The impacts of mining activities on the environment and the necessity for an environmental assessment strategy for such activity in South Africa

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Abstract

Mining activities disturb the earth's geology and destabilise the geo-environment, with a consequent negative impact on sustainability. There is a close link between the mining sector, geology and urban development. A geo-environmental assessment (assessment of the spatial influence of geology on the environment), focusing on the regional geological character and setting, must therefore also lay the foundation for a long-term sustainable assessment of mining-related urban development. This must be done as a specialist study and be part of required environmental assessment on strategic level prior to development. Examples and historical cases of such developments indicate that this assessment must be based on the following three main aspects:

- **Characterisation of the underlying geology and mining-related structures:** Specific geological environments and mining-related structures result in destabilisation and sinkhole development, as well as earth movement enhanced by mining activity, with a negative impact on the sustainability of mining-related urban development.
- **Characterisation of related natural resources:** The physical character, long-term capacity, delineation and setting of all natural resources involved with mining activities affect the sustainability of related urban development. This includes water supply from groundwater resources, as well as the ore-body and natural resources needed to sustain the mining operation and urban development.
- **Characterisation of geological waste and pollutants:** The disturbances of the geology during mining activities give rise to an unnatural interaction with the atmosphere. This results in acid mine drainage, contaminating water resources and pollution of the atmosphere with negative impact on sustainability.

This article reviews the impacts of mining activities on the geo-environment and argues that the assessment thereof must be based on an integration of the legal required strategically environmental assessments, eco-efficient evaluations by the mining sector, and within the context of the global debate on sustainability.

DIE INVLOED VAN MYNAKTIWITEITE OP DIE OMGEWING EN DIE NOODSAAK VIR 'N OMGEWINGSANALISESTRATEGIE VIR SULKE AKTIWITEITE IN SUID-AFRIKA

Mynaktiwiteite versteur die geologie van die aarde en gevolglik destabiliseer die geo-omgewing, met 'n gevolglike negatiewe invloed op volhoubaarheid. Daar is 'n noue verhouding tussen die mynsektor, geologie en stedelike ontwikkeling. 'n Geo-omgewingsanalise (analise van die ruimtelike invloed van geologie in die omgewing), met 'n fokus op die streeksgeologiese karakter en ligging moet daarom ook die basis wees vir 'n langdurige volhoubaarheidanalise van mynverwante stedelike ontwikkeling. Dit moet gedoen word as 'n gespesialiseerde studie en moet deel wees van 'n vereiste omgewingsanalise oor strategiese vlak onderhewig aan ontwikkeling. Voorbeelde en historiese gevalle van sulke ontwikkelings dui aan dat hierdie analise op die volgende drie aspekte gebaseer moet wees:

- **Karaktereienskappe van die onderliggende geologie en mynverwante strukture**: Spesifieke geologiese omgewings en mynverwante strukture lei tot destabilisering en sinkgatontwikkeling, asook verhoging van aardbewings deur mynaktiwiteite, wat 'n negatiewe invloed op die volhoubaarheid van mynverwante stedelike ontwikkeling het.
- **Karaktereienskappe van verwante natuurlike hulpbronne**: Die fisiese karakter, langtermynkapasiteit, karakterisering en ligging van alle natuurlike hulpbronne betrokke by mynaktiwiteite affekteer die volhoubaarheid van verwante stedelike ontwikkeling.
- **Karaktereienskappe van geologiese afval en besoedelings**: Die versteuring van die geologie gedurende mynaktiwiteite verhoog die onnatuurlike interaksie met die atmosfeer. Hierdie het suurmyndreinering, aangetaste waterhulpbronne en afval van die atmosfeer met negatiewe invloed op volhoubaarheid tot gevolg.

Hierdie artikel verskaf 'n oorsig van die invloed van mynaktiwiteite op die geo-omgewing en argumenteer dat die analise daarvan op 'n integrasie van die wetlik vereiste strategiese omgewingsanalises, eko-effektiewe evaluerings van die mynsektor, en binne die konteks van die globale debat oor volhoubaarheid gebaseer moet wees.

