CHAPTER SIX: LANDSCAPE FUNCTIONALITY

6.1 Introduction

"Understanding the role of landscape patchiness in conserving scarce resources has important implications for managing these landscapes for sustainable land use, and for the rehabilitation of landscapes already degraded." (Ludwig & Tongway, 1995)

Landscapes are complex systems characterised by a mosaic of patches which are spatially and temporally heterogeneous (Farina, 2007; McGarical & Marks, 1995; Cadenasso *et al.*, 2003). Landscape ecology is concerned with the functional and structural dynamics of landscapes (Turner, 1989), and the relationships between ecological patterns and processes (Wu & Hobbs, 2007).

To understand how a landscape functions, and why a landscape may be deemed functional or healthy, one must obtain knowledge about the processes taking place in landscapes that enable it to function effectively as a biogeochemical or biophysical system (Tongway & Hindley, 2004). Landscape Function Analysis (LFA) is concerned with fine-scale patchiness and is based on conservation and loss of vital resources such as soil, water, and nutrients from a landscape (Tongway & Hindley, 2004). If a landscape is characterised by many vegetated patches (e.g. grass tufts) that have the ability to capture and infiltrate resources moving though the system, it may be considered functional; whilst more dysfunctional landscapes, are characterised by many bare soil patches that do not provide obstruction to overland resource flow, water and soil particles are resultantly lost from the system (Tongway & Hindley, 2003a). LFA is also concerned with soil surface properties that reflect the soil surface stability, infiltration capacity, and nutrient cycling potential of a landscape (Tongway & Hindley, 2004). The ecological integrity of ecosystems can be extensively compromised by human activities as it may consequently lead to loss in spatial and structural complexity (Chapin *et al.*, 2002) and ecosystem functioning (Vitousek *et al.,* 1997, Diaz & Cabido, 2001). According to Lindenmayer and Fischer (2006) the modification of landscapes leads to changes in the extent and spatial arrangement (horizontal patchiness and vertical structural complexity) of vegetation.

The LFA method was developed by Tongway and Hindley (2004) and may be used to assess the degradation of landscapes as brought about by human disturbances (Haagner, 2008). LFA has predominantly been used in degraded areas such as mine sites (Tongway & Hindley, 2003b; Haagner, 2008; Van der Walt *et al.*, 2012), rangelands (Ludwig *et al.*, 2004; McIntyre & Tongway, 2005; Bartley *et al.*, 2006; Marchiori, 2006; Razeai *et al.*, 2006), and semi-arid ecosystems (Holm *et al.*, 2002; Maestre *et al.*, 2006; Thompson *et al.*, 2006; García-Gómez & Maestre, 2011). Green *et al.* (2009) applied LFA in an urban environment in Canberra, Australia. The aim of their study was to quantify the urban landscape function in terms of infiltration capacity to determine and ameliorate flood risks. By applying the LFA method they were able to identify areas with poor infiltration capacities and make recommendations with regards to decreasing and preventing flood risk frequency (Green *et al.*, 2009).

6.1.1 Scale considerations

"Determining causal relations between variation in landscape patterns and variation in the composition, structure, and processes of ecological systems…is difficult to accomplish…" (Noon & Dale, 2002).

It is important to remember that only entities sharing similar scales may be able to interact with each other, and components functioning on different scales may not be able to interact, but may only be able to constrain the dynamics of other landscape levels (Wiens, 2002). There is no empirical evidence that the quality of the matrix surrounding a habitat patch (urban vs. rural) may influence fine-scale biogeochemical landscape function. It is therefore difficult to describe any possible relationships between matrix quality and landscape functionality (as determined by LFA) expressed in this chapter as direct or causal. This study may, however, form the first step for further investigations into whether or not such relationships exist.

6.1.2 Objectives and hypotheses

The aim of this chapter was to apply the LFA method in the selected grassland fragments to determine the landscape functionality of the selected grassland fragments. The information that may be obtained from LFA include physical landscape attributes and certain soil surface attributes which will reflect three main landscape functionality parameters namely soil surface stability, infiltration capacity, and nutrient cycling potential of the studied grassland fragments.

Possible patterns of physical landscape attributes and soil surface functionality along an urbanisation gradient were explored to determine whether the intensity of urbanisation has an effect on these fine-scale landscape function properties within the selected grassland fragments selected in the study area. The selected grassland remnants were classified as rural/peri-urban or urban based on the four main urbanisation measures (PURBLC, DENSPEOP, PGRALC, and ED) in the immediate 500 m matrix areas surrounding them (*Chapter 4*).

The hypotheses for this chapter are that selected grassland fragments situated in urban matrix areas exposed to increased human impacts will:

- Be characterised by a fine-scale landscape structure that is diagnostic of a system that are not actively capturing and conserving vital resources such as soil particles, water and nutrients (leaky).

- Have lower stability, infiltration and nutrient cycling soil surface indices, resulting in lower total SSA functionality, than rural/peri-urban areas.

6.2 Methods

"This (LFA) is an extremely versatile technique and a wide variety of land cover types can be included, from paving to gravel to irrigated lawn to mulched bed to hedge." (Green *et al.*, 2009)

Analysing landscape function or landscape integrity, helps the ecologist to understand and estimate how a landscape is functioning as a biophysical entity (Razaei *et al.,* 2005). This may be done by using the Landscape Function Analysis (LFA) method (Tongway & Hindley, 2004). Landscape Function Analysis consists of: 1) a conceptual framework, namely the Trigger-Transfer-Reserve-Pulse- or TTRP-framework (see 2.7.1); 2) data acquisition through field procedure; and finally 3) the data analysis and interpretation (Tongway & Hindley, 2004; Tongway & Ludwig, 2011). LFA rapidly assesses certain soil surface indicators which will indicate how successfully the system is functioning biophysically (Tongway & Hindley, 2004). Two spatial scales are examined during LFA which are linked to each other via ecohydrology. For example vegetated patches may serve as obstructions that slow and trap runoff, sediments, and nutrients from open interpatch areas (Ludwig *et al.*, 2005). The observations on the first scale involve coarser stratification of the landscape into patches and interpatches whilst the second scale is finer, involving quantification of patch characteristics.

The Landscape Function Analysis (LFA) method (Tongway & Hindley, 2004) was conducted within the selected grassland fragments from January to March, 2012. The LFA gradsects (Gillison & Brewer, 1985) of approximately 30 m were placed in a down-slope direction, thus, in the direction of resource transport such as the flow of water (direction in which vital resources will flow in the landscape). LFA may be a time-consuming procedure, and therefore one 30 m gradsect was sampled in an area representative of the fine-scale patchiness of the specific grassland fragment grassland. The gradsects started and ended at patch/interpatch boundaries and are therefore not fixed distances. The first step of LFA involved stratifying the landscape into discrete patch/interpatch units, thus creating a set of landscape units of relative uniform internal properties (*Section 6.2.1*). Eleven soil surface indicators were subsequently assessed in random query zones of each patch/interpatch type (*Section 6.2.2*) (Tongway & Hindley, 2004).

6.2.1 Landscape organisation

At a coarser (hillslope) scale, the study area was stratified into discrete units namely patches and interpatches to qualify the spatial arrangement of the landscape (Tongway & Ludwig, 2006, 2011; Haagner, 2008). Patches were differentiated by different vegetation growth forms (e.g. grass patch, shrub patch, forb patch). The spatial arrangement of various types of patches and interpatches were identified and measured directly under the measuring tape according to line-intercept criteria (Tongway & Ludwig, 2006; Haagner, 2008) (Figure 6.1). The size (length and width), location, and characteristics of each patch and interpatch (interpatch width not measured) was noted and scored according to the respective types of resource-regulating structure e.g. tree, shrub or grass patches (Tongway & Hindley, 2004).

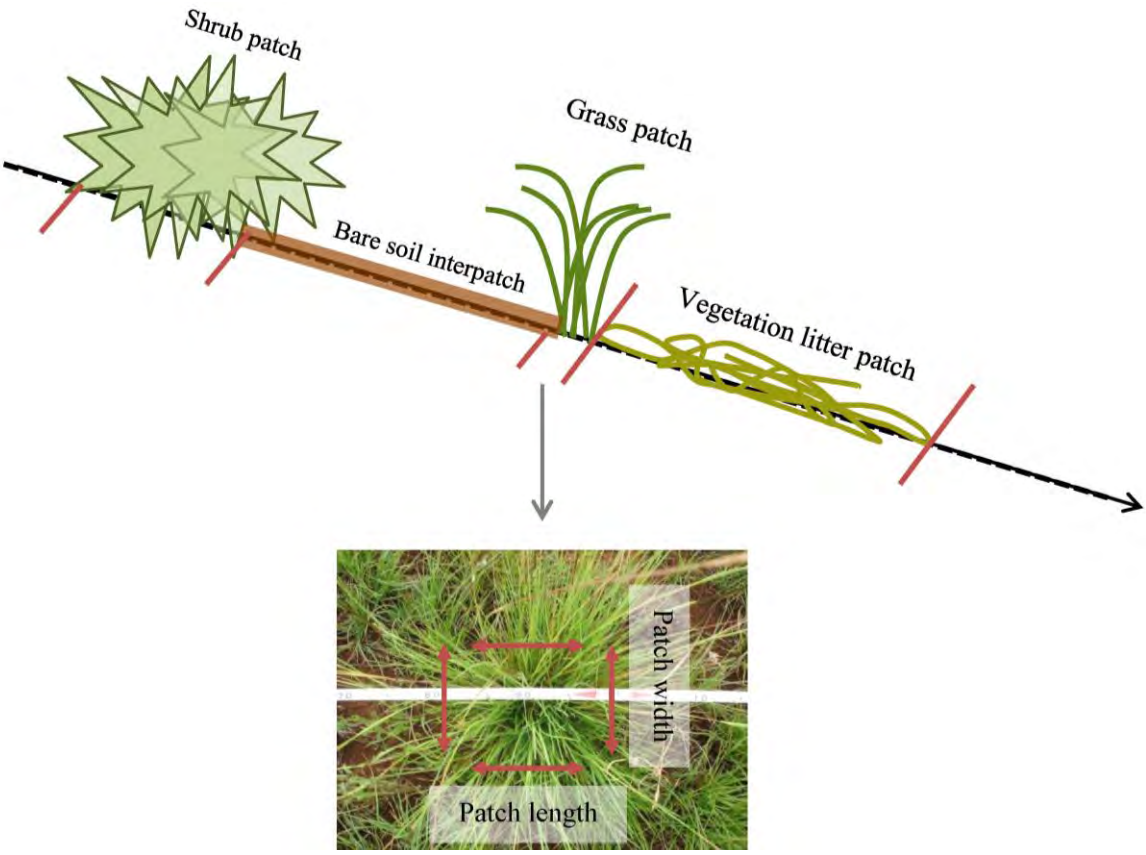

Figure 6.1: The first step of LFA namely landscape organisation. Patches and interpatches, under the gradsect line (oriented in the direction of resource flow), are identified as discrete units (after Tongway & Hindley, 2004). The length and width of each patch, and the length of each interpatch, is noted to obtain patch/interpatch structure.

The landscape organisation data will produce results representing the physical landscape characteristics, such as Landscape Organisation Index (LOI) (the proportion of the landscape consisting of vegetated, resource-conserving patches), mean patch width, total patch area, average interpatch length, as well as the shortest and longest interpatch lengths (range interpatch length). These parameters reflect the ability of a system to either conserve or lose resources (Tongway & Hindley, 2004).

6.2.2 Soil Surface Assessment (SSA)

The landscape organisation was followed by fine-scale data acquisition where eleven soil surface indicators (Figure 6.2) were assessed in the field to gain information about patch and interpatch "quality". This procedure is called the Soil Surface Assessment (SSA). Every soil surface property was evaluated and assigned a class value based on guidelines and images from a series of LFA manuals (Tongway & Ludwig, 2006, 2011; Tongway & Hindley, 2003a). For specific SSA values and scoring method see Appendix I. When they developed the LFA methodology, Tongway and Hindley (2004) tested generated stability, infiltration and nutrient cycling indices against established scientific measurements from a wide variety of habitat types where previous LFA methods were applied, to demonstrate the veracity of the SSA indices. All the SSA indices showed significant correlations with values obtained from the laboratory analysis when examined across the full dynamic range of the indicators, thus verifying the meaningfulness of the SSA indices (Tongway & Hindley, 2005).

The soil surface indicators are assessed in three to five replicates representing a set of "query zones" located in each identified patch/interpatch type per gradsect, thus assessing the patch quality (Tongway & Hindley, 2004). For example: five grass patches throughout the gradsect were randomly selected, on which the SSA was subsequently carried out. This was done for all different patch types.

6.2.2.1 The eleven soil surface indicators reflecting landscape functionality

The 11 SSA indices (Figure 6.2) were assembled in different combinations by a spreadsheet (Tongway & Hindley, 2004) to calculate three emergent indices of landscape function, namely; the 1) surface stability, 2) infiltration capacity, and 3) nutrient cycling potential of the landscape (Tongway & Ludwig, 2006) (Figure 6.2). Thus, every SSA index (scaled from 0 to 100) contributed to the total landscape functionality.

The following 11 soil surface indicators were investigated during the soil surface assessment (SSA) of LFA.

1. *Rainsplash protection*

The rainsplash protection SSA indicator relates to soil surface stability (see Figure 6.2). Aerial cover provided by perennial vegetated patches intercepts raindrops, protecting the soil surface from soil particle dislodgement, erosion, and the formation of physical crusts that diminish infiltration rate (Greene, 1994; Tongway & Hindley, 2004).

2. *Perennial vegetation cover*

The perennial vegetation cover indicator provides information about the below-ground contribution to the infiltration capacity and nutrient cycling potential of a landscape (Figure 6.2). Nutrient cycling potential of the soil is encouraged through the presence of biota, i.e. insects, fungi and bacteria, which are attracted to and consume or decompose subsurface plant organs and litter (Lavelle, 1997; Tongway & Hindley, 2004). Basal cover of perennial vegetation may also capture resources being transported through the landscape, making it available for infiltration into the system (Tongway & Hindley, 2004).

