ON-SITE EFFECTS OF ACCELERATED EROSION ON DIRECT PHYSICAL SOIL QUALITY INDICATORS

BY

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DECLARATION

I, Ravele Ndamulelo, hereby declare that this dissertation for Master of Science in Agriculture degree at the University of Venda, hereby submitted by me, has not been submitted previously for any degree at this or any other University. It is original in design and execution, and all references have been duly acknowledged.

RaveleN
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Signature

24/06/2020
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Date

DEDICATION

I dedicate this work to my late mother, Ravele Rudzani, and my loving family for being supportive and inspirational to me, you are the best.

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ABSTRACT

Accelerated soil erosion is a serious agricultural problem in South Africa limiting soil productivity and little it's known about its effect on soil quality. This study aimed to provide a less laborious, less time consuming and inexpensive protocol of estimating the effects of accelerated erosion on the soil quality. An assessment was undertaken in sites showing threat of accelerated erosion using various direct physical soil quality indicators. Four sites with different soil types were identified at initial survey. In each of the sites, two areas were selected. These areas were then classified as Not Visibly Eroded (NVE) and Visibly Eroded (VE). Each measurement in all site was done in those area classified respectively. The most stable structure and consistency were observed in NVE areas. Medium and large stones were observed in VE areas in all soil types studied. The VE soils were lighter in colour compared to soil colour in NVE. Aggregate stability and moisture content were significantly higher for the NVE and VE areas. Difference in values of water stable aggregates between NVE and VE was clear which showed that stability of aggregates is important in determining soil susceptible to erosion. Bulk density values were slightly different for the two areas. However, there was no significant difference between the bulk density of NVE and VE. Differences between soil texture for NVE and VE areas are only apparent for the sand, clay and silt particles with no changes in textural class. For all soil types investigated, silt was vulnerable to accelerated erosion with respect to soil texture. The research has provided baseline protocol for using physical soil quality indicators to find out effects of accelerated erosion. Soil functionality is critical in the restoration process of soil quality, and the methods used here could be effectively applied in a broad range assessment of erosion impact.

Keywords: Soil quality, physical indicator, Aggregate stability, Erosion

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LIST OF ABBREVIATIONS AND ACRONYMS

AS	Aggregate stability
BD	Bulk density
DF	Degrees of freedom
Du	Dundee
FAO	Food and Agriculture Organization
Gl	Glenrosa
Hu	Hutton
MC	Moisture content
NVE	Not visibly eroded
OC	Organic carbon
Sh	Shortlands
SOM	Soil organic matter
VE	Visibly eroded
WSA	Water stable aggregates

CHAPTER ONE

1.0 INTRODUCTION

Accelerated erosion is associated with land degradation and knowledge about its effect on soil quality is important in agriculture. Soil is an important non-renewable natural resource in which humanity and most flora and fauna dependent. According to report from Department of Agriculture, Forestry and Fisheries (DAFF) (2017) almost 70% of South Africa soil surface has been affected by varying intensities and types of soil erosion. This can be a result of poor management practices that influences destruction of soil aggregates. Accelerated erosion occurs when the loss of soil is higher than the rate of formation and many of the factors originate from human activities. In the world that we live in today, it is also important to monitor soil quality.

In quantitative terms, the average predicted soil loss rate for South Africa is 12 tons/ha/year, while the average soil loss rate under annual cropland (grain crops) is 13 tons/ha/year, which is much higher than the natural soil formation rate of less than 5 tons/ha/year (Le Roux 2011).The predicted soil loss simply means that soil loss is more due to activities such as extensive tillage-based cultivation, deforestation and overgrazing which have increased erosion by 10 to 40 times the rate at which it could be occurring naturally (Laker 2004). Accelerated erosion is largely responsible for soil degradation and is becoming a serious agricultural and environmental problem in South Africa which cannot be ignored. Land resources are facing challenge due to accelerated erosion. Most of soils in Limpopo province are highly susceptible to erosion with gully and sheet erosion being predominant all over croplands and grazing lands (Mulibana 2001).

Soil quality has been recognized and interpreted as a more sensitive and dynamic way to measure soil condition response to management changes and resilience to stresses imposed by natural forces or human uses (Karlen et al. 2003). Doran and Parkin (1994) as cited by Adeyolanu et al. (2013) defined soil quality as the capacity of the soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health.

Soil quality has received great attention in recent years and the number of studies assessing soil quality have increased worldwide. Furthermore, assessing soil quality would be helpful for evaluating the effects of accelerated erosion on soil performance and functions at a local scale (Mulibana 2001). Nevertheless, quantifying the magnitude of changes in soil quality and crop production at a regional scale is important for understanding how erosion can be better managed to increase soil quality and improve the long-term productivity of soil. The intense use of land has resulted in serious limitations on the sustainable use of soils and created a major problem in soil quality (Bobe 2004).

Indicators have been introduced as a tool to assess the state of soils and establish ways of monitoring them. Merrington et al. (2006) defined a soil indicator as a soil measurement that can represent the condition of the system or its ability to perform system functions. It is recommended that soil quality indicators should be based on soil function. The following properties are reported to be suitable for use as soil quality factors and indicators when studies on soil quality are carried out, physical properties such as texture, bulk density, water retention, aeration, compression, hydraulic properties, aggregation state, consistence properties, and surface crusting. Determinants of direct physical soil quality indicators are adversely affected by soil erosion (Rickson et al. 2012). To assess and monitor whether agricultural practices such as tillage, deforestation and grazing have an impact on soil quality, it is necessary to measure soil properties over time, with the soil properties chosen being responsive indicators of the soil function that is being assessed (Raiesi and Kabiri 2016).

