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Abstract

Soil erosion has been identified as an issue in South African farming for more than a century. Erosion of land surfaces by water or wind is a natural process which might be accelerated directly by human impact on land surface properties, e.g., vegetation and soils. An assessment of soil erosion risk indicates average soil loss rates two orders of magnitude larger than long-term soil formation rates. This challenging condition clearly underlines the need for continuous application of established policies and principles as well as emerging modes of conservation agriculture in farming activities in most parts of South Africa. In addition, conservation agriculture has been shown to have positive effects on the cost–value ratio, but diffusion and adoption of this innovative approach still meet resistance often founded in traditional faith and belief systems. However, to cope with challenges from global climate change, e.g., intensified extreme weather conditions (droughts and flooding), strengthened resilience of farming systems is required to i) meet increased domestic and global demand for food and ii) to put into practice sustainable management to diminish on-site and off-site damages from soil erosion on the way to reach sustainable development goals.

13.1 Introduction

Due to the interaction of internal (e.g., tectonic) and external (e.g., climate) processes the surface of the Earth has been constantly changing for millions of years. Plate tectonics might create mountain ranges by uplifting rocks while climate induced erosion, denudation and weathering decays rocks and minerals and lowers the mountain ranges (e.g., England and Molnar 1990). Thus, erosion and denudation are natural processes which can be accelerated by human impact resulting in what is then called soil erosion, either by water or wind or direct human action like ploughing and other means of removal of soils (Bennett 1939, Shakesby 2003, Baade 2006).

Many authors around the World (Oldeman et al. 1991, FAO 2019) and in southern Africa (Hoffman and Ashwell 2001, Boardman et al. 2012, FAO and ITPS 2015) consider soil erosion as the major land degradation process. In addition, biological (e.g., loss of soil organic matter), physical (e.g., soil compaction) and chemical degradation (e.g., nutrient loss, acidification and salinization) of soils have to be noted. In South Africa, early mentioning of soil erosion issues, initially often related to livestock farming and overgrazing date back to the eighteenth and nineteenth centuries (Hoffman and Ashwell 2001, Beinart 2003, Rowntree 2013). Widespread recognition of land degradation and soil erosion and the development of land degradation and land conservation policies started in the late nineteenth and early twentieth centuries (Cooper 1996, Beinart 2003) and provide the foundation for the status quo and future developments.

This contribution will focus on the soil erosion problem in South Africa, its extent, existing soil conservation measures and policies, socioeconomic dimensions and the challenges for future sustainable agricultural soil use preventing land degradation as much as possible. To set the scene, we first look at rates of late Quaternary and current geological erosion and soil formation. We will then briefly review the general effects of human induced soil erosion on the soils and the environment, such as the on- and off-site damages from soil erosion. Acknowledging, that the problem of soil erosion has already been noticed in the eighteenth century and soil conservation policies developed in the early twentieth century, we then review the policy development. The next two sections provide an overview of the current extent of soil erosion by both water and wind in South Africa. We subsequently examine the socioeconomic dimension of soil erosion and land degradation, focusing on stakeholder's and farmer's perspective. In conclusion, we identify some major challenges for soil conservation and soil conservation policies in South Africa. In general, the scope of this contribution is to provide a nation-wide overview and to bridge natural science-based findings and socioeconomic aspects of human induced soil erosion. Due to the rather complex physical, historical and socioeconomic causes of land degradation and soil erosion (e.g., Meadows and Hoffman 2002), it will not be possible to consider all aspects. Despite focusing on South Africa, we are convinced that many aspects discussed may be applicable to many parts of southern Africa.

13.2 Erosion and Denudation

The evaluation of the impact of human induced soil erosion on soil degradation requires us to determine the long-term geological background (kyr-scale) erosion and denudation rates which are mainly controlled by tectonic uplift modulated by climate variability (e.g., Molnar and England 1990, Raymo and Ruddiman 1992, Binnie and Summerfield 2013). Tectonic uplift results in physical erosion which produces fresh mineral surfaces, available for chemical weathering. Increased tectonic uplift and physical erosion takes place in active mountain ranges (e.g., Himalaya, Andes), but the majority of the Earth's surface, is characterized by low tectonic activity and less pronounced topography, including large parts of South Africa.

Cosmogenic nuclide methods are well suited to determine long-term denudation rates and relate them to observed current soil erosion rates (von Blanckenburg 2006). Production of cosmogenic nuclides is highest at the Earth surface and decreases exponentially, so that most nuclides are produced in the upper few meters of Earth's surface (Bierman 1994). The concentration of cosmogenic nuclides in a surface sample is inversely related to the long-term denudation rate (Lal 1991). Thus, cosmogenic nuclide-derived denudation rates average timescales of 10^2 years in active tectonic areas with several m kyr^{-1} erosion to 10^5 years in inactive areas with several mm kyr^{-1} erosion (von Blanckenburg 2006). Often the nuclide concentration is well mixed in the soil by physical and biological processes (Schaller

et al. 2018, Glotzbach et al. 2016), and therefore, recent human-induced increase in current soil erosion usually does not impact the cosmogenic nuclide concentration measured at the surface.

South Africa is characterized by a wide variety of landforms, such as flat high plateaus, steep mountains and hilly to flat coastlines (Partridge et al. 2010). Despite these great landscape variability, long-term erosion rates derived from cosmogenic nuclides do not vary much and most rates are in the order of 1 to 10 mm kyr⁻¹ with an average of 3.6 ± 3.1 mm kyr⁻¹ (see Glotzbach et al. 2016 for a review and additional references). It is noteworthy that erosion rates show no simple dependency on either topography, climate or rock type. For example, the steep mountains of the Cape (slope of up to >30°) do erode as slowly as the lowlands in the Kruger National Park with a rate of only ~5 mm kyr⁻¹ (cf. Scharf et al. 2013, Glotzbach et al. 2016). A feasible explanation is that differences in rock type and associated erodibility are offset by other parameters, such that steep regions with weathering resistant rocks (e.g., quartzite) do erode at similar rates like less resistant rocks (e.g., basalts) in flat terrain. Chemical weathering and soil production rates are in the same range as observed long-term denudation rates and suggest that the transformation from rock into soil is very likely in steady state over long timescales (e.g., Chadwick et al. 2013, Decker et al. 2011).

Short-term (decades) sediment yield rates have been determined throughout Africa using gauging stations and reservoirs establishing yields from 0.2 to 15,700 t km² yr⁻¹ with a median at 160 t km² yr⁻¹ (Vanmaercke et al. 2014). In the Kruger National Park (KNP), short-term (decades) and long-term (hundred thousand of years) sediment yields have been determined by sediment trapping in dams and cosmogenic nuclides (Reinwarth et al. 2019, Glotzbach et al. 2016). Long-term erosion rates are tightly clustered around a value of ~5 mm kyr⁻¹, whereas short-term rates range between 5 and 75 mm kyr⁻¹ and are on average ~6-times higher than the long-term rates (Fig. 13.1). The same trend with even higher short-term rates was reported by Decker et al. (2011) in south-central parts of South Africa. The rather low long-term, geologic erosion rates in the KNP can be accounted for by very low tectonic activity, low relief and rather low precipitation and weathering rates in the Lowveld. Based on the fact that the study area located in the KNP was newer exposed to European style agriculture and ploughing of soils, the current sediment yield rates were expected to be low as well. As is evident from Fig. 13.1, some catchments yield current values as low as the long-term rates, but others yielded much higher values. A similar trend can be seen elsewhere in South Africa. Only a small fraction of the catchment sediment yield rates (Vanmaercke et al. 2014) are in the range of long-term denudation rates (~3.6 mm kyr⁻¹ or ~10 t km² yr⁻¹) (Glotzbach et al. 2016).

Are these differences caused by human impact or can they be explained by climate change or methodological differences? A number of studies have shown, that erosion rates determined by sediment trapping can yield either higher or lower rates compared to long-term rates. In some cases, this was clearly attributable to the climate-induced variability in sediment transport and the magnitude of events occurring during the sediment trapping period. It is believed that inclusion or

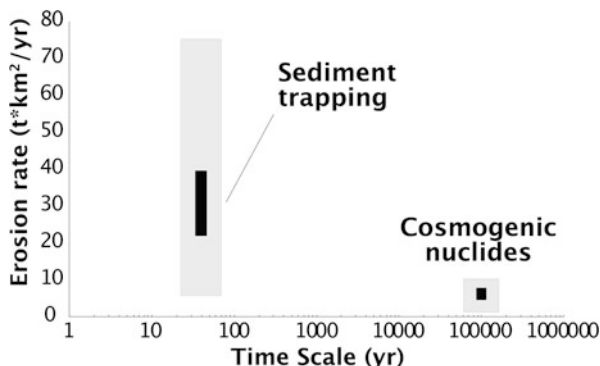


Fig. 13.1 Erosion rates [$\text{t km}^{-2} \text{yr}^{-1}$] of dam-locked river catchments in the Kruger National Park derived from sediment trapping averaged over a few decades and cosmogenic nuclides averaging of hundred thousand years. For conversion of erosion rates between volume and mass, we use the continental crust density of about 2.7 t m^{-3} (Compilation: C. Glotzbach)

exclusion of large infrequent flood events during the monitoring period is an explanation for the different results. Some studies observed an order of magnitude increase in denudation rates over the past decades and attributed them to human impact (Hewawasam (2003) in Sri Lanka and Raab et al. (2018) in Italy).

While the observed difference between long-term and short-term sediment yield and erosion rates in the pristine Kruger National Park environment is not easy to explain cosmogenic-nuclide derived denudation rates provide a proxy for long-term soil formation rates—assuming a steady state—of about 5 mm kyr^{-1} equivalent to $13.5 \text{ t km}^{-2} \text{yr}^{-1}$. Current pristine erosion rates in the Lowveld are in the order of about 30 mm kyr^{-1} equivalent to $81 \text{ t km}^{-2} \text{yr}^{-1}$. Given the existing studies, it is suggested that sustainable agriculture should aim at limiting current soil loss in and sediment yield from catchments to the range of values presented here, i.e., to 10 to $100 \text{ t km}^{-2} \text{yr}^{-1}$.

13.3 Soil Erosion Due to Human Impact

Under steady-state conditions, natural, geologic erosion is governed by internal and external forces and is believed to be close to an equilibrium state between these two major forces. We can assume that, humans interfere with this balance by removing directly or indirectly (by livestock farming) the natural vegetation cover protecting the soil against the kinetic energy of rainfall or wind as well as disturbing the moisture conditions at the surface. Ploughing or other mechanical disturbance from working the soils or by livestock farming further alters the structure and stability of the soil facilitating its removal, i.e., soil erosion by wind or water (Bennett 1939, Shakesby 2003, Baade 2006). Considering the processes involved, soil erosion

comprises the entrainment, the transport and the sedimentation of soil and related material like nutrients, organic matter and fertilizers (Morgan 1995).

Due to generally rather low soil formation rates (Sect. 13.2), human induced soil erosion causes a degradation of the nonrenewable resource soil (FAO 2019). Damages, which affect the area under use, are considered on-site damages and usually borne by the land owner. Impacts which affect the closer and wider surroundings are called off-site damages and are usually carried by the community. Estimates indicate that the costs of off-site damages are far greater than on-site ones (Clark 1985, Pimentel et al. 1995, Hoffman and Ashwell 2001, Boardman 2021).

13.3.1 On-Site Damages from Soil Erosion

The most important on-site damage from soil erosion is the removal of the soil and related material like seeds or plants, soil organic matter, fertilizer, and other nutrients from the fields eventually depleting the thickness and the fertility of the soil (Lal 2015). This removal might occur in the form of deflation by wind or sheet (or interrill) and rill erosion caused by rainfall impact (i.e., splash erosion) and overland flow. Where overland flow concentrates, (ephemeral) gully erosion can remove considerable amounts of soil in addition. These removal processes are selective leaving coarser lag deposits behind. The effect is an extensive gradual depletion and degradation of the fine soil material at the surface thinning the ecologically important upper soil horizon which provides the base for crop production and livestock farming, among other functions (du Preez et al. 2020). When it comes to erosion by water, occurring generally in hilly terrain, redeposition within a site is another aspect of concern, e.g., due to the accumulation of sediments, crusting, burial of plants and harvest losses. The same is true for wind erosion, which additionally might affect crops by abrasion (Funk and Reuter 2006).

