

**INVESTIGATING THE RELATIONSHIP BETWEEN
LAND USE AND SOIL MOISTURE VARIATION
IN THE SUID BOKKEVELD, SOUTH AFRICA**

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Abstract

This study investigated the spatial variability of soil moisture as well as changes within the soil profile of different land use types in the Suid Bokkeveld, situated to the south-west of the Northern Cape, South Africa. This area has been experiencing harsh weather conditions that affect local agricultural production and multiple livelihood activities. The primary aim of the research was to analyse the influence of land use adopted in response to weather and climate change by studying the effects of soil moisture variations in the area.

The study found that, together with depth and soil particle size, different types of land use contribute to soil moisture variations. Out of the five types of land uses that were investigated, *rooibos cultivated* farms had the highest soil moisture variability. The second highest variability was found in *grazing cultivated* farms and the lowest in *natural* and *grazing never cultivated* land, respectively. The results confirm that the shift from *rooibos tea* and *wheat cultivation* to *grazing* has contributed to a reduction in soil moisture variations. The *grazing cultivated* and fallow system could therefore be an effective land use types to ensure water and soil conservation, reduce land degradation and adapt to weather and climate change. The significance of this study lies in it being one of the first explorations into soil moisture in this area. Other forcing factors will need to include building a comprehensive and integrated understanding of soil moisture variability based on multiple influencing factors.

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Chapter 1: Introduction

1.1. Why study soil moisture?

Soil moisture plays an important role in the interface between land surfaces and the atmosphere because it is involved in both water and energy exchanges (Zhu 2008). Soil moisture exerts a control on partitioning net radiation into latent heat and sensible heat, which determines the level of soil evaporation and transpiration. Through the evapo-transpiration process, soil moisture provides a source of water for the formation of clouds and precipitation over land, especially over semi-arid and arid areas (Zhu 2008). Furthermore, soil moisture controls the availability of water for plants through runoff and infiltration, which affects plant growth (Hupet 2002, Fu et al., 2003, Albertson 2003).

Over the last five decades, soil moisture has been given much attention because of its central role in environment and climate systems, its quantification and variability over space and time, as well as factors on which it depends. In 2010, soil moisture was recognized as an Essential Climate Variable (ECV) by the European Space Agency (ESA) and as one of the Essential Climate Variables (ECVs) required by the Global Climate Observing Systems (GCOS) and other international parties (ESA 2010). Prior to this, the International Soil Moisture Working Group, which was established in 2005, has produced three reports consistently requiring actions for the intensification of in situ soil moisture measurement and the development of its products and networks at national and international levels. Van Oevelen and Jackson (2006) produced one of these reports and recommended that the above processes would have useful application in different fields such as earth observations, weather forecasting, climate, climate modelling, water resources and agriculture.

Similarly, Fu et al. (2003) suggest that the above studies would assist in understanding and predicting hydrological processes and thereby provide important contributions to improving land management activities. It is evident that soil moisture investigations are important and would benefit land and water management activities, especially as a result of climate change.

1.2. Background and problem statement

The Suid Bokkeveld, situated to the south-west of the Northern Cape in South Africa, is the chosen site of this research project. It is a region predominated by a semi-arid and mountainous environment (Lauströer 1988). This region is prone to aridity and acidic, nutrient-poor soils (Ojeda et al., 2001). Historically, the Suid Bokkeveld was owned by small-scale farmers who used it for wheat and sheep farming as well as rooibos tea production (Louv 2006). Currently the main land use in the area comprises of rooibos cultivation, small stock (e.g. sheep and goats), and vegetable farming. However, rooibos tea production is considered as the main farming activity since it generates a significant income (Arendse 2014; Archer et al., 2008). The Heiveld Co-operative for instance, is a collective of 64 small-scale rooibos farmers (64 members) who are exporting approximately 40 tons of organic tea a year to the international market (Archer et al., 2008). Subsequently, livestock farming and other crops are considered supplementary to rooibos tea production.

However, just like many areas in south-western Africa, farmers experience harsh weather conditions that affect their agricultural production and livelihoods. These conditions include drought and intensive rainfall resulting in wind and water erosion as well as land dehydration. During the dry season the area usually suffers from wind erosion due to dry soils whereas water and soil erosion occur during the rainy season (Archer et al., 2008). Between 2003 and 2006, the Suid Bokkeveld experienced severe droughts together with dramatic rainfall events and unusually low overnight temperatures (Archer et al., 2008). The decrease in rooibos tea and stock production due to water shortage has had a negative impact on multiple livelihood activities (Archer et al., 2008). Oettlé (2012) reports that severe drought in 2003 had reduced the rooibos tea production by 40%. Therefore, studying soil moisture variation and its relation to different land use practices would be beneficial for in field water management and can contribute to maintain the agriculture production, especially during long dry seasons.

Harsh weather conditions and climate variability predicted for this region makes the above subject even more imperative. Midgley et al. (2003) report that the next 50 years will be characterized by increasing mean annual temperature and drier climate conditions together with high rainfall intensity events. The same findings were reported by the fourth assessment of the Intergovernmental Panel for Climate Change (IPCC 2007). The IPCC (2007) stressed that the predicted climate conditions will have a serious impact on the whole ecosystem of the region. It would include climate change events such as flooding, drought and other global drivers and lead to land-use changes, fragmentation of

natural systems and the over exploitation of resources. In the Suid Bokkeveld farmers are directly affected by rainfall and temperature patterns (Oettle 2012). Therefore, the best in-field water management techniques include increasing soil moisture content and ground water levels which are two important practices that farmers need to attend to in order to successfully adapt their farming practices to climate change effects (EMG 2012).

In addition to climate change effects, such as the excessive droughts mentioned earlier (see page 2, paragraph 2), farmers in the Suid Bokkeveld face many other challenges. Low and Rebelo (1998) state that during past decades, the production of rooibos has been threatened by several environmental and human activity factors such as excessive burning, over-grazing, periodic drought and fragmentation. To support this, Hawkins et al. (2011) reports that ecosystem statuses have endangered the type of vegetation where wild rooibos grows, or could be cultivated. Leipoldt Sand Fynbos is a good example and Hawkins et al (2011) state that during the past five years, the presence of this species leads to land clearing resulting in natural habitat loss of many plants.

Furthermore, Malgas and Oettle (2007) reports that ploughing of natural grassland to establish rooibos plantations, inappropriate land management, grazing systems, as well as improper harvesting practices (in the case of rooibos tea) are among the environmental problems in the area which also affect rooibos tea production. According to Arendse (2014) many farmers in the area, especially those farming rooibos tea, are not aware of the environmental implications of their land management practices. Farmers tend to respond to high market demands despite relatively small areas of arable land, resulting in an over extension of the production capacity. In addition, Malgas and Oettle (2007) observed that in the Suid Bokkeveld, land-clearing is regarded as an individual responsibility rather than a communal one.

During 2003 the Environmental Monitoring Group (EMG), together with other stakeholders, started offering small-scale farmers support to develop and adopt best agricultural practices. These included organic farming and various erosion control measures in order to cope with variable weather conditions. Efforts centered on the construction of neck dams in gullies and the establishment of shelterbelts, contour lines, and ground cover mulches (Oettle 2012; EMG 2012). Despite these efforts problems with production continued. For example, clearing and ploughing land in preparation for planting exposed the land to erosion by wind and water. Moreover, this land is exposed to dehydration from sun and wind causing biodiversity losses. This indicates that any study that contributes to the understanding of the area's water cycle and land use practices should enable optimization of water management and erosion control.

This is particularly important given the fact that if the projected climatic changes are realized, these farmers will be among those that are most affected in the region. In a study conducted by Archer et al. (2008), farmers were asked to document their current adaptation strategies as well as other strategies they would have liked to undertake. In response, it was found that rooibos tea farmer's adaptation strategies included earlier ground preparation and deeper ploughing so as to increase the infiltration rate and soil moisture holding capacity. To mitigate wind erosion, they adopted water conservation measures such as retaining bush strips or planting windbreaks. Stock farmers adopted adaptation strategies such as stock reduction, supplement feeding, water provision and the shifting of stock to camps with higher caring capacity (Archer et al., 2008). Examples of water provision included taking stock directly to the river/water source or extra water that was brought to camps. However, there is still a need to investigate the above strategies in order to quantify their implications for water management, as well as coping with climate change and soil degradation. This research project therefore examines soil moisture variability by studying different land uses and histories, as well as soil properties and depths.

Soil moisture variability is not a new topic in the environmental research. In fact, more than 75% of the literature consulted on soil moisture was dated before 2000 and only one publication from the remaining 25% was dated after 2010. However, the topic of soil moisture is full of contradictions and new researchers are still reporting it as a complex subject that involves difficult processes to understand or model (Koyama et al., 2014; Fu et al., 2003). Studies on soil moisture variation over space and time have remained misunderstood.

1.3. Justification for the study

There have been a number of studies that have contributed to understanding of soil moisture retention and hydrological services. Most of these studies were initiated because of the research interest in natural vegetation conservation (e.g. O'Farrell 2007; Donaldson 2003). Other studies were motivated by climate change effect. For instance, drought conditions during 2003 had a significant impact on livelihood systems in the area (Oettle 2012). These studies centered on climate change impacts and adaptation based on the social and traditional ability to cope with weather issues (Archer et al., 2008; Archer et al., 2009; Oettle 2012).

Furthermore, these studies have informed different adaptation actions through the development of soil and water conservation measures, as well as wind protection techniques. Some of the above adaptation

actions, for instance the establishment of shelterbelts, have continued to diversify land use practices in the area. However, there is still limited knowledge on how the shift in land use management contributes to the improvement of soil moisture retention and maintenance and how these land use adaptations mitigate the impact of weather and climate changes described above (see page 2, paragraph 2). Soil moisture investigations associated with these land uses practices are imperative.

Sustainable land management and utilization emphasizes the importance of monitoring soil moisture variations in different land use practices as well as their impact and contribution to environmental management and conservation in order to improve land use management techniques in the area.

Therefore, this study examines the affect of land use activities on the soil's ability to retain moisture within the soil profile. By working together with farmers, the study also investigates the types of historical land uses as well as soil and water management activities undertaken on their farms. The results will be used as recommendations for farmers and other stakeholders in the area that could improve land management practices and mitigate the impact of climate change and weather issues.

In addition, the outcome for this research was proposed as a starting point for soil moisture investigation in the area and could be used for future climate change prediction and/or adaptation studies in the Suid Bokkeveld.

1.4. Research aim and objectives

The aim of this study is to analyse the influence of land uses on soil moisture variations in the Suid Bokkeveld.

To meet this aim, the objectives of this study are to:

- To investigate land use types in the area
- To analyse differences in particle size distribution for different land uses
- To analyse the soil moisture variations in different depths
- To study the spatial variations of soil moisture in identified land uses types

1.5. The scope and nature of the study

Due to a limited timeframe, the scope of this study was limited in investigation of selected parameters that influence soil moisture variability, specifically on land use types in the Suid Bokkeveld. Other considered parameters were depth and particle size distribution since one of the challenges in the area was the modification of the land by human activities (agricultural practices) as a strategy to cope with weather issues or as a way to increase the agriculture production. This makes believe that diverse land modifications through different agriculture practices changes soil texture, which makes it difficult to identify the impact of land use parameter without considering the particle size distribution. However, some other important variables in controlling soil moisture variations such as topography were not considered. In order to minimise topography impact on results, the study sites were identified on a relatively flat gradient (page 10, paragraph 2).

Furthermore, the study did not deal with other important factors such as evaporation; with subsurface drainage influencing soil moisture; and it did not deal with rainfall or antecedent dry days between rainfall events. Also as a way to minimize the impact of the above parameters on the study results, all measurements were collected in only two consecutive days at approximately same hours.

1.6. Thesis outline

This study is made up of five chapters. The first chapter captures the overview of the soil moisture research and its benefits. The chapter also highlights the context of the study and discusses the background and problem statement. Finally, this chapter presents the justification of the study as well as its aim and objectives.

Chapter two presents the theory that the soil moisture studies are based on. It contains the body of literature previously published by other scholars while underlining its relevance to this study.

Chapter three describes the methodology used, outlines the types land uses and describes the grouping system adopted in this study. This chapter also contains a detailed overview of the study area, which includes specific study sample points, and their mapped locations as well as geographical characteristics and its significance to the study in general.

The results of this study are presented in the fourth chapter together with the results of the statistical analysis. The final chapter contains a summary of the findings, a conclusion and recommendations.

Chapter 2: Literature review

2.1. Introduction

The reviewed literature is divided in two parts. In the first part, previous research about the soil moisture variability and its most reported influencing factors are reviewed. These are, for instance, topography, soil texture, structure, vegetation cover and infiltration. Special focus was given to the work on vegetation cover and land use pattern factors on spatial soil moisture variability, as this was the main aim of the study. Research focusing on conservation agriculture in the Suid Bokkeveld and its implication for soil moisture retention was also consulted.

The second part of this review examines studies that use spatial soil moisture variability in order to understand the soil hydrological cycle and the implications associated with climate studies (e.g. Fitsjohn 1996). These studies include the role of soil moisture in climate predictions and weather forecast (e.g. Seneviratne 2010; Brocca 2007), as a useful tool to cope with weather and climate change issues. The above literature provides the context of the study and also shows the gaps in soil moisture variation research. This is particularly an important research since the soil moisture is a useful information in developing strategies to cope with climate and weather issues, which have been a negative impact on agricultural and other economic activities of smallholder farmers in southern Africa (Midgley et al., 2003).

2.2. Soil moisture and main factors that affect the variability

Soil moisture plays an important role in different earth system processes, which has motivated interest in quantifying and understanding this role over the last four past decades. Different studies show that soil moisture affects a range of earth system interactions with spatial and temporal scale. For example, Famiglietti et al. (1998) report that the spatial and temporal distribution of soil moisture plays a significant role in the evapo-transpiration process. Through this process, soil moisture provides a substantial source of atmospheric vapour for the formation of clouds and precipitation and plays an important role in partitioning precipitation into runoff and percolation. In so doing, it plays a role in regulating

the amount of water available to plant and vegetation restoration. It is also a decisive factor in partitioning solar energy into latent and sensible heat change (Koyama et al., 2014).

Soil moisture variability research conducted by Koyama et al. (2014) report that it is spatially and temporally variable at different scales and that the scaling behavior, as well as the processes that lead to the spatial patterns, are still not fully understood, especially on complex landscapes. Koyama et al. (2014) report further that this could be a result of two reasons. One is that the required high resolution ground-based monitoring, on a large scale over space and time, that requires budget intensive labor and equipment. Secondly, soil moisture variability over space and time is a result of many parameters and processes. In this chapter, some of these parameters are discussed in relation to land use activities and utilisation in the Suid Bokkeveld. This discussion includes those factors that play a role in its distribution and how information could mitigate weather and climate change issues in the area.