3. *Litter cover, origin, and degree of decomposition*

Litter contributes to all three LFA indices (stability, infiltration and nutrient cycling) (Figure 6.2). Litter is characterised as annual and ephemeral vegetation, and detached plant material (Tongway & Hindley, 2004). The origin of litter (local or transported) indicates the movement of vital resources through the system; vegetation litter indicates the presence of organic elements (e.g. carbon and nitrogen) in the soil surface layers, contributing to the nutrient cycling potential of the landscape. Degree of litter decomposition is an indicator of the degree to which organic material is assimilated into the soil (Tongway & Hindley, 2004). Litter serves as an obstruction for the flow of vital resources and soil particles being transported though the system, thus contributing to the infiltration and stability as two of the main functionality indices.

4. *Cryptogam cover*

Cryptogam cover contributes to the stability and nutrient cycling potential of the LFA indices (Figure 6.2). Cryptogams, also known as a "biological crust", includes algae, cyanobacteria, fungi, lichens, mosses, and liverworts, and indicates that nutrients are being assimilated in the soil surface layers (thus contributing to the nutrient cycling index) (Tongway & Hindley, 2004). Cryptogams generally colonise pre-existing stable physical soil crusts, and also slow runoff to prevent erosion (Eldridge, 1993; Greene, 1994; Tongway & Hindley, 2004).

5. *Crust brokenness*

The crust brokenness SSA indicator contributes to the soil surface stability of the landscape (Figure 6.2). A soil crust is the surface layer of the soil which is more compact than underlying soil material (Van der Watt & Van Rooyen, 1990; Valentin & Bresson, 1997). Intact soil crusts limit soil particles susceptible to erosion and thus characterises a stable landscape (Tongway & Hindley, 2004).

6. *Soil erosion type and severity*

The type and severity of soil erosion relates to the stability LFA parameter (Figure 6.2). The types of erosion which may be recorded during SSA are 1) rill and gully, 2) terracette, 3) sheet, 4) scalding, and 5) pedestal. Severe erosion indicates that the soil is not in a stable condition (Tongway & Hindley, 2004).

7. *Deposited materials*

The deposited materials SSA indicator contributes to the stability of the landscape (Figure 6.2). The presence of deposited materials (alluvium) indicates that upslope material was transported/eroded within the system, and thus suggests some instability (Tongway & Hindley, 2004; Tongway & Ludwig, 2011).

8. *Soil surface roughness / microtopography*

The microtopography SSA index contributes to the infiltration and nutrient cycling LFA parameters (Figure 6.2). This includes both the physical micro-relief of the soil, as well as the roughness provided by vegetation (e.g. dense grass tufts) (Tongway & Hindley, 2004). Surface roughness slows resource movement, making it available for infiltration into the system (Tongway & Hindley, 2004; Lechmere-Oertel *et al.,* 2005). The captured and infiltrated resources (soil, water, and nutrients) also subsequently contribute to the nutrient pool of the landscape (Tongway & Hindley, 2004; Lechmere-Oertel *et al.,* 2005).

9. *Surface resistance to disturbance*

The potential of the soil surface layers to resist disturbance relates to the soil surface stability of the landscape (Figure 6.2). Hard-setting surfaces may be resistant to physical perturbation such as erosion, implying high stability, but consequently has low infiltration capacity – the LFA data analysis software (Tongway & Hindley, 2004) takes this into account. Deep soft soils imply that with physical perturbation, large volumes of soil may be displaced (Tongway & Hindley, 2004).

10. *Slake test*

The slake test index of the SSA contributes to the stability and infiltration capacity of the landscape (Figure 6.2). A soil crust that remains intact during water submersion will indicate that the soil surface is stable due to organic matter and will not be easily eroded by water, but may not be as successful in infiltrating water and other resources (Tongway & Hindley, 2004).

11. Soil texture

Soil texture relates to the infiltration capacity LFA parameter (Figure 6.2). Different soil textures are characterised by different porosities and permeability. Porous soils such as sands will actively infiltrate water into the soil, whereas heavier textured soils such as clay-loams and clays have much lower rates of infiltration (Ashman & Puri, 2002).

The above mentioned eleven soil surface indicators will reflect the three main functionality indices (Figure 6.2), which need to have adequate values to optimise landscape productivity. For instance, a landscape may have very high soil surface stability, but low infiltration and nutrient cycling indices. The high stability index may compensate for the shortcomings in the other two soil surface indices and result in a high total SSA functionality score. But the imbalance of the SSA indices actually indicates that the landscape is not as functional, and a good score in all three SSA indices is indicative of a functional landscape.

6.2.3 Data analysis

The raw Landscape Organisation- and SSA data were entered into the LFA Data Entry Software (Version 3.0) (Tongway & Hindley, 2004). The data entry software calculated various physical landscape scale variables as well as the final main SSA indices namely stability, infiltration, and nutrient cycling that were derived from the eleven SSA indices (refer to Figure 6.2). The summarised landscape functionality data, obtained from the LFA Data Entry Software (Version 3.0), (Tongway & Hindley, 2004), was processed and tabulated using Microsoft® Office Excel® 2010 (Microsoft Corporation, 2010).

Non-metric multidimensional scaling (NMDS) analysis was executed using PRIMER (version 6.1.15) (PRIMER-E, 2012). The NMDS ordinations express the similarity between sites (Clarke & Gorley, 2006) based on the Bray-Curtis dissimilarity index (square root transformed) as a measure of similarity (Haagner, 2008). This ordination technique was thus used to visually express similarities and variability (Quinn & Keough, 2002) of respective physical landscape attributes and SSA indices of the selected grassland fragments.

The methods to express the relationships between degree of urbanisation in the 500 m radius matrix area (urbanisation measures) and landscape function, involved statistical analysis using the raw LFA data for each selected grassland fragment. It was one of the main objectives of this study to determine whether landscape function (physical landscape attributes and soil surface function) were different for selected grassland fragments exposed to different degrees of urbanisation. The four main urbanisation measures (PURBLC, PGRALC, ED, and DENSPEOP) were correlated with the various LFA variables to determine whether urbanisation has an effect on the fine-scale patchiness and biogeochemical function of the selected grassland fragments. A correlation matrix was created in

Soil surface indicator	Objective
1. Vegetation canopy/rock cover- Rainsplash protection.	Assess extent to which above ground cover mitigates the compacting effect of raindrops on the soil surface.
2. Perennial vegetation cover.	Estimate the canopy density of trees and shrubs and/or basal cover of perennial grass.
3. Litter.	Assess the amount, origin and degree of decomposition of plant litter.
4. Cryptogram cover.	Assess the presence and abundance of cryptograms visible on the soil surface.
5. Crust brokenness.	Assess the extent to which the soil surface crust is broken, leaving erodible soil particles.
6. Soil erosion type and severity.	Assess the type and severity of recent/current soil erosion.
7. Deposited materials.	Assess the amount and nature of alluvium in the query zone.
8. Soil surface roughness (microtopography)	Assess the roughness or micro-topography of the soil, thus its capacity to slow the flow of/capture resources.
9. Surface resistance to disturbance.	Assess soil's vulnerability to mechanical disturbance to yield material that can easily be eroded.
10. Slake test.	Assess the stability of the soil crust under wet conditions.
11. Soil texture.	Classify the texture of the surface soil to relate to the permeability of the soil.

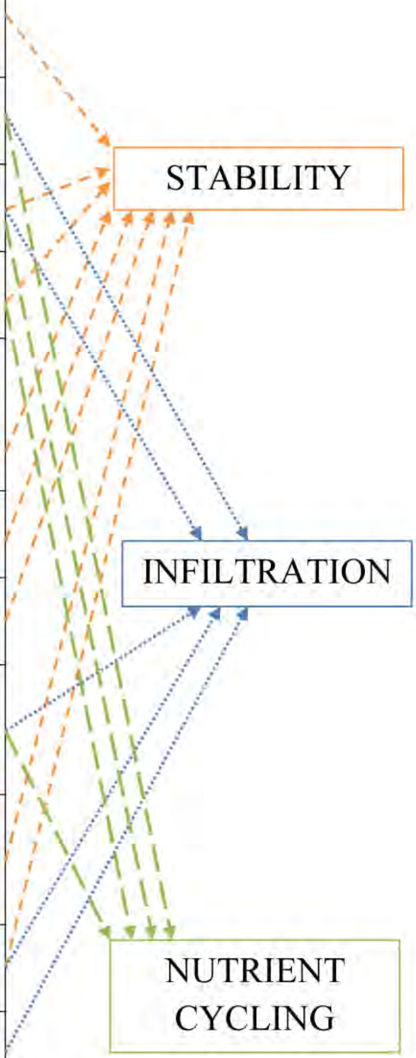

Figure 6.2: Summary of the eleven soil surface indicators used in the Soil Surface Assessment (SSA) and the main LFA parameters, namely stability, infiltration capacity and nutrient cycling potential, to which they contribute (adapted from Tongway & Hindley, 2004).

STATISTICA (version 10) (StatSoft, Inc., 2011) to indicate possible relationships (expressed as the Pearson r correlation coefficient) between physical landscape attributes and SSA indices. Pearson's r value ranges between -1.00 and 1.00 (Quinn & Keough, 2002). If the correlation matrix indicates that a relationship exists between two variables, it does not necessarily signify a cause-and-effect relationship (Brase and Brase, 1999). Multiple regression analysis (Pearson, 1908) was therefore also performed to explore possible linear relationships between various landscape physical attributes and the three main functionality parameters. An r^2 (coefficient of determination) value of <0.1 is considered small and unimportant; $0.1 < r^2 < 0.25$ indicates a medium correlation and possible relation; whilst $r^2 > 0.25$ is considered as a practically important correlation (Ellis, 2013; Steyn, 2009;

Steyn, 2012) between two variables. The small sample size, in terms of availability of Rand Highveld Grassland remnants, of this study implies that significant correlations should not be interpreted as definitive but indicative of a potential trend (Dytham, 2001), and therefore requires further supporting research incorporating more samples.

The two classes, namely "rural/peri-urban" and "urban" (determined in *Chapter 4*), were used as grouping variables in executing Tukey's Honest Significant Difference for unequal N using STATISTICA (version 10) software (StatSoft, Inc., 2011).

6.3 Results and discussion

6.3.1 Fine-scale landscape heterogeneity

The characteristics and distribution of patches within the selected grassland fragments express the spatial arrangement of resource-regulating structures of the various landscapes. This will reflect the effectiveness of the landscape heterogeneity in shaping the landscape's ability to conserve or lose resources. Larger patches and smaller interpatches imply higher functionality (Tongway & Hindley, 2004).

6.3.1.1 Patch descriptions and specific SSA function scores

A variety of patch types were recorded during the Landscape Organisation step of the LFA method (Table 6.1 and Figure 6.3).

The proportion (percentage of the gradsect) of each patch/interpatch type for each selected grassland fragment (arranged in the direction of increasing percentage impervious surfaces) is provided in Figure 6.4. Not every type of patch was present in each selected grassland fragment (Figure 6.4). For example: no bare soil interpatches (BSI') were recorded in sites 6 (urban) and 25 (rural/peri-urban); forb patches (FP's) were exclusive to sites 21, 22, 23, and 27 (rural/peri-urban), 13 and 15 (urban); and grass patches (GP's) were not present in sites 7, 8, 9 and 16 (urban) (Figure 6.4). The patch-interpatch proportion of a landscape relates to the Landscape Organisation Index (LOI) which reflects the proportion of the landscape able to capture and utilise vital resources, and what fraction of the landscape is not actively conserving vital resources. This concept will be discussed in detail in *Section 6.3.1.2 Physical landscape attributes.* The patch type composition of the selected grassland fragments vary greatly and no specific patch types and abundances were associated with specific urbanisation intensities.

Table 6.1: Patch types recorded in selected grassland fragments during the Landscape Organisation step of the LFA method.

Patch type	Code	Description
Bare soil interpatch (Figure 6.3a)	BSI	Bare soil interpatches are characterised by bare soil. No vegetation exists, but trace amounts of litter may be present. This means that no or very little rainsplash protection and basal cover occurs. There are no obstructions that can slow the flow of, or capture and retain, vital resources (Tongway & Hindley, 2004). A high frequency of this patch type may result in low functionality of the area, due to excessive runoff speed and volume.
Forb patch (Figure 6.3b)	FP	A forb patch is a patch consisting of a forb (herbaceous plants which are not grasses) such as *Lippia scaberrima* existing as a discrete unit.
Grass patch (Figure 6.3c)	GP	Grass patches consisted of one individual creating a dense tuft, or a network of overlapping individuals forming larger patches.
Grassy forb patch (Figure 6.3d)	GFP	A grassy forb patch is characterised by the presence of grass growing closely together with herbaceous vegetation to form a single dense patch.
Grassy litter patch (Figure 6.3e)	GLP	Grassy litter patches were mostly encountered where a very dense grass sward was shedding leaves, or where the grassland fragment had been mowed 6-8 weeks ago. This patch type is characterised by a combination of plant litter (mostly of local origin) and live perennial plant material. No evidence of resource movement around individual plants could be seen.
Litter patch (Figure 6.3f)	LP	Litter patches have been identified as comprised entirely of dead plant material or annual species. No bare soil or other vegetation can be seen. This patch type greatly contributes to the nutrient cycling potential of the landscape and defines fertile patches (Tongway & Hindley, 2004).
Sparse grass patch (Figure 6.3g)	SGP	A sparse grass patch is very similar to a grass patch but has been differentiated on the basis of a lower basal cover value. These are of particular interest, as they are on the cusp of increased density (grass patch) or of declining to a litter or even bare soil interpatch classification.