Usually this type of extensive, subtle soil erosion progresses slowly and often unnoticed. Visible effects include a mottled development of vegetation cover, eventually spotty exposures of parent material, and variation in forage or crop yields lowering the farmers return and eventually the Gross Domestic Product of a country. Nonetheless, estimates for the costs of on-site damages by soil erosion have not yet been established for South Africa (Turpie et al. 2017), despite early requests to do so (Braune and Looser 1989).

Compared to this, the specific type of erosion caused by the concentration of overland flow in hilly terrain, i.e., gully erosion, results in often spectacular, well visible linear erosion features dissecting the land in a way that arable farming is precluded and livestock farming constricted. Often these areas are then called badlands (Fig. 13.2, Boardman and Foster 2008; Foster and Boardman 2020). A specific issue of gully erosion is the fact that this process is governed by the overland flow originating in the uphill catchment area of the gully. Given the generally steep slopes at the gully head, gully erosion and gully head retreat are often characterized by reinforcing feedback loops and very difficult to control or stabilize. Eventually,



Fig. 13.2 Example of a strongly dissected former cultivated field, north of Ladybrand, Eastern Free State Province. In the foreground a gully head is clearly visible and brush to keep off livestock (Photo: J. Baade 2018)

gully erosion might even impede or inhibit forestry activities or result in completely dissected and barren land (Bennett 1939, Boardman et al. 2012).

13.3.2 Off-Site Damage from Soil Erosion

The material removed by soil erosion from a site will be transported and eventually deposited in the closer or wider surroundings. Details of the processes and the effects are specific to the eroding and transporting agent: water or wind, and need to be examined separately.

The extent of off-site damage from soil erosion by water is controlled by the magnitude of the rainfall and runoff event causing erosion and surface runoff as well as the configuration, density and connectivity of the drainage system downstream of the eroding sites (Rowntree 2012, Msadala and Basson 2017). Often these events cause sediment rich waters to end up downstream. Higher magnitude events might further flood roads, houses and other properties causing impacts from little discomforts to considerable damage. Some of the eroded material will be deposited along the way when flooding of river banks occurs. But, in South Africa, a considerable amount of the material is deposited in the dams and reservoirs (Braune and Looser 1989, Rooseboom et al. 1992, Msadala and Basson 2017) which serve as important sources of water to humans and semiarid agriculture. The remaining

sediments will be carried on by the main rivers to the oceans where they get deposited in estuaries, coastal lakes, harbors or on the shelf, e.g., the mudbelt off the Orange River mouth (Compton et al. 2010) (see Chaps. 27 and 28).

Using DWS (2017) data on reservoir siltation and the approach by Turpie et al. (2017) the monetary damage caused by the siltation of dams and reservoirs in South Africa sums up to about 2 billion ZAR for the period 1980 to 2000. This estimate is based on the costs to reestablish the lost water storage volume, only. It does not consider the costs for water treatment plants and other efforts to produce drinking water from heavily silted water (e.g., along the Caledon River). In addition, not included is the ecological damage caused by water enriched in silt, nutrient and possibly pesticides to the aquatic food resources in the receiving water courses including the oceans (Turpie et al. 2017) (cf. Chap. 31).

Off-site damage from wind erosion can be divided into those that occur immediately and those that show more long-term effects (Funk and Reuter 2006). Sand deposits are often found directly at the field boundaries after an event, filling ditches, developing fence-line dunes or covering traffic routes (Holmes et al. 2012). The immediate effects are further related to the dust emissions (Fig. 13.3). They cause reduction in visibility affecting traffic safety, and air pollution with particles of the fractions PM_{10} and $PM_{2.5}$, which are harmful to human health (Vos et al.



Fig. 13.3 Dust event near Bultfontein, Free State Province. Dust traps are collecting saltating and suspended sediments originating from a bare peanut field in August 2018. PM_{10} concentrations peaked at 2500 ppm during this two-hour event and resulted in the collection of 26 grams of sediment from the 4 traps (Photo: F. Eckardt 2018)

2021). Contamination of crops and fruits by dust deposits can also be considered as immediate off-site damage in the agricultural sector. Long-term damages are caused by repeated sand and dust input into adjacent sensitive areas, such as settlements or natural aquatic or terrestrial biotopes.

13.4 Soil Erosion and Conservation Policy in South Africa

13.4.1 Development of Soil Conservation Policy

According to Kanthack (1930, p. 516), the “devastation of large areas due to soil erosion” has been an issue for the general public and the farmers at least since the beginning of the twentieth century. Rowntree (2013) provides a recent review of early discussions of land degradation in the *Agricultural Journal of the Cape of Good Hope* published between the 1890s and 1910s. This concern stimulated the development and further refinement of soil conservation policies. A detail account of these developments in the twentieth century up to 1994 is provided by Cooper (1996) who presents a unique and in-depth perspective of soil conservation policies in South Africa focusing on the human dimension thereof. According to her, the first documented policies on soil conservation go back to the early Cape settlers who provided directives to land users in the form of “Placaaten” starting already in the seventeenth century (Cooper 1996, 83 f.). Most of these included indirect reference to soil conservation.

The first attempt by the Union of South Africa to formally investigate the effect of land degradation, especially soil erosion, was through the Drought Investigation Commission in 1923, followed by a Soil Erosion Conference in 1929 (Adler 1985). Initial governmental funding of erosion-control schemes to rehabilitate and prevent further erosion took place in the 1930s (Bennett 1939, Beinart 2003). The first formal legislation to address soil degradation was through the Soil Conservation Act, Act 45 of 1946 (SCA_1946, Table 13.1, Hoffman and Ashwell 2001).

The Union Government soon realized that without support, farmers will be unable to successfully rehabilitate eroded and degraded land and a number of schemes were developed, namely the Grass Ley Crop Scheme (1958–1972), Veld Reclamation Scheme (1966–1971) and the Stock Reduction Scheme (1969–1979).

Table 13.1 Overview of important acts related to soil degradation and soil conservation

Year	Act No	Name	Abbrev.
1946	45	Soil Conservation Act	SCA_1946
1949	6	Soil Conservation Amendment Act	SCAA_1949
1960	37	Soil Conservation Amendment Act	SCAA_1960
1967	15	Soil Conservation Amendment Act	SCAA_1967
1983	43	Conservation of Agricultural Resources Act	CARA
1998	107	National Environmental Management Act	NEMA
2004	10	National Environmental Management Biodiversity Act	NEM:BA

Based on these interventions, considerable subsidies and other investments to combat and rehabilitate land degradation were provided to, e.g., lower stock numbers per unit area to combat erosion due to overgrazing, terracing of arable land and the development of contour banks or runoff bunds (Cooper 1996, von Maltitz et al. 2019).

The amended Soil Conservation Act of 1967, repealed the SCA_1946 (Theron 1985) and in 1983 was replaced by the Conservation of Agricultural Resources Act (CARA) (South Africa 1983). It is important to note that CARA build on the previous act's success and shortcomings. Many of the current concepts were born from the preceding Soil Conservation Acts (Departement van Landbou-Tegniese Dienste 1966). CARA was at its inception applicable to white owned agricultural land, only, and excluded the African self-governing homeland areas. This exclusion of former homeland areas was repealed through the Abolition of Racially Based Land Measures Act, Act 108 of 1991. Within homeland areas the "Betterment" scheme was used to improve land use planning and land degradation. But these efforts were met with considerable resistance and also had unintended environmental consequences like the degradation of resources around the newly build villages (Hoffman and Ashwell 2001).

The scope of CARA includes control measures on soil cultivation, alien invasive plants, veld management, veld fires, management of wetland and soil conservation works. The act made provision for the establishment of a number of incentive schemes and subsidies for soil conservation, agricultural land rehabilitation, the reduction of stock numbers, the establishment of specific crops to enhance soil fertility and combating of alien plants. The schemes were governed by regulations (South Africa 1984) under CARA and a variety of manuals and guidelines were made available (e.g., Department of Agriculture 1984, 1997, Russell 1998).

Any soil conservation activities were based on farm plans drafted by soil conservation technicians and were kept on file at the local extension office. CARA further made provision for the expropriation of land for the restoration or reclamation of the farm. Based on this, a number of farms were expropriated due to the extent and severity of erosion on these farms. Examples from the Eastern Cape include a number of farms in the Molteno area as well as the Weenen Nature Reserve that was converted in 1975. Further examples exist where townlands (commonage) were so overgrazed that they were handed over (in 1973) to Agriculture Technical Services and converted to a research station, e.g., Adelaide Research Station, Eastern Cape (pers. Comm. Craig Trethewe 2021).

Although numerous attempts have been made within the National Ministerial Department responsible for Agriculture after 1994 to put in place a more inclusive act that conforms to the constitution, CARA remains the only agricultural legislation governing natural resource use and protection of agricultural land. Its role to oversee agricultural land management has in part been replaced by the National Environmental Management Act (NEMA) in 1998 and the National Environmental Management Biodiversity Act (NEM:BA) in 2004 (Table 13.1, De Villiers and Hill 2008). After 1994 large sections of the act became redundant and inactive. Funding for soil conservation committees ceased, although a few committees are

still semiactive through the initiative of farmers. Financial provision for schemes stopped because the schemes before 1994 exclusively assisted white commercial farmers.

Post 1994 the role of funding rehabilitation degraded land is shared between the Department of Environment, Forestry and Fisheries (DAFF) Working for Water (WfW) and the Department of Agriculture Land Reform and Rural Development (DALRRD) LandCare Program. The LandCare program was established in 1997 in South Africa (Mulder and Brent 2006). Here, LandCare is a labor-intensive public works social program aimed at poverty alleviation and job creation while assisting rural communities to improve their livelihoods through soft interventions (e.g., clearing of alien invasive plants, fencing to rehabilitate cultivated fields, promoting better livestock production and conservation agriculture) (Kepe et al. 2004). According to Nabben and Nduli (2001), the new postapartheid policy direction was toward commitment to address the needs of people living in the former impoverished homelands, community empowerment and partnership with government. Kepe et al. (2004) stated that natural resources can ultimately contribute to poverty alleviation if key principles of LandCare are considered, i.e., that land degradation is addressed and sustainable natural resource utilization is achieved. A similar program, the Working for Wetlands, was initiated by the Department of Water Affairs in 1996 and later transferred to the Department of Environmental Affairs. Similar to LandCare, the program focuses on poverty alleviation by providing work to marginalized groups. Working for Wetland concentrates on the rehabilitation of wetland systems through, e.g., building erosion structures and sediment traps, plugging artificial drainage systems, revegetation and bioengineering. Part of the program is also to conclude contractual agreements with landowners where rehabilitation took place to secure the sustainability of the interventions and also to develop ecotourism opportunities through the establishment of bird hides and boardwalks (Dini and Bahadur 2016).

Recently, the DALRRD has developed a Conservation Agriculture (CA) Policy for South Africa (DAFF 2017). The policy aims at promoting sustainable management practices to increase soil cover, biological diversity and minimum soil disturbance. It is grounded on the principles of farmer empowerment, addressing social inequality, implementing sustainable agricultural practices and knowledge development and sharing. The CA principle of minimum or no tillage is increasingly adopted by (commercial) farmers as it reduces mechanization and input costs (see Box 13.1 for a personal view). Rotation of monocrops is preferred above intercropping in annual dryland cropping, although none is widely practiced (Van Antwerpen et al. 2021). Although CA promotes the increase of soil cover either through crop residues or cover crops, the preservation of crop residues is a challenge in mixed cropping/livestock systems, since many farmers rely on crop residues for overwintering of livestock (Thierfelder et al. 2015). As part of South Africa's UNCCD Land Degradation Neutrality (LDN) Targets (von Maltitz et al. 2019), 60,000 km² cultivated land needs to be converted to CA systems by 2030. There is considerable literature pointing to CA as a farming system of importance within a South African context (De Wit et al. 2015, Van Antwerpen et al. 2021). A recent

study by Smith (2021) estimated that the total area of crop-livestock systems under CA in South Africa is 16,300 km² with the highest adoption in the Western Cape (51%). However, CA adoption under semicommercial and small holder systems is only 0.8%.