An analysis of the literature indicates that the main variables in which the spatial and temporal variability of soil moisture result in are classified firstly in static parameters such as topography, structure and soil texture (Reynolds 1970; Beckett and Webster 1971; Burt and Butcher 1985). The third variable is classified as a dynamic one that is associated with vegetation cover and land use that includes different agricultural practices (Reynolds, 1970; Hawley et al., 1983; Le Roux et al., 1995; Fu et al., 2000). Furthermore, the level of variability has been found to be dependent on parameters such as spatial scale (Rodriguez-Iturbe et al., 1995; Crow and Wood, 1999), different seasons and the soil depth (Famiglietti et al., 1999; Hawley et al., 1983; Hupet and Vanclooster 2002; Albertson and Montaldo 2003). In this study, both static and dynamic variables were analyzed but the main focus was on the dynamic variables, specifically on land use types in the Suid Bokkeveld. Given the limited scope of the present study and purpose, some static variables such as topography could not be considered. It is acknowledged that topography is an important variable in controlling the soil moisture variations; the identified study sites were relatively flat with a low gradient. This was confirmed by previous research in the area such as O'Farrell (2007) who showed that topography was not the main factor controlling the soil moisture because the area had a low gradient. Based on O'Farrell's (2007) research results, it was assumed that the topography would not have a significant influence on the moisture variation.

Soil moisture variation in space and time could be also explained by different methods of measurements. Koyama et al. (2014) reports that previous soil moisture studies were performed at different depths as well as at a spatial and temporal scale, and that various measurement techniques were used (e.g. gravimetric sampling, Time-domain Reflectometer (TDR) and remote sensing). These studies were also performed in various hydrological and climatic conditions, which could be the reason for contradictory results. It also shows that soil moisture studies need to be area specific.

Since the Suid Bokkeveld is an area that is predominately used for agricultural activities, the soil moisture samples were taken at different depths at the sample sites that represent these activities. For the purpose of this study, the term “land use” is adopted from the FAO/UNEP (1999b) and refers to arrangements, management actions and anthropological activities undertaken on various land cover types over a set time period to produce products or benefits. Based on the above definition, five different land uses were identified. These land uses include rooibos and vegetable cultivation as well as fallow grazed land. Each of these land uses is associated with root activity that could influence the soil moisture variations. This is particularly true for rooibos cultivation due to its long roots that reach up to 1m in length and extracts water from the soil (Matimati et al. 2014). Other land uses include grazing and natural lands that have not been cultivated. These two land types have minimal root activities that would contribute less to soil moisture variability when compared to the first two land uses, namely *rooibos* and *vegetable cultivation*.

2.2.1. Dynamic factors that influence the variability of soil moisture

a) Vegetation cover and land use patterns

Vegetation cover is one of the major factors that influence the variability of soil moisture. Famiglietti et al. (1999) suggest that this variation is influenced by the patterns of through-fall imposed by the canopy or by shading the ground surface, which affect the evapotranspiration rates. Moreover, the vegetation cover affects soil hydraulic conductivity through root activity and contributes to organic matter on the soil surface layer.

The degrees to which the above processes affect the variability of the soil moisture differ according to vegetation type, density and season. Several studies have assumed the amount

or density of vegetation cover to be the major factor influencing this variability (Lull and Reinhart 1955; Reynolds 1970). Furthermore, Hawley et al. (1983) found significant soil moisture patterns to be a result of differences in the vegetation type. They further suggest that these variations were often greater on wetter than drier days.

This last point highlights the relationship between the variability of soil moisture and seasons. Measurements provided by Famiglietti et al. (1998) indicate that soil moisture variation decreases with mean moisture content. Other researchers who have found similar results include Owe et al. (1982), Western and Grayson (1998), Albertson and Montaldo (2003) as well as Choi and Jacobs (2007). There have however, been researchers who found contradicting results that show increasing moisture variability with decreasing mean soil moisture (Hupet and Vanclooster 2002; Oldak et al., 2000). According to Koyama et al. (2014), the above contradiction indicates that in a complex landscape, the spatial variability is a result of the interaction of many different parameters and processes. In addition, Teuling and Troch (2005) show that both soil and vegetation controls can cause either the creation or destruction of spatial variance. All these parameters are influenced in some way by farming practices over short or long time periods as well as land histories resulting from social, economic, geological and cultural contexts. This shows the importance of soil moisture investigations as they further the understanding of these above processes and parameters.

There have been a number of studies about the influence of vegetation cover on soil moisture variations worldwide. Including structures and types, Fu et al. (2003) analyses different land use patterns in China, and found that, beside rainfall and topography, land use types contributed significantly to the soil moisture variations. In their results, the influence of shrub land on mean soil moisture content during their study period was significantly different in comparison to the cropland, orchard and intercropping land. Fu et al. (2003) point out that in practice, the quantification of impacts on land use patterns on soil moisture variation is complex due to the multiple factors that contribute to the variations. José et al. (1995) suggest that the above factors could be the non-uniform vegetation distribution, geology and pedological properties, together with different management histories. Fu et al. (2003) report however, that there is still minimal knowledge about the effect of land use patterns and different farming practices on soil moisture variability.

On the Suid Bokkeveld Plateau, different studies have contributed to understanding the role of vegetation and land use practices for soil and water conservation, as well as biodiversity

conservation. Donaldson (2003) identifies different land use practices that have been influenced by the conservation farming principle. This principle was commonly adopted in South Africa and adopted since the agricultural sector realized that the decline in agricultural production, advanced desertification, and the high impact of drought were linked to the loss of ecosystem services, specifically those relating to soil fertility, soil structure and the resilience of natural systems (Donaldson 2003).

Furthermore, O'Farrell (2007) investigated different land use types and the ecosystem services, including hydrological and soil retention services provided by indigenous species on the Bokkeveld Plateau, namely the *renosterveld*. He found that *renosterveld* had a significant impact on landscape conservation and also in retaining soil moisture in the area. O'Farrell (2007) observed that infiltration was primarily linked to the vegetation cover, with the highest infiltration experienced in the area that was managed and transformed by *renosterveld*. Alien grasses dominate this area and the higher infiltration rate was explained by the alien grasses having more leaves to intercept the rain, which in turn reduced the raindrop impact. This is one of the reasons why vegetation cover is considered to be the main factor that enhances the infiltration rate and reduces runoff in vegetated areas. Morgan et al. (1997) support this theory by demonstrating that soil losses exponentially decrease by increasing the vegetation cover and conclude that vegetation exerts an important hydrological control that increases the soil infiltration capacity.

The above studies conducted in the Suid Bokkeveld focus on the conservation of natural vegetation found in the region. However, as mentioned above, the area has been highly modified by human activities. More research is necessary in order to fully understand the hydrological process to successfully adapt to climate change effects, weather and land degradation issues. O'Farrell (2007) found that land use patterns had an impact on windbreak and aeolian load as well as reducing runoff, the facilitation of infiltration rates and retaining topsoil, which did not require expensive interventions. The present study supports the hypothesis that different land uses, defined by farming practices and management histories, have a significant influence on soil moisture variation in the Suid Bokkeveld. The understanding of this variation could cast attention on soil erosion control prediction since the area has been experiencing high levels of soil and wind erosion during the winter. Soil erosion destroys rooibos tea cultivations and other crops during the wetter winter months, and causes stock to suffer from water shortage during dry season.

b) Overview of land use types in the Suid Bokkeveld

The most recent information about land uses types in the Suid Bokkeveld was obtained from the Conservation Farming Project coordinated by National Botanic Institute in 2010. The project aimed to understand the conservation benefits of different farming practices. Conservation farming practices were given much attention in the area since it was found that land use changes have disturbed and influenced the functioning of the ecosystem (National Botanical Institute 2010). It was suggested that ploughing changes the natural soil structure, which in turn affects the distribution and perseverance of natural species. The project also found that sheep passing through an area affects water infiltration as well as seed dispersal. The hooves compact the soil, while the seeds are either eaten and/or transported to other areas. Even footprints of tourists affect the natural functioning of the ecosystems (National Botanical Institute 2010).

Sheep, goat farming and rooibos tea cultivation were identified as the most important land uses in the area. These are currently complemented by a small amount of potato production and ecotourism as alternative forms of land use. In recent years, land use has been influenced by the abundance of natural biodiversity remaining in the area and many of farmers have tried different approaches to preserve the natural biodiversity on their farms. These approaches include shifting from wheat farming to rooibos cultivation, grazing and the adoption of organic farming (National Botanical Institute 2010).

2.2.2. Static factors that influence the variability of soil moisture

a) Soil properties

Soil properties affect the distribution of soil moisture through variation in texture, organic matter content, structure and the existence of macro porosity (Famiglietti et al., 1998). These parameters influence the transmission and retention properties of the soil column. Weil (2008) reports that soil texture has a major influence on soil moisture retention and that a well-granulated soil has more capacity to retain water than poorly granulated soils. Similar findings have been previously reported by Reynolds (1970), who found that variations in soil moisture were mostly related to variation in soil texture.

On the Suid Bokkeveld Plateau, O'Farrell (2009) studied the influence of soil texture on infiltration and erosion rates, and found that infiltration rates were positively correlated with medium sand and negatively correlated with clay. However, consideration is made for further research to be conducted into soil profile differences between land use types, which would provide clearer indications of the magnitude of the hydrological and soil retention services provided by the natural vegetation in the area.

Similar to the effect of vegetation cover and land use patterns discussed earlier in this chapter (see page 10 paragraph 1), the level of soil moisture variation under different type of soil might have seasonal differences (Hawley et al., 1983; Famiglietti et al., 1998). Although this study agrees that seasonality is important in determining the level of soil moisture variations, it also limits the understanding of variations in a specific post winter period (September) and compares this variation in different land uses. The understanding of seasonal effects was left beyond the scope of this research and is recommended for future research.

2.2. Implications for hydrology models

Soil moisture variability is vital for improving rainfall runoff models and predicting hydrological processes in semi arid environments (Yair and Lavee 1985; Berndtsson and Larson 1987). Fitzjohn (1998) suggest that soil moisture variation in space and time could present an advantage in minimizing widespread catchment runoff and erosion. This is done by creating a spatial isolation of runoff producing areas and by promoting discontinuity in hydrological pathways. He further suggests that temporal measurement of soil moisture can be used to identify critical wetness in which extensive runoff and erosion may occur. His findings provide a possible way of manipulating soil moisture to create a self-regulating system for runoff and erosion control. The above study shows that spatial soil moisture patterns could provide the most effective management strategy in runoff and erosion control for a semi-arid environment.

Phillips (1992) supports this view and emphasizes the interdependence of runoff and soil moisture. He suggests that without information on soil moisture variability, prediction and interpretation of catchment hydrology is challenging. In addition, a study conducted by Aronica and Candela (2004) suggest that the flood information process in the Mediterranean

area is strictly due to the spatial variability of the moisture prior to the rainfall. Therefore, investigating soil moisture variability in the Suid Bokkeveld contributes to the understanding of soil hydrology in the area. This could be used for future research on developing models to predict runoff and wind erosion, which are among the main challenges in the area O'Farrell (2007).

2.3. Implication for climate change adaptation in the Suid Bokkeveld

Soil moisture is a key variable in climate systems because it impacts other variables such as water, energy and the biogeochemical cycle (Seneviratne 2010). It is seen as an important water source for the evapo-transpiration process because, as the major component of the continent water cycle, it returns as much as 60% of the land precipitation back to the atmosphere (Oki and Kanae 2006). Soil moisture is also an important energy regulator through its impact on the proportion of incoming energy in the underlying and sensible heat fluxes (Trenberth et al., 2009). Furthermore, it is a storage component of precipitation and radiation anomalies thereby inducing persistence in the climate system. Seneviratne (2010) concluded that soil moisture is involved in a number of climatic feedbacks at local, regional and global scales, and plays a major role in climate change projections.

Seneviratne's (2010) analysis on the role of soil moisture in climate systems highlights the need for an improved understanding of the relevant processes, such as the exact behavior of vegetation under enhanced CO₂, the processes affecting infiltration as well as the spatial variation in soil and vegetation properties. He claims that this would significantly help to reduce uncertainties in future climate scenarios, particularly changes in climate variability and extreme events as well as ecosystem and agricultural impacts. His work recommends that this could help the development of relevant applications for society such as improved drought monitoring, numerical weather prediction, and seasonal forecasting.

Similarly, Huszar (1999) studied the importance of soil moisture on regional climate change in a Hungarian catchment area of 24km² and found that various impacts of climate change were manifested in a cumulative way. Changes in soil moisture variability and an increase in global temperature tends to control the heat and water cycles, and both present a critical challenge for agriculture production. To give few examples, Novasky (1991) calculated that 0.5 K hemisphere warming, directed to the local estimated soil moisture content series of the

upper 1 meter layer, decreases soil moisture by 20% as observed in the Kisalfjld region in Hungary. A previous study conducted by Baint et al. (1996) in the same region found a 9% decreases of annual runoff.

Based on the above studies, it is evident that soil moisture plays a major role in climate change processes. Further research could inform climate change adaptation options in areas where farming is the main activity, which is the case for the Suid Bokkeveld area. The work of Steiner et al. (1990) also supports this by showing that the probability distribution of evapo-transpiration, runoff, and soil water depletion during the growing season were very similar for observed and predicted values by using soil moisture variability data.

Although farmers in the Suid Bokkeveld have successfully coped with climate effects in previous years, investigating soil moisture variability under different land uses could provide an opportunity to explore the benefits of the adopted strategies and practices. Since an area that has been seriously affected by climate change, and is predicted to be the most affected if anticipated future climate change scenarios occur, a better understanding of the spatial variation of soil moisture could further an understanding of climate change in the area. This is of key importance because climate continues to change under the influence of natural and anthropogenic forcing (e.g. diversification of land uses and overexploitation of the land). Thus, it is argued, that soil moisture investigations need to be inform local climate change adaptation plans.

Chapter 3: Methodology

3.1. Introduction

In situ soil moisture measurements provide information that enables the study of spatial and temporal soil moisture variability at different scales (Famiglietti et al., 1999; Entin et al., 2000; Brocca et al., 2007). However, on a global scale, the number of long-term in situ monitoring networks is small and mostly restricted to mid-latitude regions. Only a few measurements are currently being taken in Africa and South America (Dorigo et al., 2011).

On a small scale, in situ soil moisture measurements are often constrained by the high cost of fieldwork, especially indirect expenses associated with accommodation, transport and use of reliable sensors (Dorigo et al., 2011). In order to reduce the fieldwork cost, this study applied two approaches. The first was to conduct the study on a small area of approximately 577.642 km² and to only select three sample sites. Farm sites selected for this study were owned by farmers whom have been working with EMG on adoption of different agricultural practices as a strategy to cope with weather issues. Also the sites were selected according to their positions in order to cover a representative part of the area. The first site was located approximately in the north of the Suid Bokkeveld area, the second and the third in the middle and south consecutively.

