Soils – a wasteland of opportunities

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1. Introduction

Charles E. Kellogg (1938) summed up soils as follows which is relevant to this paper: “Essentially, all life depends upon the soil. There can be no life without soil and no soil without life; they have evolved together.” The General Assembly of the United Nations declared 2015 as the “International Year of Soils” with 5 December 2015 as World Soil Day. Hereby they acknowledged that “soils constitute the foundation for agricultural development, essential ecosystem functions and food security and hence are key to sustaining life on Earth”. As part of this they also recognized “the urgent need, at all levels, to raise awareness and to promote sustainability of the limited soil resources, using the best available scientific information and building on all dimensions of sustainable development”.

One of the first questions we should be able to answer is, “what is soil?” The answer to this question will have several interpretations depending on the individual concerned. For most people living in towns and cities, it may be regarded as “dirt and dust” that has to be cleaned from their houses, hands and cars. For the farmer (and to gardeners on a smaller scale) it is a great resource and medium in which crops are grown to attract economic impact; with the produce being bought and consumed by those living in cities. To the biologist, it is the habitat of numerous living creatures to be investigated and studied. Many other examples exists viz. engineers, hydrologists, soil scientists, exploration geologist, building contractors, etc.

Soil is all of these things and with the next sections this will be elaborated i.e. what soil is from my research focus’ point of view. Soil contamination, acidification, desiccation and erosion have caused negative impacts on land surfaces which are still on the increase. Soil functions like primary plant production, natural soil-water clean-up, basis and substrate for the above ground biodiversity and food chains have become completely or partially impaired.

The aim of this paper is to highlight soils and the fact that, in terms of research, it is a wasteland of opportunities. The first objective is to give an introduction on soils and the roles it plays with regards to life, followed by how soils are turned into wastelands by human activities. In the latter specific focus will be mining in South Africa. Finally, some personal insights on how these negative aspects give rise to scientific opportunities especially from a South African perspective and also some not so scientific opportunities will be given.
Soil

Soil is a non-renewable resource which impacts the lives of people, animals and plants in numerous ways. One of the biggest differences between water and soil, apart from for the physical and chemical characteristics, is that soil (or land) can be owned by people, whilst it is not the case for water. This gives another major dimension to how soil is perceived and treated. People will seldom look at soil as a living entity with vitality (Eijsackers et al. 2006) but rather as non-living on which to farm, live and mine. Soil is, however, a living entity which plays important roles as the foundation for vegetation which is cultivated or managed for feed, fibre, fuel and medicinal products. It also plays a role in ecosystem services i.e. the benefits provided by ecosystems to humans (de Groot et al. 2002).

Soils and land also play an important role in achieving the goals (at least nine) of the UN Sustainable Development Goals (SDGs) (Müller et al. 2015). The latter is a proposed set of targets that were discussed and developed by the United Nations (UN) during a UN conference in Rio de Janeiro 2012 (Rio+20). The proposal contains 17 goals with 169 targets covering a wide range of issues pertaining to sustainable development strategies. Some examples include the eradication of poverty and hunger, improving health and education and combating climate change. Some selected SDGs where soils and land play a fundamental role include the following:

- **SDG 1**: End poverty in all its forms everywhere
- **SDG 2**: End hunger, achieve food security and improved nutrition and promote sustainable agriculture
- **SDG 7**: Ensure access to affordable, reliable, sustainable and modern energy for all
- **SDG 15**: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

On a closer examination it can, however, be seen that some of these goals in themselves will place additional strain on soils. An example is SDG 2; “achieve food security” this implies that more food will have to be produced. This additional demand on soil and land resources raises further concern on the future sustainability of it.

When looking at a few numbers and statistics (see [www.fao.org/soils-2015](http://www.fao.org/soils-2015)) with regards to soils it is estimated that 33 % of the soil is degraded due to erosion, salinization, compaction, acidification, nutrient depletion and chemical pollution. These will all have a negative effect on soil functions which in turn will impact negatively on food production. From a Sub-Saharan viewpoint it is estimated that 83 % of rural people in Sub-Saharan Africa depend on land (soil) for their livelihood while 40 % of soils in Africa are currently degraded with little or no opportunity to expand the arable land.

