An Overview of Landslide Occurrence, Inventorization and Susceptibility Mapping in South Africa

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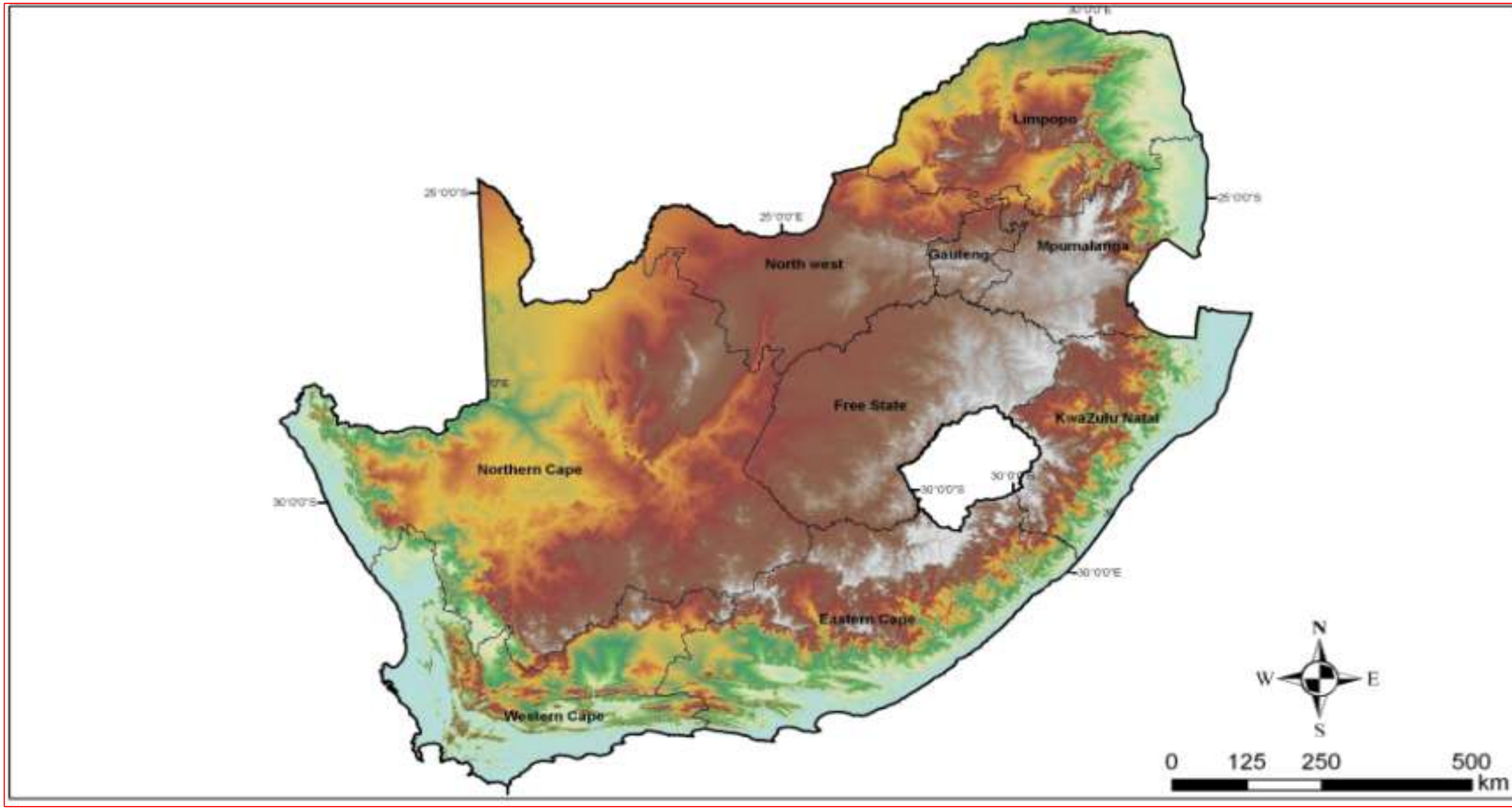
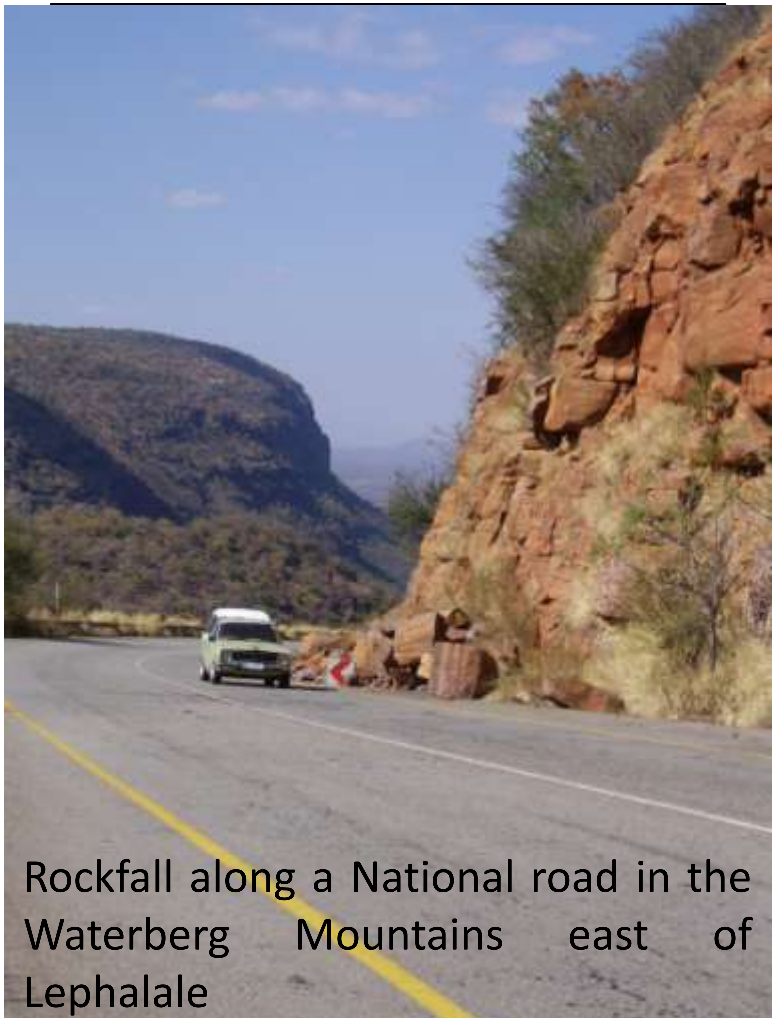
Landslide in South Africa



