Environ Dev Sustain (2015) 17:1045–1063
DOI 10.1007/s10668-014-9589-7

An assessment of the impacts of acid mine drainage on socio-economic development in the Witwatersrand: South Africa

Suvania Naidoo

Received: 11 November 2013 / Accepted: 25 September 2014 / Published online: 6 November 2014

Abstract For more than a century, the mining sector has played a crucial role in the economic development of South Africa. However, it also causes immense harm to the country's people and environment. Gold and coal mining have serious implications for water management. The problem arises when contaminated water in the form of acid mine drainage (AMD) reaches the river basin systems and affects water usages important for socio-economic development. This article looks at the impacts of AMD on different constituencies in the Witwatersrand Basin for the South African society and on sustainable socio-economic development. It includes different responses by the media, civil society, scientists and Government on AMD, how they interpret AMD and its effects on socio-economic development.

Keywords Water · Acid mine drainage · Socio-economic development · Sustainable development · South Africa

1 Introduction

Water is the most vital resource essential for the survival and the growth of human beings and natural systems (Prasad 2003). 'Access to clean water is universally accepted to be a precondition for economic and social development' (Oelofse et al. 2007: 4). We are aware that in many parts of the world today, a large segment of the development challenges leads to ongoing conflict—especially in the developing world—which is motivated by a quest for secure access to clean water. Without access to clean water, poverty prevails in the developing world because the health status of many people and food systems are continuously and negatively affected by it.

S. Naidoo (✉)
Department of Development Studies, UNISA, P.O. Box 392, Pretoria 0003, South Africa
e-mail: naidos@unisa.ac.za

Sustainable development is a 'dynamic concept' and widely debated; it is a term that is of utmost importance for human beings and our environment. For the purpose of this discussion, a sustainable development approach is selected in which development is continuous and which increases the well-being of life over a long period of time. The overall objective of sustainable development is to increase the well-being of an ecosystem (humans and the natural environment) over time (United Nations 2008: 20). According to the United Nations (2008: 20), 'simply being sustainable does not make a development path desirable. It also matters whether it is the sort of development path that society wants to follow and this depends on what determines well-being for its members'. According to section 24 of the Constitution of the Republic of South Africa, 1996 (Act 108 of 1996) (the Constitution): 'Everyone has the right—(a) to an environment that is not harmful to their health and well-being and (b) to have the environment protected, for the benefit of present and future generations'.

Thus, the dynamic nature of sustainable development stems from its ability to ensure that the well-being of current and future generations requires protection of the environment and the earth's resources. However, there are endless possibilities for changes to occur that could negatively affect the environment and this could hamper with the aims of sustainable development to ensure that current and future generations have access to resources. Acid mine drainage (AMD) is one example of interference with the aims of sustainable development by harming our already scarce water resources. Thus, there must be processes in place to address such negative impacts immediately before they cause everlasting harm.

Water is universally acknowledged as a scarce resource, and its scarcity is increasing (WWF 2008). Acid mine drainage (AMD) was first identified in 1556 by Diego Delgado, who reported on the state of mining in the Rio Tinto district and found that iron placed in a river dissolves in a few days. He discovered that both aquatic life and human beings were negatively affected by it (Liefferink 2012). Despite the very early establishment of AMD and the serious impacts it can have, it is a relatively new phenomenon to the South African public, and they have only become increasingly aware of the implications since 2002. AMD has been prevalent in many mining countries, and it has already put South African water systems under severe stress (Mariette Liefferink, interview 4 April 2013). AMD has been described by some as 'the single most significant threat to the environment' (Ochieng et al. 2010: 3352) which is a result of derelict or abandoned mines.

Despite the negativity surrounding mining activities, the mining industry remains a significant economic sector in South Africa. The country is known for its mineral resources and has been responsible for significant proportions of world production and reserves (Mbendi 2012). South African mining companies are therefore essential role players in the global industry (Kearny 2012) with the industry being described as the 'bedrock of Africa's economic powerhouse' (GCIS 2010: 366). Almost all the provinces in South Africa are likely to be affected by AMD, except for the Western and the Eastern Cape (Guedes 2010: 69). Historically, most of the gold mining occurred in the Gauteng province (and especially in the Witwatersrand's Western, Central and Eastern Basins) where 'the AMD sources sat atop the continental watershed, the waters of which ultimately drained into the Vaal, Orange and Limpopo rivers' (Esterhuizen 2012).

The South African Department of Water Affairs has spent more than R120 million over the last decade to investigate and clean up the historic pollution caused by abandoned and liquidated mines (Department of Water Affairs 2011). What is concerning is that this amount is not nearly close to what is required to cover overall costs. The interconnectedness of underground mine workings associated with different mining companies increases the liabilities associated with AMD.

In response to this emerging crisis, the South African Government appointed an Inter-Ministerial Committee (IMC) in 2010 to investigate AMD and propose policy options. In the same year, a report (Coetzee et al. 2010) was submitted to the IMC by an advisory team of experts. There are also various role players involved with the AMD phenomenon. We have the mining sector, government, consultants (NGOs, civil society and activists) and the media. Each of these role players has different views on AMD and each approaches the issue from different perspectives.

On the one hand, we have the mining industry which is largely responsible for the intense debates and issues surrounding AMD today, including the abandoned mines from decades ago have caused the effects and current mining companies now have to abide by laws and principles—which have been in place for a long period already—to ensure that they take responsibility for any damage caused. On the other hand, we have the government who is dependent on the mining industry for the economic wealth that it is has brought to South Africa and its significant contributions to the gross domestic product (GDP). However, at the same time, it has caused immense harm to the environment and has delayed our aims towards a sustainable future. At present, the government needs to act at a rapid pace to clean up the damage. We also have consultants who include experts and advisors on how the environment should be cared for and who are fighting for a sustainable way forward that includes mending the damages caused. They are also taking the needs and health of people into account, by making the public aware of the impacts that AMD already has, and can have on socio-economic development. Lastly, we have the media, who are alerting the public on the impacts and severity of AMD.

The fact remains that all these role players have the same goal in mind and that is to address this issue. The problem that occurs is that there is no 'team effort', and each one wants to raise awareness about the issue on their own—by attributing blame to whom they find responsible—rather than by following a 'working together' approach. This article discusses the various views on AMD and its impacts, and it looks at the current situation and lastly discusses an approach that could be followed as a way forward so that South Africa remains in line with the aim towards a sustainable future.

2 Methodology

This research followed a qualitative design; key informants were selected due to their expert knowledge on the topic. These participants were identified and were asked to be interviewed; they included: government representatives, private sector (mining) representatives, consultants (NGOs and activists) and Tourism and the Agricultural industry officials. The participants were not selected on the basis that they are representative of, or specifically attached to, the main groups of role players in this study (i.e. mining sector, government, consultants and the media). They were identified for their ability to provide substantial qualitative information that enhances the understanding of the different groups of role players in the AMD debate. Face-to-face interviews were conducted with each of the participants. The interview questions were designed based on their role in the AMD debate, or their knowledge of it, and what role they or their department play[s] in addressing this issue. Media reports and official policy documents formed a vital source of information for this study. The use of qualitative methods was to measure the quality of the information found. This allowed for assuring the reliability and validity of information based on the media reports and official policy documents in comparison with that of the interviews.