Since 95% of food is produced in soil, ([www.fao.org/soils-2015](http://www.fao.org/soils-2015)) it gives an indication that if soils become compromised; so will food security. Soils are, however, not just a medium in which food is produced but also hosts a wide variety of organisms responsible for making all life in it possible. Typically, we’ll find
vertebrate animals, invertebrates (earthworms, nematodes, insects and mites) and microorganisms. The protection of soil biodiversity is of more importance since it is essential for ecosystem services, food security and nutrition.

Despite the fact that there is relatively an abundance of information on soils in the world, this unfortunately was not the case for Africa (and in particular Southern Africa). In 2010, the Director of the Earth Institute’s Tropical Agriculture and the Rural Environment Program (Pedro Sanchez) stated that “Soil is the source of all life. Yet we know more about soils of Mars than about soils of Africa”. This has, however, been addressed with the first ever African soil atlas that has seen the light in 2013. This innovative “Soil Atlas of Africa” aims to raise public awareness on the importance and key role of soils in Africa as a non-renewable resource essential to human existence. In so doing, it supports the development of protective measures to safeguard soils for current and future generations. The atlas compiles existing information on different soil types in easily understandable maps that cover the entire African continent. While it is intended primarily for the educational sectors and policy makers, the atlas aims to bridge the gap between soil science and the society at large.” This was a collaborative effort between soil scientist from Europe and Africa. An electronic version of this download is available on http://eusoils.jrc.ec.europa.eu/library/maps/africa_atlas/

3. Soil wastelands

Different human activities e.g. industry, mining and agriculture have caused soils to become polluted and turned into wastelands. In order to illustrate this brief overview from a global perspective, focus will be placed on soils in South Africa specifically. This due to the fact that although soil ecotoxicology is recognized and relatively a well-studied field in the United States and Europe but is not the case in Africa and Southern Africa. An example of how human activities directly influence other people negatively was illustrated in a study by Moreno et al. (2010) conducted in Mexico. These authors found that children living near gold and silver mines had elevated levels of metals in their blood and urine. This might lead to a range of health and mental developmental issues. In addition, Guillette et al. (1998) found that children exposed to pesticides exhibited decreased levels of stamina, 30-minute memory and did not have the ability to make a drawing of a person. This was in contrast to children not exposed to pesticides who fared better in all these endpoints measured.

South African (SA) soils, like those in the rest of the world, have become increasingly deteriorated due to anthropogenic activities (Maboeta et al. 2008, Eijsackers et al. 2014, van Coller-Myburgh et al. 2015). Important soil functions have, as a result, become completely or partially impaired (Eijsackers et al. 2006, Eijsackers 1998). Policy and soil management initiatives are needed to address this deterioration of our soils (Eijsackers et al. 2014). In order to succeed in doing this, stakeholders from the government, industry and research entities each have crucial roles to play (Eijsackers et al. 2006).
Mining is a vital industrial activity that significantly contributes to the economy of South Africa as well as to other countries where mining is performed. It has been stated that in developing countries, mining is regarded as the “engine of development” which contributes immensely to the gross domestic product (GDP) of these countries. This is not only unique to SA but also to other developing countries since most developed countries were once dependent on mining for their advancement by utilizing abundant mineral deposits which accelerated their industrialization.

3.1 Relevant aspects of mining for risk assessment
South African soils are typified as dry (annual average rainfall of 450 mm) and susceptible to degradation (Department of Environmental Affairs and Tourism DEAT 2006). Soils are heavily degraded due to biophysical and socio-economic factors (Hoffman and Todd 2000) e.g. grazing, cultivation practices and poverty. Mining is a key source of soil contamination in South Africa. In 2010 there were 1600 registered mines in SA (South African Chamber of Mines SACM 2011). It is estimated that over 418 million tonnes of hazardous wastes are generated in SA (1997/1998 estimates) with 90% originating from mining (Department of Environmental Affairs and Tourism DEAT 2006). Based on land cover, Fairbanks et al. (2000) estimated that South Africa has 4.9% degraded land, 1.1% urban/built-up land and 0.14 % (175 421 ha) mines and quarries. Although this seems a relatively limited area, however, the negative impact it exacts on the surroundings is enormous and un-accounted for. Twelve per cent of SA’s soil is arable (GCIS 2012) but the extent to which the mines and quarries affect it (the 12% of arable soil) is not known.