Landslide in Limpopo



Rockfall along a National road in the Waterberg Mountains east of Lephalale

The towering quartzite cliff failure scarp above the dammed Mutale River. Past seismicity, toe undercutting and rock shear failure occurred.

Landslide in Western Cape

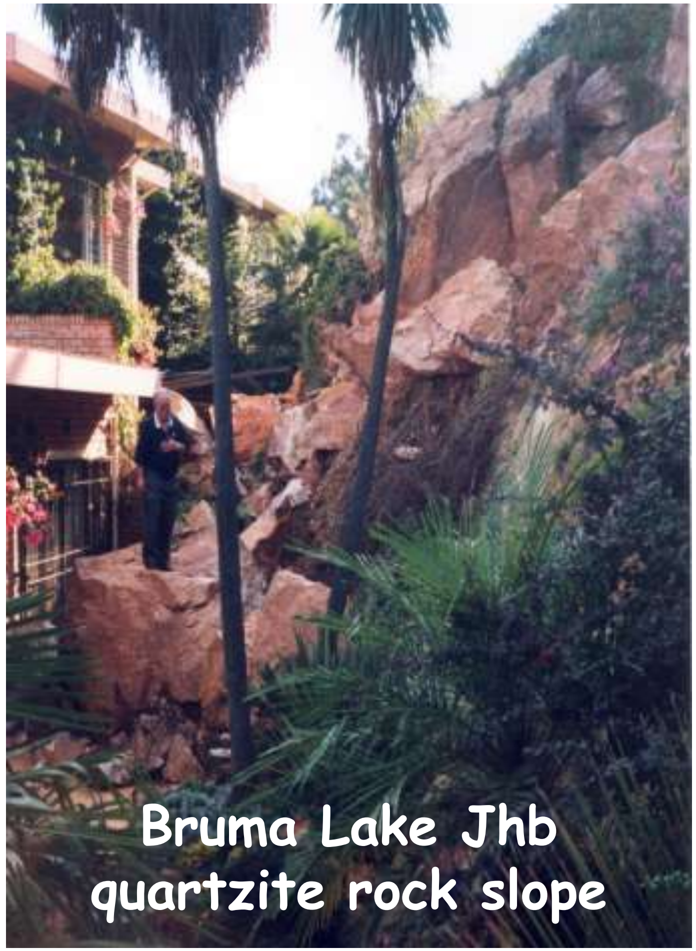
Debris slide in highly weathered quartzitic sandstone near Garabouw, Western Cape.