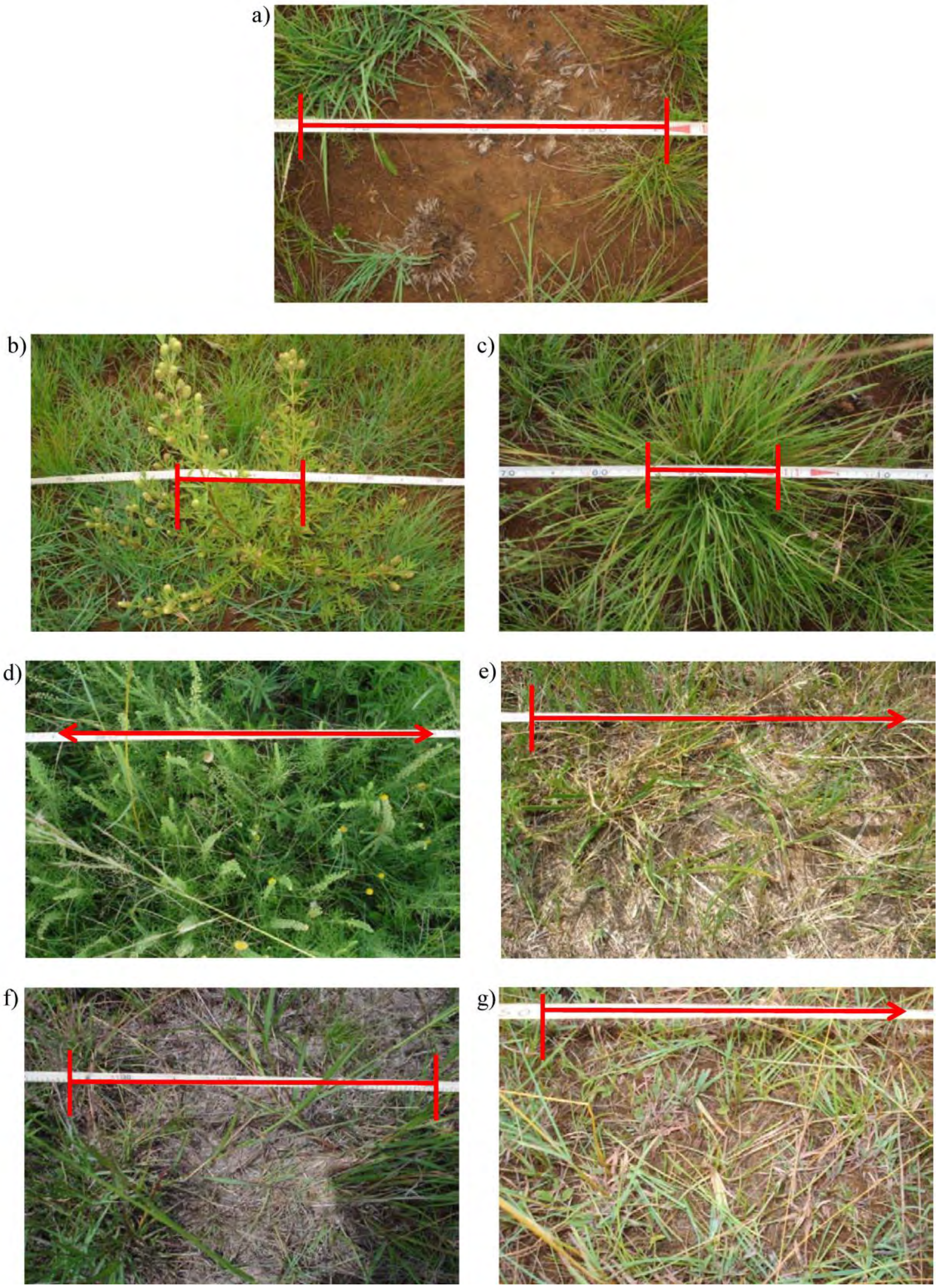

Figure 6.3: Examples of the different patch types encountered within the gradsects in the selected grassland fragments a) Bare soil interpatch (BSI), b) Forb patch (FP), c) Grass patch (GP), d) Grassy forb patch (GFP), e) Grassy litter patch (GLP), f) Litter patch (LP), and g) Sparse grass patch (SGP).

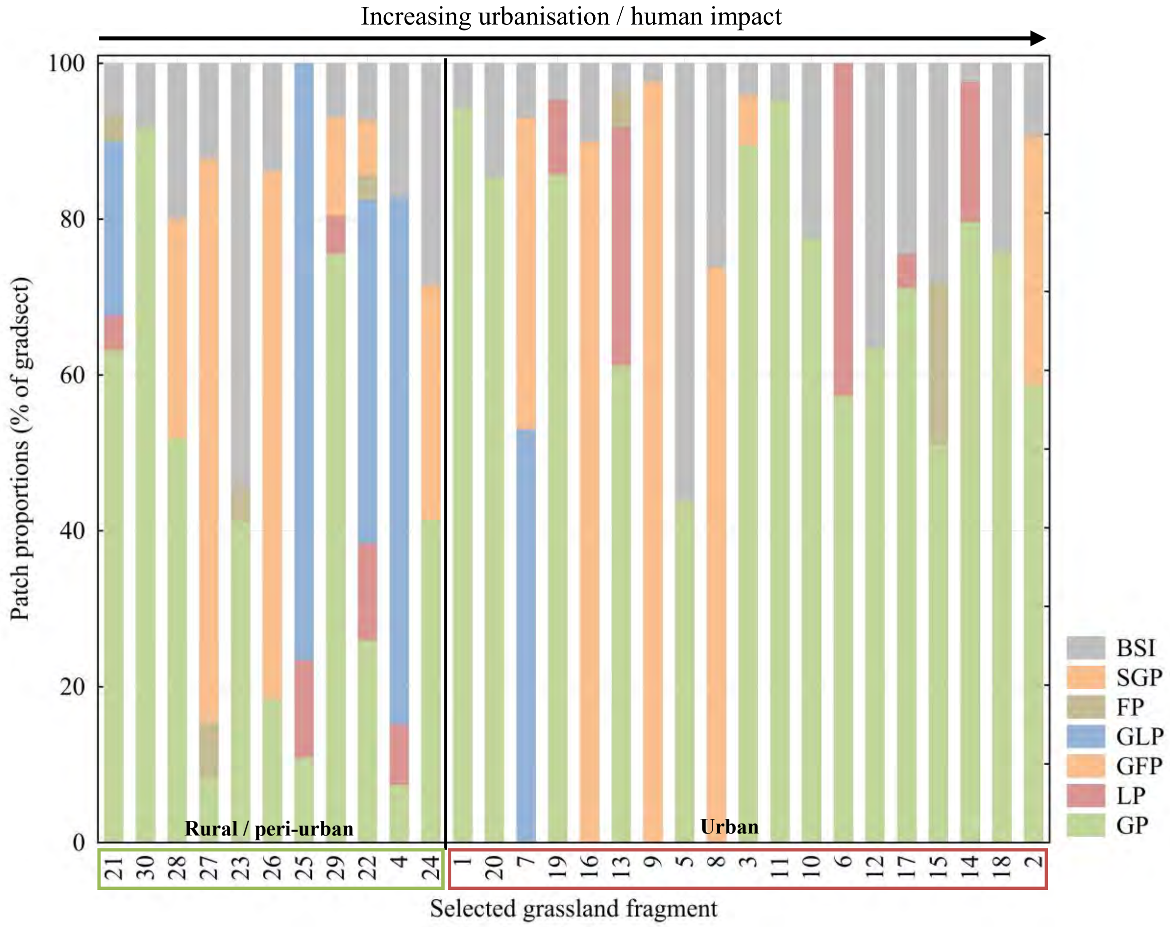

Figure 6.4: Percentage cover of the patch/interpatch types recorded in each gradsect within the 30 rural/peri-urban and urban selected grassland fragments arranged in the direction of increasing percentage impervious surfaces. BSI = bare soil interpatch; SGP = sparse grass patch; FP = forb patch; GLP = grassy litter patch; GFP = grassy forb patch; LP = litter patch; GP = grass patch.

Bare soil interpatches (present in all sites except sites 6 and 25 (see Figure 6.4) contributed the least to the landscape functionality SSA indices, whilst vegetated patches scored the highest functionality indices (Figure 6.5). The specific SSA index scores for the various patch types recorded during the study will now be discussed.

1. *Specific stability SSA index of patch types*

Grass patches (GP's) were generally the patch type with the highest stability indices. They act as obstructions for slowing down and capturing overland flow, providing soils with physical stability (Yao *et al.*, 2009) and therefore prevent soil erosion. There were some grassland fragments where grassy litter patches (GLP's) outperformed the soil surface stability of GP's (sites 4, 7, and 25) (Figure 6.5a). The reason for this is that the GLP's, in these instances, were characterised by a crust, whilst no crust was present under the dense tuft of the GP's. Bare soil interpatches (BSI's) were characterised by the lowest stability SSA index (Figure 6.5a), mainly due to the absence of physical rainsplash protection, as provided by vegetated patches, leaving the soil surface exposed to erosion and resource-loss. There were three exceptions where other patch types had the lowest stability indices (Figure 6.5a). Firstly, litter patches (site 13) – this may be due to extensively broken soil crust present in the litter patches (LP's), soil particles were susceptible to erosion and signs of slight sheeting was evident. Secondly, grass patches (GP's) in (site 20), and thirdly sparse grass patches (SPP's) (site 26) – possibly also due to unstable soil crusts which may easily be broken, as well as signs of slight sheet erosion in both the GP's of site 20 and the SPP's of site 26.

2. Specific infiltration SSA index of patch types

Litter cover and degree of decomposition, and basal cover seem to be the basic functionality indicators that determine high or low infiltration capacity (Van der Walt *et al.*, 2012). Therefore, where LP's and GLP's were present, they scored the highest infiltration SSA index (see for example sites 4 and 25 in Figure 6.5b). BSI's may contribute the least to the infiltration capacity of selected grassland fragments due to the absence of vegetation basal cover, which would normally slow down and capture resources being transported through the landscape making it available for infiltration. In sites 20 and 24 the grass patches (GP's) and bare soil interpatches (BSI's) had similar infiltration scores. This was possibly due to some uncharacteristically high litter presence (±25%) in the BSI's, of sites 20 and 24, whilst no litter was recorded in the grass patch query zones. This indicates that similar scores can be obtained with different combination of individual SSA indicators.

3. Specific nutrient cycling SSA index of patch types

The highest nutrient cycling SSA indices were achieved by vegetated patches (e.g. GP's in sites 1, 5, 10, 11, 12, 14, 19, 20, 21, 23, 27, 28, and 30; SGP's in sites 8, 27, 28, and29; LP's in sites 4,6, 13, and 17) (Figure 6.5c). The properties of vegetated patches are related to soil surface nutrients (Holm *et al.*, 2002). BSI's played the least substantial role in contributing to the nutrient cycling SSA index (Figure 6.5c). This may once again be contributed to the small amounts of litter cover, and absence of basal cover. BSI's generally scored a litter cover value of 1 (litter cover < 1%) when compared with vegetated patches and litter patches that scored a 3 (litter cover 25-50%) or higher, and a basal cover score of 1 (perennial vegetation cover < 1%) versus the basal cover of vegetated patches (perennial vegetation cover > 15%). Local litter cover and degree of decomposition increases the nutrient cycling index as nutrients are effectively returned into the soil. Low basal cover allows vital resources to be lost from the system, instead of being infiltrated to the soil substrate, which implies low soil carbon sequestration (Van der Walt *et al.*, 2012).

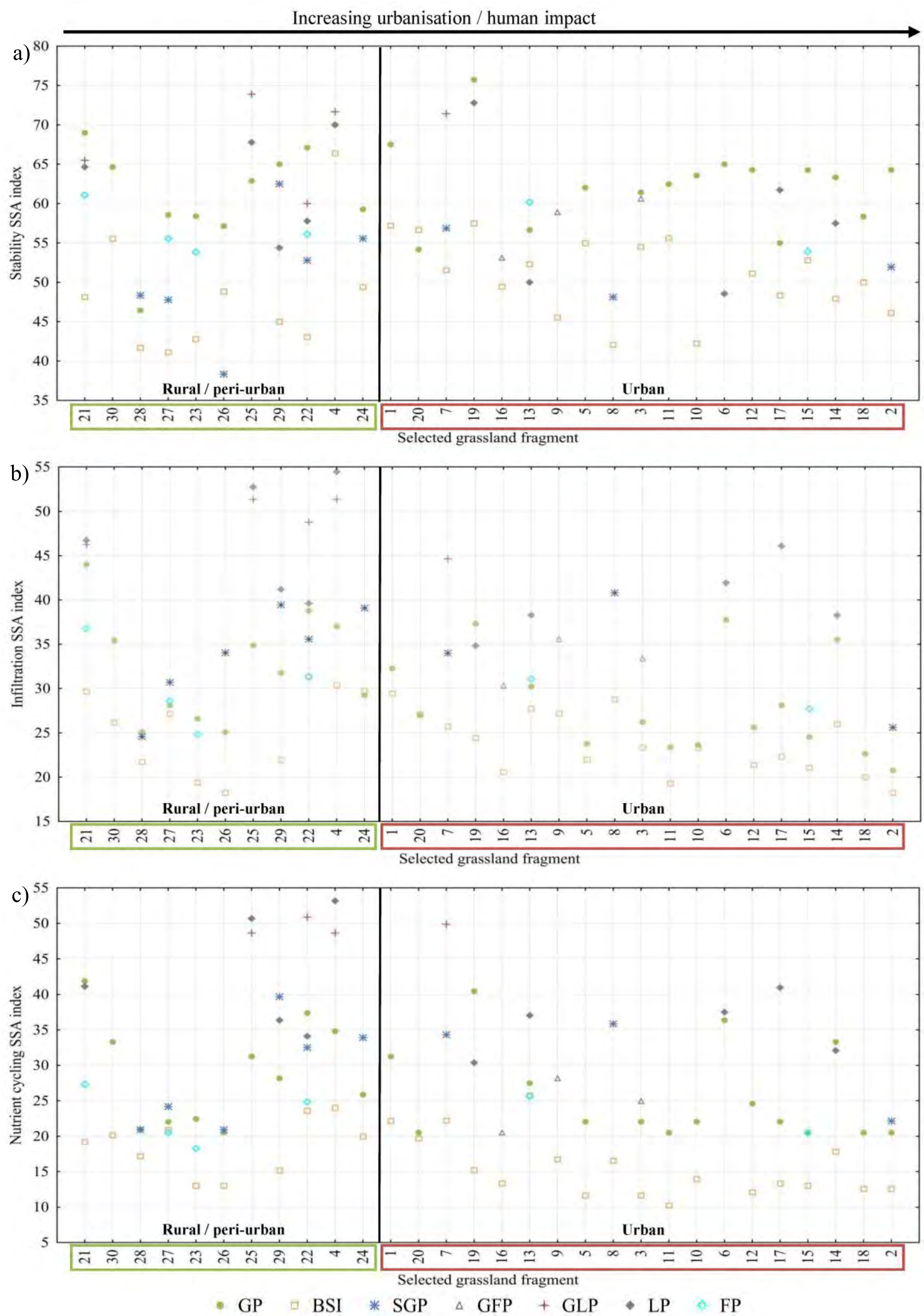

Figure 6.5: a) Specific stability, b) infiltration, and c) nutrient cycling SSA index scores of the most commonly encountered patch and interpatch types in rural/peri-urban and urban selected grassland fragments arranged in the direction of increasing percentage impervious surfaces. GP = grass patch; BSI = bare soil interpatch; SGP = sparse grass patch; GFP = grassy forb patch; GLP = grassy litter patch; LP = litter patch; FP = forb patch.