Mining operations are responsible for the creation of many anthropic soils i.e. soils physically modified by human activities (Fey 2010). These comprise of Anthrosols (which are several decades or centuries old) and Technosols (which have a more recent anthropogenic origin). Mining deposits and wastes fit into both categories. Few studies from southern Africa (or Africa in general) have focussed on the effects of mining on soil. Examples include effects of platinum mining in SA (Jubileus et al. 2013, Maboeta et al. 2008, Wahl et al. 2012) tailings dams in Zimbabwe (Meck 2013) and South Africa (Blight 2012). Soils in these areas are apparently not being considered a scarce resource as is the case with water (Eijssackers et al. 2006). Many human settlements in SA are located near mining tailings disposal facilities (TDFs) as illustrated in Figure 1; and in some cases as close as a few meters (Van Rensburg et al. 2009).
Map indicating the close proximity of residential areas (dotted line) to tailings disposal facilities (approximate scale 1:6 km). The example is of a small town (Welkom in the Free State Province of SA) with an area of ±210 km² and a population of ±211 000 people. (Eijsackers et al. 2014)

3.2 Legislation

South Africa is well positioned with legislation as regards to agriculture as well as land and water management. An example of this is the National Norms and Standards for the Remediation of Contaminated Land and Soil Quality in the Republic of South Africa (South Africa 2014) which is part of the National Environmental Waste Act (Act no. 59 of 2008). The purpose of this document is to:

“(a) provide a uniform national approach to determine the contamination status of an investigation area;

(b) limit uncertainties about the most appropriate criteria and method to apply in the assessment of contaminated land; and

(c) provide minimum standards for assessing necessary environmental protection measures for remediation activities.

Some definitions that I want to highlight in this document are:

"Soil Screening Value 1" means soil quality values that are protective of both human health and ecotoxicological risk for multi-exposure pathways, inclusive of contaminant migration to the water resource;
"Informal Residential" means an unplanned settlement on land which has not been zoned as a residential consisting mainly of makeshift structure not erected according to approved architectural plans;
and

"Standard Residential" means settlement that is formally zoned and serviced, and generally developed according to approved building plans, including land parcels such as plots or erven;

When we have a look at the proposed soil screening values (Table 1) it is obvious that there are glaring differences between the lowest protective level, “Soil screening value 1” [SSV1] (as regards to all land uses and protection of water sources) and even between informal residential and standard residential sites. In the case of copper (Cu), the lowest value is 16 mg/kg for SSV1 followed by 1100 mg for “informal residential” and 2300 mg/kg for “standard residential”. The same is true for nickel with values of 91 mg/kg, 620 mg/kg and 1200 mg/kg for these respective areas. From these values it can be assumed that the protection of water resources is of more critical concern to the SA government. Further, that the protection of soil is not as critical, since these values are much lower than values proposed by e.g. the Netherlands (Swartjes et al. 2012) e.g. 36 mg/kg for Cu (190 mg/kg; remediation intervention value) and 35 mg/kg for Ni (210 mg/kg; remediation intervention value). From these values it can also be considered that the guidelines assume that people from informal residential areas are spending more time outdoors and being exposed to contaminants to a greater extent. A word of caution would however, be, that children in e.g. kindergartens in standard residential areas also spend a fair amount of time outdoors playing in/on soil with these higher allowed levels of contamination.
In South Africa there are good policies in place which provide guidance to industry and other stakeholders as illustrated by these guidelines. The theoretical relationship between policy, science and research can be conceptually shown as three interconnected rotating disks (Figure 2). To be realized, intensive collaboration between policy, research and practice (industry), are needed and it must be understood that these sectors cannot function independently of each other. If one of these begins to move the others will (have to) follow. On this figure it can be seen that policy represents the largest circle with industry and research as two equally smaller ones. This gives an indication on how small movements by policy require faster action from science and industry. There is therefore, a need for policy and industry to be guided by research and vice versa. The connection between research is, however, “broken” since research does not influence policy (in the case of soil related research) as the case should be.
Currently, there exists a gap between legislation and practice of environmental protection in SA (Papu-Zamxaka et al. 2010). This has been illustrated by these authors using a case of mercury contamination in a rural area. It was concluded that contamination levels remain high; two decades after the original pollution incident took place.