Chapmans Peak Drive, June 1994

Landslide in KZN

Deeply eroded gullies threatening the infrastructure of communities living on the hillsides of Kwanoshezi, SW of Pietermaritzburg, KZN.

Landslide in Gauteng



Theoretical Background

To date **2,367** landslide events have been recorded in South Africa (only a small selection of landslides are illustrated and not all nine provinces are represented due to data deficiencies).

Province	Event	Date	Causalities
Kwa-Zulu Natal	Stanger: debris flow	Sept 1987	6 deaths
Western Cape	Chapman's Peak Drive: rock falls	1988-2000	5 deaths
Free State	Merriespruit: slimes dam failure	Feb. 1994	17 deaths
Limpopo	Multiple	Feb. 2000	101 deaths

Theoretical Background

The annual costs of landslide associated expenses in southern Africa, were estimated at approximately US$ 20 million (Paige-Green, 1989). Based on an annual standard inflation rate of 10%, the current annual landslide associated expenses would be **~$163 million**.

Predictable Surprises???

Over the next three years, the South African government plans to invest **R845 billion** to remedy the skewed implementation of infrastructure in a bid to meet the demands of a growing economy and population by building roads, hospitals, dams, schools, electricity plants, ports and rail systems

Theoretical Background

- The CGS has initiated a systematic inventorization and susceptibility mapping of zones prone to slope instability for the entire country in response to the needs of local and provincial authorities for effective management strategies for reducing economic and social losses due to landslides.

- In 2008, the Engineering Geoscience Unit of the CGS was identified as one of the World Centre of Excellence (WCoE) on Landslide Risk Reduction by an independent Panel of Experts, and approved by the IPL Global Promotion Committee, during the First World Landslide Forum in Tokyo.

Research Objectives

- This project is intended to meet the growing demands of local authorities for a reliable predictive system, warning of the likelihood of landslide occurrence.

- It is intended that through its use, a new approach to risk assessment will thus be implemented in order to assess the vulnerability of local communities to the effects of landslide hazards.

Methodology

Phase 1- Compilation of all the CGS landslide inventory data and literature.

The landslide susceptibility modeling methodology followed the hypothesis which suggests that slope-failures in the future will be more likely to occur under those conditions which led to slope instability and failure in the past (Ermini et al, 2005).

Phase 2 - Two types of landslide susceptibility modeling techniques were used:

- the bivariate statistical landslide susceptibility modeling method (Soeters and van Westen, 1996) aided by the Analytical Hierarchy Process (AHP) (Saaty, 1980).
- the weights of evidence/logistic regression method was used to produce a comparative map of national landslide susceptibility.

Methodology

Phase 3 - Quality control or accuracy assessment where landslide test points independent of those landslides incorporated in the landslide susceptibility modeling exercise were compared with the landslide susceptibility maps produced.

Landslide causal factors

The following landslide influencing parameters, with the exception of human-initiated effects, were selected for the national-scale landslide susceptibility analyses:

1. Slope Angle
2. Relative relief
3. Rainfall
4. Geology
5. Seismicity
6. Terrain morphology
7. Dolerite contact zones
8. Lineaments
9. Human-initiated effects