Box 13.1 On the Implementation of Conservation Agriculture (CA) in the Free State Province: A Farmer's and CA Consultant's Personal View by J. Knot

It is fulfilling to be a steward of the soil. Working with small and commercial farmers is exciting especially when they are zealous in applying all sorts of soil conservation and regenerative farming practices. What is a farmer's opinion about soil degradation and soil conservation? Here, I'll share some of my findings, perceptions and interpretations.

Farmers are not ignorant of soil degradation. They see the gullies (dongas) become deeper and wider and obviously note that their maize yield (mostly without synthetic inputs) dropped over time. The question is what they can do about it? What can individual farmers do inside a current collective system where action is defined by faith and belief systems?

At district level these farmers cannot do much as grazing laws and regulations, etc. are the responsibility of the government. But, success stories at farm and village level have been noted: farmers that adopted CA applied compost, manure and soil cover. Fields were not ploughed anymore and tillage reduced enormously. Cover crops have been adopted into the maize production systems especially as relay cropping. They managed to a certain extent to reverse the traditional uncontrolled "free for all" grazing on their crop residues and winter cover crops.

Commercial farmers have probably more advanced and better access to social media, internet research on reading about soil erosion and land degradation. Many conventional commercial farmers however are not convinced that tillage is necessarily degrading the soil. Many if not all (conventional) farmers measure farm performance in financial terms only. If the crop yields decline then many find resort in using improved seed cultivars and apply higher fertilizer rates. Simply said, the crop yields remain the same, but the soil quality decreases gradually. The journey of soil conservation along with keeping farming profitable is a far more difficult road to travel. It requires more hands-on management, but it is the MUST-road to travel. Look after the soil and it will look after you, your crops and the livestock.

It appears that combating soil degradation in southern Africa will best be via a bottom-up approach driven by devoted, visionary, regenerative lead farmers in a supportive innovative environment who successfully implement CA and stimulate farmer groups around them to also try, research and practice CA. Soil and water conservation is related to implementation of principles

(continued)

Box 13.1 (continued)

but the HOW TO DO remains farm-specific. Unfortunately, as agricultural extension and research support is lacking soil conservation is solely on the shoulders of the farmers.

Soil conservation committees provided an important means to promote conservation of agricultural resources (Theron 1983) and to the implementation of CARA. Although the success and efficiency of soil conservation committees varied, clear legislative and regulative guidelines existed (South Africa 1983, 1984). Based on this, farmers must be responsible for interventions and ideally share the cost of interventions. In addition, policies and legislation must be implemented by a capable and motivated staff component and knowledgeable farmers to ensure that land degradation can be quickly identified, and the most appropriate soil conservation interventions can be applied. In the past considerable emphasis existed on training a skilled workforce both on a technical but also academic and managerial level. For this purpose, curriculums within agricultural engineering and extension were developed at Technicon's to train soil conservation technicians and practitioners.

The recent Land Degradation Neutrality (LDN) document revolves around three strategies of avoiding degradation, reducing degradation and restoring degradation (Cowie et al. 2018, von Maltitz et al. 2019). Any policy needs to consider all three with the emphasis on the first. Farmers can avoid and reduce further degradation by adopting practices and behavior that conserve and improve ecological capital, e.g., the soils. However, it remains very difficult for farmers or land users to rehabilitate severely eroded land and any intervention requires long-term dedication and sacrifice.

13.4.2 Soil Erosion and Soil Conservation Research Development

The visible effects of land degradation and the desire to optimize production stimulated research interest and created the awareness that a better understanding of soils and vegetation in South Africa would be needed (Cooper 1996). Thus, the Land Type survey came forth from the need to have a nationwide map of soil information as good soil data is imperative for setting policy guidelines on soil conservation. From early 1970 up to 2000 various soil scientists contributed to define homogenous areas called land types according to terrain, climate and soil (Land Type Survey Staff 2012). The land type survey remains the only nationwide survey of soils in South Africa. A similar exercise was completed by Acocks (1988) to define vegetation types for livestock and agricultural production. In addition to this, considerable research on the most sustainable veld management strategies to prevent land degradation was undertaken.

Since 1994, research emphases have shifted away from innovative veld and cropping system research at Government owned research institutes. Greater emphasis is on on-site trials focusing on smallholder farming and communal farming systems testing traditional, low-input approaches. The focus of extension services has shifted toward project implementation aiming at poverty alleviation and small-scale farmer assistance. Within commercial livestock farming, holistic farming and high intensity grazing has been adopted because of the perceived benefits the adaptive management decision-making framework brings. Holistic farming or Holistic Management (Savory and Butterfield 2016) is however seen as highly controversial from an ecological point of view (e.g., Briske et al. 2011, Mann and Sherren 2018). Through intensification of livestock rotational systems (smaller camps and faster rotation) and higher camp stocking rates, grass utilization efficiency is increased but grass recovery becomes longer, stimulating cover, nutrient cycling and carbon sequestration (Gosnell et al. 2020).

13.4.3 A Successful Soil Conservation Policy

Strong legislation and regulations regarding soil conservation developed over a period of 40 years spanning three acts. The CARA act is still relevant, but it is an old legislation that needs review. It does not consider new philosophies of holistic management, carbon sequestration and conservation agriculture. Tools to assist with implementing the act have also progressed significantly. Without sound implementation any form of legislation is ineffective. A strong and capable personnel corps is needed with an enduring institutional memory, an issue discussed as well in Europe (Boardman and Vandaele 2010), for administrating the acts, regulations, policies and strategies on soil conservation.

There exists a wealth of data on methods to prevent soil degradation and to restore degraded soils. A good example is the World Overview of Conservation Approaches and Technologies (WOCAT) containing a database of various sustainable land management practices including a guideline book for southern Africa (Liniger and Studer 2019). Nonetheless, the need for constant data on the state of the resource and research on testing new technological advances in sustainable land management is essential. Although remote sensing provides a rather new dimension in natural resource monitoring (see Chaps. 24 and 29) the collection and monitoring of ground base measurements still remain essential. Although sufficient research is available on basic methods to prevent, reduce and restore soil degradation, continued training and research on newer technologies toward building human capacity are needed. Considering the time for rehabilitated land to recover, the benefit for current land users remains minimal. Policy decision makers should understand that benefits after land rehabilitation are only visible over the long-term and often beyond the lifespan of a farmer.

13.5 The Extent of Soil Erosion by Water in South Africa

While long-term, geological erosion and denudation rates seem to be quite low and uniform over South Africa, current rates of soil erosion show a strong spatial variation. Due to a still missing uniform soil erosion model which would assess sheet and rill erosion as well as gully erosion at the same time, these two forms need to be looked at separately. Together, they are good proxies for the on-site damages from soil erosion by water, while sediment yield assessments are a good proxy for the off-site damages.

In order to assess the actual risk of soil loss from sheet and rill erosion in South Africa, the Universal Soil Loss Equation (USLE, Wischmeier and Smith 1978) was interfaced in a Geographical Information System (GIS) and applied to the whole country. The (R)USLE represents the globally most frequently applied soil erosion by water model (Borrelli et al. 2021). It has sufficient simplicity for a risk assessment (not actual rates) on a national scale by incorporating the main factors causing soil erosion, i.e., rainfall erosivity, soil erodibility, topography and vegetation cover. Details on the method and the data used to account for the main factors are provided in Le Roux et al. (2008).

To additionally assess concentrated flow erosion a gully erosion location map for South Africa was created by visual interpretation and vectorization satellite imagery acquired in 2008 to 2012 (Mararakanye and Le Roux 2012). SPOT 5 satellite imagery was utilized because it provides high resolution air photo-like quality for erosion mapping and was acquired from government agencies for the whole country. As a result, the study successfully mapped over 150,000 gully erosion features ranging from just a few square meters to several hectares of surface area each. However, one has to note that this mapping exercise is a first step in providing an assessment on gully erosion in South Africa. In particular, it does not consider the status of a gully (active or inactive) and does not provide any estimates on the age or lifetime of the gullies and thus gully erosion rates.

Figure 13.4 illustrates the distribution of areas with a high erosion risk for sheet and rill erosion, basically under conventional tillage operations on arable land. Arable land is defined here as the interpretive groupings of Land Types (Land Type Survey Staff 2012) with cultivation potential ranging from least suitable (requires careful management) to most suitable (for safely and profitably cultivating crops) (Schoeman et al. 2002). Areas are classified as having a moderate to high erosion risk when the average annual soil loss rate exceeds $1200 \text{ t km}^{-2} \text{ yr}^{-1}$ (thereafter shortly called water erosion risk areas). This classification applies to about 25% of the land in South Africa. In total, approximately $96,350 \text{ km}^2$ and 30% of all potential arable land can be considered at risk of water erosion. The average predicted sheet and rill erosion soil loss rate for arable land in South Africa is $1260 \text{ t km}^{-2} \text{ yr}^{-1}$, a value recently confirmed by Borrelli et al. (2017, Fig. 4). Looking at the total area classified as water erosion risk areas (Table 13.2), the Eastern Cape ranks first, followed by the Free State and the Northern Cape provinces. But if one considers

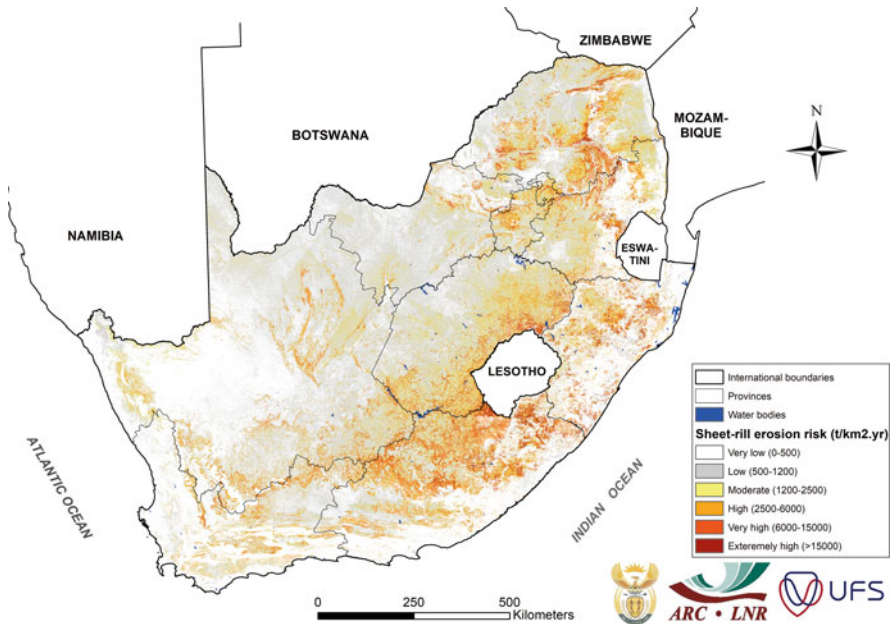


Fig. 13.4 Water erosion risk map of South Africa (emphasizing sheet-rill erosion) (modified from Le Roux et al. 2008, p. 310)

Table 13.2 Assessment of the extent of soil erosion by water (sheet and rill erosion and gully erosion) in South Africa

Province	Total Area [km ²]	Area affected by sheet and rill erosion [km ²]	Area affected by sheet and rill erosion [%]	Area affected by gully erosion [km ²]	Area affected by gully erosion [%]
Western Cape	129,462	20,653	16.0	254	0.2
Northern Cape	372,889	54,071	14.5	1608	0.4
North West	104,882	14,853	14.2	108	0.1
Free State	129,825	55,039	42.4	647	0.5
Eastern Cape	168,966	61,886	36.6	1518	0.9
Limpopo	125,755	44,227	35.2	587	0.5
Gauteng	18,178	7757	42.7	1	0
Mpumalanga	76,495	25,784	33.7	174	0.2
KwaZulu Natal	94,361	21,380	22.7	875	0.9
Total	1,220,813	305,650	25.0	5772	0,5

the proportion of areas at risk compared to the total area, then Gauteng and the Free State show up as hotspots followed by Eastern Cape, Limpopo and Mpumalanga.