Worldwide the training of soil ecotoxicologists is very good. This in terms of soil biology and –biochemistry, soil ecotoxicology also afford these candidates relatively good research and job opportunities. The same is, however, not the case for South Africa where most soil ecotoxicological research is done by zoologists (Haynes and Graham 2004). This research is usually done on the borders of the mainstream with results typically discussed from a European viewpoint. At present, my research group at the North-West University is the only (to the best of my knowledge and based on publications in peer-reviewed scientific journals) in South Africa doing soil ecotoxicological research. This in itself is a challenge but also puts the university in a position to exploit unique research opportunities.

4. Soil opportunities

4.1 Research

Based on the fact that soil is a great indispensable resource, and is threatened by various anthropogenic activities, it does create various opportunities in diverse perspectives which will be highlighted in the following section. These can be split up into three categories namely science, art and tourism. For the purpose of this paper the focus will be on the scientific aspect that is afforded by soil contamination.

Anthropogenic activities like mining and other industrial activities have increasingly deteriorated South African soils like in the rest of the world (Eijsackers et al. 2014, Maboeta and Fouché 2014). Mining contributes significantly to the gross domestic product (GDP) of numerous countries (as earlier stated).
Associated with mining is waste produced (tailings) i.e. the discard generated after beneficiation of mined ores. Discard is disposed of on tailings disposal facilities which cover large expand of land and contains high levels of metals and other contaminants. As previously stated, South Africa is well positioned with regards to environmental legislation. Policy dictates that mining companies are responsible for rehabilitating (revegetating) tailings disposal facilities however; this is only the ideal and not the practice.

Based on this, earthworms can be utilised as bioindicators to assess the potential risks that mining activities pose on the environment. Furthermore, is to provide baseline information in assisting rehabilitation specialist and environmental managers. This information enables them to make informed decisions as regards to the management and remediation of contaminated sites. The following will include examples of studies in which soil organisms are employed to assess soil contamination with a specific focus on mining activities. Mining operations that were focussed on in these studies were chromium, gold and platinum as well as a copper polluted industrial site.

Growth, reproduction and lysosomal membrane stability of earthworms have been shown to be sensitive endpoints to assess the ecological toxicity (ecotoxic) effects of mine tailings (van Coller-Myburgh et al. 2015). These indicators are effective tools in the assessment and management of these areas with regards to the effectiveness and success of the rehabilitation strategies. Studies have also shown that in future studies, standardised ecotoxicological tests could be used not only to assess rehabilitation success but also to determine if there are any differences between the ecotoxicity of gold tailings disposal facilities with different ages, as well as being rehabilitated vs. unrehabilitated (Jubileus et al. 2013). Studies like these and my own research will be of specific interest and international impact for countries like, e.g. China, Australia, US Russia, Peru and South Africa who are currently the top gold-producing countries. It is also important to critically review the current state of soil quality risk assessment in an attempt to highlight the shortcomings of European risk assessment schemes within a southern African context (Eijsackers et al. 2014). This should provide information on the current status of soil quality risk assessment procedures and how it could be utilised from a South African perspective. Because there are differences between the western countries and Africa, adaptations are needed to develop an “African contaminated sites risk assessment procedure”. A first step will be to highlight the shortcomings of current European risk assessment regimens within a South African context; i.e. highlighting the problem as a first step to solving it. When doing this it is clear that the majority of risk assessment systems have been developed in countries in the western world e.g. the United States, European Union, Canada and Australia. In South Africa, contamination origin, climate, soil types, lifestyle, culture and traditions differ from western countries. Suitable risk assessment systems should therefore be developed. Regarding ecological risk assessments, the major differences include the type of soil species, few earthworms but more termites and ants, the sensitivity of these organisms to pollutants and different climatic conditions. Moreover, bioavailability characteristics of mining-impacted
soils mentioned above also strongly impacts on ecological risks. It is recommended that several relevant exposure parameters must be adapted for South African conditions. Furthermore, the South African-specific Species Sensitivity Distribution must be developed, accounting for the sensitivity and exposure pathways of typical South African organisms as termites and ants to contamination exposures and different climatic and bioavailability characteristics.

