100	1466	2.9	1100	5
5	37.0	12.3	0	0	100	1505	3	400	4
6	45.4	8.9	10	0	90	1505	3	250	11
7	32.1	6.4	0	0	100	1272	2.4	300	7
8	32.1	0.8	0	0	100	1388	2.7	2750	35
9	26.1	30.7	1	0	99	2437	5.4	3050	22
10	32.5	5	0	0	100	922	1.5	550	19
11	36.0	11.4	0	0	100	922	1.5	200	8
12	37.3	15	8	0	92	1078	1.9	1100	13
13	40.0	6.6	10	5	85	1427	2.8	1050	7
14	50.0	10.5	11	20	69	1738	3.6	800	9
15	43.4	8.7	10	5	85	1039	1.8	450	8
16	34.5	12	6	22	72	1117	2	1800	11
17	33.3	17	0	25	75	1078	1.9	1850	14
18	33.1	13.6	7	14	79	1311	2.5	1500	9
19	40.2	1.89	2	6	92	1117	2.0	1300	23
20	30.7	4.93	3	10	87	1660	3.4	1200	17
21	62.0	4	8	26	66	2049	4.4	0	0
22	50.8	14.9	5	7	88	1388	2.7	800	18
23	29.7	20.3	0	0	100	884	1.4	300	6
Mean	**35.53**	**11.36**	**3.43**	**5.33**	**91.24**	**1334.81**	**2.56**	**1047.62**	**12.52**
CV	**17**	**62**	**122**	**152**	**11**	**27**	**36**	**75**	**59**
Std Err	**1.29**	**1.53**	**0.91**	**1.77**	**2.23**	**78.55**	**0.20**	**172.60**	**1.61**

Note: Std Err = Standard error

that is not controlled in a natural game reserve (Wiegand et al., 2004). Sustained selective grazing by range animals could alter the species composition of the rangelands from perennials to annuals with potentials to decrease veld production (Snyman, 2004; O'Connor, 1994). The distribution also suggested that the bulk of the degraded sites fall into the poor veld categories.

The basal cover of the grass sward ranged from 12 - 39% with an average distance of 0.8 – 30.7 cm between plants, which showed that the degraded sites were poorly covered by vegetation and hence, susceptible to soil erosion. The vegetation of the sampled sites is dominated by *Cynodon dactylon, Eragrostis chloromelas*, *Karoo spp* and forbs which consisted of 22, 13, 14 and 7%, respectively of the species in the sampled sites. These species have low forage factors of 2, which implied that they are not very palatable to grazing animals and could be selected against (Table 2). The decreaser species contents are very low (0 - 11%), while increaser I (0 - 26%) and increaser II (66 - 100%) are substantially high (Table 1). The observed botanical composition with high content of increaser II species depicts a rangeland with poor veld condition (Trollope, 1990; Hardy et al, 1999). This condition could be due to veld management issues as stocking rate, rotational grazing, type of animal etc. under communal rangeland system or managed pasture practices. However, in a natural game reserve where there is little or no range management practice, the population of the game animals and their selective grazing habit for the more palatable species could be responsible for this.

Land degradation index: Table 3 showed the land degradation index (LDI) derived from six visual indices of

Table 2. Indicators species identified on degraded portion of Tsolwana game reserve and their respective forage factors.

Decreasers species	Increaser I species	Increasers II species	Invaders species
Heteropogon contortus (7)	*Hyparrhenia hirta* (4)	*Aristidia congesta* (0)	Pen cla (7)
Panicum stapfianum (7)	*Melica decumbens* (0)	*Cynodon dactylon* (2)	*Chloris gayana* (7)
Panicum maximum (10)	*Cymbopogon plurinodis* (4)	*Eragrostis obtuse* (0)	Bro wii
		Eragrostis chloromelas (2)	
		Eragrostis curvula (2)	
		Eragrostis leh (7)	
		Microchloa caffra (0)	
		Digiteria eriantha (4)	
		Sporobolus fimbriatus (7)	
		Forbs (7)	
		Karoo (7)	
		Sedge (7)	
		Traber (7)	

Note: Values in parenthesis are the species forage factor

rangeland degradation. The derived index ranged between 5 – 24 and from which four land degradation classes denoted with 1 = Non degraded; 2 = Moderately degraded; 3 = Poorly degraded; 4= Extremely degraded were derived. The LDI multiple regression model was significant (P>0.001) with a R^2 = 0.997. The relative contribution of each variable to the model was in the order of Erosion severity (32%)> Presence of gully (22%) > Sand deposition on roads (19%) > Soil looseness (12%) > degree of slope (11%) > presence of animal tracks (4%) (Table 3). The observed high contribution of erosion severity (32%) to the model confirms the role of soil erosion in land degradation episodes (Valentin et al., 2005). Soil erosion is often preceded by a number of other occurrences, such as removal of vegetation cover, destruction of soil aggregates, soil sealing, impact of climatic variables etc. Uncontrolled soil erosion over time could result in gully formation; this is often seen as a point of no easy return in land degradation episodes. The observed least contribution by animal tracks to the LDI model (4%) suggests that the presence of animal tracks may have an indirect contribution to land degradation. This effect was negligible but could become more prominent where soil is bare and susceptible to surface sealing and crusting.