Accelerated erosion results in alteration in soil properties, such as structural stability, particle-size distribution, bulk density, porosity, infiltration rates, water holding capacity and moisture content to mention few. Accelerated erosion is a selectively destructive process because it preferably removes organic matter or clay content of soils and leads to degradation of soil physical properties (Saraskanroud et al. 2017).The extent of changes in these soil quality indicators vary considerably, depending on the severity of the erosion and type of soil.

Several researchers (Giordano1984, Hsieh et al. 2009, Choi et al. 2005 and Bobe 2004) have suggested different methods to use in order to determine the effect of erosion, but those methods focus more on soil loss due to accelerated erosion rather than the actual damage on soil. An important consequence of accelerated erosion is its contribution to the decline in soil quality. The negative effects of accelerated erosion on soil quality are of two types: the on-site or long-term adverse effects and the off-site or short-term effects. On-site effects occur when there is loss of soil itself, which causes removal of organic matter and fine soil mineral from the topsoil (Le Roux 2011). Moreover, there is loss of nutrients, deterioration of soil structure and reduced water infiltration with increase runoff because of accelerated erosion. This study used soil quality indicators to investigate the on-site effect of accelerated erosion.

1.1 Problem statement

Accelerated erosion is threatening soil quality and is an acknowledged problem limiting soil productivity. Little is known about its effects on soil quality. The severity of this problem is recognized in South Africa. However, strategies proposed are time consuming and expensive and therefore further investigations are still required. The effect of accelerated erosion on soil quality is mostly discovered at a stage that it becomes expensive to recover the soil quality in a way that it will be productive again.

1.2 Justification

A better understanding of the effects of accelerated soil erosion on soil properties is necessary in minimizing loss of soil quality. Physical soil quality indicators assessment is less laborious, less time consuming and cheap. Direct physical indicators provide current information about soil status during the assessment of soil health. Assessing and monitoring soil quality can provide effective tools for determining the properties of degraded soils. This study will also raise awareness about soil quality to the community and promote sustainable land management and making it possible to design effective policies to protect and improve quality of soils.

1.3 Aim and objectives

1.3.1 Aim

To provide a less laborious, less time consuming and inexpensive protocol of estimating the effects of accelerated erosion on the soil quality.

1.3.2 Objectives

(1) Characterise direct soil quality indicators of the surface horizons in terms of their physical attributes such as stoniness, colour, soil consistence, and texture.

(2) Determine the effect of accelerated erosion on aggregate stability and size distribution in the topsoil.

(3) Estimate soil water status in the topsoil.

1.4 Hypotheses

(1) The physical characteristics and related direct quality indicators of the soil are not affected by the erosional processes.

(2) Aggregate stability and size distribution in the topsoil are affected by accelerated erosion.

(3) The soil water status is not affected by accelerated erosion.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Accelerated soil erosion

Accelerated erosion is related to any soil erosion which is perceived to be detrimental to soil quality (Tegene 2004). Like other erosion, it involves detachment and transportation of soil particles. Data from a wide variety of sources, including forestry industry research, shows the main land uses contributing to accelerated erosion are agriculture, earthworks, roading and tracking activities, establishment and harvesting of forests, and mining (Bobe 2004). In agriculture accelerated erosion is caused by deforestation, overgrazing, tillage and unsuitable agricultural practices (Adgugna et al 2005). The intensity of soil erosion has increased considerably. Accelerated erosion has major implications for agricultural production because of its effects on soil hydrological properties, erosion and crop establishment (Bobe 2004). Kaihura et al. (1999) also indicated that accelerated erosion from tillage operations contribute to changes of soil depth in cultivated fields.

The Food and Agricultural Organization (FAO) led Global Soil Partnership reports that 75 billion tons of soil are eroded every year from arable lands worldwide (Adugna et al. 2015). Borelli et al. (2017) performed an assessment of the global impacts of 21st century land use change on soil erosion and found out that accelerated soil erosion is primarily driven by modifications in land use. Worldwide average rate of about 35t/ha/year. The area of land with a moderate to severe potential risk is found to total approximately 61 million ha (50%). Although more than 91 million ha (75%) are classified as having only a very low to low actual risk, approximately 26 million ha (20%) are eroded at a rate greater than a soil-loss tolerance of 10t/ ha/yr (Bobe 2004).

In South Africa accelerated erosion is responsible for 84% of degraded areas, making excessive erosion one of the most significant global environmental problems (DAFF 2017). In quantitative terms, the average predicted soil loss rate for South Africa is 12, 6 tons/ha/year, while the average soil loss rate under annual cropland (grain crops) is

13 tons/ha/year, which is much higher than the natural soil formation rate of less than 5 tons/ha/year (Le Roux 2011). The Eastern Cape, Limpopo and KwaZulu-Natal provinces have the highest erosion potential. The level of knowledge and experience of land managers is a major contributing factor to the severity of accelerated erosion arising from specific land disturbance activities (Starker et al. 2018).

2.2 Soil quality indicators

In order to measure soil quality and functions, soil quality indicators are commonly used. The soil quality indicator gives overall assessment of soil quality, reflecting management practice effects on soil function (Aziz et al. 2013). The use of soil quality indicators is an effective approach to assess functionality of topsoil and novel substrates used in restoration (Costantini et al. 2015). Indicators are being increasingly used in the assessment of soil quality, soil health and importantly in monitoring and evaluating their direction of change with time or after disturbances (Muñoz-Rojas et al. 2016). Although some indicators are more suitable than others to capture differences among different soil types, the use of individual soil properties (in particular physical and chemical) can have serious limitations (Muñoz et al. 2016). Soil indicators need to integrate both soil physical, chemical, and biological properties (Schimann et al. 2012). Raiesi and Kabiri (2016) also agreed that soil quality indicator of sustainable soil management can be assessed most effectively using a combination of physical, chemical and microbiological properties that reflect management-induced changes in soil conditions following tillage or land use changes.