The participants who were selected for this study are often quoted in media reports on the most recent developments on AMD and the areas affected, as well as being part of the teams compiling official policy documents on AMD. These participants were found to be useful for this study due to their knowledge of AMD and their inputs in addressing the issue.

3 Geographic location of mining in South Africa and the Vaal water management

For the purpose of this study, a map has been included to illustrate the mining activity in South Africa. Most of the mining activity takes place in the Gauteng Province, followed by the North West, Mpumalanga, Limpopo and Northern Free State. The economic activities especially in Gauteng and in the traditional mining areas are the cause of serious deterioration of the water quality in the Vaal River. For more than a century already, this river system is the most crucial water source for human life, agriculture, industry, aquaculture and an entire aquatic ecosystem (Cele 2009).

The Vaal River system originates in the eastern Highveld plains, in the Ermelo area. Shallow hollows and low hillocks form a natural sponge where water collects in pans, vleis and streams. These streams link up and the Vaal River is born, flowing westward on a long course, without rapids or waterfalls, broadening into a large river' (Rand Water 2012). The Vaal Dam is the most important dam and the primary supplier of water to Gauteng as the 'economic heartland of South Africa' (Rand Water 2012). Below are two maps: firstly an overall view of all three basins in the Vaal River system and secondly a map of the Upper Vaal Management Water Area 8 which is this article's main area of focus (Figs. 2, 3).

4 Acid mine drainage

AMD affects several of the provinces in South Africa, which include Gauteng, Mpumalanga, North West and the Free State. Its potential threat to the Johannesburg CBD and other economic and population centres have become clearer in the last few years (Guedes 2010: 69); however, after several expert interviews (Turton 2013; Nienaber 2013; Govender 2013; Mills 2013), it became clear that AMD's potential threat has alarmed the public without providing them with information about the advancements already made, and how the issue can be addressed. The exact extent of the phenomenon is, however, a matter of serious debate amongst the South African scientists (Shanna Nienaber, interview 12 March 2013).

AMD is a major environmental problem relating to mining in many parts of the world, because it involves uncontrolled discharge of contaminated water from mostly abandoned mines. It is, however, not the only manifestation of acid mine drainage. AMD is characterised by low pH (high acidity) and high salinity levels in the water emerging from underground as well as surface water polluted by mine waste (Oelofse 2008: 1; Turton, interview 24 April 2013). AMD's surface and groundwater pollution is responsible for the degradation of soil quality, aquatic habitats and for allowing heavy metals to seep into the environment. The South African Government's view is that 'an exacerbating characteristic of AMD is its persistence—it is extremely difficult to rectify' (Oelofse 2008: 1).

It is important to note that the general public's view of AMD—i.e. that it is only about underground acidic mine water contaminating surface water—does not encapsulate all its manifestations. What happens above the mine shafts with the mine waste is also very

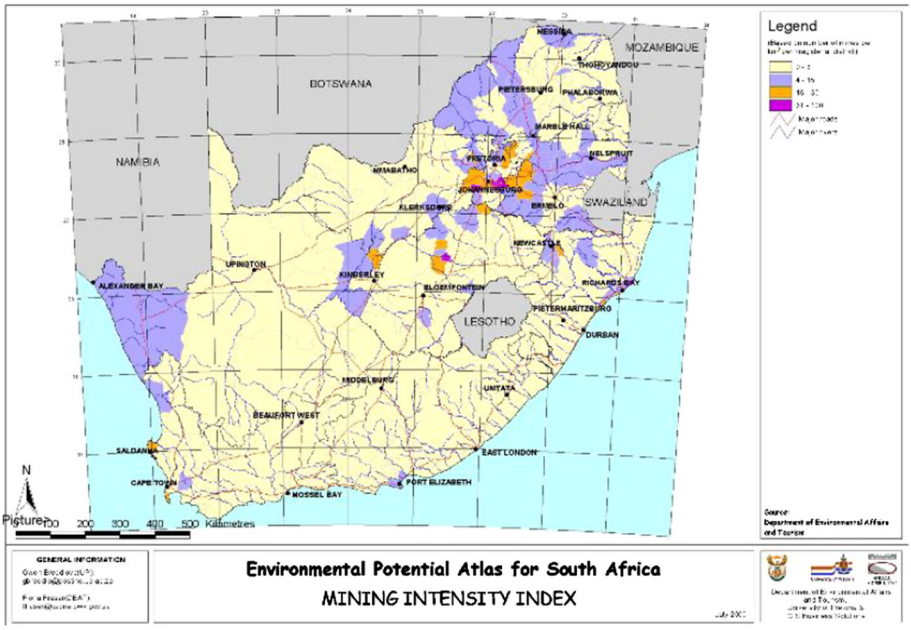

Fig. 1 Location of mining activities in South Africa (*Source* Department of Environmental Affairs and Tourism, University of Pretoria, and GIS Business Solutions)

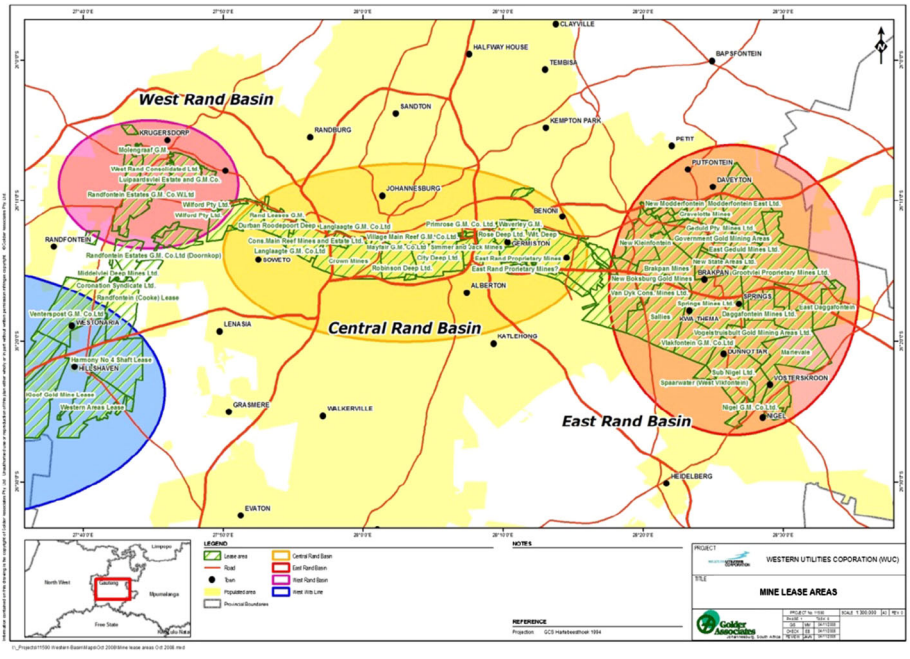

Fig. 2 The Western, Eastern and Central Basins in the Witwatersrand where AMD occurs (*Source* Liefferink 2012)