Soil properties of degraded land

The major physical agent of land degradation at Tsolwana game reserve is soil erosion. Its immediate causes include topography, rainfall, vegetation cover, soil properties and previous land use practices. In our study, the soil particle size fractions had pronounced effect on the observed land degradation. Percentage sand content of the soil was significantly ($P < 0.05$) higher in the extremely degraded lands, compared to clay and silt, while silt content was significantly ($P < 0.05$) higher in the non-degraded lands (Figure 2). The particle size distribution plays a pivotal role in the erodibility of rangeland soil (Snyman 1999), since the water retention in the soil profile is influenced by the silt and clay content among other variables (Okatan and Reis, 1999; Mwendera and Saleem). The observed higher quantity of sand fraction associated with the degraded lands in our study could be attributed to its ability to increase water infiltration, lower the soil aggregate stability and lead to increased susceptibility to erosion (Holm et al., 2002) (Figure 3).

The soil aggregate stability depicted by aggregates mean weight diameter ranged from 1.7 -2.6 mm for the non degraded; 1.1 -1.6 mm moderately degraded; 1.2 -16 mm poorly degraded and 0.8 - 1.4 mm for the extremely degraded landscape across the fast wetting, slow wetting and mechanical disaggregation test. The non-degraded sites had aggregate mean weight diameter values that are significantly ($P < 0.05$) higher compared to the degraded sites for the three stability test, similar result was obtained by (Snyman, 2005). Low soil aggregate stability is known to be associated with the sealing of the soil surface and reduction of pore spaces for air and water movement. This phenomenon often results in higher impact of raindrops on soil and further susceptibility to rill erosion (Russel et al., 2001). A prominent observation at the Tsolwana game reserve is the structural destabilization of the sealed soil surface by animal tracks. This effect was more prominent in the highly degraded sites, since every animal track is a potential takeoff point for deeper rill erosion on surface sealed soil. The trampling effects of heavy range animals as rhinoceros was also observed, which could have some surface compaction effects and further result in land degradation (Russel et al., 2001).

Soil acidification was not a problem at the Tsolwana game reserve. The soil pH of the sampled degraded land ranged between 5.5 and 6.5. The soil pH (H_2O) tend to

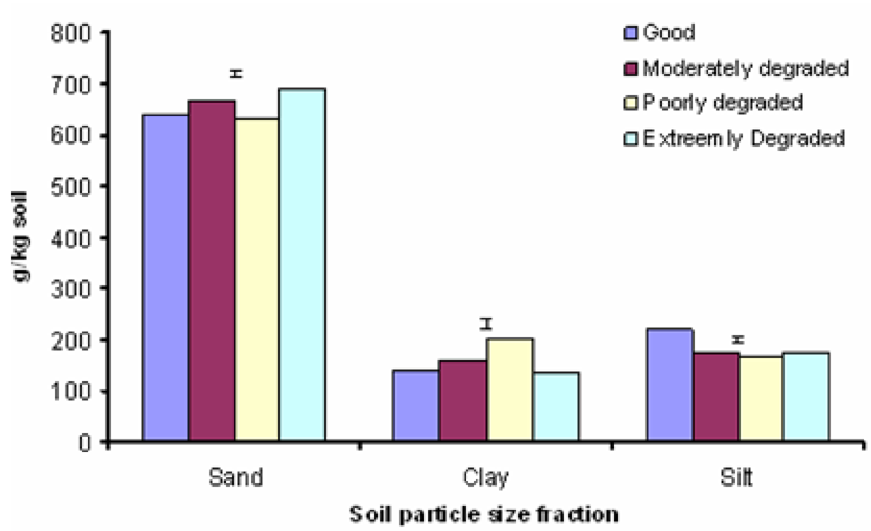

Figure 2. Effects of soil particle size fraction on land degradation. Bars represent SED (0.05).