Doran and Zeiss (2000) suggest that indicators should meet the following criteria (1) sensitive to variations in management, (2) strongly correlated with soil functions, (3) useful for describing ecosystem processes, (4) easy to use and understood by land managers, and (5) simple and cost-effective. Selected soil properties are used as indicators of soil quality to assess soil functionality (Muñoz Rajas et al. 2016). Soil quality indicators should be simple and robust yet providing enough information to address the state of the soil (Muñoz Rajas et al. 2016). The soil parameters commonly used as indicators to estimate soil quality or functionality in restoration include individual determinations of basic physical and chemical factors (Sheoran et al. 2010). Soil quality indicators may be direct or indirect (Merrington et al. 2006). Direct indicators are associated directly with a soil function, whereas indirect indicators are indirectly related to soil function (Merrington et al. 2006). Assessment and monitoring of soil quality involve the use soil aggregate stability, bulk density, depth of soil and soil structure/consistence as key direct indicators (Black et al. 2002). Measurement of macro porosity is regarded as indirect soil quality indicators because it involve the use of moisture release characteristics and require particle and bulk density to calculate (Bone et al. 2010).

Moebius et al. (2007) indicated that using indicators leads to early participation of farmers in problem identification on soil erosion. A study conducted on soil quality concluded that soil quality indicators differ from place to place and that farmers would use multiple indicators to draw conclusions on soil quality (Millls and Fey 2004). Millls and Fey 2004 showed that the most common used soil quality indicators in South Africa include pH, electrical conductivity, bulk density, infiltration rate, water holding capacity and soil respiration. Skukla et al (2004) noted that aggregate stability is also a good indicator of soil quality as it affects infiltration in soils.

2.3 Physical soil quality indicators

Traditionally, physical soil attributes have been the main indicators used to assess soil quality. Physical indicators of soil quality are required for environmental monitoring and provide basis for soil protection policies and monitoring programme (Pulleman et al., 2012). An effective physical soil quality indicator would need to detect meaningful change in a given soil property and be responsive to this in the light of expected changes in soil quality (Singh and Khera 2009).They include particle size distribution, bulk density, available water, soil structure, and aggregate stability (Muñoz et al. 2016). A report from the environment agency indicated that of the 67 potential indicators identified, only a limited number were found to be relevant to the soil’s interaction with the environment and from physical category they include integrated air capacity and the number of locations with erosion features (Merrington et al. 2006).

Aggregates are the main physical indicators of soil status as shown by the number of stable aggregates. Gorter (2012) found that aggregate stability was significantly higher for the non-erodible fields for both wet- and dry aggregates. A study on physical indicators of soil quality in relation to soil erodibility under different land uses found out that soil depth was very low at eroded locations and varied from 15 to 56 cm as compared to the other three locations (Singh and Khera 2009). Soil quality indicators were used to assess degraded land and found that bare soil have low water holding capacity as compared to covered soil (Muñoz et al. 2016).

A comparison of aggregate stability test using physical soil quality indicators include the use of soil structure, bulk density, particle size distribution, plant available water to develop soil quality index (Armenise et al. 2013). Indicators such as soil organic carbon, topsoil surface condition, aggregate stability, top bulk density, topsoil plastic found limited to a depth of 1 m by erosion (Merrington et al. 2006). Bulk density can be used as physical soil quality indicators because a high bulk density indicates low porosity and compaction (Pulido et al. 2015). A study done by Stavi and Lal (2011) showed overall mean bulk density in eroded area was larger than that in uneroded area by more than 0.5 g cm^{-3}. Another study found that bulk density in conventional tillage systems can be 10% higher than in no till systems particularly in the 0–10 cm layer (Corstanje et al. 2017).

Mills and Fey (2004) carried a study aimed at finding the effect of land use using soil properties. The results showed that aggregate stability is highly sensitive to management and bulk density had been successfully used to represent soil quality, thus, a useful soil physical quality indicator. Barthès and Roose (2002) from their study concluded that experiments done using physical indicators are easy to implement, less expensive and time come consuming than field experiments. Reynolds et al. (2002) indicated that analyses using physical indicators are representative of agriculturally relevant soil processes, and routine measurements of soil physical quality indicators must meet several criteria to promote widespread adoption.

2.4 Direct physical soil quality indicators and soil function

Direct indicators are associated directly with a soil function, whereas indirect indicators are indirectly related to a soil function (Merrington et al. 2006). Direct soil quality indicators such as bulk density, aggregate stability and soil water retention characteristics are directly associated with soil function. Change in indicator has direct effect on the soil quality and in some cases, it affects other soil properties. Indirect indicators are not directly associated with soil function (Zornoza 2015).

Aggregate stability is also used as one of the direct physical properties that are used to indicate soil quality because it affects erosion, movement of water, and plant root growth (Chivenge et al. 2011). Changes in aggregate stability may serve as early indicators of recovery or degradation of soils (Tesfahnegn 2016). Stable aggregates favour high infiltration rates and appropriate aeration for plant growth. Surface crusts and filled pores occur in weakly aggregated soils which prevent infiltration and promote erosion, subsequently resulting in a decline of soil productivity and quality (Raiesi and Kabiri 2016). Gorter (2012) observed that measured values of aggregate stability showed clear differences between the erodible and non-erodible fields in relation to soil degradation rates. Both the dry-aggregate stability and wet-aggregate stability were significantly different between the erodible and non-erodible fields. Results showed that dry aggregates from non-erodible fields required 5285 drops and erodible used 2631 drops to be disrupted (Gorter 2012).

The physical and chemical behavior of a soil is influenced strongly by soil texture. Soil texture affects water movement and soil erodibility. Water moves more freely through sandy soils than it does through clayey soils which influences how much water is available to the plant (Ighodaro et al. 2016). Soils also differ in their susceptibility to erosion (erodibility) based on texture and it has been reported that soil with silt content of more than 40% are highly erodible than a sandy soil under the same conditions (Gorter 2012). These properties can be measured once and used to group sites that are likely to respond in similar ways to management hence this is used as direct soil quality indicator.