6.3.1.2. Physical landscape attributes

The physical and distribution attributes of patches within a landscape will reflect the system's ability to act as obstructions that capture vital resources moving through the system, providing opportunity for infiltration into the system's reserve (Ludwig and Tongway, 1995; Schlesinger *et al.*, 1996; Ludwig *et al.,* 1999a, 1999b, 2001, 2005; Vásquez-Méndez *et al.,* 2010).

No significant linear relationships were found between physical landscape attributes (intra-patch variable) and the four urbanisation measures (matrix variable) for the selected grassland fragments (see Table J.1, Appendix J for full multiple regression analysis results).

1. *Landscape organisation index (LOI)*

The landscape organization index (LOI) is the proportion of the length of all patches to the total length of the gradsect, thus the percentage of the gradsect that consisted of patches (Tongway & Hindley, 2004). LOI is a good indicator of vegetation cover, and may be related to the three main LFA parameters (stability, infiltration, and nutrient cycling), as well as carbon and nitrogen reserves (Rezaei *et al.*, 2006).

Except for sites 5 and 12 (urban), and 23 (rural/peri-urban - grazed), the selected grassland fragments had LOI values exceeding 70 (see Table 6.2 and Figure 6.6). This means that 70% or more of the ±30 m gradsect area that was sampled consisted of patches where resources are conserved, and the other 30% consisted of interpatches were resources may be lost from the system.

Sites 6 (urban - mowed) and 25 (rural/peri-urban) both had LOI's of 100% (Figure 6.6), entailing that there were no interpatches recorded in the gradsect of these grassland fragments (refer to Figure 6.4). An LOI value of 100 can be expected in areas that receive more than 500 mm rainfall per year (Tongway, 2012). The Rand Highveld Grassland receives between 570 mm and 730 mm per annum (Mucina & Rutherford 2006), but high LOI values could possibly be the result of other factors than rainfall alone, such as mowing. Site 6 (urban) had recently been mown and was consequently characterised by vast litter patches. No bare soil interpatches were recorded in this gradsect (Figure 6.7a), resulting in a LOI of 100%. The LOI of 100% in site 25 (rural/peri-urban) can be contributed to *Elionurus muticus,* which was the dominant grass in this selected grassland fragment. *E. muticus* grass species has leaves located predominantly at the base of the plant, forming dense tufts (Van Oudtshoorn, 2006). These grass tufts were so densely arranged that no bare soil interpatches were recorded in site 25 (Figure 6.7b).

Sites 5 (urban) and 23 (rural/-peri-urban) had the lowest LOI values (43.7 and 44.4 respectively) (Figure 6.6 and Table 6.2). This may be attributed to the great number of smaller patches surrounded by interpatches recorded within the LFA gradsects sampled in these grassland fragments. For site 23 the presence of grazing may have resulted in smaller vegetated patches (Freudenberger et al., 1997;

Tongway and Ludwig, 1997), whilst site 5 was predominantly occupied by smaller forb plant species (57.59%) and less grasses (24.56%) possibly contributing to the presence of more open bare soil.

Patches serve as run-on areas, capturing and retaining resources such as water, nutrients and soil particles (Ludwig *et al.,* 2001; Cadenasso *et al.,* 2003; Tongway & Hindley, 2004). A landscape, therefore, that consists of a greater proportion patches than interpatches (high LOI value) would be regarded as a system that can actively conserve resources.

Selected grassland fragments in rural/peri-urban and urban surroundings, thus exposed to varying degrees of urbanisation had the same LOI (e.g. site 6 (urban) and site 25 (rural/peri-urban) both had an LOI of 100%) (Figure 6.6), therefore the mean LOI for the rural/peri-urban and urban grassland fragments did not differ significantly from each other (see Table K.1, Appendix K for ANOVA results).

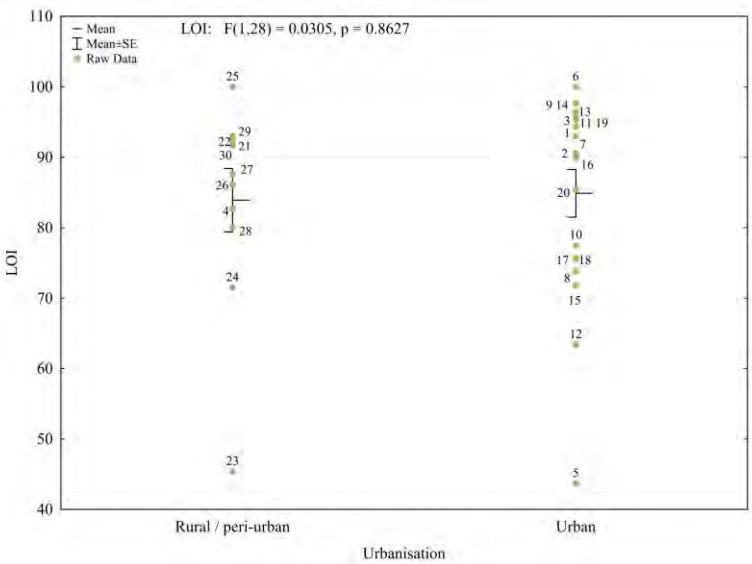

Figure 6.6: Mean Landscape organisation index (LOI) for rural/peri-urban and urban selected grassland fragments. The green dots represent the LOI (raw data) of each selected grassland fragment.

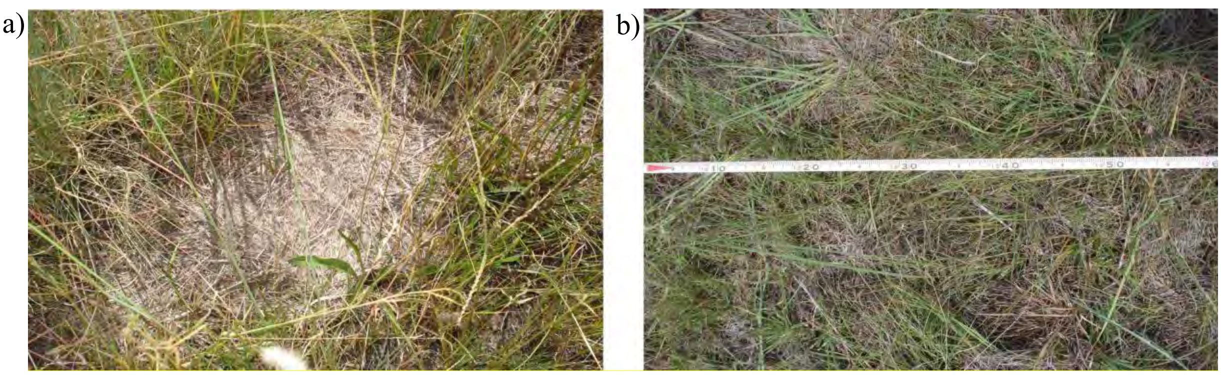

Figure 6. 7 a) Dense litter present in site 6 (urban) due to mowing. No bare soil interpatches recorded; b) Dense tufts of *Elionurus muticus* recorded in site 25 (rural/peri-urban). No bare soil interpatches recorded.

2. Mean patch width

The mean patch width (cm) represents the total width of all patches, divided by the total number of patches recorded along the gradsect in the selected grassland fragments (Tongway & Hindley, 2004). Two types of grass patches (GP's) were characterised, namely the denser, so called "matted", and the more tufted types surrounded by bare patches, respectively (refer to Table 6.1).

Site 9 (urban) had the highest mean patch width (538.3cm) (Table 6.2 and Figure 6.8) which may be contributed to the presence of high density, "matted" grassy forb patches, interrupted by few and short interpatches (Figure 6.9a). The patches in site 5 (urban) consisted mainly of single grass tufts, which were not very wide (mean patch width=50.1 cm), surrounded by BSI's (Figure 6.9b). Wider patches implicate wider areas that can stop or decrease the speed of overland flow, and where resources can be captured and infiltrate into the system.

The widest (site 9) and narrowest (site 5) patches were recorded in urban areas, which reflect the fine-scale variability of urban grassland fragments in the Tlokwe Municipal area (Figure 6.8). The reason for this is unclear as no specific management practices (e.g. mowing) were recorded in these two grassland fragments. The mean patch widths of the selected rural/peri-urban and urban grassland fragments did not differ significantly from each other (see Table K.1, Appendix K for ANOVA results).

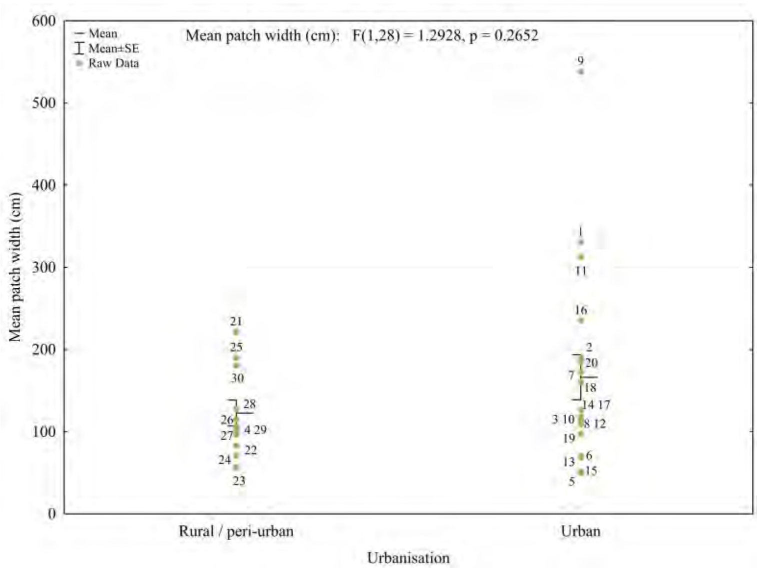

Figure 6.8: Mean patch width for rural/peri-urban and urban selected grassland fragments. The green dots represent the patch width (raw data) of each selected grassland fragment.

a) b)

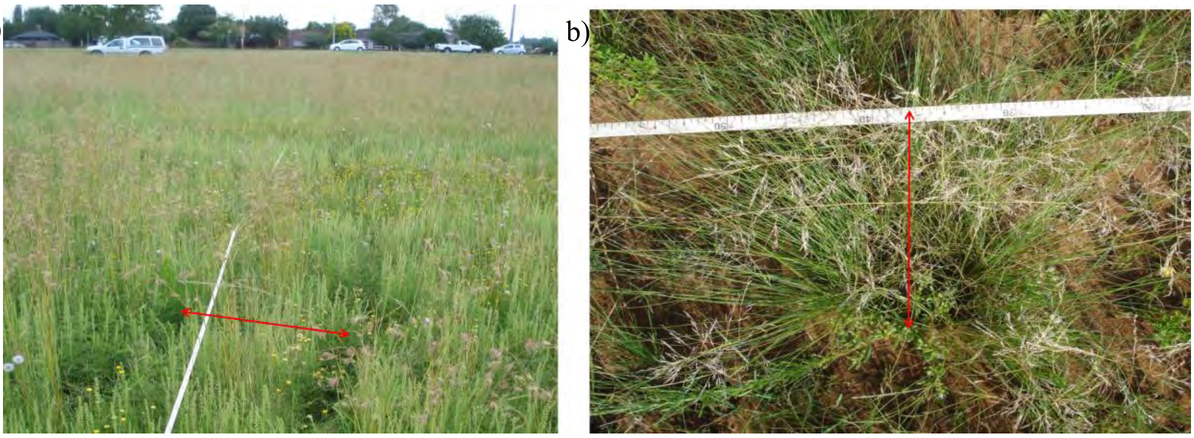

Figure 6.9: a) Wide, densely "matted" GFP's recorded in site 9 (urban), and b) patches which mainly consisted of single grass tufts, which were not very wide, surrounded by interpatches (recorded in site 5 (urban)).

3. Total patch area

Because patches retain resources, high total patch area (m²) of a landscape (where length and width of patches are taken into account) will indicate that a large area of that landscape is conserving water, nutrients and soil, and preventing soil erosion, creating so-called "fertile zones" (Ludwig and Tongway, 1995; Bastin *et al.,* 2002; Ludwig *et al.,* 1999a; 1999b; 2001; 2005).