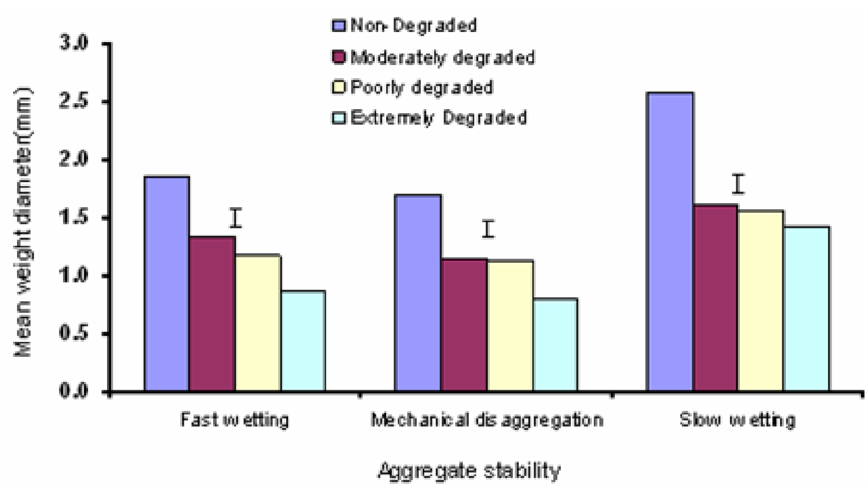

Figure 3. Effect of soil aggregate stability on land degradation. Bars represent SED (0.05)

increase with increasing land degradation but the difference between categories are not substantial (Table 4). The EC varied from 51.0 to 185.3, with coefficient of variation (CV) of 55%; the highest value being on non-degraded soil (data not shown). The role of soil organic matter in physical land degradation episodes involves the improvement of soil structure, enhancement of water infiltration rate and reduction of soil erosion through aggregate stabilization. The organic C content of soils in the sampled sites ranged between 4.0 and 32.7 gKg^{-1}. It was significantly ($P < 0.05$) higher in the non-degraded sites compared with the extremely degraded ones. However, there was no significant difference between the non-degraded and both the moderately degraded and the poorly degraded sites. Snyman et al. (2005) reported similar observation, which was attributed to the relative gradual loss of organic matter in rangelands. Since bulk of the organic matter in rangeland soils are derived from the decomposition of roots of dead or consumed grasses and herbaceous species rather than the above ground portion (Neary et al., 1999). Loss of vegetation cover may not exert profound direct effect on soil organic C until other factors such as rainfall leads to erosion and loss of top soil. This further explains the significant loss of organic C observed in the extremely degraded lands. The mean values of soil total cations from different categories of degraded soils are presented in Table 5. The concentration of K and Mg did not have a consistent trend with

Table 3. Land degradation index and degradation class derived from weighted parameter values of six indices for land degradation.

Site	Soil looseness (4)	Sand deposition (4)	Animal tracks (3)	Erosion severity (5)	Degree of landscape slope (4)	Presence of gully (5)	Degradation Index	Degradation class
1	2.4	1.6	1.2	5	1.6	5	**16.8**	**4**
2	1.6	3.2	1.8	4	1.6	5	**17.2**	**4**
3	1.6	3.2	1.8	2	0.8	1	**10.4**	**2**
4	1.6	3.2	0.6	5	1.6	2	**14**	**3**
5	2.4	3.2	3	4	2.4	4	**19**	**4**
6	0.8	2.4	3	4	1.6	3	**14.8**	**3**
7	4	3.2	1.2	5	0.8	4	**18.2**	**4**
8	3.2	3.2	1.8	5	3.2	5	**21.4**	**4**
9	4	3.2	1.8	3	2.4	2	**16.4**	**4**
10	3.2	2.4	1.2	2	1.6	3	**13.4**	**3**
11	2.4	3.2	2.4	4	0.8	1	**13.8**	**3**
12	3.2	3.2	2.4	5	1.6	3	**18.4**	**4**
13	3.2	3.2	1.8	4	1.6	3	**16.8**	**4**
14	2.4	3.2	2.4	4	1.6	3	**16.6**	**4**
15	1.6	0.8	2.4	1	1.6	1	**8.4**	**2**
16	3.2	3.2	2.4	5	3.2	5	**22**	**4**
17	4	4	2.4	5	4	5	**24.4**	**4**
18	4	4	1.8	5	3.2	3	**21**	**4**
19	2.4	2.4	1.2	2	1.6	2	**11.6**	**3**
20	3.2	3.2	1.8	4	2.4	5	**19.6**	**4**
21	0.8	0.8	0.6	1	0.8	1	**5**	**1**
22	0.8	0.8	0.6	1	0.8	1	**5**	**1**
23	1.6	1.6	0.6	2	1.6	1	**8.4**	**2**
CV	**42.3**	**35.3**	**42.6**	**41.3**	**48.0**	**52.5**	**34.4**	**31.0**
CRC(%)	**12**	**19**	**4**	**32**	**11**	**22**		

Note: Value in parenthesis is the weight of importance for the specific variable
Degradation Class: 1= Non degraded; 2 = Moderately degraded; 3 = Poorly degraded; 4 = Extremely degraded
CRC: coefficient of relative contribution

Table 4. Effects of soil pH, EC and organic C on land degradation at Tsolwana game reserve.