Secondly, all measurements were collected in only two consecutive days at approximately same hours, in order to minimise effect of diurnal soil moisture and temperature variations as well as daily rainfall. Soil moisture was measured using a high resolution, calibrated Moisture Meter type HH2, version 4.0.1 connected to a Delta-T soil moisture sensor type ML3 (Delta-T Devices, Cambridge- England). This instrument is one of the most used capacitive techniques, which gives instantaneous volumetric moisture by measuring the dielectric properties of the soil. With the development of electronic instrument for soil moisture determination, the use of volumetric method has increased recently due to it high accuracy, short response time and easy manipulating instruments (George, 2015). The high accuracy of this method was shown by Fitzjohn (1997) who found a perfect correlation between the percentages of soil moisture measured by the Time Domain Reflectometer (TDR), which is a capacitive methods as well and the gravimetric results.

There are many soil moisture measurements methods. Just as many as instruments available. The preferred method for soil moisture measurement depends on the purpose of the data required. For instance, as was mentioned by George (2015), a plant biologist would chose to discuss moisture with respect to potential, since that is the way plants respond to moisture. The gravimetric method is more appropriate in determining soil wetness. Even though the detailed discussion about the available technique and their mode of operation are beyond the scope of this discussion, it provides a brief description of the most commonly used in the table below.

<i>Soil moisture measurement technic</i>	<i>Procedure</i>	<i>Strength</i>	<i>Weaknesses</i>	<i>Instrument example and the Unit</i>
Gravimetric	<p>This method determines the soil wetness which is the ratio of mass of water over the total mass of oven dried soil.</p> $W = \frac{(\text{soil mass wet} - \text{soil mass d})}{(\text{soil mass dry})}$	<ul style="list-style-type: none"> • Samples are easily acquired and moisture content readily determined • The most accurate 	<ul style="list-style-type: none"> • Time consuming • Painstaking procedure • Nature destructive • Not useful for plant scientist 	m (water)/m (soil)
Capacitive	This technique gives instantaneous volumetric moisture by measuring the dielectric properties of the soil.	<ul style="list-style-type: none"> • Use a small volume of soil • Measurement are rapid and straightforward • Easy manipulating instruments • High accuracy 	<ul style="list-style-type: none"> • Each measurement requires it's own calibration • Metal probes are inexpensive but electronics to control and interpret results are costly 	<ul style="list-style-type: none"> • TDR • ECHO • Tetra-Probe Devices e.g. Moisture meter type HH2 (% v/v)
Conductivity	This method measures the soil conductivity,	<ul style="list-style-type: none"> • Inexpensive 	<ul style="list-style-type: none"> • Conductivity depends on 	Resistance or

y	which decreases with soil moisture.		soil types (alkaline or acidic soils) and can change with spray of fertilisers • Not accurate	gypsum probes
Soil suction	Measure the availability or water potential of the soil. This technique gives the water availability to plants rather than actual percentage of water in soil.	<ul style="list-style-type: none"> • Inexpensive • Accurate and sensitive • Electronic can be automatically linked to an irrigation system 	<ul style="list-style-type: none"> • Dependent on soil type • Unreliable and problematic when the installation is not done properly 	Tensiometers (Units of pressure, (Cbar or KPa)

To conclude, this chapter describes the measurements and analysis that were used in the study. The chapter also describes sample sites and their management history.

3.2. Description of the study area

The study was conducted in an area of approximately 577.642 km², situated between 31° 43' to 31° 86' S and 19° 05' to 19° 13' E in the Suid Bokkeveld. The area is located to the north of the Cederberg mountain range in the Western Cape and south of Nieuwoudtville in the Northern Cape South Africa. See Figure 1.

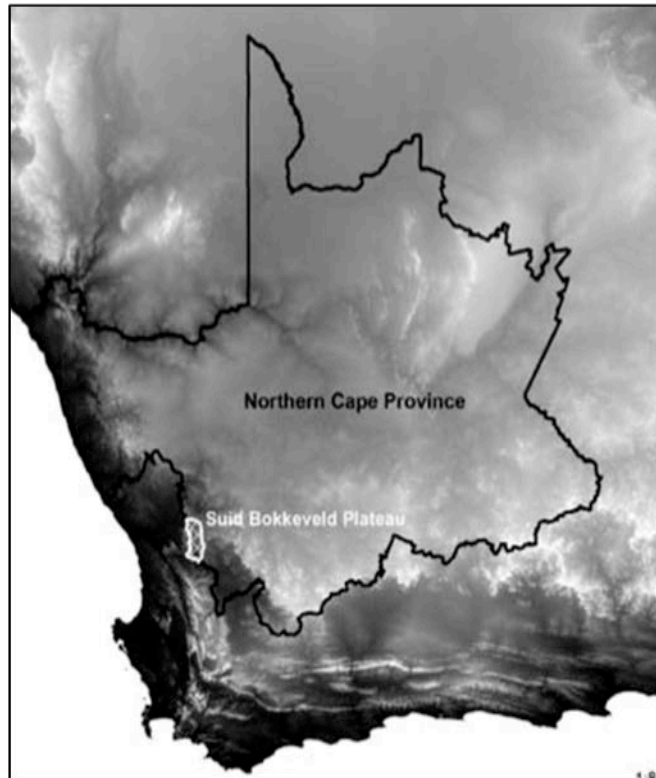


Figure 1: Map showing the location of the area known as Suid Bokkeveld situated in the south-west of Northern Cape, South Africa (Oettle 2012).

The area has a mid-Mediterranean climate with an average mean annual temperature that ranges from an average of 16.50°C on the Suid Bokkeveld to 15°C in Clanwilliam (Rebelo et al., 2006). Oettle (2012) indicates that the area receives north to south and west to east rainfall gradient of 350 to 150mm per annum. This rainfall gradient is influenced by altitude and rain shadow of the landscape on precipitation from the cold fronts arriving from the South Atlantic in the winter season. This coincides with Hayward (1996) study, who found that rainfall increases with altitude and also with the distance to the sea especially in winter months.

Winter rainfall is supplemented by only 10% of the average summer rains, which occur from tropical air masses that circulate over the subcontinent generally before reaching the arid west during late summer. A largest amount of rainfall occurs between May and August.

The Suid Bokkeveld is generally characterized by acidic and poor nutrient sandy soils, mainly derived from Oligo-Miocene sandy stone from Table Mountain (Oettle 2012; Ojeda et al., 2001). The soil varies between sandy and loamy clay (Archer et al., 2008). The sandy

soil is generally known for its poor ability to hold moisture at any given potential (Weil 2008).

Land use in the area is comprised primarily of rooibos tea cultivation (*Aspalathus linearis*). This plant originates from a local species that has been produced in the area since pre-colonial times. Other vegetation species present in the area include geophytes and shrubs derived from the loamy clay of the Bokkeveld and Karoo series of sedimentary rocks (Archer et al 2008).

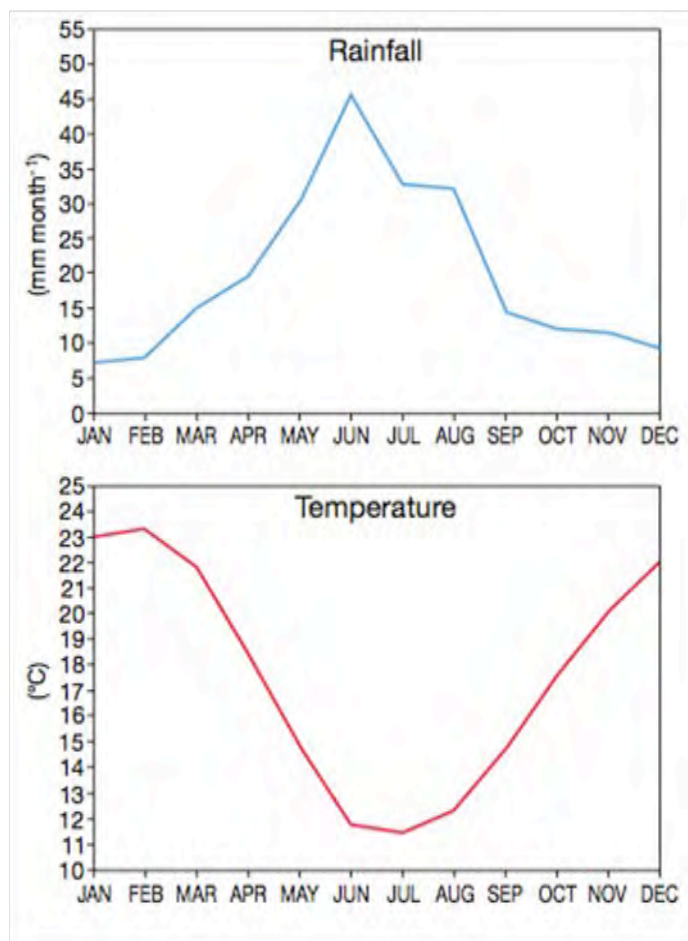


Figure 2: Average monthly rainfall and temperature for the Suid Bokkeveld Source: (Archer et al., 2008)

3.3. Data collection

Three sites were selected in the study area and are indicated in Figure 3. The selection of sites was made through physical observations, reference to previous work done in the area, and an analysis of spatial data. The sites were also selected in collaboration with the

Department of Environmental Conservation (DEC), Indigo and the Environmental Monitoring Group (EMG). Both NGOs have been supporting farmers in the area for more than 5 years and are familiar with the terrain.

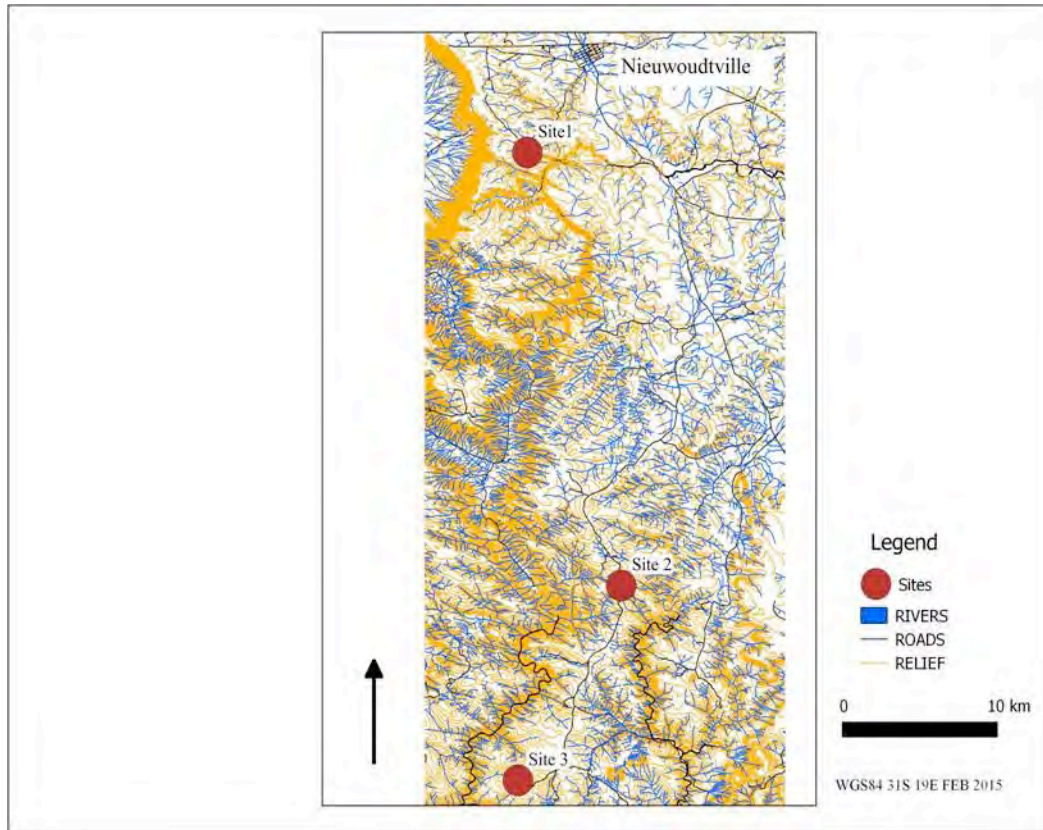


Figure 3: Map shows the position of the three sites selected for the soil moisture investigation in this study.

The first site was located approximately 9km south of the town of Nieuwoudtville at the entrance of the Oorlogskloof Natural Reserve. A transect of 1046m in length, which covered four different land uses, was chosen. This transect was bisected (i) the natural reserve, (ii) a transitional area, (iii) a rooibos tea cultivation, and (iv) grazing land that had been cultivated for two years ago but left fallow at the time of this study. This site was selected for this study because it comprises two of the main land use activities in the area (page 2) and also because one of the landuses was the natural reserve that has never disturbed by human activities and served as a control.

The second site was located further south, approximately 33.5km from the first site. The transect was 193m in length and covered two different land uses, namely grazing land that have never cultivated and a rooibos cultivation farm.

Site three comprised of two small sub-sites close to each other. It was located further south at approximately 20km from the second site. The first transect was 764 m long which covered three different land uses, namely (i) rooibos cultivation, (ii) vegetables and (iii) grazing land that have been cultivated but left fallow one year before this study. The second transect was 273 long and comprised of a rooibos cultivation farm and an uncultivated grazing area. The description of the above landuses responds to one of the main objectives of the study, since the chosen three sites covered the main land uses activities in the Suid Bokkeveld.

Soil moisture samples were systematically collected along each transect at three depths: 10cm, 30cm and 40cm. The distance between sample points along each transect was approximately 10m and at each point, soil moisture samples were taken at three depths: 10cm, 30cm and 40cm. This gave a total of 177 sample measurements. The soil moisture was measured using a moisture meter logger and probe as described earlier.

Soil samples were used to determine particle size distribution and these were also collected at different depths for each sample point. Particle sizes were measured according to their fraction using Mastersizer 2000, with wet dispersion unit Hydro 2000G. The particle size distribution was analyzed according to the Udden-Wentworth grain-size classification scheme (Wentworth, 1922). This classification scheme was used to classify the soil particle size according to three main classes. Particles smaller than $3.9\mu\text{m}$ were classified as clay. Particles between $3.9\mu\text{m}$ and $63\mu\text{m}$ were classified as silt and the particles equal or larger than $63\mu\text{m}$ were classified as sand. However, for the purpose of this study, only sand percentages were considered for the soil particle size analysis due to the collinearity between clay and silt. This relationship between particle size distribution and soil moisture will be discussed further in the result section. All measurements were taken in two days on 24 and 25 September 2014.

Statistical analysis was performed using R studio version 3.1.0 (2014-04-10). The test for overall significance of different variables was performed through ANOVA for linear mixed effects model. Depth; sand; land uses and soil moisture were considered as fixed effects with log soil moisture as a response variable. Sample sites were the random effect in the model because there was no independence between them.