Soil physical indicators such as bulk density and porosity are highly related to water holding capacity and root development which are essential factors to sustain plant communities through prolonged droughts (Sheoran et al. 2010). Merrington et al. (2006) found that soil bulk density meeting the criteria of direct soil quality indicator. Since high bulk density is an indicator of low soil porosity and soil compaction which may cause restrictions to root growth, poor movement of air and water through the soil and decrease in bulk density or an increase in porosity and cause the water to infiltrate more easily as well (Stavi and Lal 2011)

Soil consistency reflects the strength with which soil materials are held together or the resistance of soils to deformation (Bünemann et al. 2018). Consistency is important for the practical use of soils such as soil tillage and compaction by farm machinery (Bünemann et al. 2018). Soil consistency is an important factor both in water holding capacity as well as water movement through the soil for use by plants. Soil structure directly affect soil functions related to soil by sustaining biological productivity, regulating, partitioning water and solute flow, cycling and storing nutrients (Lal 2015). Granular structure is characterized by loosely packed, crumbly soil aggregates and an interconnected network of micropores that allow rapid infiltration and reduce soil loss by erosion. Platy structure is often indicative of compaction. Considering that the structural index (SI) > 9% indicates a stable soil structure, 7% < SI < 9% a low degrading risk, 5% < SI < 7% high degrading risk, SI <5% structurally degraded soils (Reynolds et al. 2007).

Soil color can also be used to indicate soil quality as it provides insight of soil environment and constituents. Color variation from black to dark brown shows that contains a high amount of organic matter. Soils containing higher amount of iron compounds generally impart red, brown and yellow tinge colour. Corstanje et al. (2017) monitored soil quality and soil water retention characteristics and soil sealing as physical indicators of soil quality. A study on variability of soil physical quality in un-eroded, eroded and depositional cropland sites found that erosion have non-significant effect on the hue and chroma but have significant effect on value (Stavi and Lal 2011).

2.5 Soil erosion and direct physical soil quality indicators

The measurable soil quality indicators that are primarily influenced by erosion includes soil-depth, organic matter, respiration, aggregation, texture, bulk density, infiltration, nutrient availability and retention capacity (Arshad and Martin 2002). Soil dry aggregate and water-stable aggregate amounts and size distributions affect the soil quality. Stavi and Lal (2011) studied variability of soil physical quality in uneroded, eroded, and depositional cropland sites and found that water stable aggregates on uneroded was 80.8% and 67.1 % on eroded phase.They reported significant reductions in both the mean weight diameter and water stable aggregates following erosion at eroded sites which reflect soil physical disruption following accelerated erosion (Stavi and Lal 2011). Therefore, these results show that the erodible fields might be more subjected to crust formation. Sigh and Khera (2009) noted that the difference between the erodible and non-erodible fields for dry aggregate stability is even more pronounced.

Mukherjee and Lal (2014) reported that the long-term effect of erosion on soil physical indicators include reduced organic matter, increased porosity and reduction in bulk density. A study done by Bobe (2004) showed increased porosity of 0.50 to 0.52 g cm^{-3} due to erosion. Erosion is said to reduce organic matter from 1.2-1.5% which affects stability of soil aggregates soil (Esmeraldo 2017). Effects of erosion on soil quality indicators was also studied by Stavi and Lal (2011), who used eroded, uneroded and depositional sites as different phase, they found that erosion has a non-significant effect on soil texture because very small difference were observed among the phases for clay, sand and silt. However, these changes will vary with long term soil management of the area such as different farming system. In non-cultivated area, percentages of organic matter were between 1.50%- 0.57% and in horticultural farm, percentages of organic matter varied from 0.21%-0.79% showing decreasing trend with increasing depths (Starker et al. 2018).

Several studies revealed that soil physical indicator in the uneroded/non erodible fields was higher than that in eroded/erodible fields (Stavi and Lal 2011, Gorter 2012) and larger water aggregate stability and mean weight diameter of aggregates was found on uneroded phase. Eroded areas showed bulk density, which is significant with soil depth, higher in the lower (1040 Kg m^{-3}) than in top layer (960 Kg m^{-3}) indicating the tendency of bulk density to increase with depth (Moges et al. 2013). Bobe (2004) found that aggregate stability is sensitive to erosion, however bulk density was not found as useful indicators on the erosion study because it is less sensitive but useful in assessing soil quality. Similar results were found by Andrews et al. (2002) who indicated that water-stable aggregates with size ranging from 0.25 to 2 mm were the most sensitive indicator of changes in soil erosion.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Sampling sites

The study was done in selected sites in Limpopo Province, South Africa. The soil samples were collected from a semi-arid environment (Mmarete 2003). The sampling sites include Ha-Davhana (23°13’09’’ S 30°27’25’’ E), University of Venda (22°58’48’’ S 30°26’13’’ E), Mukula (22°51’13’’ S 30°26’13’’ E) and Tshamutore (22°37’30’’ S 30°40’32’’),. Soil classification was done according to South African system of soil classification (1991) and their correspondent with the Food and Agriculture Organization of the United Nations classification (FAO 1998). The different land use and different soil type from study sites are presented in Table 1. The geographical location of the sampling sites is as shown in the Figure 1.

Table 1: Description of the study sites.