Figure 13.5 illustrates the distribution of gullies in the country and shows that i) all provinces are affected by gully erosion and that ii) there is a clear overlap with

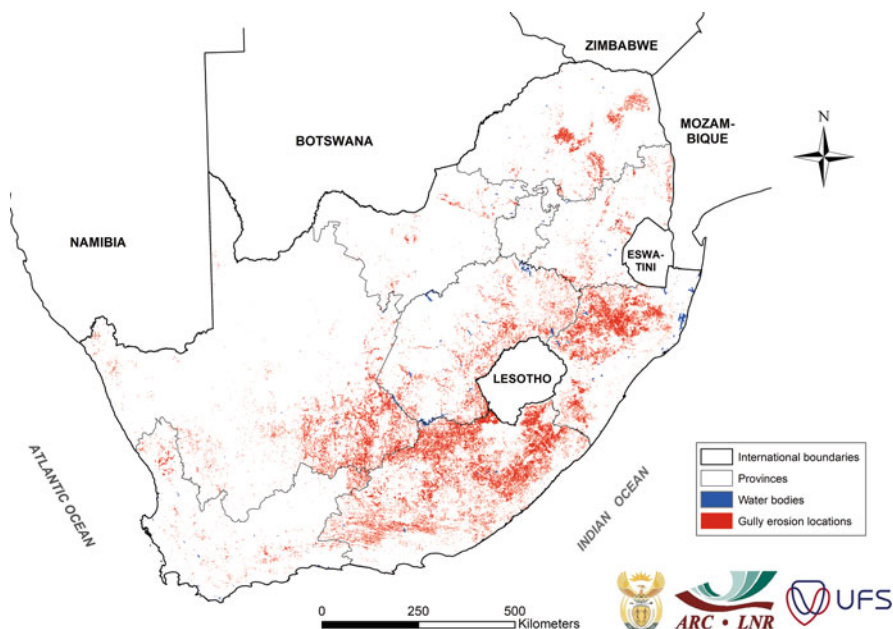


Fig. 13.5 Gully erosion location map of South Africa (from Mararakanye and Le Roux 2012, p. 213)

the water erosion risk areas (Fig. 13.4). Overall, about 0.5% of South Africa's land surface is dissected by gullies (Table 13.2). The largest areas covered by gullies are in the Northern and Eastern Cape provinces and the highest density of gullies are found in the Eastern Cape and KwaZulu Natal. These findings confirm earlier assessments by Hoffmann and Ashwell (2001, 151) about the "provinces most badly affected by soil degradation." In addition to the extent of gully erosion, Mararakanye and Le Roux (2012) determined that 1818 km² and 5.5% of arable land is affected by gully erosion. Here, poor farming practices as well as the trend toward agricultural intensification can be considered a major cause of gully erosion.

Finally, the assessment of catchment sediment yield provides a reasonable proxy for the off-site damages from soil erosion by water. Given the increasing threat of reservoir siltation, the Water Research Commission (WRC) identified the need to improve the original sediment yield map of South Africa (Rooseboom et al. 1992). The revised sediment yield map (Msadala et al. 2010) was produced using latest reservoir siltation data in probabilistic and empirical modeling. One of the improvements involved the identification of new regional boundaries based on above-mentioned USLE study of Le Roux et al. (2008). Furthermore, revised sediment yield confidence bands were developed using recent bathymetric survey data for 157 dams obtained from the Department of Water and Sanitation dam survey information book (DWS 2006).

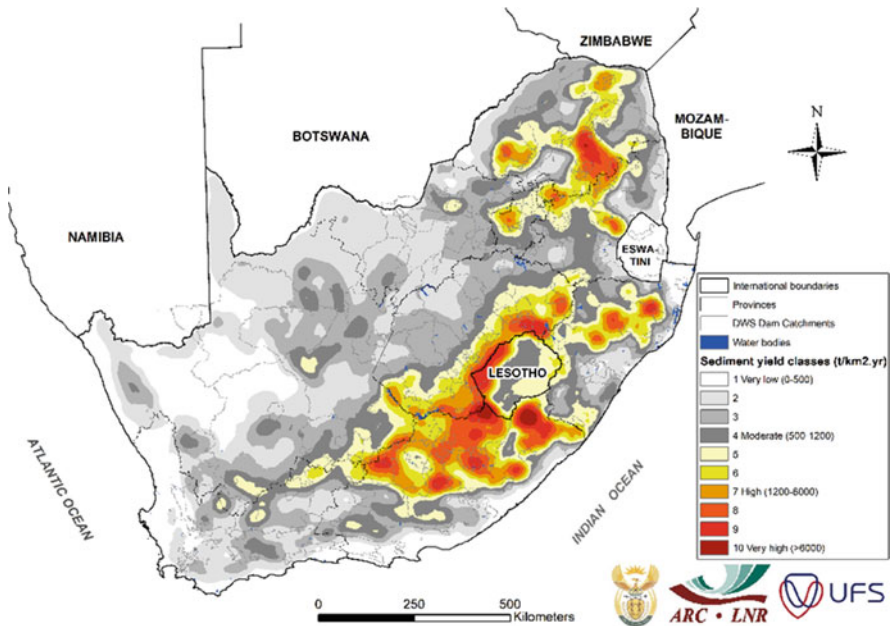


Fig. 13.6 Sediment yield map of South Africa (modified from Msadala et al. 2010, p. 243)

Figure 13.6 illustrates that the highest sediment yields are predicted in the eastern parts of the country. The spatial pattern is rather similar to the water erosion risk and gully erosion maps (Fig. 13.3, Fig. 13.4). Sediment yield ranges between 4 and 1510 t km⁻² yr⁻¹ with an average of 207 t km⁻² yr⁻¹. It is noteworthy that differences between sediment yield and soil loss can be high (Walling 1983) and often sediment yield is lower than estimated soil loss or soil detachment in the corresponding catchment area. Nonetheless, comparing the three figures provides evidence of quite similar patterns of hotspots of sheet and rill erosion, gully erosion and sediment yield across the country and a strong correlation with the distribution of dispersive and duplex soils in South Africa (see Fey 2010).

Recently, Borelli et al. (2017) published a RUSLE-based global modeling approach to assess the potential rates of soil detachment by water in the years 2001 and 2012 considering land use change, but omitting climate change. In good agreement with earlier results of Le Roux et al. (2008) they report an average annual loss of about 1600 t km⁻² yr⁻¹ in cropland for 2012 (Borelli et al. 2017, Fig. 4). In addition to this, Borrelli et al. (2020) assessed future developments for the year 2070 based on Representative Concentration Pathways (RCP). According to this, sheet and rill erosion are supposed to remain on the current level or decrease slightly for RCP 2.6 and RCP 4.5 and increase slightly for RCP 8.5. However, due to a number of uncertainties, monitoring the development by, e.g., continuous monitoring of reservoir siltation is advised.

13.6 The Extent of Soil Erosion by Wind in South Africa

Soil erosion has been identified as one of South Africa's biggest environmental problem already decades ago, but the discussion has been clearly dominated by water erosion while the problems caused by wind erosion are often considered less severe and overlooked (Laker 2004). Wind erosion research related to southern Africa can be divided into two main topics. One is the consideration of wind erosion as a geomorphological or natural process in arid environments, forming landscapes and covering large areas and long timescales (e.g., Holmes 2015). The other one is the recent effects of wind erosion on agricultural land caused by human activities and contributing to soil degradation (Wiggs and Holmes 2011, Eckardt et al. 2020, Vos et al. 2021, Salawu-Rotimi et al. 2021).

As is the case all over the world, data available on wind erosion in South Africa is very sparse. In a review, Laker (2004) refers to just a few available quantifications with soil loss rates reported for wind erosion ranging from 1100 to 5900 t km⁻² a⁻¹. In addition, he refers to findings by Schoeman et al. (2002) identifying hotspots of wind erosion in the coastal belts as well as parts of the Northern Cape, the Free State and the Northwest Provinces.

More recently, wind erosion research has increasingly addressed the problems of aeolian dust emissions on agricultural land. Wiggs and Holmes (2011) were the first to examine both issues on agricultural land in the Free State Province. Here, sandy soils, strong winds and impacts of cultivation promote the processes of wind erosion. The controlling factors vary in time and space, with saltation during high winds as a key factor. High wind speeds are not only associated with the passages of frontal systems, but also with the diurnal cycle of wind resulting in many erosion events during early daytime hours. When the fields are bare, the roughness and moisture are the crucial parameters to mitigate erosion. Perpendicular orientation of tillage induced roughness to the main wind direction is therefore a particularly effective measure to mitigate against wind erosion.

The Free State Province has been identified as a frequent dust source as well by Eckardt et al. (2020) evaluating satellite images for the decade 2006–2016 from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) (Fig. 13.7). Particularly land used for rain fed agriculture lead to increased events during drought phases, which are accompanied by reduced ground cover by vegetation. A relation to the diurnal variation of the wind speed could also be shown. Most of the dust plumes were traveling in the direction of the Indian Ocean, and rather of minor extent compared to those in the northern hemisphere. Eckardt et al. (2020) also concludes that the individual field conditions are more important for the emissions than land use in general.

The close proximity of natural and agricultural sources of dust in semiarid environments makes it also difficult to distinguish between them. Thus, a clear identification of possible source areas and the factors favoring dust emissions are important prerequisites to improve models as well as to effectively apply possible mitigation measures. Ground-based investigations of natural and agricultural dust

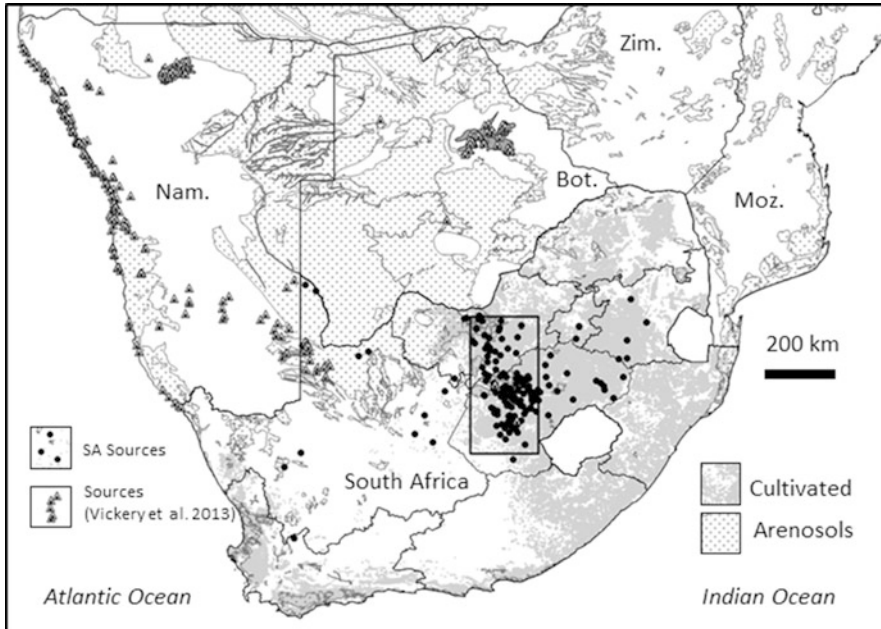


Fig. 13.7 Map of southern Africa's major dust sources based on satellite image surveys (2005 to 2008, Vickery et al. 2013) and (2006 to 2016, Eckardt et al. 2020) (modified from Eckardt et al. 2020)

emission hotspots were made by von Holdt et al. (2019) and Vos et al. (2019, 2021) to identify the most relevant controlling factors. The PI-SWERL (Portable In-Situ Wind Erosion Lab) device used allows to derive functional relationships between the force of the wind, the friction velocity (u_*), and soil properties (particle size distribution, aggregation) and soil surface characteristics (roughness, crusts), expressed as dust emission potentials.