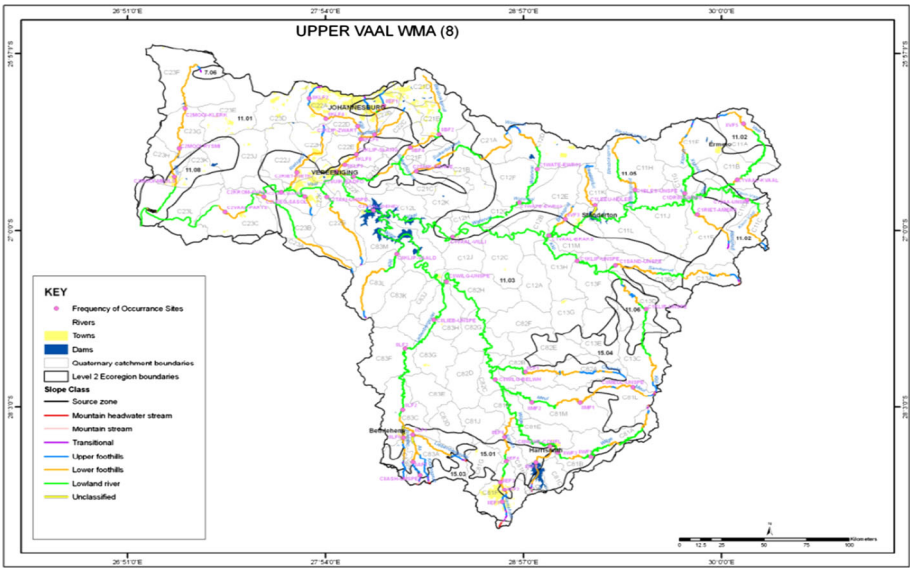

Fig. 3 Map of the Upper Vaal Management Water Area 8 (*Source* Department of Water Affairs)

relevant. In 2007, Oelofse et al. had observed that 'AMD probably presents the single most important factor dealing with tailings and waste rock and their impact on the environment' (Oelofse et al. 2007: 2). Turton and Liefferink are increasingly drawing attention to this aspect of AMD which is discussed in the next section.

In South Africa, the problem tends to be increasingly common in several parts of the Witwatersrand goldfields and the Highveld coalfields in Mpumalanga close to Middelburg and Witbank (Coetzee et al. 2010: v). In 2008, one of the Government Departments affected by it made the following observation about the Western Basin:

> Decant has subsequently been manifested at various mine shafts and diffuse surface seeps in the area. Up until early-2005, and completion of storage and pumping facilities to contain and manage an average of 15 ML/d of decant, the AMD found its way into an adjoining natural water course and flowed northward through a game reserve, and towards the Cradle of Humankind World Heritage Site (Oelofse 2008: 2).

5 How AMD is viewed among the various actors

The definition of AMD in South Africa is very important, because it largely determines how the phenomenon is assessed. A narrow definition that concentrates on a specific aspect can be restricted or confined and is easier to address. A definition broader in its scope that includes more complex phenomena is obviously more difficult to address. Therefore, if a spokesperson claims that AMD in South Africa is under control, it often depends on how they define AMD in that case. Two broad categories of definitions are used: one that concentrates on underground mine water that turns acidic and then decants at the surface to contaminate surface water systems, and the second category that in addition to the underground water includes radioactive acid water formed by the impact of acid rain on

tailing dams which involves a limited radioactive response. These categories are broadly associated with the South African government's definition in the first instance and civil society activists', researchers' and consultants' in the second instance. After comparing the different definitions of AMD, one can form a better understanding of how this issue has become the emergency it is today.

The definitions that look at AMD from a broad perspective are first discussed and are mainly associated with researchers and consultants like Tony Turton or activists like Mariette Liefferink. Tony Turton is a political scientist who specialises in transboundary water resource management. According to him, there are a number of different acid forming processes but all involve similar chemical elements, these include acid rock drainage and acid mine drainage. Another distinction can be made between surface manifestations and subsurface manifestations which are all caused by the oxidation of pyrite which produces acid in the presence of oxygen and bacteria. The necessary condition for this to occur is a minimum acid level of pH5. Thus, in summary, according to Turton, AMD is defined as 'water that is acidic arising from the oxidisation of pyrite, below pH5' (Tony Turton, interview 24 April 2013) and thereby referring to the aspect of AMD that most stakeholders have reached consensus about.

The next element of AMD is quite controversial and is seldom referred to by government representatives and thus not included by them in the AMD debate. It affects Mine Residue Areas (MRAs) on the surface where the fine sludge or residue of the crushed mine rocks are stored in tailing dams (or popularly known as mine dumps). According to Turton, if there is an acid level below a pH5, when acid rain comes into contact with the mine dust on the tailing dams, there will be a 'mobilisation of uranium' which does not happen above pH5. Thus, pH5 is a useful defining threshold especially in the Witwatersrand goldfields for both forms of AMD. This conclusion about the catalyst effect of acid rain, according to Turton, was the result of the latest research on the chemistry of AMD and the formation of acid. We are now seeing rainfall with a pH of as low as 3 in the Vaal River system and acidic rain falling on top of mine dumps triggers the initial formation of acid, which drops the pH and then triggers the second phase. Turton is one of the first people to accentuate the importance of acid rain for AMD, with the implication that even if the underground formation of acid water can be reduced or terminated, it will not be the end of AMD in South Africa. Unfortunately, the South African public and media are largely uninformed about this phenomenon (Tony Turton, interview 24 April 2013).

Mariette Liefferink is an environmental activist of the Federation for a Sustainable Environment (FSE) who provides services to communities and addresses the injustices regarding the environment such as AMD. Liefferink's main focus is on radioactivity which overlaps with Turton's linkage of acid rain to AMD. She states that the gold mining industry in South Africa is in decline, and therefore, an increasing number of mines are decommissioned. As a consequence, the risks of AMD are increasing, because mining companies are no longer able to take responsibility for managing the underground water and the tailing dams. In her view, AMD after the closure of mines is an enormous threat and could become more severe if remedial activities are not implemented as soon as possible (Mariette Liefferink, interview 4 April 2013).

In a media report, Liefferink highlights that 'it is unbelievable that the mine is only legally required to neutralise about a third of the mine water that it pumps out, they spend millions on the process yet it's not an optimal solution' (Ho 2011). She adds that government should immediately start the process of desalination of the water by removing the sulphites, so it can be used for potable water and irrigation. She also mentions that the situation in the Western Basin 'is not an emergency, it is a disaster' (Jordan 2012: 10).

In another media report, according to Liefferink, waste from gold mines constitutes the single biggest source of waste and pollution in South Africa and AMD is responsible for the most costly environmental and socio-economic impacts. According to her, mining companies believe that blame cannot be attributed to them, as there have been a large number of companies involved in mining in the Witwatersrand since the 1880s but many of them are no longer in existence (in Yende 2012). However, she states that AMD can continue for years to come after mines have been closed and tailings dams decommissioned. Her campaign warns the public against long-term exposure to AMD-polluted drinking water that can pose a threat to human health in the form of increased rates of cancer, decreased cognitive functions and the appearance of skin lesions. Heavy metals in drinking water can also compromise the neural development of the foetus which can lead to mental retardation (Liefferink 2012). Liefferink's definition, underlying her description of AMD implications, is therefore very similar to Turton's, except that she concentrates more on the radioactive dimension while he considers it as less prominent and therefore also posing less of a threat to the environment.