Location	**Soil classification**		**Land use**
	SA	**FAO**	
Ha-Davhana	Glenrosa	Acrisols	Crop farming
Tshamutore	Dundee	Ferrasols	Pasture
Mukula	Shortlands	Luvisols	Mixed farming
University of Venda	Hutton	Fluvisols	Crop farming

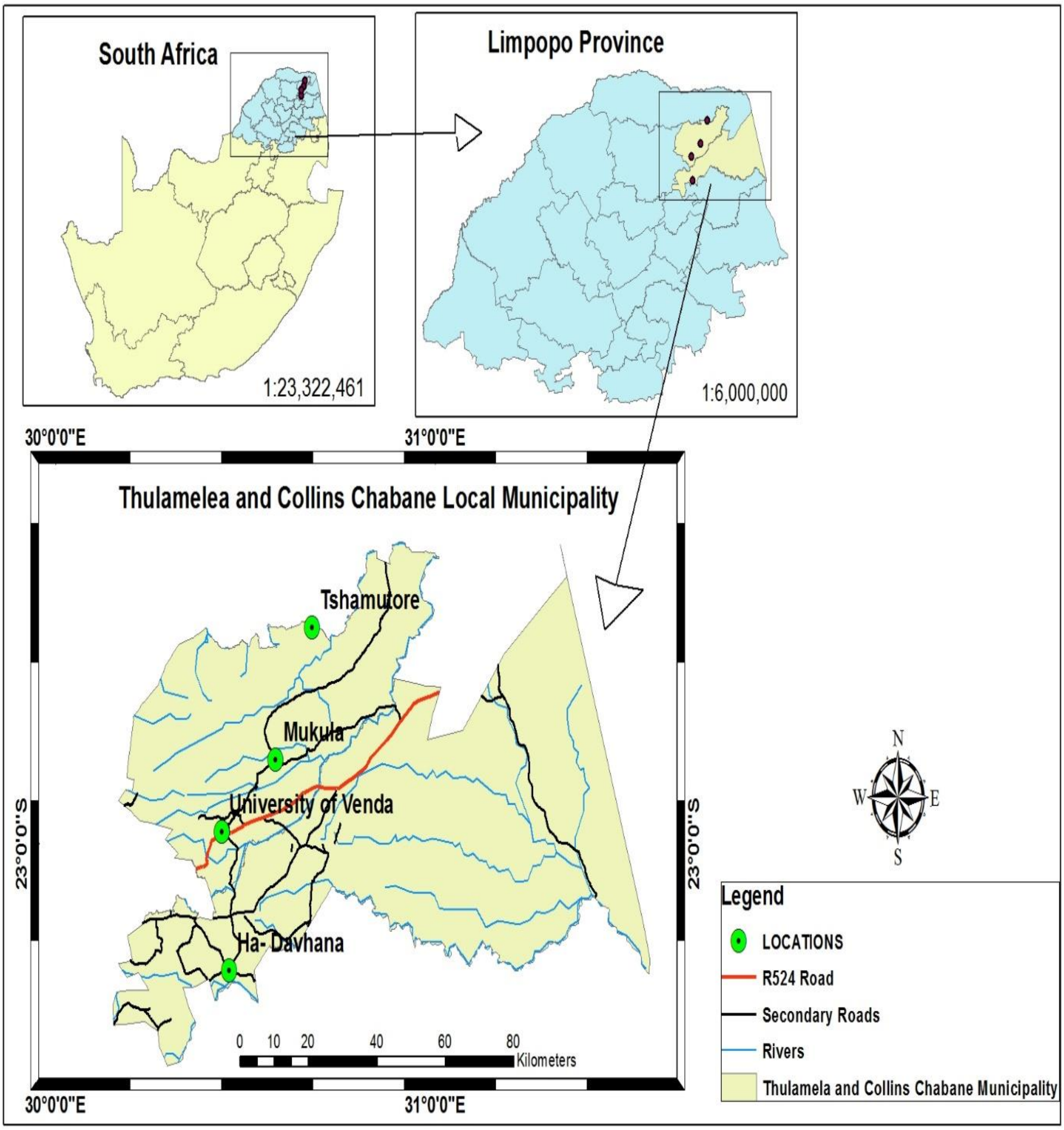

Figure 1. A map indicating study sites

3.2 Field determinations

Two adjacent sampling locations based on erosion phase classified as Not-Visibly Eroded (NVE) (Figure 2) and Visibly Eroded (VE) (Figure 3) were established from each site. Soil colour was determined by using Munsell's colour chart. Stoniness was determined using a guideline from soil survey handbook having different categories namely very small stones, small stones, medium stones and large stones (Hodgson 1976). To determine Soil consistence a ped from the topsoil was used holding it between thumb and forefinger then gently squeeze the ped until falls apart. Table 2 shows different categories used to classify soil consistency (Rawls and Pachepsky 2002).

Table 2: Soil consistency categories

Category	**Description**
Loose	had trouble picking out a single ped and the structure fell apart before you handle it
Friable	the ped broke with a small amount of pressure
Firm	the ped broke when you apply a good amount of pressure and dents your fingers before it breaks
Extremely Firm	the ped cannot be crushed with your fingers

Figure 2: Not Visibly Eroded (NVE) site

Figure 3: Visibly Eroded (VE) site

3.3 Sampling procedure

The soil samples were taken from the upper 20 cm using a spade. The sampling depth of 20 cm was chosen because erosion occurs in the topmost soil layer. Sampling entailed taking random 5 spots from NVE and VE per site. Undisturbed sample core sampler was used to collect soil in the core ring at 0-20 cm. The samples were carefully labelled and carried to the lab in plastic bags. Air-drying was done by spreading the soil on the benches in the laboratory. Large soil clods were cautiously fragmented with the hands to get smaller aggregates and undisturbed samples was not fragmented. After air drying the soil, samples were sieved through 2 mm. Texture, aggregate stability was measured from the undisturbed samples.