The Revised Wind Erosion Equation (RWEQ, Fryrear et al. 1998) is used in many parts of the World as basis to assess the wind erosion risk and to identify potential hotspots. The estimation is based on soil properties (erodibility and crusting), a meteorological parameter combining transport capacity of the wind (erosivity) and the ratio between precipitation and evaporation, and the land use to derive vegetation cover as well as landscape roughness (for details see Kestel et al. 2023). If only these most basic influencing factors are considered, the following picture emerges for South Africa (Fig. 13.8, Fig. 13.9). High sand contents and a low ability to form aggregates result in the highest susceptibilities, especially in the north-western parts of South Africa (Fig. 13.8). The climatic erosivity is highest along the coast line with decreasing tendency inland and from west to east (Fig. 13.9). The combination of all parameters results in highest susceptibilities to wind erosion in the northwestern parts of South Africa, amounting to 5.5% in the moderate to highest susceptibility level (Fig. 13.10). The soil losses assigned to the classes are in accordance with

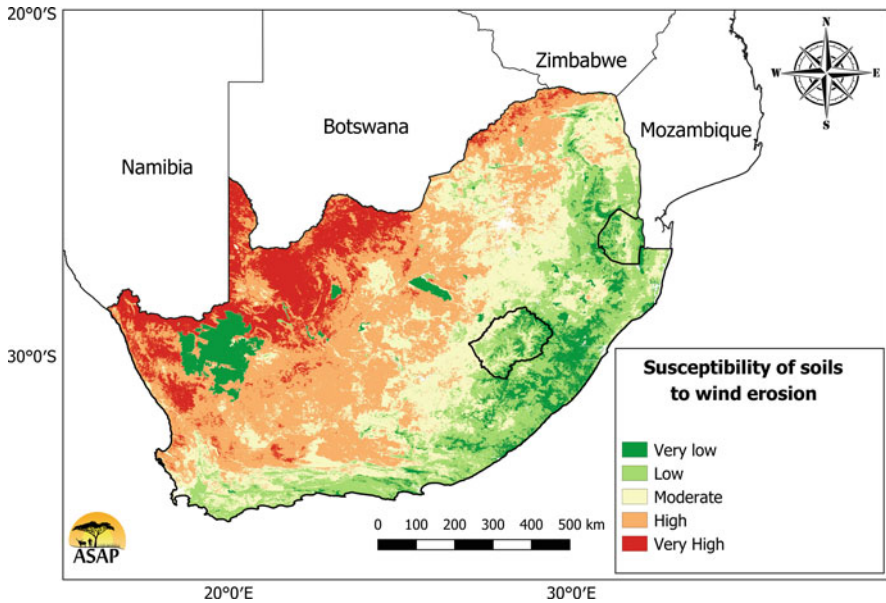


Fig. 13.8 Susceptibility of soils to wind erosion in South Africa (data sources: de Sousa et al. 2020, Fischer et al. 2008, compilation: F. Kestel)

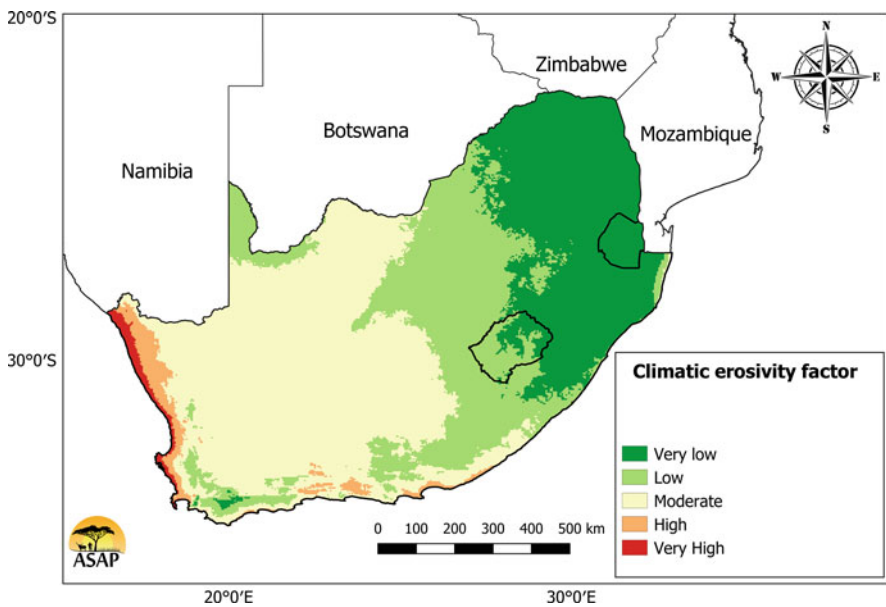


Fig. 13.9 Climatic erosivity factor in South Africa derived from mean monthly wind speed and the ratio of precipitation and evaporation (data source: Abatzoglou et al. 2018, compilation: F. Kestel)

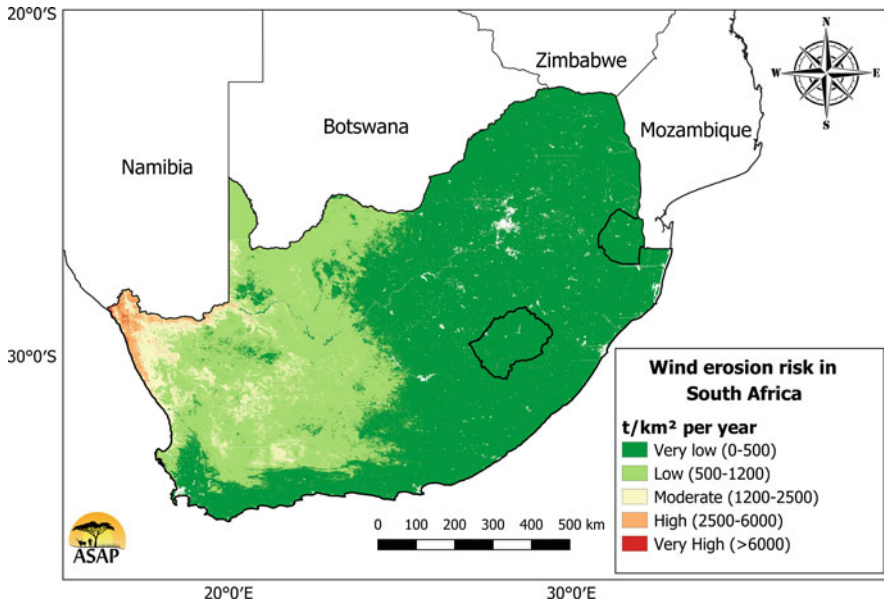


Fig. 13.10 Wind erosion risk in South Africa, 15-year average (2005–2019) (modified from Kestel et al. 2023)

water erosion levels and corresponds to measurements of wind erosion at the plot scale from different continents (Bielders et al. 2002, Sterk 2003, Funk et al. 2004).

While soils susceptible to wind erosion are found to the northwest of the country (Fig. 13.8.) and major winds (Fig. 13.9) are associated with the west coast, many of the major observed dust events in satellite imagery originate from the Free State (Fig. 13.7), where wind speeds are lower, but luvisols and arenosols supply the available fine fraction, which becomes available during drought periods when fields remain devoid of crop cover for extended periods of time.

Climate change impacts are a further factor influencing wind erosion and dust emission processes at the larger scale. Zhao et al. (2021) used the RWEQ with meteorological and remote sensing data to explore the spatial and temporal variation of wind erosion in southern Africa between 1990 and 2015. They show a decreasing tendency in the 1990s and a stabilized level after 2010, based on the annual mean maximum wind speed, which decreased by about 2 m s^{-1} in the period under consideration. This agrees with an analysis of Wright and Grab (2017) showing a decrease in mean wind speed, although not to this degree. In addition, they found seasonal trends in wind speed deviations, increasing in autumn and winter and decreasing in spring and summer. Zhao et al. (2021) also estimated potential soil losses by wind erosion with the RWEQ. They calculated soil losses less than $1000 \text{ t km}^{-2} \text{ yr}^{-1}$ for most parts for southern Africa, but also maximum values up to $17,000 \text{ t km}^{-2} \text{ yr}^{-1}$. The values are not verified by any measure, but they

show relative changes in the wind erosion risk over the regarded 25 years caused by climatic factors and associated vegetation cover changes.

13.7 The Socioeconomic Dimension of Soil Erosion

The African population is experiencing a number of socioeconomic problems such as poverty, food insecurity and increased mortality rates (UNEP 2015). These hardships are intensified by land degradation which further disadvantage people and leads to migration and conflict over arable land. Land degradation has an influence on productivity which may affect food security and the livelihoods of those who derive their well-being from practicing small scale farming or working on commercial farms (Hamdy and Aly 2014). Barbier and Hochard (2016) reason that the overall poverty in developing countries may be influenced by the concentration of communal populations on degrading, as opposed to improving, agricultural land. In South Africa for example, 68% of the country's land surface is occupied by range land and are mostly utilized for livestock agriculture. Large parts of these rangeland are already experiencing different levels of degradation. Gully erosion, scrub encroachment and a general decrease in vegetation cover pose a threat to the production of livestock, the farmer's livelihood, and the production of food in South Africa (Rabumbulu and Badenhorst 2017).

Land degradation is often identified as the consequence of existing social and economic conditions experienced by the land users and workers (Abu Hammad and Tumeizi 2012). These social and economic conditions include population growth, poverty, overgrazing, deforestation and access to agriculture extension, infrastructure, opportunities and constraints created by market access as well as policies and general government effectiveness (Jouanjean et al. 2014).

A substantial proportion of people in rural and urban areas depend on agricultural production as the main source of employment and livelihood. Therefore, population growth has an impact on land as an important economic sector in terms of food production, employment generation and improving the livelihoods of the poor to alleviate poverty (Kangalawe and Lyimo 2010). In South Africa, there has been a significant migration to urban areas. The push factors include poverty and unemployment, with the prospect of receiving high wages in urban areas being a major pull factor. The outmigration is a threat to the growth and productivity of rural agriculture due to the loss of human capital. However, studies also indicated that remittances from migrant workers are often used to purchase agricultural inputs (Mbata and Mofokeng 2021).

The socioeconomic development of smallholder farmers is dependent on access to profitable markets, thus markets where they obtain information, farm organizations and income (van Tilburg and van Schalkwyk 2012). This can contribute to profit incentives and empower farmers to upgrade yield production and mitigate land degradation through acquisition of sustainable land use information and practices, which in turn may contribute to household income and food security. In South Africa, for example, it is broadly understood that smallholder farmers experience

difficulties to access profitable markets due to poor infrastructure, long distance to access output and input markets, expensive transport costs, absence of information (regarding markets, production and environmental issues such as land degradation), lack of technical assistance (training on sustainable land use) and inefficient record keeping practices (Ngqangweni et al. 2016). These issues have been also confirmed in a case study of the South Africa Land Degradation Monitor (SALDi) project in the Ladybrand area, Free State Province of South Africa (see Box 13.2).