The next two persons work in the sphere of Government. Their definition of AMD is markedly different from Turton's and Liefferink's and can explain why the official view of the current state of AMD is less alarming. Bashan Govender from the Department of Water Affairs (interview 25 February 2013) explained how AMD is formed. He follows the conventional approach about how mine water becomes acidic. According to Govender, in gold mines, the iron sulphide reacts when it comes into contact with oxygen and water and produces very acidic water. This water then dissolves other metal salts in the mines and when this water decants on the surface it constitutes AMD. Due to the dissolving of salts (which results in high saline levels) and the high acid levels, it leads to a low pH level which will not sustain any aquatic life, and when it reaches the natural environment, it will disrupt plant life. Govender added that since the late 1990s many mines closed down in Gauteng because of the economic downturn and a decline in gold as a commodity. These closures meant that the water in the mines was left to rise to the surface without any management of its possible consequences (Bashan Govender, interview 25 February 2013). It is clear that this definition and discussion of AMD do not include any reference to the problems caused by tailing dams and acid rain, and thus their contribution to AMD. Therefore, it is confined to underground mine water and how the decanting should be managed.

Peter Kelly from the Gauteng provincial Department of Mineral Resources follows the same approach as Govender, because he also concentrates on underground mine water and how it can affect surface water systems. He explains how evident it is that water decanting from the mines is acidic and generally polluted, because when it comes into contact with the surface water you can see the iron particles which is bright red in colour (interview 6 March 2013). He also does not refer to the systemic problems caused on the surface by tailing dams and the complication of acid rain for AMD.

The opinions of other actors about the current state of AMD differ substantially and provide some indication of the diverse nature of the AMD debate. Environmental activist Dr Koos Pretorius (in Yende 2012) indicated that acid levels above acceptable quantities for human consumption have already been recorded in the Witbank and Middelburg dams. The entire region could become a 'total wasteland once the coal reserves have been fully exploited and mining has ceased (Yende 2012). Underground and river water will be undrinkable and aquatic life will be reduced to a minimum as has been the case in parts of Witbank already.' It was also evident in 2012 that the costs of water purification will be very high and these costs will be incurred by the state (Yende 2012).

Prof Frank Winde from the North West University is more optimistic. In his view, there is a large range of possibilities to explore in treating decanting mine water (in Wait 2012b). However, he is frustrated by the fact that the mining industry and Government have had enough time to search for a solution for AMD in the Central Basin, because several warnings about it have been reported over the last couple of years. This means that the issue was not treated as severe and should it become uncontrollable then it is due to Government not putting it at the forefront of the agenda.

One of the most important actors is the mining industry and the question of its liability for the environmental rehabilitation is a major point of debate. Stephinah Mudau from the Chamber of Mines (in Wait 2012b; Stephinah Mudau, interview 19 March 2013) stated in 2012 and repeated it in 2013 that the state should manage AMD and the environmental impacts of previous mining operations caused by ownerless and derelict mines that are responsible for AMD concerns today. Like most opinions on this matter, no timeframes are provided regarding the government's ostensible responsibility.

The last actor to mention is the media. The media is arguably the most important public medium to conscientise the public about AMD and to provide a platform for the public to report on its societal impact. It is therefore important to determine whether the media concentrates mainly on individual cases, on the technical aspects of AMD or also on its socio-economic impacts. Masondo et al. 2011 (in *The Times*) describes AMD as 'a ticking time bomb beneath the country's richest province.' Christine Leonardi (2011: 2) states that 'mining companies shouldn't believe that they can duck legal action against them when it comes to AMD' because it is a complicated situation. The *City Press* (Yende 2012) reported on one of the cases of AMD that has had severe impacts on local communities. Carolina (in Mpumalanga province) residents near the coal mining fields did not have access to clean tap water for months, because of AMD and the water being contaminated with chemicals such as sulphate, aluminium, chromium, manganese, cobalt, lead, zinc, copper and nickel. If the affected water is consumed, it is expected to cause chronic health problems for residents.

The current situation regarding a search for solutions is receiving much more attention in the media than in the past. An indication of the popular attention given to it is the fact that for more than a month every evening in September 2012, the SABC3 television soap opera that depicts the reality of South Africans' lives, *Isidingo*, concentrated on the perceived social and health consequences of AMD.

A recurring theme in the media is the responsibility of the mining sector in dealing with AMD. Related to this is the emphasis on early warnings that were not beheaded by both the Government and the mining sector. In the specialised mining publication *Mining Weekly,* the focus was on the opinion that 'South African mining companies are not fulfilling their obligations to set aside money for the clean-up operations for mines before they are officially closed' (Wait 2012a). This particular media response highlights the continuous concerns of environmental degradation in the mining areas, stating that the large number of ownerless and abandoned mines and incidences of AMD have shown that there is a need for improved environmental maintenance and rehabilitation in the mining sector (Wait 2012a).

'While jobs and revenue generated by mining are essential to the South African economy, the costs of mining borne by the environment, mine neighbours, downstream water users and the taxpayer are an unacceptable consequence of a poorly managed sector' (Wait 2012a). Thus, the economic significance of mining is accentuated, but at the same time the cost to the environment should be calculated. It was estimated that it will require R2 billion to deal with AMD in the Witwatersrand Basin (Wait 2012a).

An urgent concern is the prediction that from 2015 the quantity levels of Gauteng's acid mine water will exceed the Vaal River's ability to absorb it for safe human use (Esterhuizen 2012). On a positive note, it is stated that it also provided a potential solution to water problems. 'Treating AMD could help to relieve this water shortage. It could also create opportunities for users, such as Eskom (electricity), mining companies and agricultural users that are short of water' (Esterhuizen 2012). Overall, the problem largely remains that the AMD issue has not been addressed fully and partly misunderstood from the time it became a concern.

In summary, the socio-economic dimension of AMD is clearly less emphasised in the media than the environmental quality of water and its business relevance for current and former mining companies. Its impact especially on human security receives far less attention than what can be expected. Part of the explanation is because it is reduced by most of the media reports to a matter between the Government and mining companies while its social impact is regarded as of secondary importance. Only activists like Liefferink succeed in drawing some media attention to some of the socio-economic aspects that can exist.

6 Policy on mine closure and water usage

Legacies of mining activities in South Africa are faced with legal and financial responsibility to address the water-related impacts of many abandoned and ownerless mines (DWAF 2008a: 5). In the past, these mining companies have never been required to take on the legal liability for the damages caused (Fig. 2011: 313). It, however, remains extremely difficult to allocate the proportion of damage for which each mining company is responsible, given the fact that these companies are no longer in existence. According to the national department responsible for water affairs, there should be legally binding processes to be adhered to when a mine closes. When it closes, there should be assurance that the mine has a plan to implement, sustain, protect and preserve the water quality and quantity upstream and downstream of the mine after mine closure, and that those who are dependent on that water are identified and protected (DWAF 2008a: 5).