State of degradation	pH	EC	Org C
		*u*scm^{-1}	gkg^{-1}
Good	**5.8**	**98.3**	**13.8**
Moderately degraded	**6.1**	**80.5**	**13.3**
Poorly degraded	**6.1**	**79.5**	**13.1**
Extremely Degraded	**6.2**	**70.8**	**10.6**
SED (0.05)	0.1	7.3	1.3

the degree of land degradation, unlike Na and Ca which increased with increasing land degradation.

Relationship among variables

The observed relationship between land degradation index and other soil erosion variables as shown in (Table 6) indicated that erosion is the foremost contributing factor to the observed land degradation at Tsolwana game reserve. The observed positive correlation between the degree of landscape slope and erosion severity implied that soil erosion is more severe on steep slope side than on plain landscape or long slope (Thomas, 1997). This could be due to the more rapid soil particles movement down the slope. The observed positive rela-

Table 5. The influence of soil total K, Na, Mg and Ca on land degradation at Tsolwana game reserve.

State of degradation	K	Na	Mg	Ca	K
	mgkg^{-1}				
Good	**2683.1**	**1885.2**	**407.5**	**2842.3**	**2683.1**
Moderately degraded	**4639.2**	**1702.4**	**600.2**	**2645.4**	**4639.2**
Poorly degraded	**6125.7**	**1959.2**	**463.7**	**3368.5**	**6125.7**
Extremely degraded	**4246.3**	**2160.8**	**468.9**	**3618.1**	**4246.3**
SED (0.05)	816.8	109.5	47.1	260.8	816.8

Table 6. Correlation coefficient (*r*) showing the relationship of indices of soil erosion on land degradation index and other soil erosion variables.

Variables	Correlation coefficient (*r*)
LDI x Total soil loss	0.579 ***
LDI x Pedestals soil loss	0.502**
LDI x Soil erosion severity	0.886***
LDI x Degree of landscape slope	0.749**
Degree of landscape slope x Erosion severity	0.504***
Size of gully x Silt content of soil	0.520**
SAS (Mechanical disaggregation) x Sand content of soil	-0.425***

Note: *** = Significant at P > 0.01; ** = Significant at P > 0.05; LDI = Land degradation Index; SAS = Soil aggregate stability

** Please confirm that soil looseness (Table 3) = soil loss (Table 6). The two are different soil variables. The former is subjective as you had measured while the latter is quantitative and must be determined.

Table 7. Correlation coefficient (*r*) showing the relationship of vegetation assessment variables with land degradation Index.

Variables	Correlation coefficient (*r*)
LDI x VCS	-0.534 ***
LDI x Veld Basal Cover	0.358 **
LDI x Percentage of the area covered	0.637***
VCS x Veld Basal cover	0.4913***
VCS x Percentage of the area covered	-0.5938***
VCS x Percentage of decreasers species	0.638***
VCS x Percentage of increaser 1 species	0.4368***
VCS x Percentage of increaser 2 species	-0.5846***

Note: *** = Significant at P>0.01; ** = Significant at P>0.05; VCS = Veld Condition Score; LDI = Land degradation Index.

tionship between the silt content of the soils and size of gully indicated the contribution of silt particles to disintergration of soil aggregates and subsequent erosion. The measured disaggregation potentials of the soil showed a negative correlation between sand content and mechanical disaggregation. This suggest that the aggregates of soils with high sand content are more stable under torrential rainfall and animal tracks which are the major cause of mechanical disaggregation observed at the reserve (Nill et al., 1996)

The relationships of land degradation index with vegetation variables are shown in Table 7. The veldt condition score was negatively correlated (r = -0.534 P < 0.01) with the LDI, suggesting that veldt condition is an indicator of land degradation. The basal cover and the percentage of the land area covered by vegetation also correlated significantly with land degradation index. This explains the importance of vegetation cover in land degradation scenario. The association of VCS with the basal cover, percentage area covered, percentage of degreaser's species, percentage of increasers I and percentage of increasers II, agrees with theoretical basis and other reports

Conclusion

Preservation of a natural reserve ecosystem is central to prevention of land degradation. This is very important as Land degradation could attain a threshold where reclamation could be slow or impossible. Convectional interventions aimed at controlling land degradation have often been targeted at the end result e.g the gully, desiltation of waterways etc. without much cognizance of the causal factors or interaction of factors. Results from our study showed the significant of vegetation and soil variables as underlying factors that are responsible for the observed erosion dominated land degradation at Tsolwana game reserve. Control intervention should be directed towards stabilizing these factors and their specific interrelationship in order to prevent or reduce soil erosion. Activities like re-vegetation of the bare surfaces with more hardy perennial species, fencing off of bare land from range animal access pending restoration are two important activities.

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