3.3 Laboratory determinations

The soil bulk density (BD) was determined using core method (Blake et al. 1965). Samples were obtained with a cylinder of 50 mm in diameter and 100 cm^3 in volume and were inserted into the soil with the use of a hammer. Bulk density was determined by weighing the dry weight core and the ring and this was divided by the volume of the core sampler. Same samples was used to determine moisture content using gravimetric method (Topp 1993).

Soil texture was determined according to the hydrometer method (Bouyoucos 1962) using sodium hexametaphosphate (Calgon) as dispersing solution and texture classes were determined using textural triangle. Organic carbon content was determined by the Walkley–Black procedure as described by Rowell and Coetzee (2003) and use Bemmelen factor 1.724 to convert organic carbon (OC) to soil organic matter (Nelson and Sommers, 1982).The soil aggregate stability was determined according to the method developed by Kemper and Rosenau, (1986) using wet sieving apparatus. Then 4g of soil were placed on the sieves of wet sieving apparatus and washed in cans filled with distilled water and dispersing solutions, respectively. Both set of cans were oven dried. After drying the fraction of water stable aggregates (WSA) was determined by dividing the weight of the stable aggregates over the total aggregate weight.

3.4 Experimental design and data analysis

The experimental setup was completely randomised design (CBD). Each treatment was replicated three times and data were recorded and processed using Microsoft office excel 2016. Analysis of variance and paired t-test were performed following GLM using Minitab version 17 software (Meyer et al. 2004). Means separation were done using Turkeys honest significance difference at $P \leq 0.05$. The photos was analysed by comparing vegetation cover between the NVE and VE.

CHAPTER FOUR

4.0 RESULTS

4.1 Characteristics of visual soil quality indicators

The soil colour analysis showed 10R 4/6 red (dry) and 10YR 6/8 (dry) brown as the dominating colour. Dark soil colour was dominating in NVE (dark brown) and light colour dominating in VE (light brown) in all studied soils. The soil structure showed different types which include prismatic in NVE of Glenrosa, granular (Figure 5) in NVE of Dundee and other sites have blocky (Figure 4) in VE. Soil consistence before erosion soils are friable or loose but after erosion it change from firm in soil dominated by sand particles to moderately/extremely firm in soils dominated by clay. Not visibly eroded points contain very small stones a visibly eroded have medium to large stones as shown in Table 3.

Figure 4: Blocky Structure

Figure 5: Granular Structure

Table 3: Visual soil quality indicators on the surface horizon

Soil Type	**Treatment**	**Soil color**	**Structure**	**Consistency**	**Stoniness**
Glenrosa	NVE	10YR 6/8 brown	prismatic	friable	small stones
	VE	7.5YR 6/4 light brown	platy	firm	medium stones
Dundee	NVE	7.5YR 3/4 dark brown	granular	loose	very small stones
	VE	7.5 YR 6/3 light brown	granular	loose	very small stones
Shortlands	NVE	2.5YR 4/6 red	blocky	firm	small stones
	VE	2.5YR 4/4 reddish brown	platy	moderately firm	medium stones
Hutton	NVE	2.5YR 5/6 Red	blocky	firm	very small Stones
	VE	2.5YR 5/4 Reddish brown	blocky	extremely firm	medium stones

NVE-Not Visibly Eroded, VE- Visibly Eroded

4.2 Visual physical soil quality indicators

Results obtained on physical soil quality indicators for all sites are shown in Table 5. The texture analysis showed four textural classes which included sandy loam, loamy sand, sand and clay. Glenrosa and Dundee was dominated by sand fraction while Shortlands and Hutton dominated by clay fractions (Table 4). Higher mean values for bulk density was found in visibly eroded sites and the soil bulk density ranged between 1 to 1.4 g cm^{-3} for all studied soils. The soil moisture content decreased from NVE to VE. Soils such as Glenrosa and Dundee which are dominated by sand particles had very low moisture content between 3.74% and 5.12% respectively. The soil organic matter for the studied soils ranged from 1.43 to 3.46% (Table 4). Aggregate stability showed decreasing trend by more than 5% from the NVE to VE area in all studied soils.

Table 4: Mean Bulk density, moisture content, aggregate stability, soil organic matter, aggregate stability and texture

Soil Type	**Treatment**	**BD (g cm^{-3})**	**MC (%)**	**WSA (%)**	**SOM (%)**	**Sand %**	**Clay%**	**Silt %**	**Textural class**
Glenrosa	NVE	1.28	2.26	15.35	1.89	72.6	14.2	13.2	Sandy Loam
	VE	1.33	1.67	13.01	1.52	74.0	14.9	11.1	Sandy Loam
Dundee	NVE	1.43	1.71	37.07	2.19	86.4	9.6	4.0	Loamy sand
	VE	1.51	1.14	28.38	1.74	89.8	8.4	1.7	Sand
Shortlands	NVE	1.09	13.66	75.82	3.46	32.2	38.9	28.9	Clay
	VE	1.11	9.32	63.19	2.56	36.0	40.2	23.8	Clay
Hutton	NVE	1.11	14.25	67.63	3.03	25.5	56.3	18.2	Clay
	VE	1.38	5.81	53.42	1.43	15.3	72.1	12.6	Clay

NVE-Not Visibly Eroded, VE- Visibly Eroded

4.3 Effects of accelerated erosion on physical soil quality indicators

4.3.1 Texture

There was no significant difference observed between soil texture on NVE and VE area in all studied soils (Table 5). However, soil type had a very significant effect on the contents of these soil fractions (Table 10).

Table 5: Accelerated erosion effects on soil texture

Treatment	Sand	Clay	Silt
NVE	54.08^{a}	33.78^{a}	14.38^{a}
VE	53.33^{a}	31.2^{a}	12.88^{a}

NVE-Not visibly eroded, VE- Visibly Eroded, Similar superscript letters indicate means were not significantly different within columns.