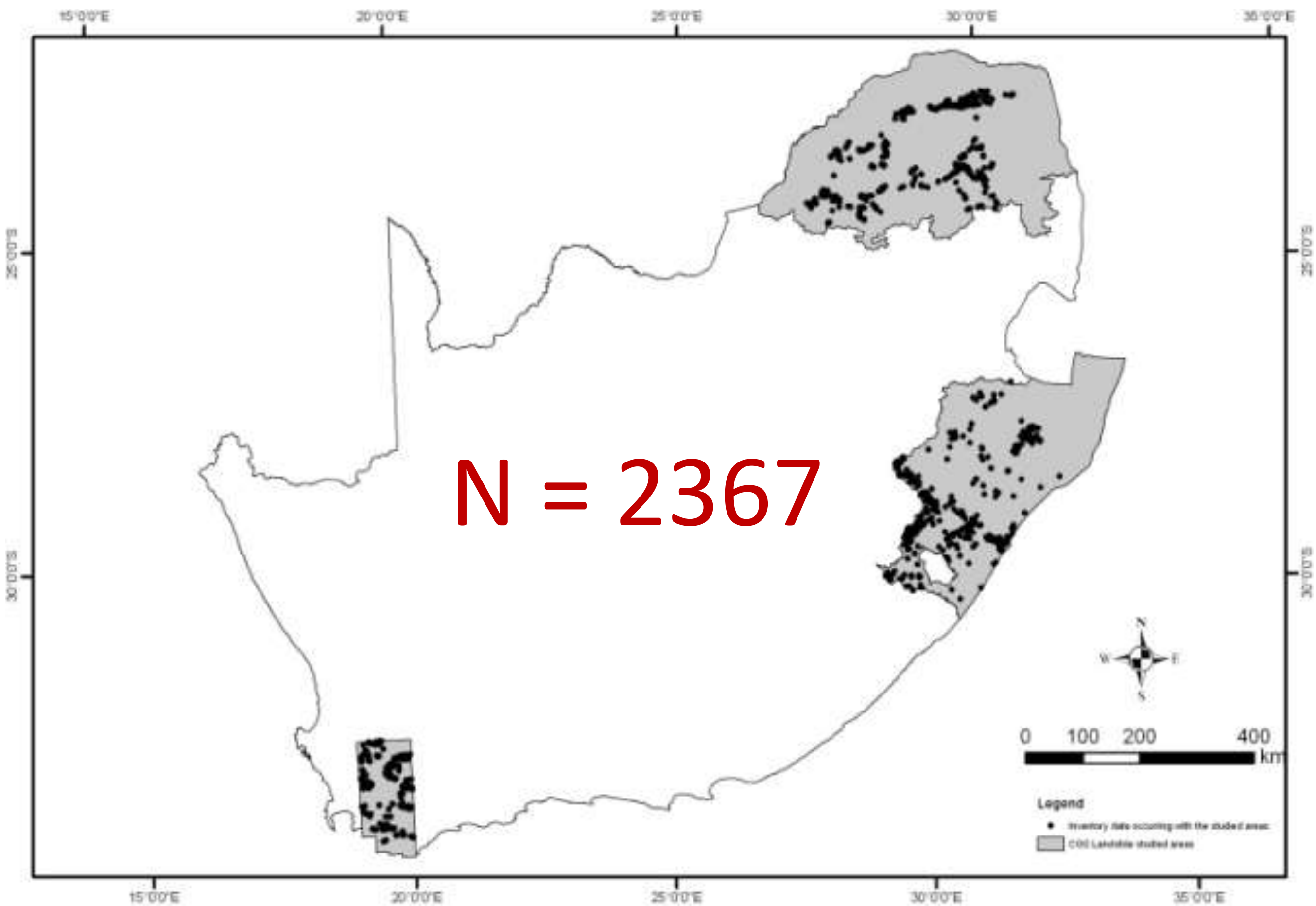
Bivariate Statistical Analysis

Individual Causal Factor (CF) maps are combined with the landslide inventory data to give weighting/ranking values per CF sub-class based on landslide densities.

$$L_{den} = \frac{\text{Number of landslides in sub}-\text{class}_a}{Total\ area\ of\ sub-class_a}$$

Density graphs of each CF are plotted and categorised to facilitate the assessment of ranking values . Ranking values of 1, 2 or 3 were assigned relative to the position of each sub-class on the density graph, where a value of 3 represents areas of highest landslide susceptibility.