3.4. Land use description and grouping

The purpose of the land use description was to understand the potential for different agricultural land use management to adapt to both weather and climate change issues, e.g. drought. Land use description also served to compare and understand different management activities effect on soil moisture variability under rooibos cultivation in comparison to other forms of land uses (e.g. other crops, livestock as well as the natural land).

The identification and grouping of these land uses is similar to previous research outcomes in the area and suggests that sheep and goat farming, rooibos cultivation and natural biodiversity conservation were the most important land uses in the area (Arendse 2014; Archer et al., 2008). However, it was noticed that wheat farming has been abandoned for rooibos cultivation in the last 2 to 5 years.

Meetings with farm owners were conducted in order to understand the farming history, different management activities and factors affecting the adoption of a specific land uses in the area. After collecting the above information, all land uses were grouped into five main land uses. These were (i) natural, (ii) rooibos cultivation, (iii) grazing and cultivated, (iv) grazing but never cultivated, and (v) vegetable land. For the purpose of this study, these five descriptions are referred to as the main land uses for this research project and are described in the following section.

3.4.1. Natural land

The land use named “ natural” comprises a part of the Oorlogskloof Natural Reserve and its transitional area. This land use was used to serve as a control to the other types, since it had been a protected natural area for over 20 years and had not been modified or disturbed by human activities.

The natural reserve covers 6097ha and is situated between approximately 538m and 915m above sea level (National Botanical Institute 2010). The need to protect this area was motivated by the increased use of wild plants for food, which had resulted in a loss of biodiversity over time. The transitional area was also created to serve as a boundary between the natural reserve, the cultivated area and other sorts of human activities. This boundary covers 30m in diameter around the reserve.

The Oorlogskloof Natural Reserve lies in a typical Mediterranean climate with an average rainfall of 414.9mm and a temperature that varies between 25 and 10 degree Celsius. Other sources of water in the area are the Oorlogskloof River, which normally flows from May to November and sporadically during December through to April. The valleys around the natural reserve are usually ploughed.

There are generally three types of soils that found in the area. The soil delivered from the top of Table Mountain is the sandstone, which is generally acidic and low in nutrients, whereas the opposite soil characteristics. These are clay and higher in nutrients soils found in George, which is derived from shale and siltstone. The sandstone is generally not good for agriculture, but is suitable for rooibos tea cultivation, which makes use of a Fynbos plant that is indigenous to the area.

The third soil type available in the area is the tillite soils locally named *vaalgrond*. These soils were formed about 300 million years ago from Dwyka sediments. They are rich in clay with a yellow grey colour, which comes from the waterlogged soils during winter. These soils are crusted as one moves to the surface. This is due to excessive cultivation and overgrazing, which result in greater erosion. Another type of soil found in the Nieudtville is *vertisols*, which is used to grow many Nieudtville endemics. These two soils, *vaalgron* and *vertisols*, are known locally as *rooigrong*, which means ‘red soils’ in English. This is due to their high iron content. Other characteristics include a high capacity for shrinking and swelling during alternative dry and wet periods which gives rise to massive cracks in soil allowing self mulching to occur and increasing its fertility level. However, cultivation can deplete the soil of nutrients (National Botanical Institute 2010).

3.4.2. Rooibos tea cultivation

Rooibos cultivation was the only land use type found at all four sites, confirming that it is the most important land use in the area. This was explained by the large part of the land in the area increasing with wild rooibos for several years. With an increase in population and the high demand for rooibos tea, farmers have shifted from wild rooibos to the cultivated species (Oettle 2012).

Rooibos grows in sandy, acidic and low nutrient soils. It is an important cash crop since because it generates income for both commercial and small-scale farmers. However,

rooibos tea production depends heavily on the season (drought or dryness), rainfall and temperatures. Generally the farms that use rooibos tea cultivation are not suitable for other crops or for grazing since there is no cultivation of other vegetation.

During farmer's meetings, one farmer responded by saying that before he bought the land, it was used for grazing but did not continue with type of farming, as the land was not suitable for grazing. He added that excessive dry summers exacerbated the situation. In fact it has been said that water is usually scarce during summer and that the lack of precipitation is one of serious issues facing rooibos tea farmers in the area (Oettle 2012). In addition, during the dry season, wind removes rooibos seedlings before they grow and that insects such as *bladluis* became more abundant (e.g. Aphids =Aphidoidea) due to high temperatures from September through to March. Furthermore, the high temperature increases the growth of harmful plants that produce toxins, which are harmful to the rooibos tea and also contribute to the increased amount of insects.

In order to cope with the above weather and climate change, as well as land degradation due to over cultivation, farmers adopted different management techniques on their farms. These include the establishment of shelterbelts to protect farms from wind erosion as well as general conservation measure. For example, farmers cultivate pioneer plants such as *Cliffortia Ododrata* after every three harvests, in order to improve the soil fertility. The four rooibos tea farms investigated were all two to three years old.



Figure 4: Picture showing the rooibos tea cultivation farm bounded by shelterbelt. The farm was located at site 3.



Figure 5: Picture showing rooibos tea cultivation farm situated at site 2

3.4.3. Grazing and cultivated land

This land use type refers to the farms that have been cultivating their land for several years but have currently left it for grazing purposes.

Most of these farms were used for wheat cultivation over the last 20 years and were cultivated with the application of phosphate fertilizers. Wheat cultivation was abandoned for sheep and goat grazing due to high climate variability with excessive drying.

Currently issues of excessive drought still persist. To cope with these dry conditions, one farmer stated in an interview, that during the dry season, only 1 out of 30 sheep can be accommodated. The rest were moved to wetter areas.



Figure 6: Picture showing a grazing cultivated farm located at site 1.

3.4.4. Grazing never cultivated land

A fourth land use type is used for grazing but had never been cultivated. This land use is similar to the natural land in terms of soil properties. The only difference is that sheep, cattle and goat have grazed the land for over 20 years. Due to high temperature and excessive droughts over the last 10 years, livestock are also moved area by area for better grazing place.



Figure 7: Picture showing a grazing never cultivated farm located at site 1

3.4.5. Vegetable and other crops

For the purpose of this study, *vegetable land* use refers an area where organic vegetable production and other crops are observed. Mainly, vegetables and other crops, such as watermelon and potatoes, were cultivated in areas with suitable soils. In addition, this land use receives much attention in terms of management practices. For instance, these farmlands are irrigated during the dry season in order to assure its productivity throughout the year.

3.5 Conclusion

This data collection was undertaken in two consecutive days in order to reduce fieldwork expenses. Despite limited time, the study covered a large area with four transect in three different sites from the north to the south of the study area. This gave a total of 177 sample measurements. Soil moisture was measured using a high resolution and reliable sensor and logger. Soil samples were also collected and particle size description were measured using a Mastersizer 2000.

Finally, the land uses were identified and described in order to compare soil moisture variability across different land uses types to address the primary aim of the study.

4. Results

4.1. Spatial variations of soil moisture and factors affecting the variation

ANOVA results for the linear mixed effects model are shown in Table 1. These findings indicate significant influence of depth, soil particle sizes and land use parameters in relation to variation of soil moisture ($P < 0.0001$). However, it was noted that the effect of different sites on this moisture variation was not significant ($P = 0.0138$).

Table 1 also shows that soil depth has the greatest significance on the variation of soil moisture when compared to other parameters measured in the study. This is followed by soil particle size distribution, which, in this case, was represented by the percentage of sand in the sample. Furthermore, the effect of different land use types is ranking third and deemed to be less significant. The order of the above parameters could be explained by sample site being used for agricultural activities. These activities involve the cultivation of different crops; a different ploughing system and management decisions that could have continuously affected the soil profile and natural vegetation cover over time. These land management decisions affect the level of infiltration, which makes soil depth the most significant factor in soil moisture variability.

Some crops require deep ploughing while others adapt well to surface ploughing. This is of importance for this study since different land uses involved different ploughing systems and frequency. For instance, rooibos cultivation has long roots in comparison to other crop types found on the land under investigation (Matimati et al. 2014). Paruelo et al. (1999) report that root distribution may contribute to this difference in soil moisture. Therefore, rooibos tea roots might contribute to modifying the soil structure and increasing water infiltration across the rooting system. However, grazing land, another land use type investigated in this study, has never been cultivated and therefore it is assumed that water infiltration has never been disturbed by anthropocentric influences including grazing. These differences in land management, which also modify soil properties, could be the reason for the highest variations in soil moisture being observed at different soil depths.

	NumDF	DenDF	F-value	p-value
(Intercept)	1	114	383.1191	< .0001
Sand	1	114	72.3062	< .0001
Land use	4	51	9.7924	< .0001
Depth	1	114	128.0220	< .0001
Site	3	51	3.9075	0.0138

Table 1: ANOVA table for linear mixed effects model with land use, sand and depth as fixed effects and site as random effect

The results in Table 1 correspond to other studies that reported an interconnection of different factors in controlling soil moisture, even in small study areas (Henninger et al.1976; Hawley et al. 1983). Some of these studies noted that it was difficult to distinguish the relative importance of each of these factors (e.g. Henninger et al.1976; Famiglietti 1998). Others fail to link the variation of soil moisture to any factor because they were studying them separately (e.g. Charpentier and Groffman1992; Whitaker 1993; Niemann and Edgell 1993; Hawley et al. 1983).

Furthermore, Fu et al. (2003) considered this interconnection as a reason for the contradictions discovered when trying to study each parameter separately. For instance, it has been said that topography has the highest significant relationship with soil moisture variability in comparison to other factors (Moore et al., 1988; Nyberg 1996; Qiu 2001). However, this factor was not considered in this study due to the area with a low gradient without much slope differential. Instead the results, which show a high variability in moisture, emphasises the role of land use types, management decisions/activities and histories, especially those on agricultural lands, in controlling soil moisture variations.

Therefore, this study suggests that factors affecting soil moisture variability depend on the context of the land - its history and respective managements are important factors in determining the level of infiltration. These management actions could also influence other parameters such as particle size distribution.

4.1.1. Soil moisture variability in five land uses

The summary of the linear effect model also shows detailed estimated significance of different land uses on soil moisture. In this case, the *natural land* is used as a reference to other types of land use. Firstly, it shows a non-significant difference when compared with *grazing never cultivated land* ($p= 0.7354$). The similarities between these two land use types could be explained by similar soil properties. Both land uses have a rock layer at the surface. Secondly, these land use types have never been cultivated or disturbed by human activities, which impedes infiltration.

A significant difference was observed when natural areas were compared with other land use types. As expected, land used for vegetable crops shows the highest significance ($p= 0.0003$) because it was regularly ploughed and irrigated. Furthermore, rooibos farms had the second highest significant difference ($p= 0.0025$), which could be explained by the plant's rooting system and its role in distributing moisture, which drives water from deep to shallow levels (Matimati et al. 2014). The third level of significance was found in grazing cultivated farms ($p= 0.0239$). The soil moisture behavior in this type of land use may be explained by a shift in management activities from the deep and regular ploughing of crops, typical of wheat farming, to that of grazing land, where the growth of vegetation cover reduces the level of evaporation and dry out.

These results correspond with previous research findings such as Hawley et al. (1983) about the influence of different vegetation covers, farming practices over short or long term periods, and land histories about the social, geological and culture context of soil moisture variability. Figure 6 shows that in the case of all five land uses under investigation, it becomes obvious that *natural land*, which has never been ploughed or transformed by human activities, presents less soil moisture variability even when the land has been used for grazing purposes. Secondly, although slightly higher than *grazing cultivated land*, *rooibos cultivation* yielded soil moisture variations that were very similar. This shows that different farming practices, for instance shifting from *wheat farming* (which is an annual crop) to *rooibos tea cultivation* and *grazing*, have contributed to a reduction in soil moisture variations. This supports the contention that management practices need to incorporate weather and climate change and reinforces the need for land conservation.

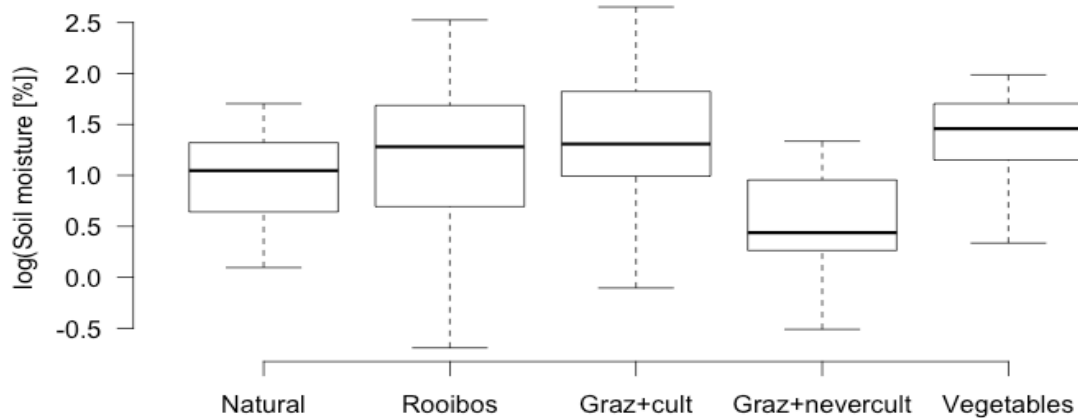


Figure 8: Boxplot summary for linear effect model indicating soil moisture variability for different land use types

Similar results were reported by Fu et al. (2003) who showed that the impact of shrubland on mean soil moisture (9.67%), being a perennial crop, were significantly different than in cropland, orchard and intercropping lands that were 13.08; 13.12; 13.71% respectively. Once again, management history and different agricultural practices should be considered when studying soil moisture variability since these factors contribute to the variations. Each site and land history needs to be understood in terms of how its hydrology and other soil properties change over time. This is supported by research conducted by José et al. (1995), who suggest that management histories should be considered together with other known key factors such as topography, geology and pedological properties.

Furthermore, O’Farrell (2007) reported that in the Suid Bokkeveld, it is the natural renosterveld vegetation that contributes to an increase in moisture when compared to the transformed and managed renosterveld. This reinforces the importance of agricultural conservation for soil and water management as well as climate change adaptations.

It is acknowledged that the results are limited to transformed and untransformed land and does not measure the level of land transformation and its implication for water and soil conservation. Considering that the study site of this research has been highly modified by agricultural activities, it is hoped that the findings will contribute to an understanding of in-field water management and land conservation associated with various land uses. It also

has useful benefits for climate change mitigations by providing a better understanding of how different land uses and management practices can adapt to climate change effects and contribute to land and biodiversity conservation in the area.

4.1.2. Effect of soil properties on soil moisture variation

A statistical analysis of the soil particle size distribution shows a positive correlation between clay and silt particles $R= 0.9959327$ (see Figure 7). Therefore, only a proportion of sand was considered for further analysis to determine the effect of soil particle size distribution on soil moisture variations.