MATLAFATSO YA MESEBETSI YA MERAFONG TIKOLOHONG LE TLHOKEHO YA LEANO LA TEKANYETSO LA TIKOLOHO LA TSHEBETSO E JWALO HO LA AFRIKA BORWA

Mesebetsi ya merafong e sitisana le bobopeho ba lefatshe le ho baka pherekano ya tikoloho ya lefatshe, e tlisang kgatello e mpe polokong. Ho na le kamano e tiileng pakeng tsa lefapha la merafong, ntshetsopele ya tsa gology le metse ya ditoropo. Tekanyetso ya tikoloh ya lefatshe (tekanyetso ya tshusumetso ya sebaka ya lefatshe tikolohong), ho tadinngwe mofuta le sebaka sa lefatshe le yona e thehe wa nako e telele wa poloko ya tekanyetso ya tsa merafong e amanang le ntshetsopele ya metse ya ditoropo. Ntho ena e etswe e le thuto e ikgethileng le ho ba karolo ya tekanyetso ya tikoloho e hlokwang boemong bo leano lena pele ho ntshetsopele. Mehlala

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le ditaba tsa nalane tsa ntshetsopele ena di bontsha hore tekanyetso ena e lokela e thewa mafapheng ana a mararo (dintlheng tsena tse tharo):

- Tlhaloso ya tse bopang bobopeho ba lefatshe (naha) le metheo e amanang le tsa merafo:
- Ditikoloho tse ikgethileng tsa bobopeho ba naha le metheo e amanang le tsa merafong di qetella di bakile pherekano le ho wela ha mekoti ya merafo, esitana le ho baka tshisinyeho ya lefatshe ho bakwang ke ho tjhekwa ha merafo, ho bang le kgatello e mpe polokong ya ntshetsopele ya dibaka tsa ditoropo tsa merafo.
- Tlhaloso ya tse tjhekwang tse amanang le hona: Bobopeho, bokgoni ba nako e telele, pontsho ka ditshwantsho le tlhophiso ya mahakwe ao ho sebetsanwang le ona merafong di ama (sitisa) polokeho ya ntshetsopele ya dibaka tsa ditoropong tse amanang le tsona. Tsena di kenyeletsa tsamais ya metsi ho tswa mehloding ya metsi e ka tlasa lefatshe, esitana le manya a tshepe le mahakwe a hlokehang ho boloka tshebetso ya merafong le ntshetsopele ya metse ya ditoropo.
- Tlhaloso ya tshilafalo ya lefatshe le disilaftsi: Ditshitiso tsa (jeoloji) bobopeho ba naha (lefatshe) nakong eo ho sebetswang morafo ka yona di hlahisa dithulano le tsa boemo ba lehodimo. Sena se qetella se tletse ka peiping ya dikgwerekgwere ya esete ya morafo, se bake tjhefo mehloding ya metsi le tshilafalo ya boemo ba lehodimo mme ho bakee mpe tabeng ya polokeho.

Ditaba tsena di fana ka ho tadingwa hape ha dithulano tse bakwang ke ditshebetso merafong bobopehong ba tikoloho le ho hlahisa hore tekanyetso ya sena e thehwe hodima tekanyetso ya leano la tikoloho le hlokehang le kopaneng, ditlhatlhobisiso tsa moruo tse matla tse etswang ke lefapha la tsa merafong, esitana le ka hara

1. BACKGROUND

1.1 Relationship between the mining industry, geology and urban development

From the beginning of mining as a human activity, the exploitation of the riches of the earth was associated with positive and negative effects. Man has interfered with ground and geology by the extraction of minerals over the past 3000 or more years (Culshaw, McCann, & Donnelly, 2000). This activity disturbed geology and thus destabilised the geo-environment, with a negative effect on sustainability.

This negative influence includes and results from:

- What has been taken from the ground (long-term subsidence over large areas and catastrophic failure and destabilisation of surface).
- What has been put into the ground (waste disposal and pollution).
- Major changes to the ground (engineering - change in topography by opencast, stripping of overburden, waste dumping) (Culshaw *et al.,* 2000)

From ancient times there is a close relationship and interaction between geology and urban development and a close relationship between urban sites and mineral resources (McCall, 1996). The development of the Johannesburg greater urban area and interaction with the Witwatersrand gold mine activities, as well as the development related to the Kimberley diamond sector, are well-known examples of this close relationship.