Several policies are significant for this study, but AMD has emerged as a serious issue, because these policy stipulations and the legal framework are not complied with in reality. The following are important National Acts that have some consequences for AMD:

1. The National Water Act (NWA) (Act 36 of 1998)
2. The National Environmental Management Act (NEMA) (Act 107 of 1998a)
3. The Minerals and Petroleum Resources Development Act (MRPDA) (Act 28 of 2002), as amended.

The NWA, which was administered by Department of Water Affairs and Forestry (now called the Department of Water Affairs [DWA]) is the principal Act that governs water resource management in South Africa. This stipulates that those who are responsible for producing, allowing or causing pollution should be held liable for the costs of clean-up and the legal enforcement.

Bashan Govender from the DWA (personal interview, 2013) stated there was a twofold governance approach to how the state had reacted to AMD. The first was that mining companies were regarded as accountable and should therefore solve the problems of AMD on their own. The second approach was that government has, since approval of the MRPDA in 2002, been the custodian of water resources and water in South Africa, and

therefore, water resources could not be owned privately by anyone. He added that water in this country belonged to the state and therefore to the people of South Africa. Government was just the caretaker on behalf of the state and had to protect the water resources and should intervene to deal with AMD in keeping the water clean. In accordance with the NWA, the minister had to take responsibility to ensure protection of, and access to, water resources (RSA 1998a).

The Trans Caledon Tunnel Authority (TCTA) is an important implementation instrument of the NWA and has also become directly involved with the AMD issue. It is a state-owned entity providing advisory support to the DWA on the AMD project that has been implemented since 2010 (Govender, personal interview, 2013).

The NWA states that sustainability and equity are central guiding principles in the protection, use, development, conservation, management and control of water resources. These principles recognise the basic human needs of present and future generations, the need to protect water resources, the need to promote social and economic development through the use of water, and the need to establish suitable institutions in order to achieve the purpose of the Act (RSA 1998a). National government, through the Minister of Water Affairs, is responsible for achieving the principles of this Act on behalf of the nation. The minister, thus, has ultimate responsibility for fulfilling certain obligations relating to the use, allocation and protection of, and access to, water resources (RSA 1998a).

Mining legislation in South Africa has existed for many years, and the MPRDA include very specific requirements for mine closure (RSA 2002). One of the main objectives of the MPRDA that is related to this study is to

> give effect to section 24 of the Constitution by ensuring that the nation's mineral and petroleum resources are developed in an orderly and ecologically sustainable manner while promoting justifiable social and economic development; and ensure that holders of mining and production rights contribute towards the socio-economic development of the areas in which they are operating (RSA 2002).

According to section 39 (3)(b)(i–ii) of the Act, which deals with the environmental management programme and environmental management plan, an environmental impact assessment (EIA) must be conducted within 180 days of the date on which he or she is notified by the Regional Manager to do so (RSA 2002). However, in the latest amendment of the MRPDA, this requirement has been relaxed.

The NEMA contains certain principles in section 2 that are applicable throughout the country. It must serve as a general framework within which environmental management and implementation plans must be formulated regarding the protection of the environment (DWAF 2008a: 41–42).

These laws and principles have been around for years and the legislation that governed the mining sector remained the same, even when changes were made in government departments. The major concern then is why there is such a crisis and why is there so much uncertainty about who is responsible for the clean-up and the extensive costs regarding AMD. The fact remains that irrespective of what the law stipulates and what government's role is as the trustee of natural resources—water and minerals—the problem of AMD and its effect on the water resources and the environment have become a factual reality.

Fig (2011: 312) states that mining has always been relieved from the environmental impact assessment requirement. Whereas, it is compulsory in other industries to obtain an environmental impact assessment for any new project, in the mining industry, there is an environmental reporting system that is managed by the Department of Mineral Resources and mining is not open to a more rigorous regulation by the Department of Environmental

Affairs. Thus, there is a serious shortfall in these systems, because they only control individual sites and do not examine the accumulated impacts on a region of new development (Fig 2011: 312).

According to Fig (2011: 312), post-apartheid governments had observed a common interest between the political elite and the mining industry, and instead of pushing for a balance between growing the economy and protecting the environment, the new laws try to magnify opportunities for new entrants in the mining industry to address the racial economic inequalities of the past, with environmental protection being perceived as a barrier to these opportunities.

Being aware of the evolution of water governance and AMD management in South Africa allows one to understand the problem that the state faces in being able to manage liabilities and successfully implement new legislation. According to Hobbs et al. (2008: 422), in the cases of mines that closed in the period 1976–1986, the state and the mine owners have to share the responsibility of the post-mine closure costs. However, in the case of the mines that closed after 1986, their owners would remain responsible for all post-mine closure costs. Thus, mine owners had to comply with the environmental management programme for mines that were closed, taking into account the effects that their mining activities have had on the environment (Hobbs et al. 2008: 422).

As a representative body of the mine companies, the Chamber of Mines is a key role player in ensuring that the mining sector is properly governed. Stephinah Mudau (personal interview, 2013) said that the Chamber of Mines did not allow mines to be granted a licence if the mine was not sustainable or justifiable. She said that the laws that were now in place made that industry sustainable and that the Chamber was already promoting sustainable development in all its operations.

Peter Kelly from the Gauteng Department of Mineral Resources (personal interview, 2013) is of the opinion that government should in general support the mining industry but should become directly involved only when the mines do not have a big enough rehabilitation fund.

7 Current issues with AMD

According to Hobbs et al. (2008: 417), AMD is one of the largest liabilities of the mining industry due to its potential threat to South African water resources, human health and the environment. According to Cobbing (2008: 452), the debate about AMD issues is whether the main focus should be on 'the immediate technical or financial challenges, [or] rather in the domain of institutional cooperation, planning and coordination'? These institutions include national government departments, research councils, municipalities as well as private sector consultancies and mining houses.

Policy and legislation in the form of the Mineral and Petroleum Resources Development Act (MPRDA) of 2002 has been implemented by Government to address mine water management. This obliges the mining industry to conform to new regulations, which is not often the case. At the same time, new technological innovations to manage AMD are being developed—and the national Department of Science and Technology attends government meetings together with the private company Aurecon in assessing their viability for the South African conditions (Shanna Nienaber, interview 12 March 2013).

Since 2002, AMD has been active in the Western Basin where extensive pumping from a number of mine shafts has recently successfully curbed the decant. The exceptionally wet rain seasons of 2010 and 2011 and again in 2014 have complicated

management of the rising mine water levels and have created an unusual sense of crisis (Peter Mills, interview 20 February 2013; Bashan Govender, interview 25 February 2013). Various interventions together with a more normal season in 2012 have curbed AMD and created a more positive outlook. The Inter-Ministerial Committee report (in Coetzee et al. 2010) was of the opinion that there is time to address the issues and that appropriate decisions about mine water, its potential impacts, management strategies and treatment technologies in the Witwatersrand goldfields could be made. The areas affected by AMD include the following: Witwatersrand goldfield, the Mpumalanga (Carolina) and KwaZulu-Natal coalfields, and the O'Kiep Copper District. The Western, Eastern and Central Basins of the Witwatersrand and Highveld are regarded as priority areas that need immediate action. Below specific cases in the Western and Central Basins are discussed in more detail.