Results: Inventory Data



Preference rating values

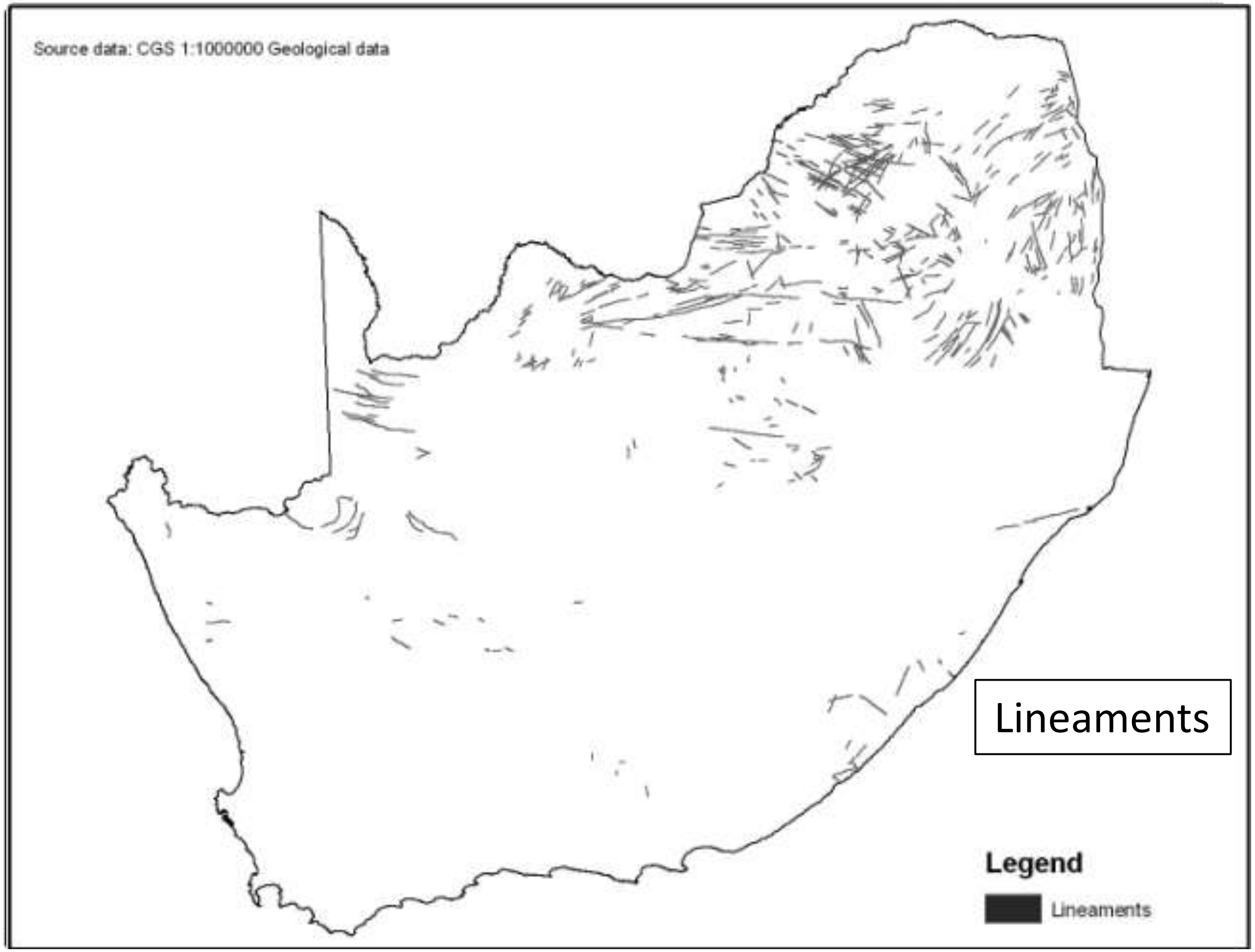
Slope Angle

Grid code	Slope class	Landslide point count	Area (km²)	Arithmetic density	Ranking value
1	0-6°	325	155391.887	0.002	1
2	6-12°	681	47548.543	0.014	1
3	12-18°	728	21802.485	0.033	2
4	>18°	633	8453.043	0.075	3

Relative relief class

Grid code	Relative relief class	Landslide point count	Area (km²)	Arithmetic density	Ranking value
1	<10	2	32640.405	0.000	1
2	10-25	55	63983.293	0.001	1
3	25-50	181	46184.561	0.004	1
4	50-100	641	50138.127	0.013	1
5	100-150	629	22857.501	0.028	2
6	150-200	397	9443.832	0.042	2
7	>200	462	7269.079	0.064	3

Causal Factor maps



Analytical Hierarchy Process

The AHP uses the mathematical pair-wise comparison technique for deriving importance values.