Another opportunity with regards to soil pollution is to critically evaluate the legislative soil screening values proposed in South Africa and how it relates to real-world levels of metal pollution. This, by utilising standardised ecotoxicological assessments with earthworms. As mentioned earlier; the purpose of these values (guidelines) is to, amongst others; provide benchmarks to determine the contamination status of investigation areas. These soil screening values enables soil assessment, but they lack a clear risk-based scientific foundation. To exemplify this, a copper manufacturing industry site was investigated (Maboeta and Fouché 2014). Copper concentrations were measured and compared to these legislative screening values proposed. Specific objectives included determining growth, reproductive success, mortality and a biomarker (neutral red retention assay) of *Eisenia andrei*. It was shown that this Cu manufacturing industry had an effect on the immediate soil environment. The effect of Cu concentration on soil was ten times less in an area 500 m away from the point-source, with no effect at 5 km. However, organismal and biomarker responses exhibited adverse effects at the point-source and 500 m distant sites, despite the fact that soil Cu concentrations were within their respective norms. It was concluded that this warrants further investigation into how these benchmarks relate to real-world levels and ecotoxicological assessments.

Utilising enchytraeids (mortality and reproduction) to assess mine tailings ecotoxicity is a relatively new assessment used in South Africa (Otomo et al. 2014, Otomo et al. 2013). Results show that this could be a quick tool for the assessment of the ecotoxicity of metal contaminated soils. In emerging economies such as South Africa, this bioassay could be an affordable way of assigning relative intervention values for the remediation of soils. This bioassay is being further used in conjunction with earthworm bioassays to investigate how it might be a tool for environmental managers and mine rehabilitation specialist. This will enable them to make informed, quick and relatively cheap management decisions and work done in the laboratory would have an industry impact.

### 4.2 Tourism and art

Sites that were negatively impacted by human activities can also have touristic opportunities. Examples of these include the “Big Hole” in Kimberley which is the result of diamond mining from approximately 1871 – 1914. The resultant hole has a depth of over 200 metres and a perimeter of over 1.5 km. It has been developed into a world-class tourist attraction. Further examples include Chernobyl (Ukraine) and Fukushima (Japan) which are both sites where nuclear accidents took place and are now open to be visited
by the public as tourist attractions. Moreover, soil has also been the inspiration for artist like Verena Reinmann from Germany who creates artwork made exclusively with sand and soil (http://www.verena-reinmann.de) having been exhibited at major galleries and United Nations initiatives. Contaminated sites and mining tailings disposal facilities have also been artistic inspiration for artist like Jason Larkin (http://jasonlarkin.co.uk/). He published a photographic legacy of mine dumps in the Johannesburg area and how these areas form an integral part of people living close to it. In this work he “explores these tailings as an integrated extension of the thriving metropolis that surrounds them”. Giving the viewer an insight on how integral to society the “toxic monuments” have become. To such an extent that to the observer and inhabitants of these areas, it seems normal and not even noticed.

5. Conclusions
Considering the effects of mining on soil worldwide and in particular South Africa it is evident that studying these impacts is extremely important. This, in the light of soil being a living entity which should be treated as such. It is paramount that scientific research on soils should be accessible to politicians and policy makers who will ultimately guide role players from industry with regards to soil protection. As such, marketing of soil and its protection is important. Soil is a wasteland of opportunities as was illustrated in the preceding sections which includes scientific research, tourism and art.
6. References