Many of the problems of today's major urban centres are directly or indirectly related to the geological and/or geohydrological conditions beneath and around cities (De Mulder, 1996). Based on this close relationship, the effect of geo-environment (the spatial influence of geology on the environment) can be categorised according to the bearing on the structure and function of urban areas, namely:

- Raw materials used to develop and maintain urban structure and infrastructure and to feed industries which are located in and related to the urbanised zones.
- Characteristics of the ground and surface processes which constrain or prevent development of urban areas, or which present hazards to existing properties and their occupants (McCall, 1996).

In South Africa, this interaction between the mining sector, geology and urban development is even more important due to the major role the mining sector plays in our society. South African mineral resources are among the largest in the world. South Africa has the largest reserves of gold, platinum, titanium, chromium, manganese and vanadium, the second largest reserves of zirconium and significant reserves of phosphates, antimony, coal and nickel. It produced a fifth of the world gold output until 1996, and is the fifth largest producer of diamonds (Stillwell, Minnitt, Monson, & Kuhn, 2000: 17). Coal has been and is currently still the cornerstone of the South Africa energy economy. It provides 75% of South Africa's primary energy requirements. Approximately 90% of the electricity in South Africa is generated from coal. Coal is the third largest resource export earner after platinum and gold. The South African coal reserve is estimated to be in the order of 34.3 billion ton (Mangena & Brent, 2006: 1073).

The interaction between mining and the total social environment is very complex. Despite this enormous natural endowment, South Africa remains a third-world country. The economic situation can be described as being in crisis, even after over 70 years of governmental planning (Stilwell *et al*., 2000: 17).

1.2 Defining the framework for a geo-environmental assessment

1.2.1 Sustainable development, mining and the environment

In order to understand the effect of mining on the environment it is interesting to consider the following statistics:

- It requires approximately 700 kL to produce 1 kg of gold (Mudd, 2007: 48). This compares to the water usage for a full service South African household of 36 kL/month and 2-2.5kL/month of an informal household (Schlemmer, L., Markdata (Pty) Ltd. & Eric Hall and Associates, 2001).
- It requires approximately 140 GJ energy to produce 1 kg of gold (Mudd, 2007: 48). Compare this value with the 1991 per capita consumption of modem energy in Africa which was estimated to be 12 GJ (World Resources Institute, 1994: 334).
- Gold mining typically releases approximately 11.5 ton CO_2 to produce 1 kg of gold. The primary function of gold for jewellery leads to major ethical and social issues in terms of accounting for greenhouse costs (Mudd, 2007: 53). This should be compared with the approximate CO_2 emission of less than 200g per km emission of an average car (Toyota, 2008: online).

In recent years, due to public concern over perceived and actual environmental effects, the global mining industry has moved towards a more sustainable framework. Since the 1970s mining projects have increasingly been forced to meet environmental requirements set by legislation, but also to ensure social acceptance (Mudd, 2007: 43).

In 1987, the World Commission on Environment and Development (WCED) published its report *Our common future*. This report laid the foundation for the global development of the concept of sustainable development on all political and societal levels (Langhelle, 1999: 129). The task given to the Commission by the United Nations General Assembly was to formulate 'A Global Agenda for Change' by proposing long-term environmental strategies for achieving sustainable development on an international level. The resulting report was one of the first to use the word 'sustainable development' (Langhelle, 1999: 132). Sustainable development is defined as "development that meets the need of the present without compromising the ability of future generations to meet their needs" (WCED, 1987: 43). Through sustainable development the well-being of people is thus the ultimate goal of all environmental and development policies.

The environmental impact of mining operations and therefore the effect of mining on related urban settlement must be viewed in the light of the *South African Constitution of 1996 (Act 108 of 1996)* (South Africa, 1996). Section 24 stipulates that the quantity and quality of the natural resources (land resources, water resources, air resources, and mined abiotic resources) must be maintained for society (human health and welfare) for present and future generations.