Saaty's Preference Rating Value	CCI* Importance Scale	Significance Level (*How important is A relative to B?*)
9	9	**Extremely** more important
7	7	**Very strongly** more important
5	5	**Strongly** more important
3	3	**Moderately** more important
1	1 or -1	**Equally** important
1/3	-3	**Moderately** less important
1/5	-5	**Strongly** less important
1/7	-7	**Very strongly** less important
1/9	-9	**Extremely** less important

* Canadian Conservation Institute

Analytical Hierarchy Process

In this study landslide experts were required to respond to pairwise comparison questions asking the relative importance of *factor A* over *factor B*

Number of Decision elements	Relationship			Decision maker 1	Decision maker 2	Decision maker 3	Sum	Mean
	Factor A		***Factor B***					
1	Slope Angle	vs	Relative relief	3	5	1	9	**3**
2	Slope Angle	vs	Rainfall	7	7	7	21	**7**
3	Slope Angle	vs	Geology	5	5	5	15	**5**
4	Slope Angle	vs	Seismicity	9	9	5	23	**8**
5	Slope Angle	vs	Terrain morphology	5	5	5	15	**5**
6	Slope Angle	vs	Dolerite contact zones	7	7	5	19	**6**
7	Slope Angle	vs	Lineaments	9	9	7	25	**8**