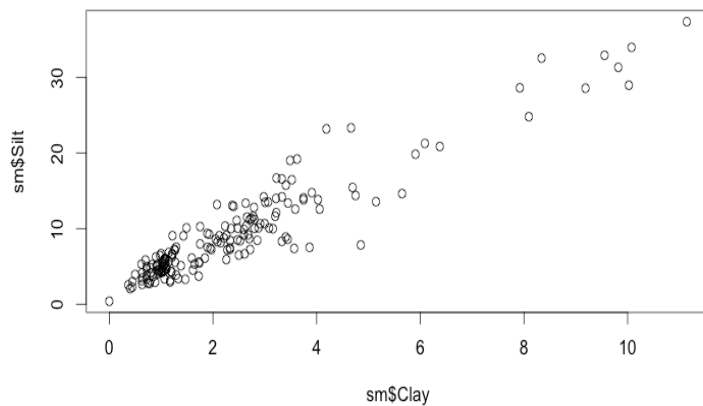


Figure 9: Statistical analysis showing a positive correlation between silt and clay particles

Furthermore, sand particles were negatively correlated with soil moisture (see Figure 8). This was explained by a higher percentage of sand at the soil surface than in soil profile. Similar results were found by O’Farrell (2007) who reported that the infiltration rate was positively correlated with sand and negatively correlated with clay in natural and non-modified renosterveld from the study site of this research. His study recommended that particle size distribution should be combined with other parameters such as vegetation cover and land management histories when conducting soil moisture variability studies.

The purpose of the soil particle size distribution analysis was to understand the impact of particle sizes and an influencing factor for soil moisture variability. It was found that, after depth, particle size distribution was a secondary factor that had significant influence on soil

moisture variations. Contrary to a number of studies reporting that variations in soil moisture were mostly related to variations in soil texture (Weil 2008; Reynolds 1970), this study shows that the variation in soil moisture could be a result of several factors. These include ploughing methods, its frequency as well as other land use management activities, namely a shift from the cultivation of annual crops (e.g. wheat) to perennial crops (e.g. rooibos) and fallow land. This study shows that these land use management activities affect soil particle size distribution as well as soil properties.

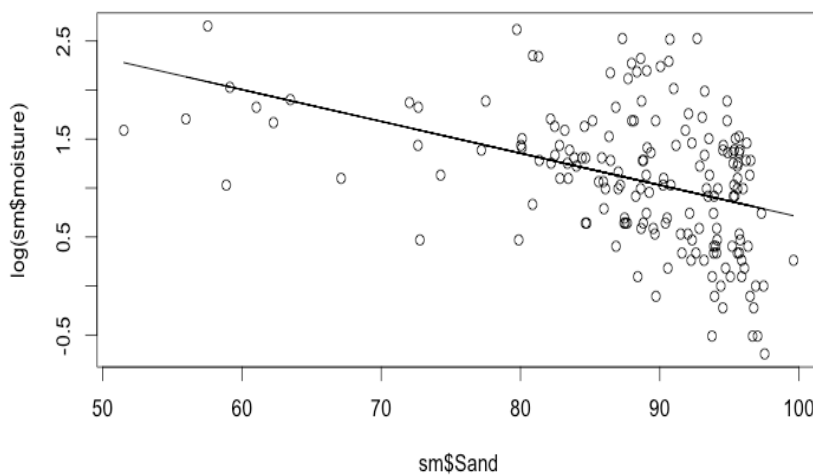


Figure 10: Negative correlation between sand percentage and soil moisture

4.1.3. Profile of soil moisture variations for different land uses

The profile variation of soil moisture is presented in Figure 9 and shows that soil moisture increases with depth. As it was mentioned above, this can be explained by the negative correlation between sand and moisture (see Figure 8).

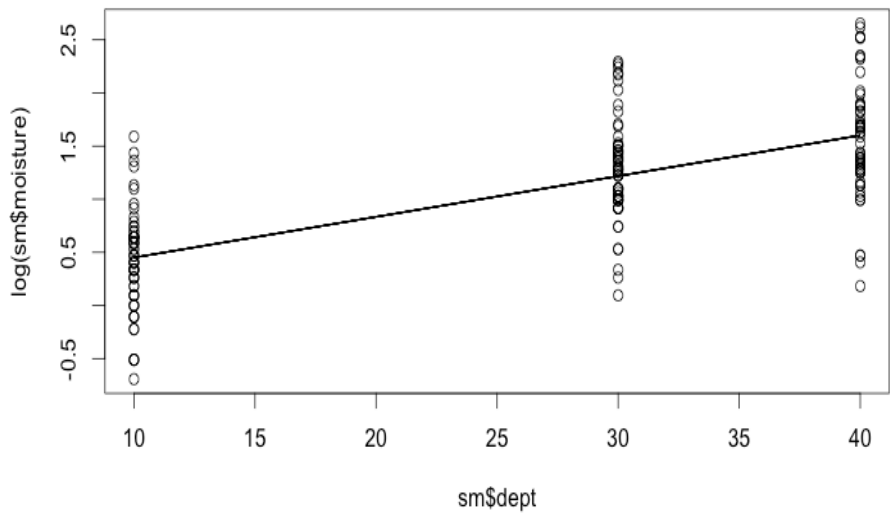


Figure 11: Boxplot showing the variation of soil moisture with depth

In addition, Figure 10 shows a partially opposite correlation between sand percentage and depth variables. This explains the high mean soil moisture levels found in the profile when compared to the surface of all the land use types investigated. This also explains the high influence that depth has on soil moisture variability in the area.

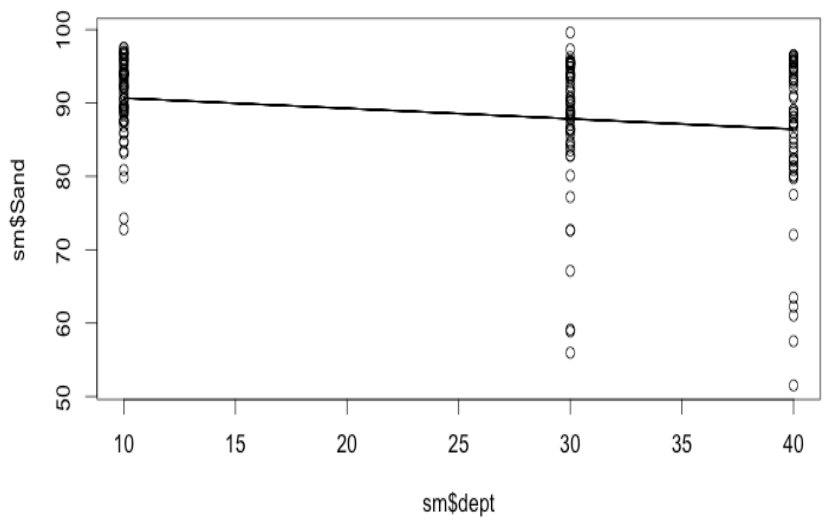


Figure 12: Boxplot showing the variation of particle size with depth

As shown in Figure 11, the mean soil moisture clearly increases with depth for all land use types. However, there was a large degree of variation for moisture within each land use type at different depths.

Figure 12 compares the level of soil moisture variability in different land use types. It was noted that the levels of mean soil moisture and soil moisture variability increase with depth in (a) *natural*, (b) *rooibos*, (c) *grazing cultivated* and (d) *grazing uncultivated* land use types. However, Figure 12 also shows that the level of variation in these land uses is different. For instance, the soil moisture variation was higher in rooibos and grazing cultivated than in other land use types.

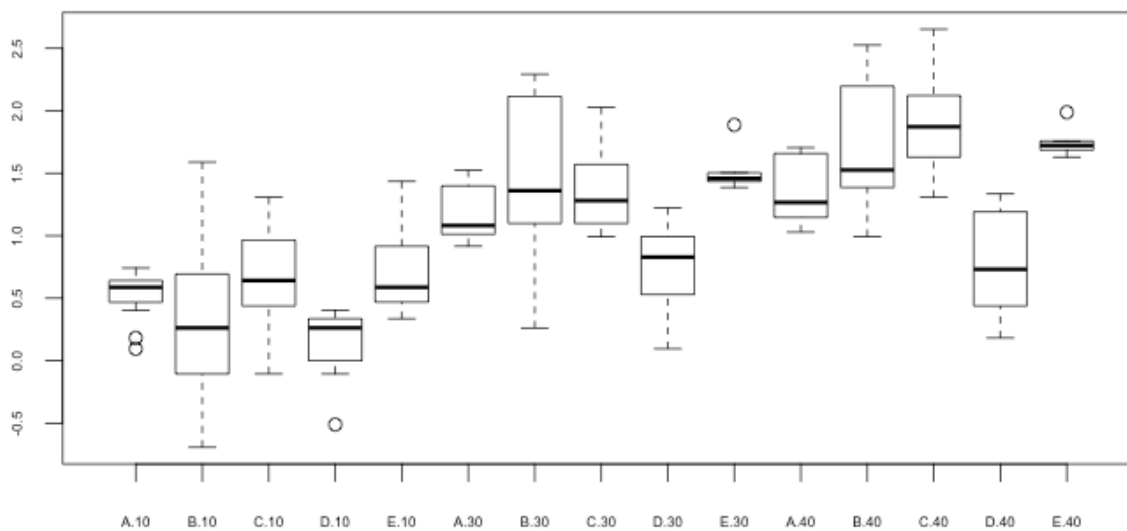


Figure 13: Soil moisture variation at different depths and for different land use types: (a) natural, (b) rooibos, (c) grazing cultivated, (d) grazing never cultivated, and (e) vegetables.

Rooibos cultivation shows the highest soil moisture variations at different depths. The standard deviation increases from (s=0.8%) at 10cm to (s=3.3%) at 40cm. This shows that the shift from wild to cultivated rooibos has impacted the soil structure and increased the soil moisture variability. Another possible explanation for the increased variation is the plant's root system, which can reach up to 1m long. Fu et al. (2003) indicated that the distribution of roots and physical soil properties could contribute to this difference. In addition, long roots could possibly transform the soil properties such as soil bulk density, physical composition and porosity, which in turn affects the infiltration and storage rate as well as the redistribution of soil water (Zhu 2008).

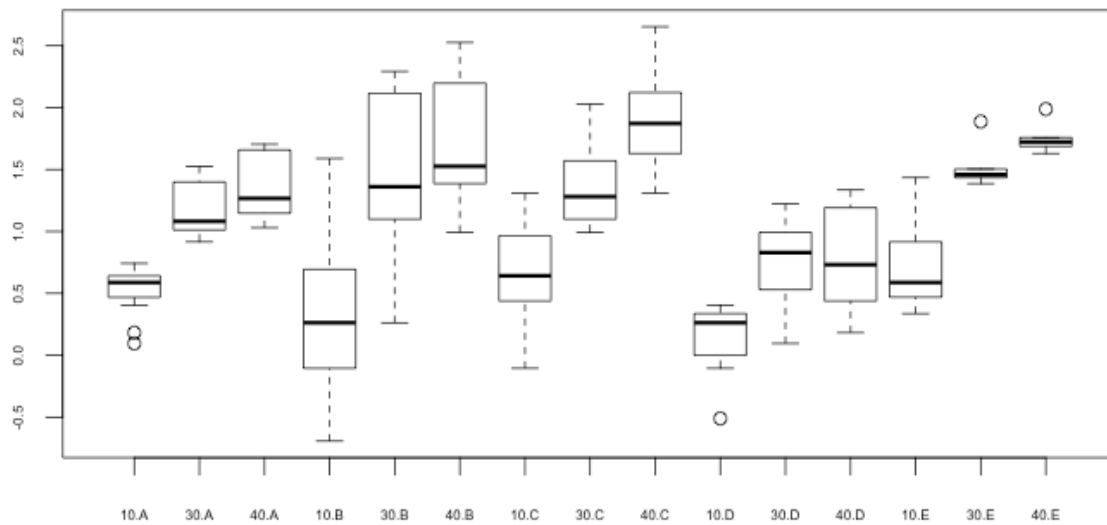


Figure 14: comparison of profile soil moisture in five land uses: (a) natural, (b) rooibos, (c) grazing cultivated, (d) grazing never cultivated, and (e) vegetables.

Similar to *rooibos cultivation*, the *grazing cultivated* land presents the second highest variations in soil moisture, which increases with depth: ($s=0.8\%$, 1.6% and 3.5%) at 10, 30 and 40cm respectively. This could be explained by the fact that this land use type has been left uncultivated allowing for the growth of natural vegetation. This reduces the evaporation rate and increases the water storage capacity of the land (Jiang, 1997; Kang et al., 1996). Therefore, this study recommends this land type as good land and water management practice in the area.

The *natural* land shows low levels of moisture variation, which increases gradually from ($s=0.3\%$) at 10cm to ($s=1.2\%$) at 40cm. This low level was expected because this land type has not been disturbed by human activities. The same process was observed for *grazing never cultivated* land, which also presented the lowest moisture variations: ($s=0.2\%$) at 10cm to ($s=0.9\%$) at 40cm. In addition, it was found that the soil moisture variation was low for the *vegetable cultivated* land, with the standard deviations of ($s=0.4\%$) at 10cm and ($s=1.8\%$) at 40cm. A possible explanation is that these farms are well maintained, that the vegetables are grown in the best soil in the area and that organic fertilizers are used. This also shows that adoption of organic fertilisers and other soil fertility measures could be a useful practice for land and soil management that mitigates the effect of climate change.

In conclusion, these findings confirm the influence of land modification (i.e. ploughing and the cultivation of different crops) on soil moisture variation: it results in high risks of climate variability effects and environmental degradation. It also shows that farming interventions, such as the adoption of grazing and fallow practices on uncultivated land, also plays an important role. However, these interventions are not the most effective since there are still high levels of soil moisture variability. This shows that more effort is needed to expand agricultural conservation in the area. Such conservation measures could even be adopted on rooibos tea cultivations, as well as vegetable and other crops farms to further mitigate the effects of climate variability and land degradation.

5. Conclusion and recommendations

The spatial variability of soil moisture as well as changes within the soil profile of different land use types in the Suid Bokkeveld were the focus of this study.

The study found that, together with depth and soil particle size, different types of land use contributes to soil moisture variations. Out of the five types of land uses that were investigated, *rooibos cultivated* farms had the highest soil moisture variability. The second highest variability was found in *grazing cultivated* farms and the lowest in *natural* and *grazing never cultivated* land, respectively. Similar moisture variations were found at the different depths (10cm, 30cm, and 40cm). These variations were greater in *rooibos tea cultivation* followed by *grazing cultivated* land. *Natural* and *grazing areas* that were never cultivated had the lowest variations. The results indicate that the shift from *rooibos tea* and *wheat cultivation* to *grazing* has contributed to a reduction in soil moisture variations. This shift has the potential to reduce land degradation as well as adapting to weather and climate change.

These findings answer the primary aim of this study: to analyse the influence of land uses on soil moisture variations in the Suid Bokkeveld. The study also met specific objectives by investigating five land use types in the area. For the purpose of this study, these five descriptions were referred to as the 'main land uses' for this area.