Site 5 (urban) and site 23 (rural/peri-urban) had the lowest total patch area (8.5m²) (Table 6.2 and Figure 6.10). This low total patch area value was expected when considering the low LOI index and low patch widths for these grassland fragments. Site 9 (urban), on the other hand, had an LOI of 97.7 and very wide patches, contributing to a large total patch area of 163.7 m² (Table 6.2 and Figure 6.10).

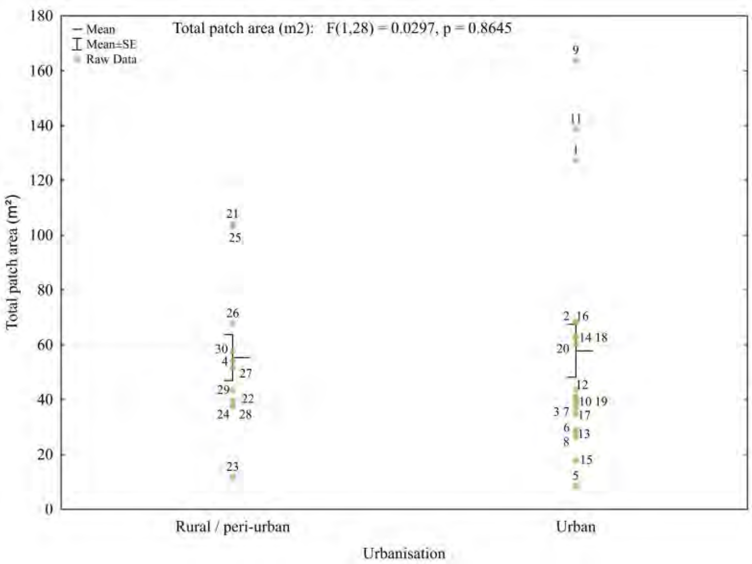

Figure 6.10: Mean total patch area for rural/peri-urban and urban selected grassland fragments. The green dots represent the patch area (raw data) of each selected grassland fragment.

More urbanised areas contained the largest and smallest total patch area (m²) again entailing the fine-scale patch variation of urban areas (Figure 6.10). The mean patch area of the selected grassland fragments did not differ from each other in a statistically significant way (see Table K.1, Appendix K for ANOVA results).

4. *Mean interpatch length*

Average interpatch length (m) represents the average distance of unobstructed resource transport as runoff (Tongway & Hindley, 2004).

Site 8 (urban) had the highest mean interpatch length (0.67 m) (Table 6.2 and Figure 6.11). This site had been recently mowed (approximately two months ago – adequate time was provided for vegetation to recover before sampling) and the plant litter had possibly been removed, consequently it was characterised by many interpatches and did not have a dense grass layer or a significant litter layer. Site 3 (urban) had the lowest average interpatch length (0.12 m) (Table 6.2 and Figure 6.11) due to the presence of a dense *Themeda triandra* grass layer. No interpatches were present in sites 25 (rural/peri-urban) and 6 (urban). Site 25 was characterised by a dense "mat" of *Elionurus muticus* grass species, whilst site 6 showed signs of mowing where litter had not been removed resulting in a thick layer of grassy litter where no bare soil could be observed.

Shorter average interpatch length implies that the momentum of overland flow is low, so that resources are not transported at all and certainly not across large portions of the landscape during which these resources may be lost from the system.

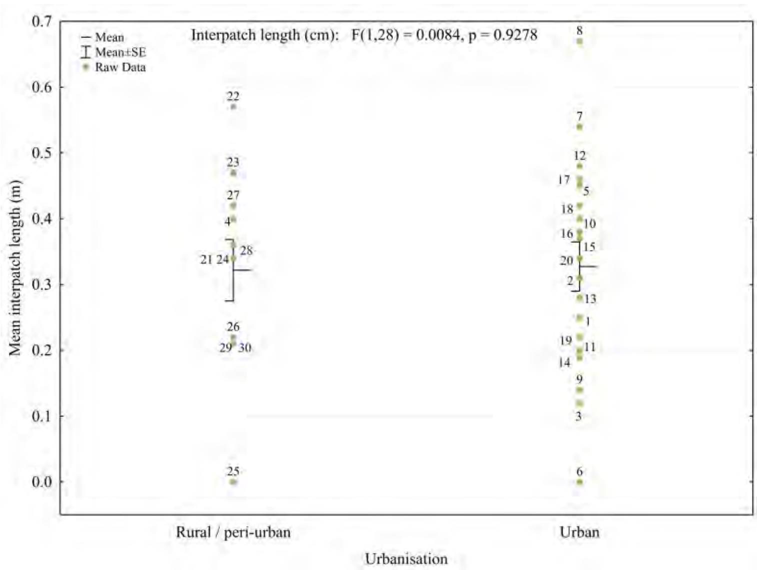

Figure 6.11: Mean interpatch length for rural/peri-urban and urban selected grassland fragments. The green dots represent the mean interpatch length (raw data) of each selected grassland fragment.

The differences in mean interpatch lengths for the selected rural/peri-urban and urban grassland remnants were not statistically significant (see Table K.1, Appendix K for complete ANOVA results). The fine-scale patch heterogeneity of urbanised areas become evident once again in containing grassland fragments that were characterised by both the longest interpatches (Site 8) and no interpatches at all (Site 6) (Figure 6.11).

5. *Range interpatch length*

The range interpatch length (m) represents the minimum and maximum interpatch lengths within the sampled landscape (Tongway & Hindley, 2004).

Sites 25 (rural/peri-urban) and 6 (urban) contained no interpatches (Figure 6.12a and b). Site 25 was characterised by a dense "mat" of *Elionurus muticus* grass species, whilst site 6 showed signs of mowing where litter had not been removed resulting in a thick layer of grassy litter. Site 9 (urban) contained the shortest interpatch of 0.06 m (Figure 6.12a) due to a very high and dense cover of the forb *Lepidium didymum*. Site 3 (urban) contained the second shortest interpatch, whilst the longest interpatch of this selected grassland fragment was only 0.19 m long (Figure 6.12b). This may be attributed to the dense *Themeda triandra* grass layer present in this urban grassland fragment. The shortest interpatch in site 28 (rural/peri-urban) had a length of 0.23 m (Figure 6.12a), whilst the longest recorded interpatch in this site was 0.98 m long (Figure 6.12b). This is possibly due to grazing that was recorded in this selected grassland fragment which may lead to the reduction of vegetated patch sizes and increased bare soil fetch-lengths (Freudenberger et al., 1997; Tongway and Ludwig, 1997). The fetch-length is described as the distance of unobstructed resource transport by water or wind through the system, where resources may be lost from the system (Kakembo, 2009; Tongway & Ludwig, 1997). Site 10 (urban) contained the longest interpatch (2.1 m) (Figure 6.12b).

Less and shorter interpatches imply that more patches are available to actively capture resources, decreasing the distances between the patches and therefore decreases open areas. In a landscape with often occurring and longer interpatches the transport of vital materials by water or wind as runoff are able to gain velocity and transporting capacity. Increased velocity of runoff may increase the severity of soil erosion (Fox & Bryan, 2000; Rezaei *et al.,* 2006).Urban areas have the highest variability in interpatch length (Table 6.2 and Figure 6.12), again indicating the fine-scale patch heterogeneity of these areas. The mean longest and shortest interpatch length of selected rural/peri-urban and urban grassland fragments, however not differ significantly from each other (see Table K.1, Appendix K for ANOVA results).

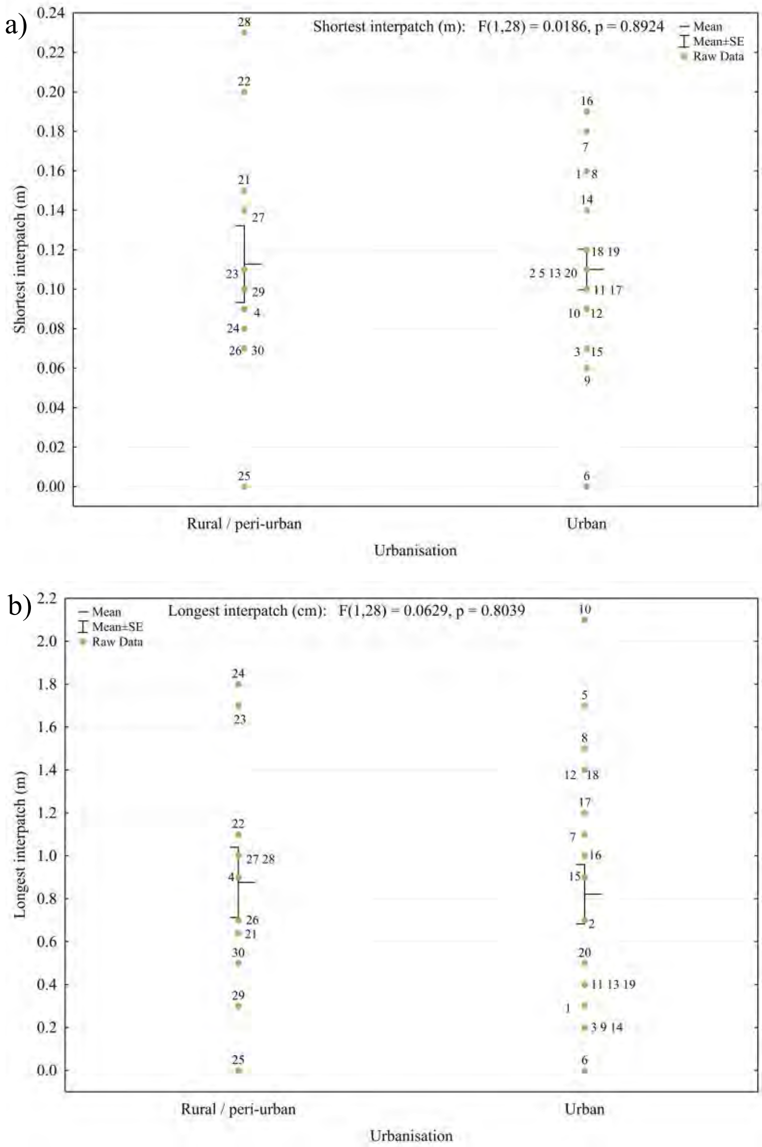

Figure 6.12: Mean a) shortest and b) longest interpatch lengths for rural/peri-urban and urban selected grassland fragments. The green dots represent the length of the shortest and longest interpatch (raw data) recorded in each selected grassland fragment.

The variability within the physical landscape attributes of all selected grassland patches is high, and there does not seem to form an apparent pattern indicating clear difference between rural/peri-urban and urban grassland fragments (Table 6.2). Also the physical landscape attributes of the selected grassland fragments in urban and rural/per-urban matrix areas showed no statistically significant differences (see Table K.1, Appendix K for ANOVA results).

Table 6.2: Summary of the physical landscape heterogeneity of the rural/peri-urban and urban selected grassland fragments, arranged according to increasing percentage impervious surfaces. Green boxes indicate the physical landscape attribute values that would be associated with a more resource conserving landscape ("better" or "non-leaky"). Red boxes indicate physical landscape attribute values that are more likely associated with landscapes where resources are not as actively conserved ("worst" or "leaky"). The anthropogenic influences (visually estimated) on the grassland fragments are also indicated.

Site	LOI	Mean patch width (cm)	Total patch area (m²)	Mean BSI length (m)	Range BSI length (m) Shortest interpatch	Range BSI length (m) Longest interpatch	Antropogenic influences	Urbanisation
21	93.3	232.6	104.0	0.34	0.15	0.64	Grazing	Rural / peri-urban
30	91.7	180.5	57.8	0.21	0.07	0.47	N/A	Rural / peri-urban
28	80.0	127.8	37.7	0.36	0.23	0.98	Grazing	Rural / peri-urban
27	87.6	96.6	51.8	0.42	0.14	1.00	Grazing	Rural / peri-urban
23	45.4	56.8	11.7	0.47	0.11	1.74	Grazing	Rural / peri-urban
26	86.1	114.4	67.7	0.22	0.07	0.72	Grazing	Rural / peri-urban
25	100.0	190.2	103.3	-			N/A	Rural / peri-urban
29	93.0	106.3	43.5	0.21	0.10	0.33	Grazing	Rural / peri-urban
22	92.7	82.9	39.6	0.57	0.20	1.06	Grazing	Rural / peri-urban
4	82.7	102.1	54.4	0.40	0.09	0.86	N/A	Rural / peri-urban
24	71.5	70.8	37.7	0.34	0.08	1.81	N/A	Rural / peri-urban
1	94.3	330.6	127.3	0.25	0.16	0.32	N/A	Urban
20	85.4	184.6	60.5	0.34	0.11	0.54	N/A	Urban
7	93.0	172.5	40.6	0.54	0.18	1.10	Mowing	Urban
19	95.3	97.9	38.8	0.22	0.12	0.38	Mowing	Urban
16	89.9	235.2	68.4	0.38	0.19	0.96	N/A	Urban
13	96.4	68.9	27.8	0.28	0.11	0.35	Mowing	Urban
9	97.7	538.3	163.7	0.14	0.06	0.22	N/A	Urban
5	43.7	50.1	8.5	0.45	0.11	1.70	N/A	Urban
8	73.8	109.3	26.4	0.67	0.16	1.52	Mowing	Urban
3	95.8	117.3	37.0	0.12	0.07	0.19	N/A	Urban
11	95.3	313.0	138.7	0.20	0.10	0.41	N/A	Urban
10	77.5	113.8	41.0	0.40	0.09	2.09	N/A	Urban
6	100.0	70.6	29.0	-			Mowing	Urban
12	63.4	110.3	43.7	0.48	0.09	1.42	N/A	Urban
17	75.5	118.5	34.9	0.46	0.10	1.21	N/A	Urban
15	71.8	51.2	17.9	0.37	0.07	0.93	N/A	Urban
14	97.6	126.4	63.0	0.19	0.14	0.23	Mowing	Urban
18	75.7	160.7	63.1	0.42	0.12	1.36	N/A	Urban
2	90.6	189.4	68.5	0.30	0.11	0.66	N/A	Urban

Increasing urbanisation / human impact

Rural/peri-urban and urban grassland remnants did not form distinct clusters (Figure 6.13) and no obvious pattern of the effect of urbanisation on resource conserving landscape structure was evident. This indicates, once more, the fine-scale variability of the physical attributes of patches and interpatches of the selected grassland fragments within the study area. Site 5 (urban – less resource conserving) had a physical fine-scale landscape structure which is more characteristic of a landscape that is not conserving resources as actively as, for example, site 9 (urban – more resource conserving) (Figure 6.13). Selected grassland fragments situated in urban areas were characterised by more and less resource conserving fine-scale patchiness, and are thus situated at both ends of the potential resource conservation gradient (Figure 6.13) (e.g. sites 1, 5, 9, 11). This emphasises the spatial habitat heterogeneity that is characteristic of urban areas (Rebele, 1994; Savard *et al.*, 2000; Pickett *et al.*, 2011). Furthermore, the degree of urbanisation in the direct 500 m radius matrix areas surrounding the grassland remnants alone does not appear to have an effect on the physical landscape attributes (intra-patch variable) of the grassland fragments.