Deep-rooted poverty leads to overdependence on natural resources for livelihoods which in some instances have undermined the capacity of the population to manage the resources sustainably (Kangalawe and Lyimo 2010). Kirui (2016) and Mbata and Mofokeng (2021) observe that the connection between land degradation and poverty is greater in rural areas of developing countries such as South Africa, where the livelihoods of the majority of the population are attached to agriculture. Poverty inhibits farmers to have access to equipment that enhances the rehabilitation of the land (Birungi 2007). Most small-scale farmers live barely on subsistence level and do not have the capacity to use purchased inputs or to pay for labor to use the labor-intensive conservation technologies (Birungi 2007). Thus, farmers are disadvantaged if they are unable to utilize effective land productivity enhancing inputs such as fertilizers which contributes to the degradation of natural resources (Kirui 2016). Poor small-scale farmers are often unable to compete for resources, including high quality and productive land and are therefore restricted to peripheral land that cannot sustain their practices which prolong land degradation and advance poverty (Birungi 2007). Even where small-scale farmers may have access to productive land and infrastructure in South Africa, the sociopolitical context may prevent them from using the land. This can play out through corruption, nepotism or imbalances in power relations.

Box 13.2 South Africa Land Degradation Monitor (SALDi) Case Study on Small-Scale Farmers and Land Care Workers' Perceptions of Land Degradation: Main Results

A case study in the Ladybrand area in the Free State Province that includes commercial, small scale and commonage farmers was conducted between 2019 and 2021. Information was gathered through observation, focus group discussions and face to face interviews (for details see Msipa 2022). The study investigates the community perceptions about land degradation and the impact of land degradation on the livelihoods of the communities. The study shows that the main driver for farming in the area is the provision of a livelihood. Soil quality and land degradation is seen as something that prevents commercial gains.

Commercial farmers have more access to resources such as fertilizer, equipment and manpower to prevent soil degradation. Although there are some conservation farmers in the area, it requires a different mindset. Doing

(continued)

Box 13.2 (continued)

things nature's way makes it more difficult to manage your farm and it appears "less neat." From a commercial farming perspective, the study area is a high input driven farming society.

Commonage farmers rent municipal land to farm on. About 60 farmers from the area use the commonage to graze cattle. Many people using the commonage are poor and don't have resources to conserve the soil, have no training, no equipment and limited options. It is also difficult to manage the numbers of the cattle and because of the bad condition of the land, yields are low and the contribution to their livelihood security is limited. Farmers are reluctant to invest in land that they do not own. Commonage farmers list their biggest challenges as lack of access to land, limited space, lack of equipment, no access to capital, bad management skills and no safety nets. They feel that the land is "sour" and needs something added to the soil to improve it.

Small scale farmers also have challenges with land degradation. The degradation is attributed to invasive plants, lack of fences, proximity to waste sites and urban areas and illegal grazing. They attempt to do things like rotational grazing to protect the soil, but due to illegal grazing this often does not work, as they are left with no grazing for their cattle. Due to the proximity to the urban area, their land is susceptible to veld fires started in the township. Land degradation causes lower yields, which with the other challenges, have a real impact on their livelihoods. Small scale farmers in this area tend not to grow commercial crops because they don't have the equipment to plant and harvest crops. When renting equipment timing becomes an issue, and sometimes they are late with planting or harvesting. Buying things like fertilizers and chemicals to control weeds are beyond their budgets and often the yield of the crops does not cover these costs. Thus, they report that crop farming is not profitable at all. There is a dire need for mentorship programs and skills development. Small-scale farmers feel that they cannot produce the same quality as the commercial farmers, and that the markets favor the products of commercial farmers because these are of a higher quality due to their access to resources.

The poor and food insecure households may contribute to land degradation because they are unable to set land aside for given periods of time (fallow), make investments in land improvements or use cost-effective external inputs (Birungi 2007). Given the over dependency on natural resources, stagnation or reduction in agricultural productivity due to land degradation imposes serious income and livelihood constraints for rural and urban households and therefore leading to poverty. Poverty contributes to land degradation and the latter contributes to poverty; it is a cyclic process, as the commonage and small-scale farmers in Ladybrand confirm.

13.8 Challenges for Soil Conservation in South Africa

Soil erosion is the most important soil degradation process in South Africa and has been considered an issue for over a century. Already at the beginning of the twentieth century, this problem was addressed in policy, and around the mid of the century, extensive measures were taken to combat soil erosion on (commercial) arable land and rangeland. Visible features include contour tillage and runoff bunds, usually considered effective measures to diminish soil erosion by water as well as wind breaks to control wind erosion. In addition, strict guidelines concerning livestock numbers accompanied by subsidies to reduce stocks were implemented.

Nonetheless, sustainable soil use (in agriculture and beyond) remains a challenge. The urgency to control soil erosion by the application of established policies and principles as well as emerging modes of conservation agriculture (CA) in farming activities is best illustrated by the following comparison (Table 13.3): The average geological denudation and erosion rate, indicating long term soil formation rates varies in South Africa between 3 and 27 t km⁻² yr⁻¹ (Table 13.3). Compared to this, the mean USLE-based predicted sheet and rill erosion soil loss rate for arable land is assessed to range between 1260 and 1750 t km⁻² yr⁻¹ and the predicted soil loss from wind erosion is about 750 t km⁻² yr⁻¹. Thus, there is evidence that current soil loss is two orders of magnitude higher than the long-term soil formation rates and still more than one order of magnitude higher than values for tolerable soil loss rates reported for Australia (20 to 85.5 t km⁻² yr⁻¹, FAO 2019).

The United Nations Convention to Combat Desertification (UNCCD) recently began endorsing a response hierarchy that invests resources to avoid future degradation, followed by a reduction in current degradation and lastly to restore degraded land (Cowie et al. 2018). Specifically, in South Africa it will not be feasible to rehabilitate erosion features with large and expensive structures at a broad or catchment scale due to limited financial resources. Not only are large structures costly, structures in dispersive soils enhance subsurface accumulation of water and cause further erosion around structure walls (van Zijl et al. 2014). Thus, it is important to prevent further erosion by protecting susceptible areas that are currently not eroded (Le Roux and van der Waal 2020).

It is postulated that prevention measures cost far less than repairing the on- and off-site damage caused by soil erosion (Boardman 2021). It is imperative to prevent

Table 13.3 Summary of soil formation, denudation and erosion rates in South Africa (for details see Sects. 13.2 and 13.5)

Process	Time span [yr]	Rates [t km ⁻² yr ⁻¹]	Remarks
Soil formation	10 ⁴ –10 ⁵	3–27	South Africa (range)
Soil formation	10 ⁴ –10 ⁵	13.5	In Kruger National Park, Lowveld
Sediment yield	10 ¹ –10 ²	81.0	In Kruger National Park, Lowveld
Sheet and rill erosion	10 ¹	1260–1750	USLE soil loss risk for arable land
Wind erosion	10 ¹	~ 750	RWEQ soil loss risk,

erosion with appropriate soil conservation measures and expansion of conservation agriculture (CA) in cultivated areas, as well as to protect (natural) vegetation from overgrazing through rotational grazing management systems. The potential of CA to protect and improve soil health has been well documented (De Wit et al. 2015, Van Antwerpen et al. 2021). Under CA, crop residues are retained on the soil surface to protect it from the erosive impact of rainfall, runoff, and wind. The use of cover crops can further increase the crop canopy- and ground cover on the soil, while the presence of permanent and strong living root systems in the soil greatly enhance the resistance of the soil against erosion. Ultimately, the increased organic matter level in the soil is the key factor stabilizing cultivated lands against the devastating effect of erosion. Soil erosion prevention by means of CA will not only prevent soil loss and sustain agricultural production, but will also prevent siltation of water resources and increase the life span of dams and reservoirs in South Africa.

In recent years, devastating droughts and local to regionalized flood events have severely affected South Africa. Agriculture as one of the main sectors of the economy in South Africa ranging from the intensive, large-scale, commercial agricultural to the low-intensity, small-scale, and subsistence farming, will in any case be strongly influenced by climate change in the coming decades. Thus, there is a need to strengthen the resilience of farming operations to i) meet increased domestic and global demand and ii) to put into practice sustainable management to diminish on-site and off-site damages from soil erosion on the way to reach sustainable development goals.

Tangible and reciprocal partnerships between research institutes, farmers, consumers and government are needed to foster knowledge of sustainable land use practices. A broader view is needed to recover productivity and promote sustainable land management practices including good land use practices and efficient engineering design implementation. Land degradation also needs to be seen within the bigger picture of agricultural and nonagricultural land use and activities. Good soil conservation and sustainable agricultural practices intersect with the preservation of high potential agricultural land, conservation of natural ecosystems, including wetlands, good catchment management and the conservation of water resources.

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References

- Abatzoglou JT, Dobrowski SZ, Parks SA, Hegewisch KC (2018) Terraclimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958-2015. *Scientific Data* 5:170191. <https://doi.org/10.1038/sdata.2017.191>(2018)
- Abu Hammad A, Tumeizi A (2012) Land degradation: socioeconomic and environmental causes and consequences in the eastern Mediterranean. *Land Degrad Dev* 23(3):216–226. <https://doi.org/10.1002/ldr.1069>
- Acocks JPH (1988) Veld types of South Africa. *Memoirs of the Botanical Survey of South Africa* 57(3)
- Adler ED (1985) Soil conservation in South Africa. Bulletin 406. Department of Agriculture and Water Supply, Pretoria
- Baade J (2006) Soil erosion. In: Geist H (ed) *The Earth's changing land: an encyclopedia of land-use and land-cover change*. Greenwood, Westport, pp 539–542
- Barbier EB, Hochard JP (2016) Does land degradation increase poverty in developing countries? *PLoS One* 11(5):1–12
- Beinart W (2003) The rise of conservation in South Africa. In: *Settlers, livestock, and the environment 1770–1950*. Oxford University Press, Oxford
- Bennett HH (1939) *Soil conservation*. McGraw-Hill, New York
- Biielders CL, Rajot J-L, Amadou M (2002) Transport of soil and nutrients by wind in bush fallow land and traditionally managed cultivated fields in the Sahel. *Geoderma* 109:19–39
- Bierman PR (1994) Using in situ produced cosmogenic isotopes to estimate rates of landscape evolution: a review from the geomorphic perspective. *J Geophys Res* 99B:13885–13896
- Binnie SA, Summerfield MA (2013) Rates of denudation. In: Shroder J, Marston RA, Stoffel M (eds) *Treatise on geomorphology, Mountain and hillslope geomorphology*, vol 7. Academic Press, San Diego, CA, pp 66–72
- Birungi PB (2007) The linkages between land degradation, poverty and social capital in Uganda. University of Pretoria. Environmental Economics. PhD Thesis. Available <http://hdl.handle.net/2263/25109>. Accessed 22 June 2020
- Boardman J (2021) How much is soil erosion costing us? *Geography* 106(1):32–38. <https://doi.org/10.1080/00167487.2020.1862584>
- Boardman J, Foster I (2008) Badland and gully erosion in the Karoo, South Africa. *J Soil Water Conserv* 63(4):121A–125A. <https://doi.org/10.2489/jswc.63.4.121A>
- Boardman J, Vandaele K (2010) Soil erosion, muddy floods and the need for institutional memory. *Area* 42(4):502–513. <https://doi.org/10.1111/j.1475-4762.2010.00948.x>
- Boardman J, Hoffman MT, Holmes PJ, Wiggs GFS (2012) Soil erosion and land degradation. In: Holmes P, Meadows M (eds) *Southern African geomorphology: recent trends and new directions*. Sun Media, Bloemfontein, pp 307–328
- Borrelli P, Robinson DA, Fleischer LR, Lugato E, Ballabio C, Alewell C, Meusburger K, Modugno S, Schütt B, Ferro V, Bagarello V, Oost KV, Montanarella L, Panagos P (2017) An assessment of the global impact of 21st century land use change on soil erosion. *Nat Commun* 8(1). <https://doi.org/10.1038/s41467-017-02142-7>
- Borrelli P, Robinson DA, Panagos P, Lugato E, Yang JE, Alewell C, Wuepper D, Montanarella L, Ballabio C (2020) Land use and climate change impacts on global soil erosion by water (2015–2070). *Proc Natl Acad Sci USA* 117(36):21994. <https://doi.org/10.1073/pnas.2001403117>
- Borrelli P, Alewell C, Alvarez P, Anache JAA, Baartman J, Ballabio C, Bezak N, Biddoccu M, Cerdà A, Chalise D, Chen S, Chen W, De Girolamo AM, Gessesse GD, Deumlich D, Diodato N, Efthimiou N, Erpul G, Fiener P, Freppaz M, Gentile F, Gericke A, Haregeweyn N, Hu B, Jeanneau A, Kaffas K, Kiani-Harchegani M, Villuendas IL, Li C, Lombardo L, López-Vicente M, Lucas-Borja ME, Märker M, Matthews F, Miao C, Mikoš M, Modugno S, Möller M, Naipal V, Nearing M, Owusu S, Panday D, Patault E, Patriche CV, Poggio L, Portes R, Quijano L, Rahdari MR, Renima M, Ricci GF, Rodrigo-Comino J, Saia S, Samani AN, Schillaci C, Syrris V, Kim HS, Spinola DN, Oliveira PT, Teng H, Thapa R, Vantas K, Vieira D, Yang JE, Yin S,