The second objective, which involved analysing the soil particles, was also met. It was found that comparatively larger soil particle were at the surface and that there was a negative correlation between sand particles and depth. This explains the higher soil moisture content at surface level than at greater depths in the profile indicating a negative correlation between sand and soil moisture.

Analysing the variations in depths across different land use types was the third objective. The results show that means soil moisture increases with depth in all land use types. However, there were different levels of soil moisture variability when compared to individual land use types. The higher variations were found in the *rooibos*, *grazing cultivated*, *grazing uncultivated* and *natural* land types, respectively.

5.1. Implication for land & water management and conservation in the Suid Bokkeveld

According to Blevins (1983), soil moisture has to be maintained and conserved in order to avoid continued degradation and excessive dehydration. This is even more crucial when attempting to increase crop yields. This is especially significant for areas that typically experience low rainfall and a high occurrence of droughts because it makes them more susceptible to climate change. The Suid Bokkeveld is such an area.

Soil and water conservation is also considered important since the area is generally characterized by acidic and nutrient poor sandy soils. A recent FAO article states that soil and water conservation are particularly important for farms with low rainfall and those with poorly structured soils (FAO 2015).

There have been a number of projects aimed at improving water conservation and promoting sound agricultural management in the area. Although this study was too small to evaluate all of the soil and water conservation strategies, it covers a number of them. These comprise organic farming, which was adopted in the *vegetable* land type area, and also on a *rooibos cultivation* farm. Others include erosion control measures such as establishing shelterbelts that were adopted on some of rooibos cultivation farms. This study also considered the *grazing* and *fallow* land use types adopted by farmers who were more involved in livestock. Based on the results of this study, the *grazing* and *cultivated* land was recommended as a way to improve water conservation and also reduce land degradation in the area. This was concluded because soil moisture variations were always lower in the other land use types that have been cultivated or are still under cultivation, i.e. *rooibos tea* and *vegetable* land.

The *grazing*, *cultivated*, and fallow system could therefore be an effective way to ensure water and soil conservation. This system should also be adopted on the *rooibos tea cultivation* farms. It would be a useful way to help farmers not only meet their needs, but to increase their income through rooibos tea production and simultaneously mitigate land degradation and promote biodiversity conservation.

These issues had been addressed previously by Donaldson (2003) who stated that if farmers and rural communities do not benefit from biodiversity conservation, then society needs to provide incentives to achieve conservation objectives on agricultural lands. The adoption of

grazing and *cultivated* land use means that the *rooibos* and *vegetable* cultivation is left fallow and used for grazing purposes after several years of cultivation. It would also provide water and soil conservation benefits and allow farmers to increase their profits by raising the production of different crops.

In addition, this study shows that the *natural* and *grazing land that has not been cultivated* are characterised by low water infiltration rates. It suggests that land that has not been cultivated experiences reduced infiltration. The assumption is that the cultivation of the land could provide more water management benefits, but also strengthens the need for adopting the practice of holding some land fallow for different cultivated land types after several harvests.

5.2. Implication for climate change adaptation in the Suid Bokkeveld

The Suid Bokkeveld is among several regions in Southern Africa that have been severely affected by climate change during past decades. These impacts include but are not limited to severe drought and intensive rainfall. Both result in wind and water erosion, as well as land dehydration. These conditions directly affect agricultural production and negatively impact on livelihoods in the area because most livelihoods depend on small scale and rain fed agriculture activities.

Some of the land use management activities investigated in this study were adopted as measures to cope with weather and climate change issues in the area. The land use description also seeks to understand farmers' responses to these weather conditions and the implication of these activities on soil moisture variations. Furthermore, it was observed that the adaptation measures adopted in the area were mostly rooted in the social and traditional ability to cope with weather issues.

This study found that different land use types and management activities significantly affected the soil moisture variation in the area. Therefore, the type of land use and management activity could be used to mitigate climate change and associated issues. The study also shows that the understanding of soil moisture variation across different land use types can be used in local adaptation plans or could be the starting point in developing one.

Furthermore, the regular monitoring of soil moisture variability could help in developing relevant applications for climate change adaptation in the area and has potential to reduce

uncertainties in future climate scenarios. Regular monitoring of soil moisture under different agricultural practices provides a useful tool to equip farmers to adapt to local climate change issues, namely drought events in the case of Suid Bokkeveld.

5.3 Recommendation for future research

The study provides one of the first explorations into soil moisture in this area and it cannot offer a comprehensive account at this stage. Other forcing factors will need to include building a comprehensive and integrated understanding of soil moisture variability. This will require a bigger sample size, more time, further funding and regular soil moisture monitoring.

Reference List

- Adele, A. 2014. *Rooibos tea trade and small-scale production*. Available: [http://www.emg.org.za/images/downloads/publications/rooibos tea and small-scale production.pdf](http://www.emg.org.za/images/downloads/publications/rooibos%20tea%20and%20small-scale%20production.pdf) [2014, August 20].
- Albertson, J.D. & Montaldo, N. 2003. Temporal dynamics of soil moisture variability: 1. Theoretical basis. *Water Resources Research*. 39(10).
- Andrew, W., Western, R., Rodger, B., Grayson, R. & Gunter, B. 2002. Scaling of soil moisture: A hydrologic perspective. *Annu. Rev. Earth Planet. Sci.* 30:149. DOI:10.1146/annurev.earth.30.091201.140434.
- Archer, E., Conrad, J., Münch, Z., Opperman, D., Tadross, M. & Venter, J. 2009. Climate change, groundwater and intensive commercial farming in the semi-arid northern Sandveld, South Africa. *Journal of Integrative Environmental Sciences*. 6(2): 139-155.
- Aronica, G., Candela, A. 2004. *A regional methodology for deriving flood frequency curves (FFC) in catchments with uncertain knowledge of soil moisture conditions*. University of Osnabrück, Germany: In iEMSs 2004 International Conference 14–17 June 2004.
- Baint G., Dobi, I., & Mika, J. 1996. *Runoff simulation assuming global warming scenarios*. Australia: Proc. 18th Conf. of Danube Countries, Graz.
- Beckett, P. & Webster, R. 1971. Soil variability: a review. *Soils and Fertilizers*. 34(1): 1-15.
- Berndtsson, R. & Larson, M. 1987. Spatial variability of infiltration in a semi-arid environment. *Journal of Hydrology*. 90(1): 117-133.
- Blevins, R., Smith, M., Thomas, G. & Frye, W. 1983. Influence of conservation tillage on soil properties. *Journal of Soil and Water Conservation*. 38(3): 301-305.
- Brocca, L., Morbidelli, R., Melone, F. & Moramarco, T. 2007. Soil moisture spatial variability in experimental areas of central Italy. *Journal of Hydrology*. 333(2): 356-373.
- Burt, T. & Butcher, D. 1985. Topographic controls of soil moisture distributions. *Journal of Soil Science*. 36(3): 469-486.
- Charpentier, M.A. & Groffman, P.M. 1992. Soil moisture variability within remote sensing pixels. *Journal of Geophysical Research: Atmospheres (1984–2012)*. 97(D17): 18987-18995.
- Chen, L., Wang, J., Fu, B. & Qiu, Y. 2001. Land-use change in a small catchment of northern Loess Plateau, China. *Agriculture, Ecosystems & Environment*. 86(2): 163-172.

- Choi, M., Jacobs, J.M. & Cosh, M.H. 2007. Scaled spatial variability of soil moisture fields. *Geophysical Research Letters*. 34(1).
- Christian, N. K., Wolfgang, K., Peter, F. & Karl, S. N. 2014. Variability of Surface Soil Moisture Observed from Multitemporal C-Band Synthetic Aperture Radar and Field Data. *Vadose Zone Journal*. 9(4):1014-1024.
- Cosby, B., Hornberger, G., Clapp, R. & Ginn, T. 1984. A statistical exploration of the relationships of soil moisture characteristics to the physical properties of soils. *Water Resources Research*. 20(6): 682-690.
- Cowling, R., Esler, K. & Rundel, P. 1999. Namaqualand, South Africa—an overview of a unique winter-rainfall desert ecosystem. *Plant Ecology*. 142(1-2): 3-21.
- Crow, W.T. & Wood, E.F. 1999. Multi-scale dynamics of soil moisture variability observed during SGP'97. *Geophysical Research Letters*. 26(23): 3485-3488.
- Donaldson, J., Mills, A., O'farrell, P., Todd, S., Skowno, A. & Nanni, I. 2003. Conservation farming with biodiversity in South Africa: a preliminary evaluation of ecosystem goods and services in the Bokkeveld Plateau in conserving biodiversity in arid regions. Springer : 41-54.
- Dorigo, W., Wagner, W., Hohensinn, R., Hahn, S., Paulik, C., Xaver, A., Gruber, A., Drusch, M. et al. 2011. The International Soil Moisture Network: a data hosting facility for global in situ soil moisture measurements. *Hydrology and Earth System Sciences*. 15(5): 1675-1698.
- Dunjo, G., Pardini, G. & Gispert, M. 2003. Land use change effects on abandoned terraced soils in a Mediterranean catchment, NE Spain. *Catena*. 52(1): 23-37.
- E.R.M. Archer, N.M. Oetlé, R. Louw and M.A. Tadross 2008. 'Farming on the edge' in arid western South Africa: climate change and agriculture in marginal environments. *Geography*. 93(2): 98-107.
- Environmental Monitoring Group (EMG) 2012. *Summary Annual Report, 2012*. Cape Town: Environmental Monitoring Group.
- Entin, J.K., Robock, A., Vinnikov, K.Y., Hollinger, S.E., Liu, S. & Namkhai, A. 2000. Temporal and spatial scales of observed soil moisture variations in the extratropics. *Journal of Geophysical Research: Atmospheres (1984–2012)*. 105(D9): 11865-11877.
- European Space Agency Wed, 2010-09-01 12:03. *Soil Moisture Essential Climate Variable*. Available: <http://www.esa-soilmoisture-cci.org/node/1> [2014-10-23].
- Famiglietti, J., Rudnicki, J. & Rodell, M. 1998. Variability in surface moisture content along a hillslope transect: Rattlesnake Hill, Texas. *Journal of Hydrology*. 210(1): 259-281.

- Food and Agriculture Organisation (FAO) 2015. *The Importance of cover crops in conservation agriculture*. Available: <http://www.fao.org/ag/ca/2a.html> [February 2015].
- Food and Agriculture Organisation (FAO) United Nations Environmental Programme (UNEP) 1999. *The Future of Our Land Facing the Challenges*. Rome: Land and Water Development Division.
- Fitzjohn, C., Ternan, J. & Williams, A. 1998. Soil moisture variability in a semi-arid gully catchment: implications for runoff and erosion control. *Catena*. 32(1): 55-70.
- Fu, B. & Gulinck, H. 1994. Land evaluation in an area of severe erosion: the Loess Plateau of China. *Land Degradation & Development*. 5(1): 33-40.
- Fu, B., Chen, L., Ma, K., Zhou, H. & Wang, J. 2000. The relationships between land use and soil conditions in the hilly area of the loess plateau in northern Shaanxi, China. *Catena*. 39(1): 69-78.
- Fu, B., Wang, J., Chen, L. & Qiu, Y. 2003. The effects of land use on soil moisture variation in the Danangou catchment of the Loess Plateau, China. *Catena*. 54(1): 197-213.
- Fu, B., Chen, L., Ma, K., Zhou, H. & Wang, J. 2000. The relationships between land use and soil conditions in the hilly area of the loess plateau in northern Shaanxi, China. *Catena*. 39(1): 69-78. DOI: [http://dx.doi.org/10.1016/S0341-8162\(99\)00084-3](http://dx.doi.org/10.1016/S0341-8162(99)00084-3).
- Gérard, A. 2010. Habitat conditions of wild Rooibos tea (*Aspalathus linearis*): Environmental abiotic and biotic drivers of its performance. *Universität Hamburg*.
- Gomes, L., Arrúe, J.L., López, M.V., Sterk, G., Richard, D., Gracia, R., Sabre, M., Gaudichet, A. et al. 2003. Wind erosion in a semiarid agricultural area of Spain: the WELSONS project. *Catena*. 52(3-4): 235-256. DOI: [http://dx.doi.org/10.1016/S0341-8162\(03\)00016-X](http://dx.doi.org/10.1016/S0341-8162(03)00016-X).
- Gómez-Plaza, A., Alvarez-Rogel, J., Albaladejo, J. & Castillo, V. 2000. Spatial patterns and temporal stability of soil moisture across a range of scales in a semi-arid environment. *Hydrological Processes*. 14(7): 1261-1277.
- Grayson, R.B. & Western, A.W. 1998. Towards areal estimation of soil water content from point measurements: time and space stability of mean response. *Journal of Hydrology*. 207(1): 68-82.
- Hawkins, H., Malgas, R. & Biénabe, E. 2011. Ecotypes of wild rooibos (*Aspalathus linearis* (Burm. F) Dahlg., Fabaceae) are ecologically distinct. *South African Journal of Botany*. 77(2): 360-370. DOI: <http://dx.doi.org/10.1016/j.sajb.2010.09.014>.
- Hawley, M.E., Jackson, T.J. & McCuen, R.H. 1983. Surface soil moisture variation on small agricultural watersheds. *Journal of Hydrology*. 62(1): 179-200.

- Hayward, D. & Clarke, R. 1996. Relationship between rainfall, altitude and distance from the sea in the Freetown Peninsula, Sierra Leone. *Hydrological Sciences Journal*. 41(3): 377-384.
- Hillel, D. 1998. *Environmental soil physics: Fundamentals applications and environmental considerations*. Academic press.
- Hupet, F. & Vanclooster, M. 2002. Intraseasonal dynamics of soil moisture variability within a small agricultural maize cropped field. *Journal of Hydrology*. 261(1): 86-101.
- Huszar, T., Mika, J., Loczy, D., Molnar, K. & Kertesz, A. 1999. Climate change and soil moisture: A case study. *Physics and Chemistry of the Earth, Part A: Solid Earth and Geodesy*. 24(10): 905-912.
- Islam, K.R. & Weil, R.R. 2000. Land use effects on soil quality in a tropical forest ecosystem of Bangladesh. *Agriculture, Ecosystems & Environment*. 79(1): 9-16. DOI: [http://dx.doi.org/10.1016/S0167-8809\(99\)00145-0](http://dx.doi.org/10.1016/S0167-8809(99)00145-0).
- Jamieson, T., Gordon, R., Cochrane, L., & Patterson, G. 2001. *Soil Moisture Conservation*. Nova Scotia Agricultural College.
- Jiang, D. 1997. *Soil erosion and control models in the Loess Plateau*. China Water Power Press, Beijing.
- Kathleen Jaehrmann. 2007. *Report on Climate Change Impacts*. gtz.
- Keith Bellingham. 2014. *The Role of Soil Moisture on our Climate, Weather, and Global Warming*. Available: <http://www.stevenswater.com/articles/soilandclimate.aspx> [09/09/2014].
- Kirstenbosch Research Centre, National Botanical Institute. 2010. Nieuwoudtville A Biodiversity Hotspot information maps: Landuse and soil maps. (Unpublished).
- Lauströer, B. 1988. Environmental drivers of population structure of wild Rooibos (*Asplanthus linearis*). Available: http://www.mechal.org/Bachelor_thesis_Balten_Laustroeer_2011.pdf [February 2015]
- Le Roux, X., Bariac, T. & Mariotti, A. 1995. Spatial partitioning of the soil water resource between grass and shrub components in a West African humid savanna. *Oecologia*. 104(2): 147-155.
- Lemons, J., Victor, R. & Schaffer, D. 2003. *Conserving biodiversity in arid regions: best practices in developing nations*. Springer.
- Lørup, J.K., Refsgaard, J.C. & Mazvimavi, D. 1998. Assessing the effect of land use change on catchment runoff by combined use of statistical tests and hydrological modelling: Case studies from Zimbabwe. *Journal of Hydrology*. 205(3-4): 147-163. DOI: [http://dx.doi.org/10.1016/S0168-1176\(97\)00311-9](http://dx.doi.org/10.1016/S0168-1176(97)00311-9).