4.3.2 Bulk density and Soil organic Matter

The bulk density was higher for VE area in all studied soils but not significant different (Table 6).There was significance difference in SOM in both treatment as $p<0.05$ (Table 6).

Table 6: Erosion effects on Bulk density and Soil organic matter

Treatment	BD	SOM
P value	0.066	**0.0037**
NVE	1.2250a	2.6425a
VE	1.2975a	1.8108b

NVE-not visibly eroded, VE -visibly eroded, BD- bulk density and SOM-Soil organic matter. Bolded P values highlight significant effect. Means within a column followed by different letters differ at the 0.05 probability level according to Tukey's pairwise comparisons.

4.3.3 Aggregate stability

The aggregate stability was significantly different between the two-sampling location (NVE and VE) off all studied soils (Table 7). VE had few stables aggregates as compared to NVE. Therefore, erosion negatively influenced the stability of soil aggregates.

Table 7: Effect test of erosion on aggregate stability

Source of Variation	**SS**	**Df**	**MS**	**F**	**P-value**	**F critical**
Replicates	11905.54	11	1082.32	45.85	1.44	2.82
Erosion	537.61	1	537.61	22.77	**0.00**	4.84

SS-sum of squares, df-degree of freedom, MS-means of square.

4.3.4 Soil water Status

Soil water status was tested in terms of moisture content of soil from the NVE and VE. There was significance different ($p \leq 0.05$) in moisture content of both NVE and VE areas in all studied soils (Table 8).

Table 8: Test effects of erosion on Moisture content

Source of Variation	***SS***	***Df***	***MS***	***F***	***P-value***	***F crit***
Replicates	506.33	11	46.03	7.31	0.00	2.81
Erosion	72.70	1	72.69	11.54	0.01	4.84

SS-sum of squares, DF-degree of freedom, MS-means of square.

4.3.5 Soil type

The interactive effect of erosion and soil type was significant in all studied physical soil quality indicators (Table 9). Bulk density of Shortlands was 1.1 g cm^{-3} less than Glenrosa and Dundee which exhibited high bulk density of 1.35 g cm^{-3} and 1.50 g cm^{-3}, respectively, in the VE. Dundee had the lowest moisture content as compared to other soils studied. Soils found in the NVE had higher aggregate stability as compared to VE areas.

Table 9: Effect of Erosion and soil type on physical soil quality indicators

	NVE						**VE**					
Soil type	BD	MC	AS	CLAY	SAND	SILT	BD	MC	AS	CLAY	SAND	SILT
Gl	1.27ab	2.26b	15.35c	13.47d	72.33b	12.87b	1.32ab	1.67c	13.01d	14.27c	74.33b	11.4b
Du	1.43a	1.71b	37.07b	9.33c	85.67a	5c	1.50a	1.14c	28.38c	8.2d	89.67a	2.13c
Sh	1.09b	13.66a	75.82a	47.33 b	32.67c	20a	1.11b	9.32a	63.19a	39.33b	35.67c	25a
Hu	1.10b	14.25a	67.63a	54.67a	25.67d	19.67a	1.28ab	5.81b	53.42b	73.33a	13.67d	13b
p value	*	***	***	***	***	***	**	***	***	***	***	***

Means with different letters in the same column are significantly different from each other. * = significant at P < 0.05, ** = significant at P < 0.01, ***=significant at P=0.00.BD- bulk density, MC-moisture content, AS- aggregate stability, NVE-not visibly eroded and VE-visibly eroded.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Soil colour, structure, consistency and stoniness

Shortlands had 2.5YR 4/6 NVE and 2.5YR 4/6 VE. With regard to Munsell variables this showed that effect of erosion was on the chroma which gives the saturation of the colour. However, Stavi and Lal (2011) found that erosion had non-significant effect on hue and chroma but a significant effect on value. Soils on the VE wer light in colour than the initial colour found on the NVE, this could be due to removal of topsoil during erosion process. The NVE area of Glenrosa and Dundee had dark brown colour but on the eroded area colour changed to light brown. Hutton and Shortland resulted in mixed colour on VE, this implies that the mineral found in red soils such as iron have been reduced and new mineral has been introduced from the brownish colour. Literature reveals that accelerated erosion removes topsoil with the dark colour of the soil leaving pale colours (Antwerpen 2005).

Stone size and abundance showed remarkable difference between NVE and VE areas of all studied soils. It appears from the results that medium and large stones are found in VE than on NVE. As accelerated erosion occurs it left medium and large stones dominating on the surface (Kaihura et al 1999). Sarker et al (2018) reported that even deposition of materials after erosion is attributed to abundance of stone on VE area. Abundance of stones with medium to large size limits seed germination and water movement, thus poor soil quality. Most soil had changed in structure between NVE and VE except for Dundee. This is because accelerated erosion causes destruction of the soil structure through cultivation and overgrazing or trampling by humans (Adguna et al. 2015). In glenrosa and hutton soils don’t have peds on VE conforming the lack of soil structure. Platy structure had tendency of easily compacted and blocky structure tend to resists soil penetration by plants (Cotching 2009). Without good soil structure, soils will have poor infiltration.

Accelerated erosion appears to harden the top soil surface. Shortlands and Hutton had consistency between firm and extremely firm on VE area because of they have high clay content. This support the results of soil structure obtained and it implies that crusting is likely to happen on the eroded areas. As reported in previous studies accelerated erosion is attributed to the exposure of soil surface, resulting in poor structure and compaction which is assumed to decrease soil quality (Stavi and Lal 2011).

5.4 Texture

Insignificant different were observed on soil texture between NVE and VE. Richter and Negendank (1977) found similar results and concluded that soil with high silt content (>40%) are highly erodible. The investigated soils contain less percentage of silt, hence no significant difference. Also, from the perspective of determining the susceptibility of soils to erosion, clay content analysis from soil texture analysis show a value higher than 30% clay on Hutton and Shortlands, while Glenrosa and Dundee soils with clay content between 9 and 30% are the most susceptible to erosion, due to the lack of combining clay particles with organic matter to form soil aggregates (Morgan, 2005). This indicates that NVE had higher chance of being eroded further.