- Zema DA, Zhao G, Panagos P (2021) Soil erosion modelling: a global review and statistical analysis. *Sci Total Environ* 780:146494. <https://doi.org/10.1016/j.scitotenv.2021.146494>
- Braune E, Looser U (1989) Cost impacts of sediments in South African rivers. In: Hadley RF, Ongley ED (eds) *Sediment and the environment*. IAHS Press/IAHS Publication, Wallingford
- Briske DD, Sayre NF, Huntsinger L, Fernández-Giménez M, Budd B, Derner JD (2011) Origin, persistence, and resolution of the rotational grazing debate: integrating human dimensions into rangeland research. *Rangel Ecol Manag* 64(4):325–334. <https://doi.org/10.2111/REM-D-10-00084.1>
- Chadwick OA, Roering JJ, Heimsath AM, Levick SR, Asner GP, Khomo L (2013) Shaping post-orogenic landscapes by climate and chemical weathering. *Geology* 41:1171–1174. <https://doi.org/10.1130/G34721.1>
- Clark EHI (1985) The off-site costs of soil erosion. *J Soil Water Conserv* 40(1):19–22
- Compton JS, Herbert CT, Hoffman MT, Schneider RR, Stunt J-B (2010) A tenfold increase in the Orange River mean Holocene mud flux: implications for soil erosion in South Africa. *The Holocene* 20(1):115–122. <https://doi.org/10.1177/0959683609348860>
- Cooper A (1996) Soil conservation policy in South Africa, 1910–1992: the ‘human dimension’. Doctoral dissertation, University of Natal, Durban. Online available: https://researchspace.ukzn.ac.za/bitstream/handle/10413/8664/Cooper_Amanda_1997.pdf
- Cowie AL, Orr BJ, Castillo Sanchez VM, Chasek P, Crossman ND, Erlwein A, Louwagie G, Maron M, Metternicht GI, Minelli S, Tengberg AE, Walter S, Welton S (2018) Land in balance: the scientific conceptual framework for land degradation neutrality. *Environ Sci Policy* 79:25–35. <https://doi.org/10.1016/j.envsci.2017.10.011>
- DAFF (Department of Agriculture, Forestry and Fisheries) (2017) Draft conservation agriculture policy. Director: Land and Soil Management, Department of Agriculture, Land Reform and Rural Development, Pretoria
- de Sousa LM, Poggio L, Batjes NH, Heuvelink GBM, Kempen B, Riberio E, Rossiter D (2020) SoilGrids 2.0: producing quality-assessed soil information for the globe. *Soil Discuss* 7:1–37. <https://doi.org/10.5194/soil-2020-65>
- De Villiers CC, Hill RC (2008) Environmental management frameworks as an alternative to farm-level EIA in a global biodiversity hotspot: a proposal from the cape floristic region, South Africa. *JEAPM* 10(04):333–360
- De Wit MP, Blignaut JN, Knot J, Midgley S, Drimie S, Crookes DJ, Nkambule NP (2015) Sustainable farming as a viable option for enhanced food and nutritional security and a sustainable productive resource base. Synthesis report. Green Economy Research Report, Green Fund. Development Bank of Southern Africa, Midrand
- Decker JE, Niedermann S, de Wit MJ (2011) Soil erosion rates in South Africa compared with cosmogenic ³He based rates of soil production. *S Afr J Geol* 114:475–488
- Departement van Landbou-Tegniese Dienste (1966) Handleiding oor die toepassing van die Grandbewaringswet (Afr.). Staatsdrukker, Pretoria
- Department of Agriculture (1984) Manual for the subsidy scheme (Act 43 of 1983) division of soil protection. Department of Agriculture, Pretoria
- Department of Agriculture (1997) National Soil Conservation Manual. Department of Agriculture, Pretoria
- Dini J, Bahadur U (2016) South Africa’s national wetland rehabilitation programme: working for wetlands. In: Finlayson CM, Everard M, Irvine K, McInnes R, Middleton B, van Dam A, Davidson NC (eds) *The wetland book*. Springer, Dordrecht, pp 1–7. https://doi.org/10.1007/978-94-007-6172-8_145-2
- du Preez CC, Kotzé E, van Huysteen CW (2020) Southern African soils and their susceptibility to degradation. In: Holmes PJ, Boardman J (eds) *Southern African landscapes and environmental change*. Routledge, London, pp 29–52
- DWS (Department of Water and Sanitation) (2006) Dam list. Ministry of Water and Environmental Affairs, Republic of South Africa, Pretoria
- DWS (Department of Water and Sanitation) (2017) Hydrological services - Surface water: reservoir sites. online <https://www.dwa.gov.za/Hydrology/Verified/HyCatalogue.aspx>

- Eckardt FD, Bekiswa S, Von Holdt J, Jack C, Kuhn NJ, Mogane F, Murray JE, Ndara N, Palmer AR (2020) South Africa's agricultural dust sources and events from MSG SEVIRI. *Aeolian Res* 47:100637. <https://doi.org/10.1016/j.aeolia.2020.100637>
- England P, Molnar P (1990) Surface uplift, uplift of rocks, and exhumation of rocks. *Geology* 18:1173–1177
- FAO (Food and Agriculture Organization of the United Nations) (2019) Soil erosion: the greatest challenge to sustainable soil management. FAO, Rome
- FAO (Food and Agriculture Organization of the United Nations) and ITPS (Intergovernmental Technical Panel on Soils) (2015) Status of the World's soil resources (SWSR) – Main report. FAO, Rome
- Fey M (2010) Soils of South Africa. Cambridge University Press, Cambridge
- Fischer G, Nachtergaele F, Prieler S, van Velthuisen HT, Verelst L, Wiberg D (2008) Global agro-ecological zones assessment for agriculture (GAEZ 2008). IIASA, Laxenburg, Austria and FAO, Rome, Italy
- Foster IDL, Boardman J (2020) Monitoring and assessing land degradation: new approaches. In: Holmes PJ, Boardman J (eds) Southern African landscapes and environmental change. Routledge, London, pp 249–274
- Fryrear DW, Saleh A, Bilbro JD, Schromberg HM, Stout JE, Zobeck TM, Schomberg HM, Stout JE, Zobeck TM (1998) Revised wind erosion equation. USDA-ARS, Southern Plains Area Cropping Systems Research Laboratory, Technical Bulletin 1
- Funk R, Reuter HI (2006) Wind erosion. In: Boardman J, Poesen J (eds) Soil erosion in Europe. Wiley, Chichester, pp 563–582
- Funk R, Skidmore EL, Hagen LJ (2004) Comparison of wind erosion measurements in Germany with simulated soil losses by WEPS. *Environ Model Softw* 19:177–183
- Glotzbach C, Paape A, Baade J, Reinwarth B, Rowntree KM, Miller JK (2016) Cenozoic landscape evolution of the Kruger National Park as derived from cosmogenic nuclide analyses. *Terra Nova* 28(5):316–322. <https://doi.org/10.1111/ter.12223>
- Gosnell H, Grimm K, Goldstein BE (2020) A half century of holistic management: what does the evidence reveal? *Agric Hum Values* 37(3):849–867
- Hamdy A, Aly A (2014) Land degradation, agriculture productivity and food security. In Proceedings, fifth international scientific agricultural symposium “Agrosym 2014”, Jahorina, Bosnia and Herzegovina, October 23–26, 2014, pp 708–717
- Hewawasam T (2003) Increase of human over natural erosion rates in tropical highlands constrained by cosmogenic nuclides. *Geology* 31(7):597–600. [https://doi.org/10.1130/0091-7613\(2003\)031<0597:IOHONE>2.0.CO;2](https://doi.org/10.1130/0091-7613(2003)031<0597:IOHONE>2.0.CO;2)
- Hoffman T, Ashwell A (2001) Nature divided: land degradation in South Africa. University of Cape Town Press, Cape Town
- Holmes P (2015) The Western Free state Panfield: a landscape of myriad pans and lunettes. In: Grab S, Knight J (eds) Landscape and landforms of South Africa. Springer, Cham, pp 139–145
- Holmes PJ, Thomas DSG, Bateman MD, Wiggs GFS, Rabumbulu M (2012) Evidence for land degradation from Aeolian sediment in the west-Central Free State Province, South Africa. *Land Degrad Dev* 23(6):601–610. <https://doi.org/10.1002/ldr.2177>
- Jouanjan M, Tucker J, te Velde DW (2014) Understanding the effects of resource degradation on socio-economic outcomes in developing countries. Overseas Development Institute, London. Available <https://cdn.odi.org/media/documents/8830.pdf>. Accessed 06 Aug 2020
- Kangalawe RYM, Lyimo JG (2010) Population dynamics, rural livelihoods and environmental degradation: some experiences from Tanzania. *Environ Dev Sustain* 12:985–997
- Kanthack FE (1930) The alleged desiccation of South Africa. *Geogr J* 76(6):516–521
- Kepe T, Saruchera M, Whande W (2004) Poverty alleviation and biodiversity conservation: a South African perspective. *Oryx* 38(2):143–145
- Kestel F, Wulf M, Funk R (2023) Spatiotemporal variability of the potential wind erosion risk in Southern Africa between 2005 and 2019. *Land Degrad Dev* 34:2945. <https://doi.org/10.1002/ldr.4659>