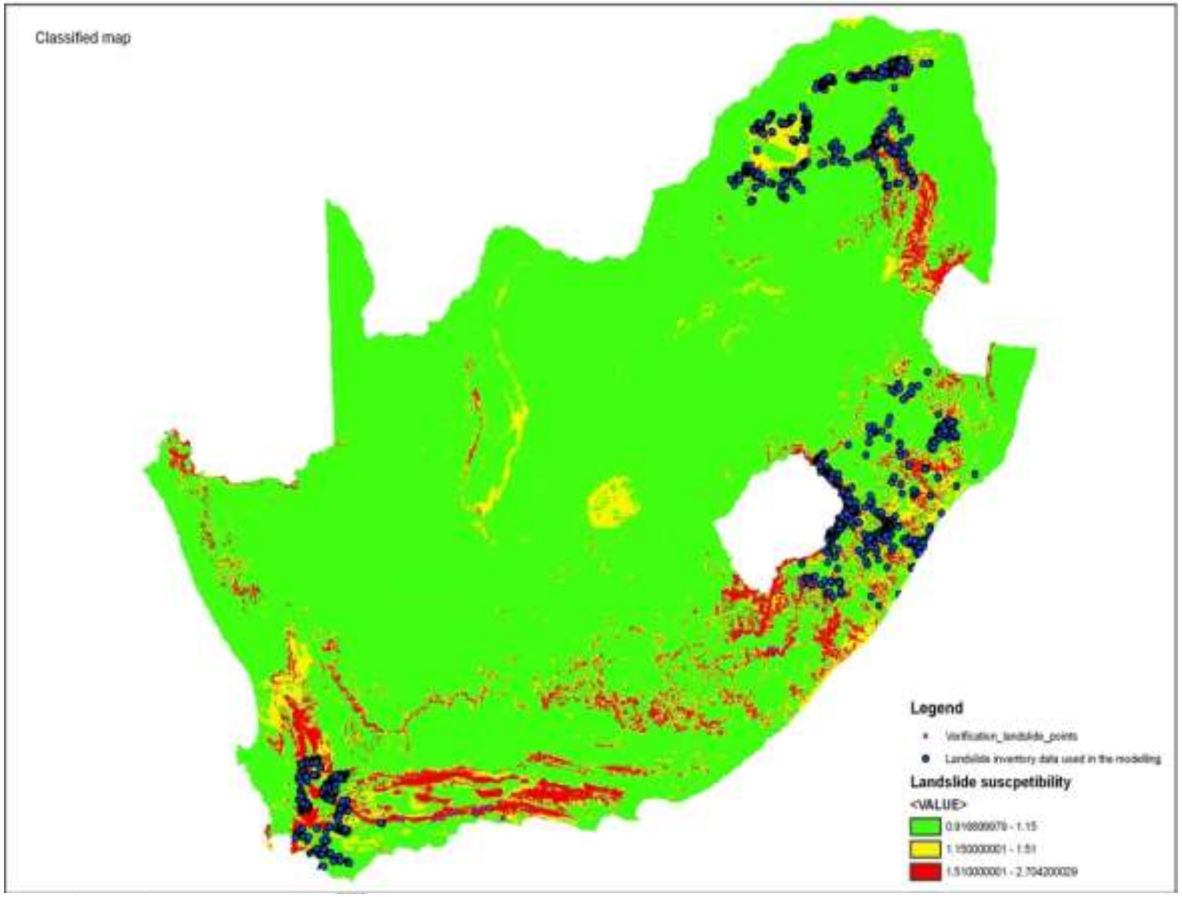
Weight values of each CF

Landslide causal factors	Weight values
Slope angle (S_a)	0.3912
Relative relief (R_r)	0.2306
Rainfall (R)	0.0761
Geology (G)	0.0937
Seismicity (S)	0.0465
Terrain morphology (T_m)	0.0788
Dolerite contact zones (D_{cz})	0.0571
Lineaments (L)	0.0261
Total (Sum)	**1.000**

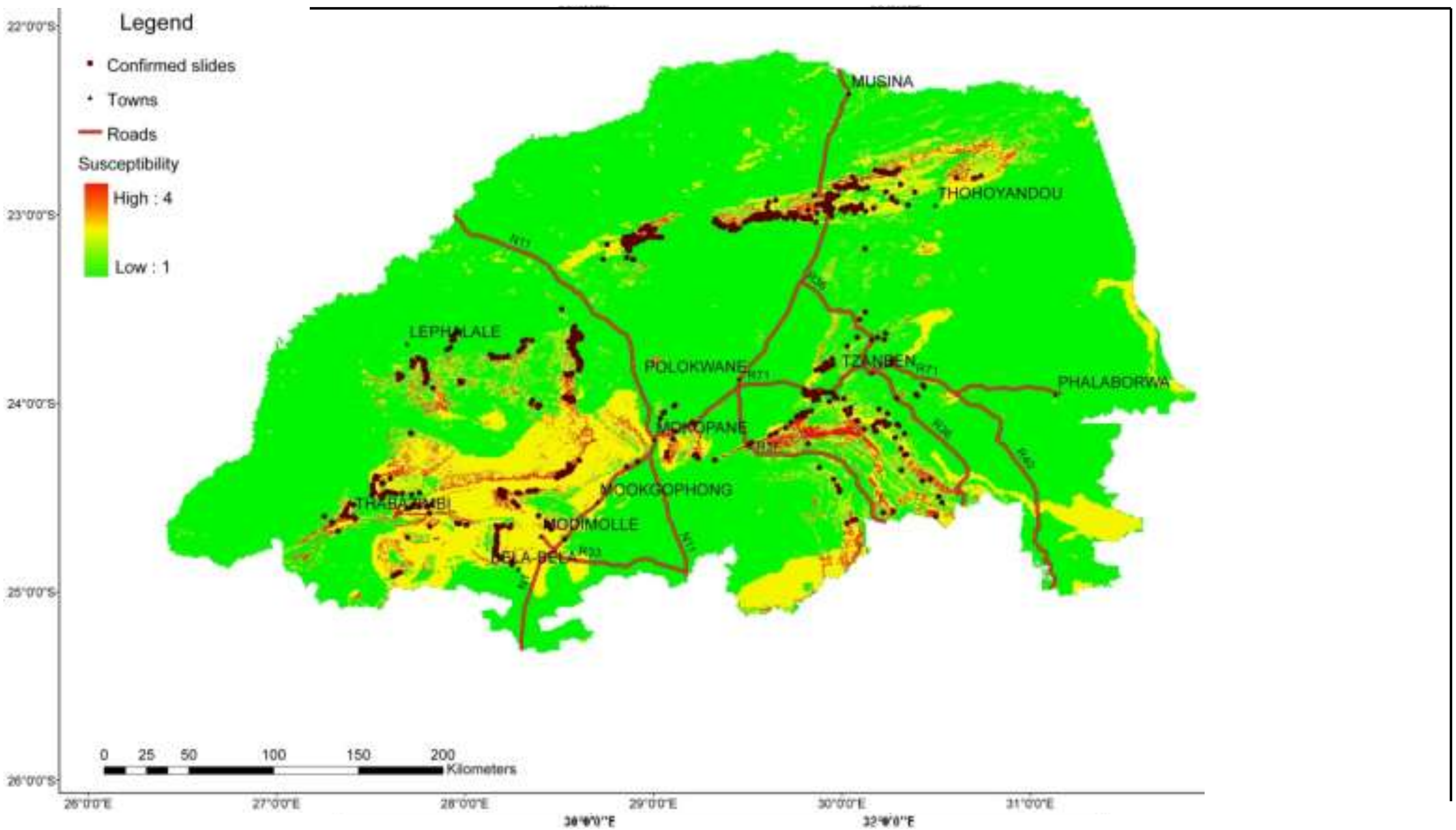
The landslide susceptibility coefficient (M) for each pixel is calculated using the expression:

$$M = (0.\ 0.3912\mathbf{S_a} + 0.2306\mathbf{R_r} + 0.0761\mathbf{R} + 0.0937\mathbf{G} + 0.0465\mathbf{S} + 0.0788\mathbf{T_m} + 0.0571\mathbf{D_{cz}} + 0.0261\mathbf{L})/1$$

National Landslide susceptibility Map



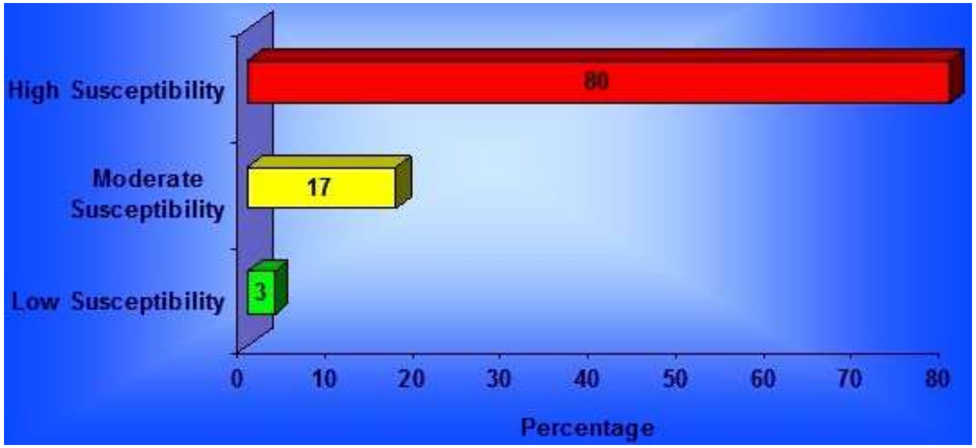
Provincial Landslide susceptibility Map



Verification

A total of 65 verification sites in the Eastern and Western Cape provinces were mapped using Google Earth™ and utilized in quality testing of the national-scale landslide susceptibility map

Landslide susceptibility class	Landslide verification point count
Low Susceptibility	2
Moderate Susceptibility	11
High Susceptibility	52



Conclusions

1. Both past and recent landslide occurrences appear to have been under-reported by various authorities and the research establishment in South Africa. This does not imply an absence of features as recent, mostly unpublished work by the Council for Geoscience, reveals a large population of events.

2. Establishment of the full spatial record and their complete characterization is necessary as communities and formal urban growth expand unwittingly into areas prone to various forms of landslides. Landslides have also not as yet been fully identified and inventorized provincially or nationally in South Africa.

Conclusions

3. Work by the Council for Geoscience is still ongoing in the Eastern and Western Cape provinces, but collation of existing data and fresh landslide mapping in the North West, Mpumalanga and the Free State, has yet to commence.

4. The landslide susceptibility maps of South Africa derived by the bivariate statistical methodology are presented as draft maps since these maps need to be comprehensively ground-truthed through an intensive fieldwork phase. There is some uncertainty inherent in the landslide susceptibility results due to the data used. The broad scales of the datasets and the mapping errors limit the accuracy of the results.

Recommendations

A mandatory standardized format and procedure of reporting to the National Disaster Management Centre (NDMC) and in turn the Council for Geoscience; by local provincial and national authorities with control over various forms of land use (road, rail, harbour, housing, agriculture), is required.

Landslide inventorization via collection of available statistics and susceptibility mapping programs by the Council for Geoscience needs to be more adequately funded and renewed at an expanded scale to be of relevance.

A comprehensive questionnaire to all local, provincial and national authorities, followed by selected interviews; will facilitate a far better status quo evaluation of past present and future remediation efforts and efficacy of mitigation strategies.

Contact Details

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