Generally, there was an increasing trend of sand, silt and clay fractions from NVE to VE. This is due to the effect of deposition of colloidal particles and the tendency of erosional processes to sort the lightweight particles led to high contents on the visibly eroded sites (Polyakov and Lal 2004). However, a non-significant effect was found on soil textural composition which resulted in no change on textural class. During the process of erosion, larger particles (sand) are more resistant to transport because of the greater force required to entrain them and finer particles (clay) are more resistant to detachment due to their cohesiveness. This builds on the existing knowledge that texture of the soil influence the severity of erosion (Paterson et al. 2013).

5.5 Bulk density

The bulk density increased with severity of erosion at VE but not significant. The increase in bulk density with erosion may be due to decrease in aggregation of soil particle because of decline in SOM content that also reduces the microbial activities in the eroded soils (Kaihura et al. 1999). Similar results were reported by Starker et al (2018) that erosion slightly increases bulk density due to compaction by tillage, grazing animals and overirrigation. The lack of significant difference between NVE and VE indicates that accelerated erosion did not have strong influence on bulk density. The non-significance was probably due to poor tillage practices from all studied sites and lack of spatial variability in BD over short period of time (Logsdon and Karlen 2004). Ramos et al (2013) indicates that in agricultural fields, increase in bulk density accelerates formation of mechanical crust which reduces water infiltrability. Soils with high bulk density also hinders seed germination and root growth, which is an indicator of poor soil quality (Bobe 2004). However the bulk density found are within ideal bulk densities for sandy/ loamy sands < 1.60 ,sandy loam < 1.40 and clay < 1.10 g cm^{-3} that will not hinder crop growth (Beutler et al. 2005). Adverse effect on accelerated erosion on bulk density occurs mostly in soils dominated by clay particles.

5.6 Aggregate Stability

Strong significant difference was found between NVE and VE. Our results correlate with the results of a study done by Gorter (2012) who also found that both the dry-aggregate stability and wet-aggregate stability were significantly different between the erodible and non-erodible fields. Although the decrease in aggregate stability on VE was mostly noticeable in Shortlands and Hutton, this soil had relatively high water stable aggregates values and the reason for this is high clay content that act as binding agents of aggregates. This difference is relevant for crust formation. Therefore, these results show that the erodible fields might be more subjected to crust formation. Stavi and Lal (2011) studied the variability of soil physical quality in uneroded, eroded and depositional cropland sites. They reported that WSA in depositional and eroded sites had significantly lower values than in uneroded site. It is said that more tillage event and cultivation of fields lead to less water stable aggregates, exposing soil to further erosion (Esmeraldo 2017).

The results show that NVE yielded the most stable aggregates from all soil type as compared to VE. This could be due to minimal disturbance of aggregates on the top soil. Therefore, it is clear from the results that accelerated erosion had negative impact on the percentage of water stable aggregates in all studied soils. Aggregate stability is more sensitive to erosion than most other indicators tested (Blanco et al. 2009). This is in line with previous studies that have shown that water-stable aggregation is sensitive to management practices such as tillage intensity, crop rotation and erosion (Moebius, et al. 2007). Aggregate stability played determination of soil susceptibility to erosion (Cerda A, 2000). Therefore, VE site have poor stable aggregates and changes in aggregate stability may serve as an early indicator of soil degradation (Cerda A, 2000).

5.7 Moisture content

The moisture content in this study was generally low. However, significant difference was observed between NVE and VE. This could be due to drought condition experienced during the sampling period. The destruction of soil aggregates by erosion and low soil organic matter could be responsible for low moisture in VE. In addition, the study sites fall under semi-arid regions with low content of organic matter and semi-arid regions have low moisture content in general, which could have worsened the low moisture contents in visibly eroded sites. Previous studies have reported that accelerated erosion reduced soil moisture content, soil organic carbon, available water capacity and water use efficiency (Tenge et al. 1998). The results suggest that VE areas are not ideal for growing crops that require more water as water availability is minimal. From the literature, soil containing low soil organic matter are most susceptible to accelerated erosion especially in soil with high clay content (Kaihura et al. 1999). Comparison of moisture content is corresponding with the results of soil organic matter, as moisture content is strongly influenced by organic matter and soil texture .Soil with low moisture hinders nutrient uptake which reduce yields (Esmeraldo 2017). Progressive accelerated erosion results in loss of moisture through exposure of soil surface by either tillage or overgrazing.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Accelerated erosion adversely affected soil colour, structure, aggregate stability and moisture content. However, effects of accelerated erosion on soil texture was not noticeable, since textural class was not changing. Most of the examined physical indicators showed significant difference between NVE and VE in all studied soils. Significant results reveal higher soil physical quality in NVE and emphasizes the degradation on VE soils. Since this study was conducted under on farm conditions, it was possible to determine onsite and direct effect of accelerated erosion using indicators and it easy and inexpensive compared to plots erosion methods that involve the use of USLE. This study suggest indicators provides reliable information about soil quality status.

6.2 RECOMMENDATIONS

It is desirable to put more land under no till since they reduce the threat imposed to soil quality by erosion especially in areas that were badly eroded. Small scale was used in this study, there is a need to investigate the effect of accelerated erosion using large scales fields to develop formal protocol to assess soil quality using indicators. The soils used contains smectite and kaolinite, so it will be good to know how soils dominated by quartz would respond to accelerated erosion. A limitation in this study was that only physical soil indicators was used. Therefore, further research is required using both physical and chemical soil quality indicators, in order to strengthen the reliability of the protocol to be developed for assessing erosion effects.

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