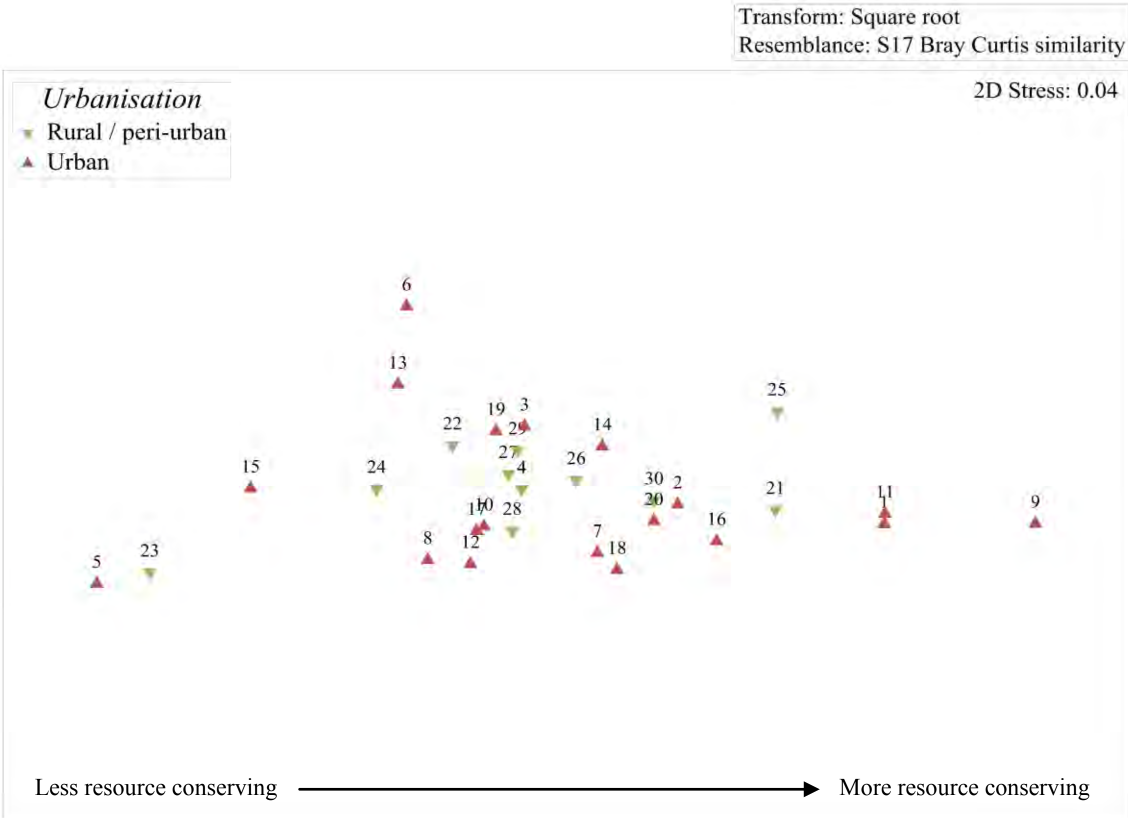

Figure 6.13: NMDS ordination of the physical landscape attributes (LOI, mean patch width, total patch area, average interpatch length, and shortest / longest interpatch length) for the representative gradsect in each selected rural/peri-urban and urban grassland fragment. A possible resource conserving gradient is indicated.

6.3.2 Soil Surface Assessment

The SSA properties of each grassland fragment are reflected in the values of the three main SSA indices (stability, infiltration and nutrient cycling) (refer to Figure 6.2) which together may be translated into total SSA functionality (Figure 6.14). 50% of the selected grassland fragments had a total SSA functionality of between 80 and 110, especially in the urban areas (indicated by grey dashed lines, Figure 6.14). In rural/peri-urban and urban selected grassland fragments both higher and lower total SSA functionality were recorded. All the selected urban grassland fragments that had been mown were characterised by total SSA functionality exceeding a value of 110, whilst only three of the grazed rural/peri-urban grassland fragments had total SSA functionality values higher than 110. This indicated that “non-natural” management practices, such as mowing, possibly may enhance the soil surface functionality of urban grassland fragments. This concept will be discussed in *Section 6.3.2: Can high patch quality compensate for low patch size: outcomes from differential management?*

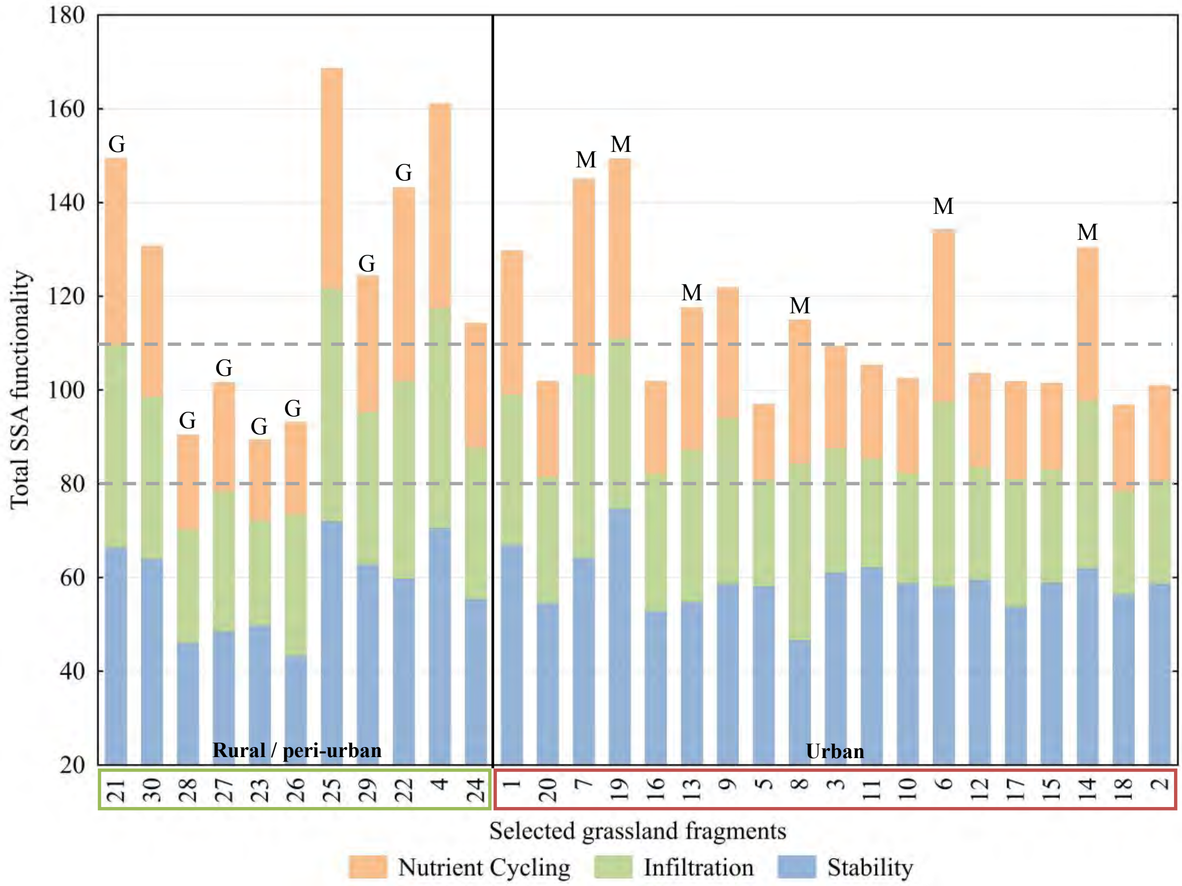

Figure 6.14: Total SSA functionality (consisting of the three main SSA indicator components namely stability, infiltration and nutrient cycling SSA indices) for rural/peri-urban and urban selected grassland fragments, arranged according to increased percentage impervious surfaces. The presence anthropogenic influences and management practices of mowing (M) and grazing (G) are also indicated.

Moderate linear relationships were found between PURBLC and PGRALC (matrix variables) and the infiltration capacities (intra-patch variable) of the selected grassland fragments (Table 6.3). This indicated that selected grassland fragments situated in increasingly built-up areas with less available Rand Highveld Grassland habitat resulted in decreased infiltration capacities of the grassland remnants. Although this linear relationship exists, they are only moderate – indicating possible, not absolute, trends. Refer to Table J.3, Appendix J for full multiple regression analysis results.

Table 6.3: Correlation matrix and multiple regression analysis results for the soil surface indicators and total SSA functionality with the selected four urbanisation measures (representing pattern/process associated with urbanization). Only significant correlations ($p < 0.05$) are indicated. Correlation directions are indicated in grey and moderate linear relationships ($0.1 \leq r^2 < 0.25$) in orange.

		PURBLC % Impervious surfaces		**ED** Fragmentation		**PGRALC** Habitat loss		**DENSPEOP** Urbanisation
Infiltration	-	**0.178353**	-	0.115926	+	**0.132673**	-	0.041104

Each SSA index for selected rural/peri-urban and urban grassland fragments in the Tlokwe Municipal area will subsequently be discussed.

6.3.2.1 Stability

Site 19 (urban) had the highest stability SSA index (74.57) (Figure 6.15), which may be accounted for by high rainsplash protection (>50%) and basal cover (>20%) provided by grass patches. This site showed signs of being mown in the past and therefore contained litter patches which contributed to soil surface stability. During the slake test the soil crust of this grassland fragment remained intact with no swelling when submerged in distilled water. This shows that the soil remains coherent when wet and implies low erosion potential during rainfall events. No significant erosion was observed in this site, and only a small amount (0-5%) of transportable deposited material (alluvium) was recorded in the query zones.

Slight sheet erosion and a moderate amount of deposited material (20-50%) susceptible to transport was recorded in site 26 (peri-urban/rural – grazed), possibly contributing to the lowest stability SSA index (43.26) (Figure 6.15). The presence of alluvium and erosion indicates that soil particles and resources are available to be transported and lost from the system. Grazing in sites 23, 26, 27, and 28 (rural/peri-urban) possibly resulted in the lower stability SSA for these selected grassland fragments. The hoof action of grazing cattle may decrease the stability of surface soils and increase soil erosion potential (Freudenberger et al., 1997; Tongway and Ludwig, 1997; Van der Walt *et al.*, 2012). The mean stability SSA index of the selected rural/peri-urban and urban grassland fragments did not differ significantly (see Table K.2, Appendix K for complete ANOVA results).

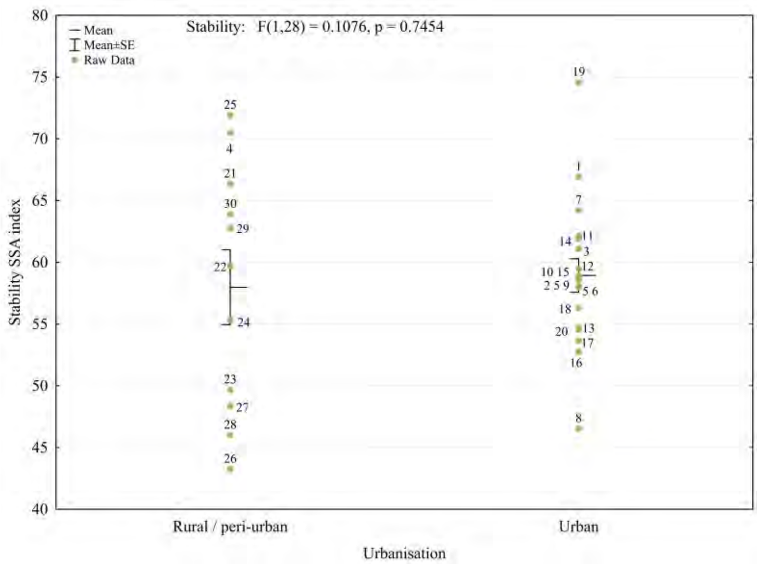

Figure 6. 15: Mean stability SSA index for rural/peri-urban and urban selected grassland fragments. The green dots represent the stability SSA index (raw data) for each selected grassland fragment.

6.3.2.2 Infiltration

The infiltration SSA index values for rural/peri-urban grassland fragments showed the most variation from low in sites 23 and 28 which were grazed (hoof action of grazing cattle may constrict soil pores, and therefore restrict water infiltration into the soil (USDA, 1998)), to site 25 which had the highest infiltration SSA index (49.72) (Figure 6.16). Soil texture, as well as litter cover and degree of litter decomposition seem to be the functionality indicators determining high or low infiltration capacity. Soil texture and the nature of the physical soil crust alter the infiltration capacity of a landscape (Ashman & Puri, 2002). Site 25 was characterised by sandy loam to silt loam soils which indicate a moderate infiltration rate. The coarser, slightly sandy soil texture implies that there are larger pores between the soil particles into which water can seep (Ashman & Puri, 2002). Also, when considering the physical landscape attributes (refer to Table 6.2), the LOI value for site 25 is 100, indicating that no interpatches were recorded in the gradsect. Very dense grassy litter patches (GLP's) were the predominant patch type encountered in this grassland fragment. This patch type acted as a physical obstruction to overland flow, making resources available for infiltration into the system (USDA, 2001).