AMD near Krugersdorp in the Western Basin has become well-known in recent years. When the last gold mine in the area stopped underground operations in 1998, dewatering pumps were switched off and the natural regional groundwater levels started to reach levels last seen many decades ago. There is strong evidence that inputs such as sewage waste also contributed towards a deteriorating regional water quality (Cobbing 2008).

In 2005, the media focused attention on the West Rand Basin. There were reports that 'South Africa's renowned Cradle of Humankind in Gauteng, home to one of the world's richest hominid fossil sites, is under threat from highly acidic water pollution and is also threatening to drown the Sterkfontein caves' (Cobbing 2008). The newspaper columnist Hamilton (2011: 14) commented that the West Rand and the area around the Cradle of Humankind which was once 'our pristine waterways of the Witwatersrand' is now extremely acidic and hopelessly polluted, with the damage increasing daily. On the other hand, the scientist Peter Mills from the Cradle of Humankind Management Authority (interview 20 February 2013) acknowledged that there are visible effects but the impacts are on the surface because of a rise in the water table at the Cradle. According to Mills, the high rainfall seasons in 2010 and 2011 had been partly responsible for this, but that the water table has become constant thereafter. He also stated that the fossils in the caves are not damaged by the water and that tourism is not affected and is in actual fact increasing.

The residents in the Krugersdorp area who are reliant on borehole water are affected by the mine water decanting. They have raised concerns about the 'orange colour of water' that is the result of sulphur compounds present in AMD (Oelofse et al. 2007: 6). Peter Mills (interview 20 February 2013) demonstrated that since the 2010/2011 rainy seasons, the situation has stabilised in the area and that the quality of water has improved but that it is not yet suitable for drinking water.

Differences of opinion—among the various role players—exist about the water quality since the decanting that started in 2002 has been arrested. The Krugersdorp Nature Reserve, downstream of the AMD source and specifically the hippo dam in the Tweelopiespruit, is the focus of attention. According to Ho (2011) and Liefferink (in Barnard 2012), since 2002 the water in the Krugersdorp Nature Reserve has been toxic and is affecting the wildlife (hippos) in the water. However, a further concern is the fact that this can cause 'blindness and damage to the retina for humans and animals' (Ho 2011). After a personal visit to the West Rand with Mariette Liefferink (tour 4 April 2013), our observations were that there is no aquatic life in some parts of the visited areas due to the effects of AMD and specifically the tailing dams.

Already in 2011, it was reported that 'seepage and percolations from sludge dams amount to 24 tonnes of uranium water entering that region's water basins and river systems annually, this includes the Vaal River' (*The Star* 2011). This remains a problem that

extends across the gold mining areas in Gauteng and in the West Rand as a future threat to the fossil wealth of the Cradle of Humankind even though there is no direct cause for concern at present.

At present, according to Peter Mills, the Sterkfontein caves are clear of AMD but monthly water quality monitoring by CSIR and the Council for Geoscience experts are to ensure that the site is not compromised, because mines continue to be left abandoned or closed down. In order to ensure that the principles of sustainable development are adhered to, clean water needs to be secured so that the fossils in the Cradle of Humankind are protected and for the communities that rely on the water from the rivers.

It has been predicted by various scientists and activists that the Central Basin will commence decanting by October 2013 and the Eastern Basin by 2014 (Peter Mills, interview 20 February 2013; Mariette Liefferink, interview 4 April 2013). However, after several interviews with the various role players, it was interpreted that they are of the view that government will not let this happen and that solutions are being implemented to ensure the Central and Eastern Basins remain below the environmental critical level (ECL). In 2012 the construction company Group Five was given a R319 million contract by the Department of Water Affairs for the construction of high-density treatment works, a pump station and monitoring shafts to tackle AMD in the Central Basin and in August 2013 Minister Edna Molewa stated that this was scheduled to begin (Greve 2013: 2).

One particular case in the Central Basin (Johannesburg) is that of Gold Reef City. Acidic water has not yet reached the surface west of Johannesburg where Gold Reef City amusement park is located. It is a major tourist attraction that has a defunct gold mine as its central theme, together with the gold rush on the Witwatersrand (South African Tourism 2012). It is an important case study, because it can demonstrate the possible impact of AMD on tourism as an element of sustainable economic development in South Africa. According to Govender (interview 25 February 2013), the Department of Water Affairs is working on a very tight timeline to ensure that the mine water does not reach the environmental critical level (ECL) in Gold Reef City. He added that if it reaches the ECL, it will react and will be impossible to avoid that Gold Reef City becomes flooded.

Gold Reef City was therefore granted emergency status by the Minister of Water and Environmental Affairs, Edna Molewa (Jordan 2012: 10). A media report stated that 'essentially if the department does not implement certain remedial measures, rising sub-surface acid mine drainage in the Central Basin may yield undesirable environmental and socio-economic impacts' in the case of Gold Reef City and the tourism mine museum will be permanently affected (Jordan 2012: 10). In October 2012, the media reported on the anticipated effects of acid mine water in the Vaal River system. According to Jordan (2012: 10), the Government gave approval for an emergency plan to pump water from specific mine shafts to maintain the water level below the ECL. The partially treated or neutralised acid mine water would then be pumped into the Vaal River as a means to prevent overflows into Johannesburg and other areas on the Reef.

Environmental activist, Mariette Liefferink (in Jordan 2012), reiterated that pumping of neutralised water could have a severe impact on the Vaal River, because the proposed treatment cannot neutralise the heavy metals and radioactivity in the water. She emphasised that the Government was warned of the situation well in advance, from as far back as 1996, and that this should therefore not be treated as an unexpected development.

8 The socio-economic impacts of AMD

There are several negative impacts associated with AMD, and these include environmental, socio-economic, political and financial risks. The environmental risks include surface and groundwater pollution in the form of heavy metal uptake in the environment, the degradation of soil quality and the harming of aquatic fauna. AMD has also caused several health-related consequences. Groundwater contaminated by AMD might unknowingly be consumed by individuals and their treatment might often be ineffective by the time that the effects materialise (Hobbs et al. 2008: 421). Mine closures and the related issues of AMD have serious socio-economic effects for the communities surrounding mining areas as the mining industry plays a crucial role in providing employment and income to them. AMD is also known to cause 'population displacement' which in turn has various socio-economic impacts of its own (Hobbs et al. 2008: 421).

From media reports and the interviews, it has become evident that AMD has clear socio-economic implications. Shanna Nienaber (interview 12 March 2013) believes that the strategic issue is the water supply in the Vaal Dam. The whole of Gauteng is a massive water hub and has a massive water security issue. AMD is a long-term problem that needs to be dealt with, and it will have long-term socio-economic implications. It is a threat to people who live most closely to areas where there is decanting, to people who use water from boreholes in the areas affected and to those growing vegetables in the areas affected. This becomes part of a strong case to make about people living close to mining activities in general, because it is difficult to separate AMD caused by underground mine water, from the effects of the dust of tailings dams that can cause respiratory problems in communities or deterioration of soil quality by mine waste. Nienaber therefore states that this in not just an AMD problem but an integrated problem (interview 12 March 2013). What is of utmost concern is that the impacts of mine closure tend to affect the health of communities. Health-related issues have surfaced, for example, 'in Delmas, near Johannesburg, where typhoid fever related to poor groundwater quality has killed people on two separate occasions' (Cobbing 2008: 452). Such problems could start affecting other areas as well.