- Kirui OK (2016) Economics of land degradation and improvement in Tanzania and Malawi. In: Nkonya E, Mirzabaev A, von Braun J (eds) Economics of land degradation and improvement—a global assessment for sustainable development. Springer, Cham, pp 609–649. https://doi.org/10.1007/978-3-319-19168-3_20
- Laker MC (2004) Advances in soil erosion, soil conservation, land suitability evaluation and land use planning research in South Africa, 1978-2003. *S Afr J Plant Soil* 21(5):345–368. <https://doi.org/10.1080/02571862.2004.10635069>
- Lal D (1991) Cosmic ray labeling of erosion surfaces: in situ nuclide production rates and erosion models. *Earth Planet Sci Lett* 104:424–439. [https://doi.org/10.1016/0012-821X\(91\)90220-C](https://doi.org/10.1016/0012-821X(91)90220-C)
- Lal R (2015) Soil Erosion. In: Nortcliff S (ed) Task force: soil matter. Solution under foot. *GeoEcology essays*. Catena, Reiskirchen, pp 39–48
- Land Type Survey Staff (2012) Land types of South Africa: digital map (1:250,000 scale) and soil inventory databases. ARC-Institute for Soil, Climate and Water, Pretoria
- Le Roux JJ, van der Waal B (2020) Gully erosion susceptibility modelling to support avoided degradation planning. *S Afr Geogr J* 102(3):406–420. <https://doi.org/10.1080/03736245.2020.1786444>
- Le Roux JJ, Morgenthal TL, Malherbe J, Sumner PD, Pretorius DJ (2008) Water erosion prediction at a national scale for South Africa. *Water SA* 34(3):305–314
- Liniger H, Studer RM (2019) Sustainable rangeland management in sub-Saharan Africa – guidelines to good practice. WOCAT, Washington, DC. Online available: <https://www.wocat.net/library/media/174/>
- Mann C, Sherrin K (2018, 1848) Holistic management and adaptive grazing: a trainers' view. *Sustainability* 10(6)
- Mararakanye N, Le Roux JJ (2012) Gully erosion mapping at a national scale for South Africa. *S Afr Geogr J* 94(2):208–218. <https://doi.org/10.1080/03736245.2012.742786>
- Mbatha MW, Mofokeng NR (2021) A Literature Review of the Impact and Implication of Out-Migration on Rural Agriculture in South Africa. *J Soc Sci Human* 18(19):1–12
- Meadows ME, Hoffman MT (2002) The nature, extent and causes of land degradation in South Africa: legacy of the past, lessons for the future? *Area* 34(4):428–437
- Molnar P, England P (1990) Late Cenozoic uplift of mountain ranges and global climate change: chicken or egg? *Nature* 346:29–34
- Morgan RPC (1995) Soil erosion and conservation. Longman, Harlow
- Msadala VC, Basson GR (2017) Revised regional sediment yield prediction methodology for ungauged catchments in South Africa. *J South Afr Inst Civil Eng* 59(2):28–36. <https://doi.org/10.17159/2309-8775/2017/v59n2a4>
- Msadala V, Gibson L, Le Roux J, Rooseboom A, Basson GR (2010) Sediment yield prediction for South Africa: 2010th edition. Water Research Commission. Report 1765/1/10. WRC, Pretoria
- Msipa AM (2022) Small-scale farmers and land care workers' perceptions of land degradation and how it influences their livelihoods: an explorative study in Ladybrand. Unpublished Master's Thesis, University of Pretoria, Pretoria
- Mulder J, Brent AC (2006) Selection of sustainable rural agriculture projects in South Africa: case studies in the LandCare programme. *J Sustain Agric* 28(2):55–84
- Nabben T, Nduli N (2001) Lessons learned in international partnerships the LandCare partnership between Western Australia and South Africa. Paper presented at Institute of Public Administration National Conference, Sydney, Australia 28–30 November
- Ngqangweni S, Mmbengwa V, Myeki L, Sotsha K, Khoza T (2016) Measuring and tracking smallholder market access in South Africa. National Agricultural Marketing Council Working Paper (NAMC/WP/2016/03)
- Oldeman LR, Hakkeling RTA, Sombroek WG (1991) World map of the status of human-induced soil degradation: an explanatory note. Wageningen, ISRIC
- Partridge TC, Dollar ESJ, Moolman J, Dollar LH (2010) The geomorphic provinces of South Africa, Lesotho and Swaziland: a physiographic subdivision for earth and environmental scientists. *Trans R Soc S Afr* 65(1):1–47. <https://doi.org/10.1080/00359191003652033>

- Pimentel D, Harvey C, Resosudarmo P, Sinclair K, Kurz D, McNair M, Crist S, Shpritz L, Fitton L, Saffouri R, Blair R (1995) Environmental and economic costs of soil erosion and conservation benefits. *Science* 267(5201):1117–1123. <https://doi.org/10.1126/science.267.5201.1117>
- Raab G, Scarciglia F, Norton K, Dahms D, Brandová D, de Castro PR, Christl M, Ketterer ME, Ruppli A, Egli M (2018) Denudation variability of the Sila Massif upland (Italy) from decades to millennia using ^{10}Be and $^{239+240}\text{Pu}$. *Land Degrad Dev* 29(10):3736–3752. <https://doi.org/10.1002/ldr.3120>
- Rabumbulu M, Badenhorst M (2017) Land degradation in the West-Central Free State: human-induced or climate variability, the perceptions of Abrahamskraal–Boshof district farmers. *S Afr Geogr J* 99(3):217–234. <https://doi.org/10.1080/03736245.2016.1231623>
- Raymo M, Ruddiman WF (1992) Tectonic forcing of late Cenozoic climate. *Nature* 359:117–122
- Reinwarth B, Petersen R, Baade J (2019) Inferring mean rates of sediment yield and catchment erosion from reservoir siltation in the Kruger National Park, South Africa: an uncertainty assessment. *Geomorphology* 324:1–13. <https://doi.org/10.1016/j.geomorph.2018.09.007>
- Rooseboom A, Verster E, Zietsman HL, Lotriet HH (1992) The development of the new sediment yield map of South Africa. *Water Research Commission report no. 297/2/92*. WRC, Pretoria
- Rowntree KM (2012) Fluvial geomorphology. In: Holmes P, Meadows M (eds) *Southern African geomorphology: recent trends and new directions*. Sun Media, Bloemfontein, pp 97–140
- Rowntree KM (2013) The evil of sluits: a re-assessment of soil erosion in the Karoo of South Africa as portrayed in century-old sources. *J Environ Manag* 130:98–105. <https://doi.org/10.1016/j.jenvman.2013.08.041>
- Russell WB (1998) Conservation of farmland in KwaZulu-Natal. KZN Department of Agriculture, Pietermaritzburg
- Salawu-Rotimi A, Lebre PH, Vos HC, Fister W, Kuhn N, Eckardt FD, Cowan DA (2021) Gone with the wind: microbial communities associated with dust from emissive farmlands. *Microb Ecol* 82:859. <https://doi.org/10.1007/s00248-021-01717-8>
- Savory A, Butterfield J (2016) *Holistic management: a commonsense revolution to restore our environment*. Island Press, Washington, DC
- Schaller M, Ehlers TA, Lang KAH, Schmid M, Fuentes-Espoz JP (2018) Addressing the contribution of climate and vegetation cover on hillslope denudation, Chilean coastal cordillera (26°–38°S). *Earth Planet Sci Lett* 489:111–122. <https://doi.org/10.1016/j.epsl.2018.02.026>
- Scharf TE, Codilean AT, de Wit M, Janson JD, Kubik PW (2013) Strong rocks sustain ancient postorogenic topography in Southern Africa. *Geology* 41:331–334. <https://doi.org/10.1130/G33806.1>
- Schoeman JL, van der Walt M, Monnik KA, Thackrah A, Malherbe J, Le Roux RE (2002) Development and application of a land capability classification system for South Africa. ARC-ISCW report no. GW/A/2000/57. Department of Agriculture, Pretoria
- Shakesby RA (2003) Soil erosion. In: Matthews JA, Bridges EM, Caseldine CJ, Luckman AJ, Owen G, Perry AH, Shakesby RA, Walsh RPD, Whittaker RJ, Willis KJ (eds) *The encyclopaedic dictionary of environmental change*. Arnold, London, p 590
- Smith HJ (2021) An assessment of the adoption of conservation agriculture in annual crop-livestock systems in South Africa. *FAO, Rome*
- South Africa (1983) Conservation of agricultural resources act, Act 43 of 1983. *Government Gazette* 8673:883. (27 April 1983)
- South Africa (1984) Regulations: conservation of agricultural resources act, Act 43 of 1983. *Government Gazette* 9238:R1048. (25 May 1984)
- Sterk G (2003) Causes, consequences and control of wind erosion in Sahelian Africa: a review. *Land Degrad Dev* 14:95–108
- Theron CHB (1983) Internal dynamics of soil conservation committees. *Conservation Forum* 2:12–14
- Theron CHB (1985) Conservation chronicles-part two. *Conservation Forum* 3:22–25
- Thierfelder C, Rusinamhodzi L, Ngwira AR, Mupangwa W, Nyagumbo I, Kassie GT, Cairns JE (2015) Conservation agriculture in Southern Africa: advances in knowledge. *Renewable*

- agriculture and food systems, 30. *Conservation Chronicles-part two*. *Conservation Forum* 3:22–25
- Turpie JK, Forsythe KJ, Knowles A, Blignaut J, Letley G (2017) Mapping and valuation of South Africa's ecosystem services: a local perspective. *Ecosyst Serv* 27(B):179–192
- UNEP (United Nations Environmental Programme) (2015) The economics of land degradation in Africa, ELD Initiative, Bonn. Available www.eld-initiative.org. Accessed 09 Nov 2019s
- van Antwerpen R, Laker MC, Beukes DJ, Botha JJ, Collett A, du Plessis M (2021) Conservation agriculture farming systems in rainfed annual crop production in South Africa. *S Afr J Plant Soil* 2021:1–16. <https://doi.org/10.1080/02571862.2020.1797195>
- van Tilburg A, van Schalkwyk HD (2012) Strategies to improve smallholders' market access. In: van Schalkwyk HD, Groenewald JA, Fraser GCG, Obi A, van Tilburg A (eds) *Unlocking markets to smallholders: lessons from South Africa*, Mansholt publication series, vol 10. Wageningen, Wageningen Academic Publishers, pp 35–58
- van Zijl GM, Ellis F, Rozanov A (2014) Understanding the combined effect of soil properties on gully erosion using quantile regression. *S Afr J Plant Soil* 31(3):163–172. <https://doi.org/10.1080/02571862.2014.944228>
- Vanmaercke M, Poesen J, Broeckx J, Nyssen J (2014) Sediment yield in Africa. *Earth Sci Rev* 136:350–368. <https://doi.org/10.1016/j.earscirev.2014.06.004>
- Vickery KJ, Eckardt FD, Bryant RG (2013) A sub-basin scale dust plume source frequency inventory for southern Africa, 2005–2008. *Geophys Res Lett* 40(19):5274–5279
- von Blanckenburg F (2006) The control mechanisms of erosion and weathering at basin scale from cosmogenic nuclides in river sediment. *Earth Planet Sci Lett* 242:224–239. <https://doi.org/10.1016/j.epsl.2005.11.017>
- von Holdt JRC, Eckardt FD, Baddock MC, Wiggs GFS (2019) Assessing landscape dust emission potential using combined ground-based measurements and remote sensing data. *J Geophys Res Earth* 124:1080–1098. <https://doi.org/10.1029/2018JF004713>
- von Maltitz GP, Gambiza J, Kellner K, Rambau T, Lindeque L, Kgope B (2019) Experiences from the South African land degradation neutrality target setting process. *Environ Sci Pol* 101:54–62
- Vos HC, Fister W, Eckardt FD, Palmer AR, Kuhn NJ (2019) Physical crust formation on sandy soils and their potential to reduce dust emissions from croplands. *Land* 9:503. <https://doi.org/10.3390/land9120503>
- Vos HC, Fister W, von Holdt JR, Eckardt FD, Palmer AR, Kuhn NJ (2021) Assessing the PM10 emission potential of sandy, dryland soils in South Africa using the PI-SWERL. *Aeolian Res* 53:10747. <https://doi.org/10.1016/j.aeolia.2021.100747>
- Walling DE (1983) The sediment delivery problem. *J Hydrol* 65(1–3):209–237
- Wiggs G, Holmes P (2011) Dynamic controls on wind erosion and dust generation on west-central free state agricultural land, South Africa. *Earth Surf Process Landf* 36:827–838. <https://doi.org/10.1002/esp.2110>
- Wischmeier WH, Smith DD (1978) Predicting rainfall erosion losses, a guide to conservation planning. USDA agricultural handbook no 537. USDA, Washington, DC
- Wright MA, Grab SW (2017) Wind speed characteristics and implications for wind power generation: cape regions, South Africa. *S Afr J Sci* 113(7/8):2016–0270. <https://doi.org/10.17159/sajs.2017/20160270>
- Zhao C, Zhang H, Wang M, Jiang H (2021) Impacts of climate change on wind erosion in Southern Africa between 1991 and 2015. *Land Degrad Dev* 32:2169–2182

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