Due to an insignificant amount of litter cover (<10%) site 18 (urban) had the lowest infiltration SSA index (22.0) (Figure 6.16). Litter cover captures a proportion of resources moving through the landscape. The insignificant amount and absence of litter, especially in the BSI's, implicated that resources are not captured and infiltrated into the system, but transported freely through the system. The soil crust of site 18 was very hard and brittle, which indicates that it may be able to withstand physical disturbance, but does not allow for effective infiltration of water into the soil surface layers due to low porosity (Tongway & Hindley, 2004). Long interpatches (mean interpatch length = 0.42 m) and an LOI value of 75.7 (see Table 6.2) was also recorded in site 18 (urban), implying that 24.3% of the landscape consisted of interpatches with low infiltration character where resources were not actively captured and infiltrated into the system.

Urban grassland fragments had lower mean infiltration SSA index due to the very low infiltration indices of specific grassland fragments (e.g. sites 2, 3, 5, 11, 10, 12, 15, and 18 – Figure 6.16). These grassland fragments had not been mown (refer to Table 6.2). The litter presence in sites that had been mown (e.g. sites 6, 8, and 14) acted as obstructions to overland flow and resultantly provides these grassland fragments with higher infiltration capacity. The mean infiltration SSA indices for the selected rural/peri-urban and urban grassland fragments did no differ significantly (see Table K.2, Appendix K for full ANOVA results).

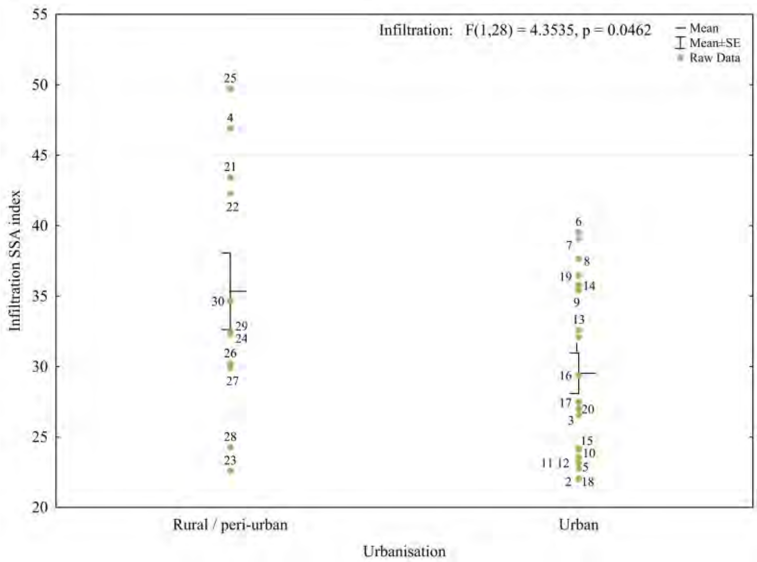

Figure 6.16: Mean infiltration SSA index for rural/peri-urban and urban selected grassland fragments. The green dots represent the infiltration SSA index (raw data) for each selected grassland fragment.

6.3.2.3 Nutrient cycling

Site 25 (rural/peri-urban) was characterised by very dense grassy litter patches (GLP's), which may account for the highest nutrient cycling SSA index value (46.9) of this grassland fragment (Figure 6.17). The litter cover of these patches, originating from the wiry leaves of *Elionurus muticus* grass species, was mostly 100% and in some cases up to 20 mm thick. High local plant litter cover contributes greatly to the nutrient cycling potential of a landscape as nutrients are returned into the soil. The high basal cover of vegetated patches in this site (no interpatches were recorded for this site - LOI=100 (refer to Table 6.2)) means that root biomass is available for decomposition, and ultimately implies high nutrient and organic material in the soil. No heavy grazing by cattle was observed in this grassland fragment, only a few antelope were present.

The insignificant amount of litter cover (<10%) contributed to the lowest nutrient cycling SSA index (16.2) of site 5 (urban) (Figure 6.17). As a result of low litter cover in this grassland remnant, nutrients are not being returned into the soil surface layers. Many interpatches (LOI=43.7), very low total patch area (8.5 m²), and narrower patches (mean patch width = 50.1 cm) (refer to Table 6.2) were recorded in this landscape. Thus the decreased perennial vegetation basal cover and ultimately lower nutrient and organic material in the soil.

Urban grassland fragments had lower mean nutrient cycling potential than rural/peri-urban grassland remnants, possibly due to the very low nutrient cycling indices of specific grassland fragments (e.g. sites 2, 3, 5, 7, 11, 10, 12, 15, and 18 – Figure 6.17). These sites were not mown and, as was also the case for the infiltration capacities (see *Section 6.3.2.2: Infiltration*) of these grassland fragments, the low litter cover resulted in lower nutrient cycling SSA indices. The mean nutrient cycling SSA indices for selected rural/peri-urban and urban grassland fragments did no differ significantly (see Table K.2, Appendix K for full ANOVA results).

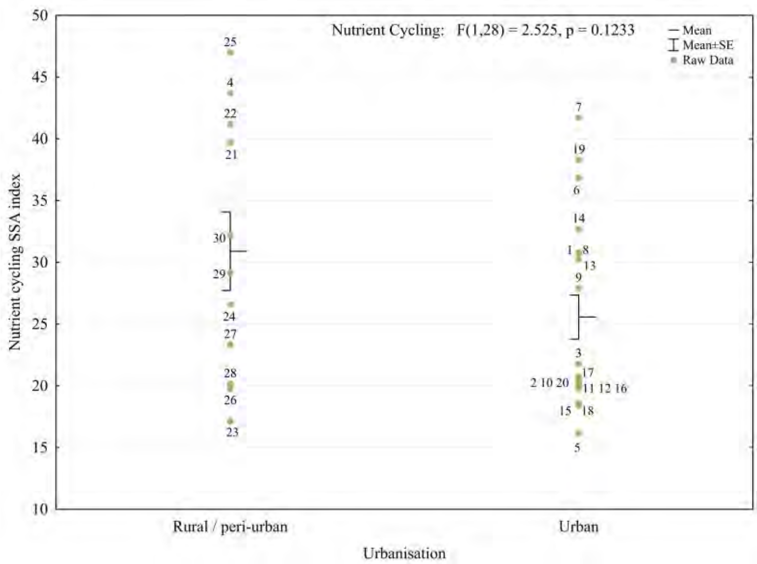

Figure 6.17: Mean nutrient cycling SSA index for rural/peri-urban and urban selected grassland fragments. The green dots represent the nutrient cycling SSA index (raw data) for each selected grassland fragment.

6.3.2.4 Total SSA functionality

Site 25 (rural/peri-urban) had the highest total SSA functionality (169.1) (Figure 6.18 & 6.19). This grassland fragment showed the most effective infiltration and nutrient cycling SSA indices, and a very high stability SSA index. The absence of interpatches (LOI=100 (see Table 6.2)), where vital resources such as soil particles, nutrients and water may be lost, contributed greatly to the high total SSA functionality of this landscape.

Site 23 (rural/peri-urban) had relatively low respective SSA indices (stability=49.7; infiltration=22.6; nutrient cycling=17.1), and the total SSA functionality of this site was the lowest (91.6) of all selected grassland fragments (Figure 6.18 & 6.19). It was visually estimated that this grassland fragment had been heavily grazed in the past, and this may have led to physical and soil surface properties of this site which have resulted in low total SSA functionality. This landscape was dominated by BSI's (LOI=54.6 of the landscape (refer to Table 6.2)) which implies that the larger portion of the landscape was susceptible to unobstructed overland flow, resulting in a "leaky" system (Tongway & Hindley, 2003a).

The mean SSA functionality of selected grassland fragments situated in rural/peri-urban areas showed the most variability, and was higher (though not significantly) than that of the urban areas (Figure 6.18). Urban grassland fragment had slightly higher mean stability, but lower infiltration, and nutrient cycling SSA indices, resulting total SSA functionality than rural/peri-urban grassland fragments.

However, the differences between mean SSA functionality parameters and total SSA function for selected urban and rural/peri-urban grassland fragments are not statistically significant (see Table K.2, Appendix K for complete ANOVA results).

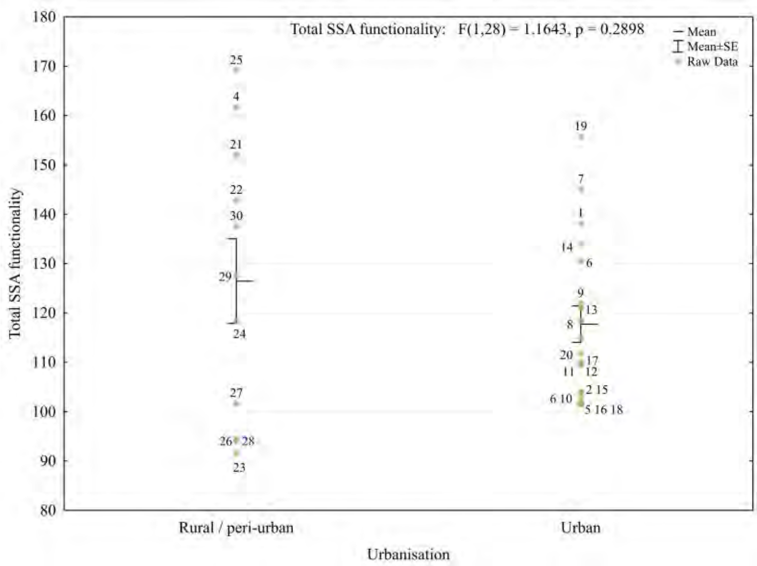

Figure 6.18: Mean total SSA functionality index for rural/peri-urban and urban selected grassland fragments. The green dots represent the total SSA functionality (raw data) for each selected grassland fragment.

A SSA functionality gradient seems to exist with selected grassland fragments characterised by higher stability, infiltration, and nutrient cycling SSA function (thus higher total SSA functionality) situated towards the right side of the ordination plot, and the less functional selected grassland fragments on the left side (Figure 6.19).

Clear clusters of urban and rural/peri-urban sites could not be distinguished, which indicates the high variability of SSA function within selected grassland fragments. Site 23 (rural/peri-urban) had the lowest total SSA functionality (Figure 6.19). If it were assumed that the degree of urbanisation in matrix areas surrounding grassland fragments negatively influenced the grassland soil surface function, the position of site 23 along the SSA function gradient would be expected to be to the more functional (right hand side) of the ordination axis. A cluster of grassland fragments (consisting of sites 2, 5, 10, 11, 12, 15 and 18 – all urban) may be seen in the upper left corner of the ordination plot. These grassland fragments may conform to the assumption that "selected grassland fragments situated in areas exposed to increased urbanisation will have lower stability, infiltration and nutrient cycling soil surface indices, resulting in lower total SSA functionality" (see *Section 6.1.2*), but this trend does not continue throughout the all the urban grassland fragments. The soil surface functionality of selected grassland remnants was thus independent of urbanisation in their direct vicinity. This may also be seen in the correlation matrix (Table J.2 in Appendix J) of the soil surface indicators and total SSA functionality with the four urbanisation measures (PURBLC, PGRALC, ED, and DENSPEOP).

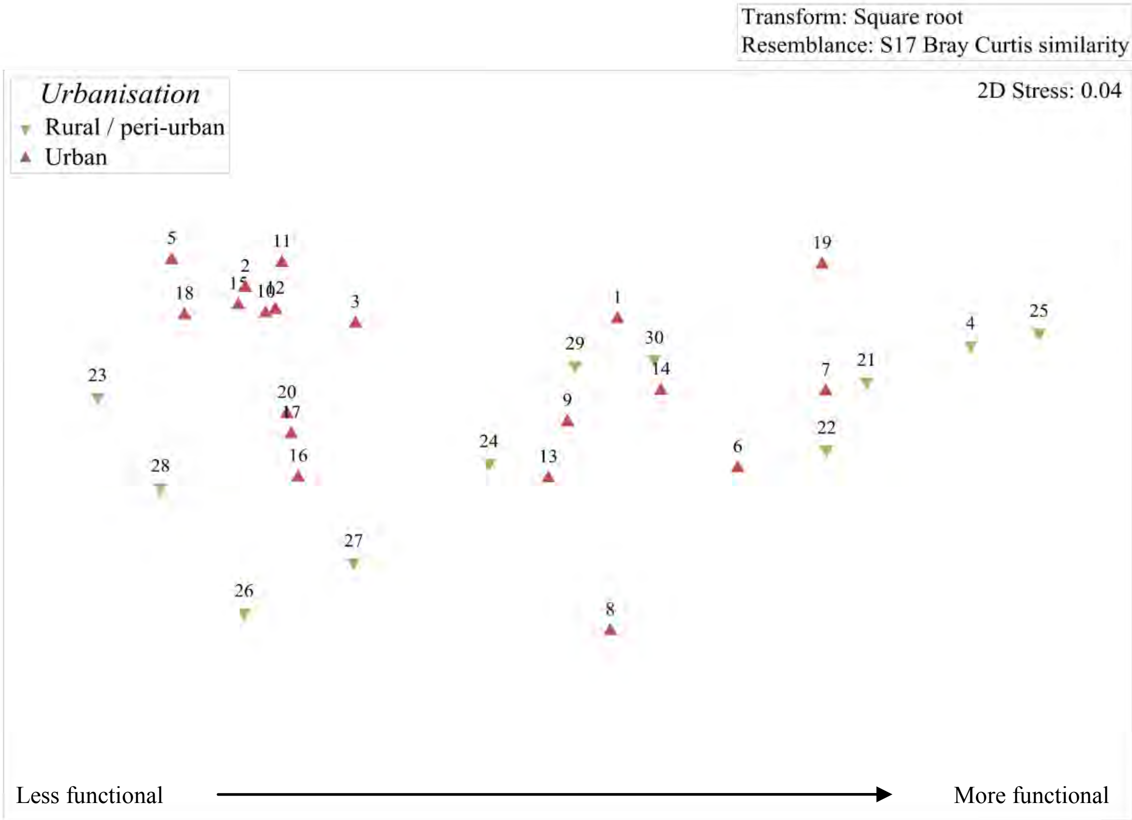

Figure 6.19: NMDS ordination of the stability, infiltration, and nutrient cycling SSA indices for rural/peri-urban and urban selected grassland fragments. A possible SSA functionality gradient is indicated.