- Lötter, D. & Maitre, D. 2014. Modelling the distribution of *Aspalathus linearis* (Rooibos tea): implications of climate change for livelihoods dependent on both cultivation and harvesting from the wild. *Ecology and Evolution*. 4(8): 1209-1221.
- Low, A.B. 1998. *Vegetation of South Africa, Lesotho and Swaziland: A companion to the vegetation map of South Africa, Lesotho and Swaziland*. Department of Environmental Affairs & Tourism.
- Lück-Vogel, M., O'Farrell, P.J. & Roberts, W. 2013. Remote sensing based ecosystem state assessment in the Sandveld Region, South Africa. *Ecological Indicators*. 3360-70.
- Lull, H.W. & Reinhart, K.G. 1955. *Soil-moisture measurement*. Southern Forest Experiment Station, Forest Service, US Forest Service.
- Malgas, R.R., Potts, A.J., Oetl , N.M., Koelle, B., Todd, S.W., Verboom, G.A. & Hoffman, M.T. 2010. Distribution, quantitative morphological variation and preliminary molecular analysis of different growth forms of wild rooibos (*Aspalathus linearis*) in the northern Cederberg and on the Bokkeveld Plateau. *South African Journal of Botany*. 76(1): 72-81. DOI:<http://dx.doi.org/10.1016/j.sajb.2009.07.004>.
- Martinez-Fernandez, J., Lopez-Bermudez, F., Martinez-Fernandez, J. & Romero-Diaz, A. 1995. Land use and soil-vegetation relationships in a Mediterranean ecosystem: El Ardal, Murcia, Spain. *Catena*. 25(1): 153-167.
- Matimati, I., Verboom, G.A. & Cramer, M.D. 2014. Do hydraulic redistribution and nocturnal transpiration facilitate nutrient acquisition in *Aspalathus linearis*? *Oecologia*. 175(4): 1129-1142.
- Midgley, G., Chapman, R., Hewitson, B., Johnston, P., De Wit, M., Ziervogel, G., Mukheiber, P., Van Niekerk, L., Tadross, M., Van Wilgen, B., Kgope, B., Morant, P., Theron, A., Scholes, R. and Forsyth, G 2005. *A status quo, vulnerability and adaptation assessment of the physical and socio-economic effects of climate change in the Western Cape*. Report commissioned by the Western Cape Government: Provincial Government of the Western Cape, Department of Environmental Affairs and Development Planning.
- Midgley, G., Hannah, L., Millar, D., Thuiller, W. & Booth, A. 2003. Developing regional and species-level assessments of climate change impacts on biodiversity in the Cape Floristic Region. *Biological Conservation*. 112(1): 87-97.
- Mills, A. & Fey, M. 2004. Soil carbon and nitrogen in five contrasting biomes of South Africa exposed to different land uses. *South African Journal of Plant and Soil*. 21(2): 94-103.
- Morgan, R., McIntyre, K., Vickers, A., Quinton, J.N. & Rickson, R. 1997. A rainfall simulation study of soil erosion on rangeland in Swaziland. *Soil Technology*. 11(3): 291-299.

- Mucina, L. & Rutherford, M.C. 2006. *The vegetation of South Africa, Lesotho and Swaziland*. South African National Biodiversity Institute.
- Niehoff, D., Fritsch, U. & Bronstert, A. 2002. Land-use impacts on storm-runoff generation: scenarios of land-use change and simulation of hydrological response in a meso-scale catchment in SW-Germany. *Journal of Hydrology*. 267(1–2): 80-93. DOI:[http://dx.doi.org/10.1016/S0022-1694\(02\)00142-7](http://dx.doi.org/10.1016/S0022-1694(02)00142-7).
- Niemann, K.O. & Edgell, M.C. 1993. Preliminary analysis of spatial and temporal distribution of soil moisture on a deforested slope. *Physical Geography*. 14(5): 449-464.
- Noel Oettle 2012. *Adaptation with a human face*. Cape Town: Environmental Monitoring Group.
- Nováky, B. 1991. Climatic effects on the runoff conditions in Hungary. *Earth Surface Processes and Landforms*. 16(7): 593-599.
- O'Farrell, P., Donaldson, J. & Hoffman, M. 2007. The influence of ecosystem goods and services on livestock management practices on the Bokkeveld plateau, South Africa. *Agriculture, Ecosystems & Environment*. 122(3): 312-324.
- Oettlé, N., Arendse, A., Koelle, B. & Van Der Poll, A. 2004. Community exchange and training in the Suid Bokkeveld: a UNCCD pilot project to enhance livelihoods and natural resource management. *Environmental Monitoring and Assessment*. 99(1-3): 115-125.
- Oettlé, N., Goldberg, K. & Koelle, B. *The Heiveld Co-operative: a vehicle for sustainable local development*. Available: <http://www.heiveld.co.za/resources/Heiveld-Case-Study.pdf> [2014, August, 20].
- O'Farrell, P., Donaldson, J. & Hoffman, M. 2009. Local benefits of retaining natural vegetation for soil retention and hydrological services. *South African Journal of Botany*. 75(3): 573-583.
- O'Farrell, P., Donaldson, J. & Hoffman, M. 2009. Local benefits of retaining natural vegetation for soil retention and hydrological services. *South African Journal of Botany*. 75(3): 573-583.
- Ogle, S.M., Breidt, F.J. & Paustian, K. 2005. Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. *Biogeochemistry*. 72(1): 87-121.
- Ojeda, F., Simmons, M.T., Arroyo, J., Marañón, T. & Cowling, R.M. 2001. Biodiversity in South African fynbos and Mediterranean heathland. *Journal of Vegetation Science*. 12(6): 867-874.
- Oki, T. & Kanae, S. 2006. Global hydrological cycles and world water resources. *Science New York*. 313(5790): 1068-1072. DOI: 313/5790/1068.

- Oldak, A., Jackson, T.J. & Pachepsky, Y. 2002. Using GIS in passive microwave soil moisture mapping and geostatistical analysis. *International Journal of Geographical Information Science*. 16(7): 681-698.
- Owe, M., Chang, A. & Golus, R.E. 1988. Estimating surface soil moisture from satellite microwave measurements and a satellite derived vegetation index. *Remote Sensing of Environment*. 24(2): 331-345.
- Van Oevelen, P.J and Jackson, T.J. 2006. *Development of Global In-situ Soil Moisture Network*. Copenhagen, DK: Soil Moisture and Ocean Salinity Mission (SMOS).
- Paruelo, J.M., Lauenroth, W.K., Burke, I.C. & Sala, O.E. 1999. Grassland precipitation-use efficiency varies across a resource gradient. *Ecosystems*. 2(1): 64-68.
- Phillips, J.D. 1992. Delivery of upper-basin sediment to the lower neuse river, North Carolina, USA. *Earth Surface Processes and Landforms*. 17(7): 699-709.
- Qiu, Y., Fu, B., Wang, J. & Chen, L. 2001. Soil moisture variation in relation to topography and land use in a hillslope catchment of the Loess Plateau, China. *Journal of Hydrology*. 240(3-4): 243-263. DOI: [http://dx.doi.org/10.1016/S0022-1694\(00\)00362-0](http://dx.doi.org/10.1016/S0022-1694(00)00362-0).
- Ray R. & Weil Ed. 2008. *The Nature and Properties of Soils*. 14th Edition ed. Ohio, USA: Pearson Prentice Hall.
- Rebello A. G., Boucher C., Helme N., Mucina L. & Rutherford, M. C. 1998. Fynbos Biome: The Vegetation of South Africa, Lesotho and Swaziland.
- Reynolds, S. 1970. The gravimetric method of soil moisture determination Part III : An examination of factors influencing soil moisture variability. *Journal of Hydrology*. 11(3): 288-300.
- Rhoda, Louw. 2006. Sustainable harvesting of wild roobos (*Aspalathus linearis*) in the Suid Bokkeveld, Northern Cape. Submitted in partial fulfillment for Degree (Bot.). University of Cape Town.
- Rodriguez-Iturbe, I., Vogel, G.K., Rigon, R., Entekhabi, D., Castelli, F. & Rinaldo, A. 1995. On the spatial organization of soil moisture fields. *Geophysical Research Letters*. 22(20): 2757-2760.
- Seneviratne, S.I., Corti, T., Davin, E.L., Hirschi, M., Jaeger, E.B., Lehner, I., Orlowsky, B. & Teuling, A.J. 2010. Investigating soil moisture-climate interactions in a changing climate: A review. *Earth-Science Reviews*. 99(3): 125-161.
- Steiner, J., Williams, J. & Jones, O. 1987. Evaluation of the EPIC simulation model using a dryland wheat-sorghum-fallow crop rotation. *Agronomy Journal*. 79(4): 732-738.
- Teuling, A.J. & Troch, P.A. 2005. Improved understanding of soil moisture variability dynamics. *Geophysical Research Letters*. 32(5). DOI:10.1029/2004GL021935.

- Trenberth, K.E., Fasullo, J.T. & Kiehl, J. 2009. Earth's global energy budget. *Bulletin of the American Meteorological Society*. 90(3): 311-323.
- Van Der Bank, M., Van Wyk, B. & Van Der Bank, H. 1995. Biochemical genetic variation in four wild populations of *Aspalathus linearis* (Rooibos Tea). *Biochemical Systematics and Ecology*. 23(3): 257-262.
- Visser, S., Sterk, G. & Ribolzi, O. 2004. Techniques for simultaneous quantification of wind and water erosion in semi-arid regions. *Journal of Arid Environments*. 59(4): 699-717.
- Wentworth, C.K. 1922. A scale of grade and class terms for clastic sediments. *The Journal of Geology*. 30(5): 377-392.
- Western, A.W., Blöschl, G. & Grayson, R.B. 1998. Geostatistical characterisation of soil moisture patterns in the Tarrawarra catchment. *Journal of Hydrology*. 205(1): 20-37.
- Whitaker, M.P.L. 1993. Small-scale spatial variability of soil moisture and hydraulic conductivity in a semi-arid rangeland soil in Arizona. Available: http://arizona.openrepository.com/arizona/bitstream/10150/192081/1/azu_td_hy_e9791_1993_576_sip1_w.pdf. [2015, February 16].
- Yair, A & Lavee, H. 1985. Runoff generation in semiarid and arid areas. In: *Hydrological Forecasting*, Anderson M.G. & Burt, T.P. Wiley (Eds). Chap.8: 183-220.
- Zhu, Y. & Shao, M. 2008. Variability and pattern of surface moisture on a small-scale hillslope in Liudaogou catchment on the northern Loess Plateau of China. *Geoderma*. 147(3): 185-191.

Appendix 1. Soil moisture data grouped by sites

Site	Landuses	Lat	Long	Soil moisture measurements in (% v/v)		
				10cm	30cm	40cm
Site 1	nature reserve	-31.44157	19.07093	1.5	2.7	2.9
	nature reserve	-31.44305	19.06993	1.2	2.5	2.8
	nature reserve	-31.44305	19.06994	1.7	2.8	3.2
	nature reserve	-31.43632	19.07098	1.9	2.9	3.6
	nature reserve	-31.4367	19.0711	1.8	2.7	3.5
	nature reserve	-31.43695	19.07121	1.9	3	3.8
	Transition area	-31.44278	19.07026	1.1	2.8	3.1
	Transition area	-31.44264	19.07047	1.9	4.5	5.4
	Transition area	-31.23569	19.07061	1.7	3.7	3.5
	Transition area	-31.43502	19.07078	1.8	4.1	5.4
	Transition area	-31.43594	19.07085	1.9	4	5.1
	Transition area	-31.43621	19.0709	2.1	4.6	5.5
	Grazing area	-31.44208	19.07074	0.9	2.7	3.7
	Grazing area	-31.44195	19.07096	1.9	3.6	4.1
	Grazing area	-31.44161	19.07088	1.9	3.7	6.6
	Grazing area	-31.43962	19.07038	2.3	7.6	6.7
	Grazing area	-31.43262	19.07038	3.7	6.2	14.2
	Grazing area	-31.43483	19.0707	3	4.2	6.5
	Rooibos tea	-31.43827	19.07228	4.9	8.8	10.5
	Rooibos tea	-31.43806	19.07227	2.2	8.3	9
Rooibos tea	-31.4377	19.07251	2.1	5.4	6.6	
Rooibos tea	-31.43768	19.07161	2	3.4	4.2	
Rooibos tea	-31.43775	19.07179	2.6	3.6	6.2	
Rooibos tea	-31.43812	19.07269	3.9	9.9	12.5	
Site 2	natural area	-31.72942	19.05612	0.9	2.1	3.1
	natural area	-31.72953	19.13623	1	2.7	3.8
	natural area	-31.72974	19.13637	1.3	1.7	1.6

	natural area	-31.72992	19.13645	1.4	3.4	3.5
	natural area	-31.73002	19.13657	1.5	2.5	2.7
	Rooibos tea	-31.73011	19.13662	1.3	2.7	4
	Rooibos tea	-31.73043	19.13652	1.4	4.9	7.5
	Rooibos tea	-31.73072	19.13648	1.8	9.4	12.4
	Rooibos tea	-31.73079	19.13634	1.9	8.9	10.2
	Rooibos tea	-31.73084	19.13621	2	9.7	12.5
Site 3	Rooibos tea	-31.85929	19.06677	0.5	1.3	3.1
	Rooibos tea	-31.85928	19.06275	0.8	2.1	3.6
	Rooibos tea	-31.85942	19.06286	1.2	3	5.4
	Rooibos tea	-31.85957	19.06303	0.9	3.5	3.9
	Rooibos tea	-31.85967	19.06321	1.1	3.9	4.2
	vegetables	-31.86017	19.06412	4.2	6.6	7.3
	vegetables	-31.86015	19.0644	2.5	4.5	5.6
	vegetables	-31.86008	19.06477	1.8	4.3	5.8
	vegetables	-31.86105	19.06492	1.6	4	5.4
	vegetables	-31.8613	19.06516	1.4	4.2	5.1
	Grazing area	-31.86054	19.06561	1.5	3.6	13.7
	Grazing area	-31.86093	19.06594	1.4	3	10.4
	Grazing area	-31.86119	19.06641	3.1	5.5	6.2
	Grazing area	-31.86142	19.06683	1.6	3	5.3
	Grazing area	-31.86169	19.06707	1.6	2.8	4.9
	Grazing area	-31.66423	19.05663	0.6	1.1	1.2
	Grazing area	-31.66434	19.05659	1	1.4	1.5
	Grazing area	-31.66442	19.05655	1.3	1.7	1.6
	Grazing area	-31.86465	19.05644	1.4	3.4	3.5
	Grazing area	-31.86469	19.05634	1.5	2.5	2.7
	Rooibos tea	-31.86509	19.05638	0.8	2.8	2.7
	Rooibos tea	-31.86534	19.05635	1	2.5	3.6
Rooibos tea	-31.86548	19.05632	0.6	4.3	4	
Rooibos tea	-31.86566	19.05634	1.1	3.9	4	
Rooibos tea	-31.86574	19.0563	0.6	4.5	4.6	