Mine closure has in certain instances led to loss of job opportunities and therefore increasing unemployment rates. 'Subsistence farming is often the last resort for such communities, but AMD may render the available water resources unfit for agricultural use' (Oelofse et al. 2007: 6).

According to Mariette Liefferink, all wetlands in the Witwatersrand have experienced heavy metal contamination. Leukaemia is one of the health impacts known to arise from this. There are immense health effects known to arise from the inhaling of uranium dust particles from the tailing dams, and it includes the following:

> Highly insoluble uranium compounds may remain in the alveoli whereas soluble uranium compounds may dissolve and pass across the alveolar membranes into the bloodstream, where they may exert systemic toxic effects. There is also known to be insoluble particles that are absorbed into the body from the alveoli. Insoluble particles may reside in the lungs for years, causing chronic radiotoxicity to be expressed in the alveoli (Liefferink 2013).

Representatives of Government and officials are much more hesitant to concede that AMD can have these consequences. Peter Kelly (interview 6 March 2013) is of the view that if the technical solutions to AMD are adequate then the social impacts will be minimal, and 'government cannot afford for the technical solution not to be successful'. Peter Mills believes that there have not been many negative impacts on tourism but it has harmed

farmers. For example, had it been necessary to establish hotels around the area of the Sterkfontein caves then there would be a need for an alternative source of water (interview 20 February 2013).

In Gauteng, the CSIR is now working on and researching the human health impacts and comprehensive information should be available soon. For agriculture, there is a concern about its impact downstream along the Vaal River where there are major irrigation schemes. There is a lot of confusion and hype about these issues and misunderstanding such as that the Cradle of Humankind is going to be destroyed or that the local farmers' ground water is being affected. Because of the media alerts, farmers and land-owners tend to panic. AMD is complex and not all these areas are affected in the same ways and neither do all areas have the same levels of pollutants (Shanna Nienaber, interview 12 March 2013). Nienaber's view is that communities are affected especially those that are near tailings dumps, and it is not just the groundwater that is polluted but also the run-off from the tailings dams themselves (interview 12 March 2013).

According to Tony Turton, there is a complex set of socio-economic impacts cause by AMD (interview 24 April 2013).The most significant is the co-existence of poverty spatially located in close proximity to Mine Residue Areas (MRA)—there are about 1.6 million people that live in informal settlements situated on this type of land. Another socio-economic impact relates to the eradication of the apartheid heritage which is still evident in the divided communities that we see. MRA land divides historically black township areas and historically white suburbs. Kagiso is a township in Krugersdorp and this forms such an example whereby MRA is owned by mining companies.

Another socio-economic impact is that caused by dust. Dust from mine dumps creates significant loads of health-related risks and this can only be minimised if tailings have been removed and the areas rehabilitated to include revegetation. Lastly is the criminalisation of communities where illegal mining in decommissioned mines takes place. This leads to harmful risks for individual informal miners caused by illegal mining (Tony Turton, interview 24 April 2013).

Thus, AMD has various socio-economic impacts, and if not addressed, it will not allow for the goals of sustainable development to be achieved.

9 Conclusion

There are several negative impacts associated with AMD-related pollution that includes environmental, socio-economic, political and financial risks. The environmental risks include surface and groundwater pollution in the form of heavy metal uptake in the environment, the degradation of soil quality and the harming of aquatic fauna. AMD has also caused several health-related consequences for humans and animals. Mine closures and the AMD issues have serious potential socio-economic effects for the communities that surround the area where the mine is situated, as the mining industry plays a crucial role in providing employment and income to individuals. AMD is also known to have an impact on populations and where they reside which in turn has various socio-economic impacts of its own. There are also financial implications for government and the mining industry and this can raise constitutional issues under certain circumstances.

Acidic mine water can cause local flooding, and it can increase the risk of ground deformation and attack man-made structures such as concrete building foundations and the liners of landfills and waste dumps. What becomes questionable here is that given these

facts, we need to see the measures that the identified institutions are taking to reduce the risks of this problem reaching crisis stage.

AMD has become a highly politicised issue in South Africa, due to mine water spilling out in the environment and the strong sentiments that exist between the mining industry and the government. Mine closure and the related increase in AMD have also had serious consequences for communities that were previously supported by the mining sector. Mine closure has in certain instances led to loss of job opportunities and therefore increasing unemployment rates. 'Subsistence farming is often the last resort for such communities, but AMD may render the available water resources unfit for agricultural use' (Oelofse et al. 2007: 6). Despite the policy procedures and laws that are in place on how environmental damage should be addressed and by whom, there is still much debate around the issue in reality.

If all the role players that are involved in the AMD debate which include the mining sector, government, consultants (NGOs, civil society and activists) and the media can form a working relationship, whereby each assists in addressing AMD based on their expertise and not interfering in the entire process from all angles, this could ensure a structured way forward. It may also cause a rapid difference in addressing AMD and the impacts that it has on the environment and the socio-economic conditions.

The media works closely with consultants and activists (environmental NGOs) to report on the government's ability to solve this issue. Government entities (such as the DWA) are trying to get the mining industry and those mining companies that are responsible for the damage to pay. However, it may be impossible considering that this environmental problem caused by the mining industry occurred decades ago and the reasons why it occurred was due to abandonment or liquidation of those mining companies. The mining industry was of crucial importance to the South African economy and thus worked closely with government. The mining industry generated immense economic benefits and continues to play a crucial role in ensuring the country's position in the global market (Adler et al. 2007: 33).

This discussion identified some of the most important socio-economic dangers of AMD but also made it clear that the socio-economic aspects do not receive sufficient public and policy attention. All the actors involved in the AMD issue should pay more attention to communities and the heavy impacts of mine dumps as well as how they can assist in reporting positive feedback to the public with practical solutions. Government is addressing the issue but in their aim towards controlling and managing these issues, they should focus equally on the potential socio-economic impacts from AMD and ensure that they are placed prominently on the public agenda.

References

Adler, R., Claasen, M., Godfrey, L., & Turton, A. (2007). Water, mining and waste: An historical and economic perspective on conflict management in South Africa. *The Economics of Peace and Security Journal, 2*(2), 33–41.

Barnard, C. (2012). AMD damage—irreparable? *Looklocal*. http://www.looklocal.co.za/looklocal/content/en/krugersdorp/krugersdorp-news-general. Accessed 3 Sept 2013.

Cele, H. (2009). *Vaal River water quality: A matter of life*. Pretoria: South African Water Research Commission. Available at http://www.wrc.org.za/News/Pages/VaalRiverwaterqualityAmatteroflife.aspx. Accessed 4 April 2013.

Cobbing, J. E. (2008). Institutional linkages and acid mine drainage: The case of the Western Basin in South Africa. *Water Resources Development, 24*(3), 451–462.

Coetzee, H., Hobbs, P. J., Burgess, J. E., Thomas, A., & Keet, M. (Eds.) (2010) *Mine water management in the Witwatersrand Gold fields with special emphasis on acid mine drainage*. Report to the Inter-Ministerial Committee on Acid Mine Drainage.