6.3.3 Correlating SSA indices and physical landscape attributes

The correlation matrix and multiple regression analysis of the SSA indices and physical landscape shows that possible linear relationships exist between some SSA functionality and physical landscape attributes (Table 6.4; also see Table J.3 in Appendix J for complete multiple regression analysis results). Strong linear relationships were found between LOI (% of gradsect that consists of patches) and the infiltration, nutrient cycling, and total SSA indices, whilst moderate linear relationships became evident between LOI and stability, mean patch width and infiltration and total SSA functionality, and between mean interpatch length and stability (Table 6.4).

The stability SSA index shows a moderate positive linear relationship with LOI (r^2=0.1503), and a moderate negative correlation (r^2=0.1372) with mean interpatch length (Table 6.4). Vegetated patches act as obstructions to overland flow, thus protecting soils from erosion; also shorter interpatches indicates that less soil is vulnerable to erosion, reflecting higher soil surface stability (Reid *et al.*, 1999; Schlesinger *et al.,* 1999).

A significant positive linear relationship (r^2=0.2662) exists between LOI and the infiltration SSA index, and a moderate linear correlation (r^2=0.1515) between infiltration and mean patch width (Table 6.4). High LOI (proportion of the landscape that consists of resource-conserving patches) and wide patches indicate that a large portion of the landscape acts as obstructions to capture resources moving through the system, making water and nutrients available for infiltration into the soil surface layers.

This positive correlation may also be observed between LOI and nutrient cycling SSA index (Table 6.4). High LOI implies that many vegetated patches are present, which means that there is a substantial amount of root biomass available for decomposition, and nutrients may be cycled back into the soil reserve (Van der Walt *et al.*, 2012).

The total SSA functionality increases with increased LOI (significant positive linear relationship, r^2=0.2924) and increased mean patch width (moderate positive linear relationship, r^2=0.1381) (Table 6.4). This makes sense when recalling the importance of vegetated patches (Ludwig and Tongway, 1995; Schlesinger *et al.,* 1996, and Ludwig *et al.,* 1999a; 1999b; 2005). Vegetated patches capture and utilise natural resources such as water, nutrients, and soil sediments (Ludwig *et al.,* 2001), and concentrate resources to prevent soil erosion, all indicating whether landscapes are functional or dysfunctional (Bastin *et al.,* 2002).

Table 6.4: Correlation matrix and multiple regression analysis results for selected physical landscape attributes and SSA indices. Only significant correlations ($p < 0.05$) are indicated. Correlation directions are indicated in grey, moderate linear relationships ($0.1 < r^2 < 0.25$) in orange, and significant linear relationships ($r^2 \geq 0.25$).

		Stability		Infiltration		Nutrient cycling		Total SSA functionality
LOI	+	**0.1503**	+	**0.2662**	+	**0.3064**	+	**0.2924**
Mean patch width (cm)	+	0.0616	+	**0.1515**	+	0.1133	+	**0.1381**
Mean interpatch length (m)	-	**0.1372**	-	0.0429	-	0.0409	-	0.0891

6.3.4 Can high patch quality compensate for low patch size: outcomes from differential management?

When considering the resource-conserving gradient (Figures 6.13 and 6.20a), some sites that are characterised by a physical landscape structure that is less resource conserving, are also characterised by better than expected SSA functionality (Figures 6.19 and 6.20b) when considering the physical landscape attributes. For instance site 6 (urban) (indicated in Figure 6.20a). This site is characterised by long interpatches and narrow patches (refer to Table 6.2), therefore its position is located on the "less resource-conserving" side of the gradient in Figures 6.13 and 6.20a. But when regarding the functionality gradient (Figure 6.19 and 6.20b) site 6 (urban) is located on the more functional side of the SSA functionality gradient. It seems that some factor in patch quality is compensating for lower resource-conserving patchiness, resulting in better overall site SSA functionality. After inspecting the change in position of sites within the ordination space of the physical landscape attributes to their position in the SSA ordination space and possible reasons for this, it was concluded that both patch type and quality interact in compensating for physical landscape attributes and resulting in high or low SSA functionality. For instance site 6 (urban) in Figure 6.20a and b (green), had narrow patches (total patch width = 1898 cm) and long interpatches (average interpatch length = 0.54 m; longest interpatch = 1.1 m), but the patch types found in this site included grassy litter patches (GLP's) which scored very high infiltration and nutrient cycling SSA indices (refer to Figure 6.15). This site had been mown (as is the general management practice in some urban areas) resulting in litter abundances which provided high infiltration and nutrient cycling SSA indices that contributed greatly to the infiltration and nutrient cycling indices of the entire grassland fragment and compensated for a physical landscape structure that was less resource-conserving.

On the other hand, site 9 (urban) (orange – Figure 6.20a and b) was characterised by an overall more resource-conserving structure (total patch width=3195 cm, average interpatch length=0.21 m) but had lower SSA functionality than expected. The patch types recorded in this grassland fragment included bare soil interpatches (BSI's), grass patches (GP's) and sparse grass patches (SGP's) which did not have high specific infiltration and nutrient cycling SSA index values, and thus not substantially contributing to the overall infiltration and nutrient cycling SSA indices of the grassland fragment. This grassland remnant was grazed and very little litter was recorded.

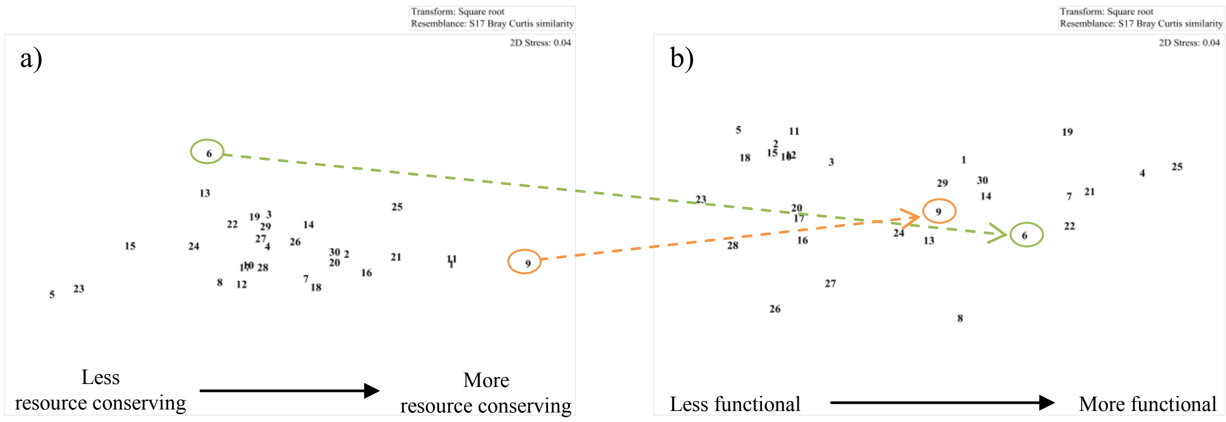

Figure 6.20: NMDS ordination presenting the positions of selected grassland fragments along possible a) resource-conserving- and b) SSA functionality gradients for the study area.

Litter cover, origin and degree of decomposition influenced patch quality in such a significant way that the value of this indicator compensated for less resource-conserving fine-scale structure. Litter abundances were most common in grassland fragments that had been mown and assessed after a four to six week recovery period. The litter cover creates "litter bridges" between perennial vegetation resulting in larger total patch area where resources may be captured and infiltrated into the system. It therefore seems that mowing (in more urbanised areas) permits fine-scale-biogeochemical landscape functions to be maintained compared to grazing (in rural/peri-urban) which totally and frequently removes material and where trampling may also affect the soil surface properties. Fire, which is also more prevalent in rural area, but was not observed in this study, also removes surface material such as litter, possibly resulting in lower fine-scale patchiness. However, fire is an important factor in shaping grasslands in South Africa (Bond, 2003& 2005; Mucina & Rutherford, 2006; O'Connor & Bredenkamp, 1997). Fire may remove above-ground litter cover which may be present in rural grassland fragments, but replenish nutrients in the sub-surface soil layers (Boerner, 1982; Marañón-Jiménez & Castro, 2013; Tongway & Hodgkinson, 1992).

6.4 Summary and conclusions

The aim of this chapter was to:

1. To apply the LFA method in the selected grassland fragments.
2. To use the physical landscape – and soil surface attributes data to determine the landscape functionality of the selected grassland fragments within the study area.
3. Correlate two aspects of landscape function, namely physical landscape attributes and soil surface function, with the four selected urbanisation measures (PURBLC, ED, PGRALC, and DENSPEOP).
4. Identify possible relationships between urbanisation and fine-scale biogeochemical landscape function.

The LFA results of this study showed that the presence and size of vegetated patches and especially the presence of litter abundances were identified in the selected grassland fragments as the main factors determining differences in the functionality indices. Vegetated- and litter patches are interdependent, as live plant material eventually contributes to the availability of litter (plants shed their foliage or die to create plant litter patches). Some of the grassland fragments in urban areas were subjected to mowing which enhanced the litter cover and possibly encouraged aboveground clonal growth (e.g. stolons) in plant species as adaptation to mowing management practices, creating greater fine-scale patchiness. Physical landscape attributes, such as wide patches and smaller interpatches played the most important roles in contributing to the three main functionality indices of stability, infiltration, and nutrient cycling.

The physical landscape attributes of selected rural/peri-urban and urban grassland fragments showed no statistically significant differences, entailing that the degree to which the landscape surrounding a grassland fragment is urbanised, does not have an effect on the fine-scale patch characteristics that allow for a landscape to either conserve or lose resources. Concerning the physical landscape attributes (e.g. mean patch width) urban grassland fragments occasionally had less leaky fine-scale patchiness. This result does not support the first hypothesis for this chapter that selected grassland fragments situated in urban matrix areas exposed to increased human impacts will be characterised by a fine-scale landscape structure that is diagnostic of a system that are not actively capturing and conserving vital resources such as soil particles, water and nutrients (leaky).

Rural/peri-urban grassland fragments had higher infiltration capacity, nutrient cycling potential, and total SSA functionality (although not significantly). This partially supported the second hypothesis for this chapter – that selected grassland fragments situated in urban matrix areas exposed to increased human impacts will have lower stability, infiltration and nutrient cycling soil surface indices, resulting in lower total SSA functionality. These differences may be ascribed to differences in management practices applied to selected grassland fragments, such as mowing in urban areas and grazing and fire in rural areas. Fire in rural grassland fragments may remove litter from the soil surface, resulting in lower surface litter cover, but also returns nutrients into sub-surface soil layers (Boerner, 1982; Marañón-Jiménez & Castro, 2013; Tongway & Hodgkinson, 1992). The presence of more annual vegetation (see *Chapter 5*) in urban grassland fragments, which is recorded during the LFA method as litter and not vegetated patches, also contributed to higher litter and subsequent SSA functionality. Although urban areas has been found to be characterised by lower aerial cover due to vegetation removal, exposed soil susceptible to crust formation, erosion and compaction, which in turn also affects the infiltration capacity of the soil (Craul, 1985), decreased soil porosity and infiltrability of the soils resulting in increased runoff and erosion (Sauerwein, 2011), and poorer quality litter that decompose and nitrify quicker (McDonnell *et al.*, 1997), such discrete relationships did not become clear during the study of fragmented grasslands. The city of Potchefstroom in the Tlokwe Municipal area is probably not "urbanised enough" and that the relationships between anthropogenic disturbances and ecosystem pattern and process are more difficult to determine in the patchy urban development of Potchefstroom that does not conform to the conventional concentric morphology of cities (Burgess, 1925) (see *Chapter 4*).

Patch quality (such as litter decomposition) compensated for less resource-conserving structures resulting in higher SSA functionality, which probably led to the little variability in overall SSA function between the selected grassland fragments in rural/peri-urban and urban areas. The practice of mowing grasslands creates a substantial amount of litter which seems to maintain function in a landscape with less resource-conserving structures. Therefore the decomposition and incorporation of litter in mown grasslands may be an interesting aspect to focus on in future research.

The results indicated that the majority of physical landscape attributes and soil surface function parameters of the selected grassland fragments in the study that are subjected to varying degrees of urbanisation, do not differ from each other in a significant manner. Mowing in some of the grassland fragments in urban matrix areas resulted in the overall fine-scale biogeochemical of urban grassland fragments to be higher. It is therefore not the influence of urban areas *per se* resulting in high or low resource conserving patchiness and patch quality, but rather the management practices of grassland fragments associated with high (more urban – subjected to mowing) or low (more rural – subjected to grazing) urbanisation influencing the landscape function. Future research observing the quality and decomposition of litter, and soil biota activity may provide an opportunity to better understand soil function and processes in urban areas, and to determine whether the litter produced by the mowing of grasslands influences sub-surface soil dynamics.

It may be assumed that anthropogenic disturbances (urbanisation processes) have no direct negative effect on the fine-scale functioning of selected Rand Highveld Grassland fragments in the Tlokwe Municipal area. Thus, grasslands in a more urbanised environment are just as conservable (on a biophysical function level involving soil processes) than their more "rural" or "natural" counterparts. But this also entails that the non-natural management practices (specifically mowing) applied in urban areas, also be conserved. If mowing of urban grassland fragments are discontinued, the total SSA functionality may decrease.

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