Appendix 2. Soil moisture data grouped by land uses

<i>Land uses</i>	<i>Smples points</i>	<i>Dept</i>	<i>Clay</i>	<i>Silt</i>	<i>Sand</i>	<i>Moisture (%v/v)</i>
Natural area	1	10	3.1574555	9.9831585	86.8593875	1.5
Natural area	2	10	1.893981	7.5256135	90.5804085	1.2
Natural area	3	10	2.087034	8.2625435	89.6504235	1.7
Natural area	4	10	2.3487525	9.989663	87.6615835	1.9
Natural area	5	10	2.258836	9.080963	88.6602045	1.8
Natural area	6	10	2.598607	9.879	87.522389	1.9
Natural area	1	30	2.640344667	10.34794667	87.01170767	2.7
Natural area	2	30	2.596243	9.12938	88.2743765	2.5
Natural area	3	30	1.9683375	7.2371335	90.7945285	2.8
Natural area	4	30	2.7791315	11.609393	85.6114795	2.9
Natural area	5	30	2.7077745	11.1942285	86.0979965	2.7
Natural area	6	30	2.9786155	14.189651	82.8317315	3
Natural area	1	40	2.7423725	11.3101305	85.947499	2.9
Natural area	2	40	2.801	10.02848767	87.170511	2.8
Natural area	3	40	2.878041333	10.09981033	87.02214833	3.2
Natural area	4	40	3.907264	14.7431535	81.3495835	3.6
Natural area	5	40	3.74574	14.057076	82.1971835	3.5
Natural area	6	40	3.330934	14.194418	82.474647	3.8
Natural area	1	10	1.489632	10.0948345	88.415538	1.1
Natural area	2	10	2.398533	12.9433645	84.658104	1.9
Natural area	3	10	1.146513	6.8359445	92.01754	1.7

area						
Natural area	4	10	1.429724	9.037125	89.533147	1.8
Natural area	5	10	2.077747	13.168653	84.753594	1.9
Natural area	6	10	1.209234	6.650368	92.140397	2.1
Natural area	1	30	2.327985	7.4427125	90.2293055	2.8
Natural area	2	30	3.3279735	16.561549	80.1104745	4.5
Natural area	3	30	3.221035	12.1018025	84.6771615	3.7
Natural area	4	30	2.523639	8.380729	89.09563	4.1
Natural area	5	30	3.622638	19.186777	77.190587	4
Natural area	6	30	2.997631	10.644059	86.358308	4.6
Natural area	1	40	2.4712205	8.5001525	89.0286295	3.1
Natural area	2	40	1.751474	10.259337	87.9891895	5.4
Natural area	3	40	4.056965	12.570965	83.3720685	3.5
Natural area	4	40	2.678898	9.170781	88.150319	5.4
Natural area	5	40	2.370705	13.038358	84.590939	5.1
Natural area	6	40	4.025274	13.815803	82.158922	5.5
Rooibos tea	1	10	3.4464	13.376371	83.177231	4.9
Rooibos tea	2	10	2.798527	11.209635	85.991843	2.2
Rooibos tea	3	10	2.212722	8.744807	89.042469	2.1
Rooibos tea	4	10	2.477044	10.052462	87.470494	2
Rooibos tea	5	10	2.330577	8.42266	89.246765	2.6
Rooibos tea	6	10	2.052453	8.587102	89.360445	3.9
Rooibos tea	1	30	2.91161	10.63635	86.45204	8.8
Rooibos tea	2	30	3.403006	8.872365	87.724631	8.3
Rooibos tea	3	30	2.149733	8.1473	89.702966	5.4
Rooibos tea	4	30	2.630425	13.355801	84.013775	3.4
Rooibos tea	5	30	2.120633	9.045945	88.833427	3.6
Rooibos tea	6	30	1.947163	7.402384	90.650454	9.9
Rooibos tea	1	40	4.750666	14.374854	80.874478	10.5
Rooibos tea	2	40	3.565946	7.370931	89.063121	9
Rooibos tea	3	40	2.855266	8.449126	88.695605	6.6

Rooibos tea	4	40	3.52098	16.449456	80.029565	4.2
Rooibos tea	5	40	3.083004	10.074536	86.842462	6.2
Rooibos tea	6	40	1.731466	5.582626	92.685908	12.5
Rooibos tea	1	10	0.403265	2.065442	97.531294	0.5
Rooibos tea	2	10	0.633252	2.622259	96.744488	0.8
Rooibos tea	3	10	0.792966	3.128889	96.078147	1.2
Rooibos tea	4	10	0.744619	2.772543	96.48284	0.9
Rooibos tea	5	10	1.173819	2.945841	95.880341	1.1
Rooibos tea	1	30	0	0.394736	99.605265	1.3
Rooibos tea	2	30	0.441947	2.255386	97.302668	2.1
Rooibos tea	3	30	1.064615	3.352087	95.5833	3
Rooibos tea	4	30	1.330385	3.394425	95.275192	3.5
Rooibos tea	5	30	1.466774	3.29329	95.239936	3.9
Rooibos tea	1	40	0.779043	2.76266	96.458294	3.1
Rooibos tea	2	40	0.884396	2.916879	96.198726	3.6
Rooibos tea	3	40	1.289503	3.870207	94.84029	5.4
Rooibos tea	4	40	1.171917	3.13337	95.694716	3.9
Rooibos tea	5	40	1.72444	3.711298	94.564267	4.2
Rooibos tea	1	10	1.018908	5.47246	94.527536	0.8
Rooibos tea	2	10	0.365382	2.544065	97.455932	1
Rooibos tea	3	10	0.444234	2.974463	97.025536	0.6
Rooibos tea	4	10	0.720169	4.933883	95.06612	1.1
Rooibos tea	5	10	0.899021	6.251503	93.748502	0.6
Rooibos tea	1	30	0.71699	4.671015	95.328984	2.8
Rooibos tea	2	30	1.100971	4.615858	95.384142	2.5
Rooibos tea	3	30	0.719915	3.749026	96.250975	4.3
Rooibos tea	4	30	1.100762	5.116129	94.883873	3.9
Rooibos tea	5	30	0.961583	4.567365	95.432639	4.5
Rooibos tea	1	40	1.047914	4.421951	95.57805	2.7
Rooibos tea	2	40	0.640579	3.474594	96.525404	3.6
Rooibos tea	3	40	1.096348	4.647466	95.352536	4
Rooibos tea	4	40	1.197074	4.259078	95.740922	4
Rooibos tea	5	40	1.198674	4.305772	95.694231	4.6
Rooibos tea	1	10	1.26985	5.551785	93.178366	1.3
Rooibos tea	2	10	1.612322	4.517128	93.870547	1.4
Rooibos tea	3	10	1.73372	5.430893	92.835388	1.8
Rooibos tea	4	10	2.329278	7.262025	90.408694	1.9
Rooibos tea	5	10	2.27532	7.195281	90.529399	2
Rooibos tea	1	30	1.090495	4.742918	94.166587	2.7
Rooibos tea	2	30	2.257883	5.904571	91.837543	4.9
Rooibos tea	3	30	2.716509	7.233306	90.050186	9.4
Rooibos tea	4	30	3.328457	8.31427	88.357271	8.9
Rooibos tea	5	30	3.442838	8.580057	87.977101	9.7
Rooibos tea	1	40	0.961165	4.504772	94.534061	4
Rooibos tea	2	40	2.499371	6.500997	90.999632	7.5

Rooibos tea	3	40	2.611447	6.661302	90.72725	12.4
Rooibos tea	4	40	3.862527	7.507604	88.629868	10.2
Rooibos tea	5	40	4.850734	7.831483	87.317786	12.5
Grazing cultivated	1	10	1.218003	9.057702	89.724293	0.9
Grazing cultivated	2	10	1.928188	9.25166	88.820153	1.9
Grazing cultivated	3	10	2.234327	10.324095	87.441581	1.9
Grazing cultivated	4	10	3.405722	15.727977	80.866304	2.3
Grazing cultivated	5	10	2.654781	11.511174	85.834043	3.7
Grazing cultivated	6	10	3.064151	13.503534	83.432317	3
Grazing cultivated	1	30	2.700108	8.676512	88.623378	2.7
Grazing cultivated	2	30	2.457499	11.074691	86.46781	3.6
Grazing cultivated	3	30	2.790483	12.788312	84.421208	3.7
Grazing cultivated	4	30	8.339108	32.533069	59.127824	7.6
Grazing cultivated	5	30	6.088263	21.250955	72.660778	6.2
Grazing cultivated	6	30	4.187222	23.177163	72.635614	4.2
Grazing cultivated	1	40	3.58708	12.56704	83.845878	3.7
Grazing cultivated	2	40	3.224354	16.675126	80.100521	4.1
Grazing cultivated	3	40	3.48844	19.006978	77.504576	6.6
Grazing cultivated	4	40	7.919355	28.60445	63.476197	6.7
Grazing cultivated	5	40	9.554309	32.903693	57.541997	14.2
Grazing cultivated	6	40	4.663337	23.309909	72.026758	6.5
Grazing cultivated	1	10	0.634823	4.170722	95.194454	1.5
Grazing cultivated	2	10	0.498066	3.924793	95.577139	1.4
Grazing cultivated	3	10	5.906221	19.828783	74.264994	3.1
Grazing	4	10	4.693298	15.433856	79.872845	1.6

cultivated						
Grazing cultivated	5	10	6.375762	20.847859	72.77638	1.6
Grazing cultivated	1	30	1.888332	9.352325	88.759342	3.6
Grazing cultivated	2	30	1.751787	7.970703	90.277511	3
Grazing cultivated	3	30	10.075118	33.954052	55.97083	5.5
Grazing cultivated	4	30	8.09339	24.788731	67.11788	3
Grazing cultivated	5	30	9.818428	31.308172	58.873402	2.8
Grazing cultivated	1	40	5.64771	14.618435	79.733855	13.7
Grazing cultivated	2	40	5.144725	13.557093	81.298182	10.4
Grazing cultivated	3	40	10.023337	28.945559	61.031102	6.2
Grazing cultivated	4	40	9.186965	28.55079	62.262247	5.3
Grazing cultivated	5	40	11.141157	37.341972	51.516871	4.9
Grazing uncultivated	1	10	0.717472	3.336985	96.663012	0.6
Grazing uncultivated	2	10	0.62749	3.111985	96.888017	1
Grazing uncultivated	3	10	0.791756	4.12034	95.879658	1.3
Grazing uncultivated	4	10	1.060917	5.921804	94.078193	1.4
Grazing uncultivated	5	10	1.081119	5.983726	94.016273	1.5
Grazing uncultivated	1	30	1.207983	6.233619	93.76638	1.1
Grazing uncultivated	2	30	1.012839	4.288699	95.711303	1.4
Grazing uncultivated	3	30	0.996451	4.287787	95.712211	1.7

d						
Grazing uncultivate d	4	30	0.935831	4.430194	95.56981	3.4
Grazing uncultivate d	5	30	1.009495	4.710888	95.289111	2.5
Grazing uncultivate d	1	40	1.065313	5.274072	94.725928	1.2
Grazing uncultivate d	2	40	0.845178	3.663087	96.336912	1.5
Grazing uncultivate d	3	40	1.022894	4.227195	95.772803	1.6
Grazing uncultivate d	4	40	1.04085	4.382633	95.61737	3.5
Grazing uncultivate d	5	40	0.935539	4.020081	95.979917	2.7
Grazing uncultivate d	1	10	0.831134	5.239196	93.929669	0.9
Grazing uncultivate d	2	10	0.789257	4.828197	94.382546	1
Grazing uncultivate d	3	10	1.216966	6.533767	92.249269	1.3
Grazing uncultivate d	4	10	1.270493	7.138731	91.590774	1.4
Grazing uncultivate d	5	10	0.920078	5.201378	93.878544	1.5
Grazing uncultivate d	1	30	1.029661	5.108178	93.862163	2.1
Grazing uncultivate d	2	30	1.049997	5.592583	93.35742	2.7
Grazing uncultivate d	3	30	1.25472	7.249003	91.496278	1.7
Grazing	4	30	1.075245	6.051521	92.873234	3.4

uncultivate d						
Grazing uncultivate d	5	30	0.92395	5.1748	93.901246	2.5
Grazing uncultivate d	1	40	1.078377	5.354327	93.5673	3.1
Grazing uncultivate d	2	40	1.148832	5.637318	93.213853	3.8
Grazing uncultivate d	5	40	0.912396	4.966843	94.120758	1.6
Vegatables	1	10	1.289632	7.543634	91.166734	4.2
Vegatables	2	10	0.69688	5.836346	93.466775	2.5
Vegatables	3	10	0.620759	5.289247	94.089993	1.8
Vegatables	4	10	0.997897	6.681997	92.320107	1.6
Vegatables	5	10	0.977898	6.428227	92.593876	1.4
Vegatables	1	30	0.959336	4.202157	94.838503	6.6
Vegatables	2	30	1.381684	5.090598	93.527717	4.5
Vegatables	3	30	1.590225	6.103926	92.305854	4.3
Vegatables	4	30	3.006516	13.471071	83.522415	4
Vegatables	5	30	3.217288	13.982845	82.799867	4.2
Vegatables	1	40	1.07311	5.70114	93.22575	7.3
Vegatables	2	40	1.643432	5.306024	93.050541	5.6
Vegatables	3	40	1.843942	6.093168	92.062891	5.8
Vegatables	4	40	3.199907	11.622161	85.177931	5.4
Vegatables	5	40	3.74576	13.801361	82.452877	5.1

Appendix 3. Maps indicating the nature of 3 sites, transects and points