Department of Water Affairs. (2011). Annual Report 2011/2012. http://www.info.gov.za/view/DownloadFileAction?id=179171. Accessed 5 Sept 2013.

Department of Water Affairs and Forestry (DWAF). (2008a). Best practice guideline G5: Water management aspects for mine closure. Pretoria: DWAF. http://www.bullion.org.za/documents/g5-water-management-aspects-for-mineclosure.pdf. Accessed 12 Oct 2013.

Esterhuizen, I. (2012). AMD feasibility study to be completed in 2013. *Mining weekly*. 9 July 2012. http://www.miningweekly.com/article/amd-feasibility-study-to-be-completed-in-2013-2012-07-09 Accessed 23 Aug 2012.

Fig, D. (2011). Corrosion and externalities: The socio-economic impacts of acid mine drainage on the Witwatersrand. In J. Daniel, P. Naidoo, D. Pillay, & R. Southall (Eds.), *New South African Review 2*. Johannesburg: Wits University Press.

GCIS. (2010). Mineral resources. *South Africa yearbook 2010/2011*. http://www.gcis.gov.za/. Accessed 3 Sept 2012.

Greve, N. (2013). Tender issues for development of Wits AMD project. *Engineering News*. http://www.engineeringnews.co.za/article/tender-issued-for-development-of-wits-amd-project-2013/08/13. Accessed 30 Aug 2013.

Guedes, G. (2010). Acid mine drainage still in focus. In *Chamber of Mines of S.A. Mining an indepth discussion of mining issues in S.A*. 2010 edition, November/December. Cape Town: Nelida Publishing. Available at http://www.bullion.org.za/documents/mining-november-2010.pdf. Accessed 14 April 2013.

Hamilton, W. (2011). Eco-disaster is your problem. *The Star*. 3 March 2011.

Ho, U. (2011). Unesco to help fund plan to advert AMD catastrophe at Cradle: Learners see first-hand poisonous effects of mining. *The Star*, 22 March 2011.

Hobbs, P., Oelofse, S. H. H., & Rascher, J. (2008). Management of environmental impacts from coal mining in the upper Olifants River catchment as a function of age and scale. *Water Resources Development, 24*(3), 417–431.

Jordan, B. (2012). Acid mine water to be pumped into the Vaal. *The Sunday Times*. October 2012.

Kearny, L. (2012). Mining and minerals in South Africa. http://www.southafrica.info/business/economy/sectors/mining.htm. Accessed 3 Sept 2012.

Leonardi, C. (2011). No acid test to find polluters. Responsible mining: Special pull-out supplement to the Mail & Guardian. 3 Nov 2011.

Liefferink, M. (2012). Environmental risks and hazards pertaining to AMD and radioactivity within the Witwatersrand Goldfields. PowerPoint Presentation. Federation for a Sustainable Environment.

Masondo, S., Du Plessis, C., Mclea, H., SAPA. (2011). Rain brings acid mine spillage closer. The Times, 18 Jan 2011.

Mbendi. (2012). Investing in African Mining Indaba (2013) Mbendi information services. http://www.mbendi.com/indy/ming/af/sa/p0005.htm. Accessed 17 Aug 2012.

Ochieng, G. M., Seanego, E. S., & Nkwonta, O. I. (2010). Impacts of mining on water resources in South Africa: A review. *Scientific Research and Essays, 5*(22), 3351–3357.

Oelofse, S. (2008). *Emerging issues paper: Mine water pollution*. Johannesburg: Department of Environmental Affairs and Tourism.

Oelofse, S. H. H., Hobbs, P. J., Rascher, J., & Cobbing, J. E. (2007). *The pollution and destruction threat of gold mining waste on the Witwatersrand—A West Rand case study*. 10th International Symposium on Environmental Issues and Waste Management in Energy and Mineral Production (SWEMP). 11–13 December 2007. Bangkok. Thailand.

Prasad, K. (2003). *Water resources and sustainable development*. India: Shipra Publications.

Rand Water. (2012). Where does our water come from? Rand Water Foundation. http://www.randwater.co.za/CorporateResponsibility/WWE/Pages/WaterOrigination.aspx. Accessed 6 Nov 2012.

Republic of South Africa (RSA). (1996). The constitution of the Republic of South Africa, 1996 (Act 108 of 1996). *Government Gazette*. Pretoria: Government Printer.

Republic of South Africa (RSA). (1998a). National Water Act, 1998 (Act 36 of 1998). *Government Gazette*. Pretoria: Government Printer. http://www.dwaf.gov.za/Documents/Legislature/nw_act/NWA.pdf. Accessed 14 April 2014.

Republic of South Africa (RSA). (1998b). National Environmental Management Act, 1998 (Act 107 of 1998). *Government Gazette*. Pretoria: Government Printer. http://www.google.co.za/search?q=National+Environmental+Management+Act%2C1998+%28Act+no.+of+1998%29.+Government+Gazette&hl=en-ZA. Accessed 14 April 2013.

Republic of South Africa (RSA). (2002). Mineral and Petroleum Resources Development Act, 2002. (Act 28 of 2002). *Government Gazette*. Pretoria: Government Printer. http://www.parliament.gov.za/…/b%2015%20%202013%20(mineral%20and%20petrolum%20resources%20dev. Accessed 25 Mar 2013.
South African Tourism. (2012). Gold Reef City. http://www.southafrica.net/za/en/articles/entry/article-southafrica.net-gold-reef-city. Accessed 14 Dec 2012.
Turton, A. (2013). Significant progress in the battle against AMD. Water Stewardship Council of Southern Africa. PositionIT.
United Nations. (2008). *Measuring sustainable development*. Report of the Joint UNECE/OECD/Eurostat working group on Statistics for Sustainable Development. United Nations: New York & Geneva.
Wait, M. (2012a). Funding for mine closure inadequate WWF-SA. *Mining weekly*. 15 Aug 2012. http://www.miningweekly.com/article/funding-for-mine-closures-inadequate-wwf-2012-08-15. Accessed 23 Aug 2012.
Wait. M. (2012b). Decanting mine water could be an opportunity. *Mining Weekly*. 26 July 2012. http://www.miningweekly.com/article/decanting-acid-water-could-be-an-opportunity-professor-2012-07-26. Accessed 23 Aug 2012.
World Wide Fund for Nature. (2008). *Living planet report*. Gland, Switzerland: WWF International.
Yende, S. S. (2012). Flagrant coal mining threatens food security. *City Press* (*Business*). 27 May 2012.

Personal interviews

Bashan Govender, Department of Water Affairs (Assistant Director), 25 February 2013, Pretoria.
Peter Kelly, Department of Mineral Resources. 6 March 2013, Johannesburg.
Mariette Liefferink, Federation for a Sustainable Environment (CEO), 4 April 2013, Krugersdorp.
Shanna Nienaber, Department of Science and Technology (Deputy Director: Environmental Sciences), 12 March 2013, Pretoria.
Peter Mills, Cradle of Humankind: World Heritage Site (Assistant Director), 20 February 2013, Centurion.
Stephinah Mudau, Chamber of Mines (Head: Environment), 19 March 2013, Johannesburg.
Tony Turton, University of Free State (Professor), 24 April 2013, Krugersdorp.