Development related to mining is, like all other developments, subjected to the *National Environmental Management Act (NEMA, Act 107 of 1998)* (South Africa, 1998b). Urban development must be screened and guided by the Environmental Impact Assessment (Chapter 5 NEMA, dealing with Integrated Environmental Management). However, a detailed geological assessment must also be regarded as an essential part of both the EIA process and the related development focuses in mining regions.

The concept of global sustainable development, along with the new constitutional dispensation in South Africa, as well as the implementation of NEMA pave the way for the development of geo-environmental assessments needed during the planning of urban development related to mining activities. This approach will assist in balancing the potential environmental and social risks with economic risks (Mudd, 2007: 43).

The future of mining depends on available resources and its associated environmental effects. From a global view, gold resources for less than 20 years at existing levels of production are left for future use (Mudd, 2007: 51). The future of mining and the relation with urban development is therefore an important concern. The environmental and social health of a region and community is affected by mining – positive or negative - and it remains a contentious issue for the sustainability debate. The present generation must meet the need for metals and minerals while allowing future generations to provide for their anticipated requirements (Mudd, 2007: 43).

1.2.2 Economic framework

The geo-environmental assessment for urban development must take into account the 'resource intensity' as defined for the related mining activity. 'Resource intensity' is a concept and analytic process used in the mining sector to determine the resource requirement for new mineral production (estimations of water, energy, required chemicals as well as resultant waste and pollutant emissions) (Mudd, 2007: 44). The concept of 'resource intensity' is also reflected in the development of Resource Impact Indicators as defined by Mangena & Brent (2006: 1075). During this process the environmental impacts and economic performance of the life cycle of a mine are evaluated within the South African context.

All developments take place within a framework of spatial planning and legal land-use requirements. Bearing the broad economic framework in mind, there must be a link between the geo-environment and the abovementioned planning and requirements.

2. GEO-ENVIRONMENTAL ASSESSMENT

The general public does not recognise that geological information contributes to the daily input and the safe and efficient execution of urban developments. The depth of understanding the earth sciences and the scope of information are often underestimated by developers with unfortunate results (Marker, 1996).

A geo-environmental assessment, focusing on the regional geological character and setting, must be the basis for a long-term sustainable assessment of mining-related urban development. Examples and historical cases of these developments indicated that this assessment must include the following three main aspects:

- Characterisation of the underlying geology and mining-related structures.
- Characterisation of related natural resources.
- Characterisation of geological waste and pollutants and identification of possible catastrophes.

2.1 Characterisation of the underlying geology and mining-related structures

Specific geological environments and mining-related structures result in destabilisation of the surface and in pollution. This has a negative impact on the sustainability of urban development due to mining.

Negative impacts due to geological and structural environments on urban development include the following:

- geohazards related to mining activities and possible catastrophes, such as liquefaction and quakes;
- destabilisation resulting from structural geology;
- sinkholes related to dolomites and karst topography, and
- discomforts such as dust, noise and visual impacts.

2.1.1 Geohazards related to mining activities

Many urban environments are located in regions where mining has occurred previously. Abandonment of the mines and associated unstable structures can be hazardous to development (Culshaw *et al*., 2000). These 'geohazards' can have considerable impact on urban areas, including:

- Loss of property value, and
- Damage to property and a threat to safety.

Abandoned mines are an important global concern and continue to pose a real or potential threat to human safety and health. The negative impact of mining activities mostly surfaces only after an elapse of time. Very few countries had government regulations and reclamation policies until the latter part of the previous century. Previously no legal, financial and technical procedures were required for existing mining operations. Mine closures were mainly due to unprofitable mining conditions and the resulting absence of responsible parties shoulders the burden of clean-up, monitoring and remediation (Maramba, Reyes, Francisco-Rivera, Panganiban, Dioquino, Dando, Timbang, Akagi, Castillo, Quitoriano, Afuang, Matuyama, Eguchi, Fuchigami, 2006: 135).

It is estimated that there are more than one million abandoned mines on earth. This includes countries like Brazil, Canada, France, Philippines, South Africa and the United States (Maramba *et al*., 2006: 136).

Geohazards are mostly related to post-mining environments. Protection of the environment and planning of urban settlements in post-mining areas is therefore an important issue. Runoff and erosion can cause undesirable material to be exported from the post-mining landscapes to contaminate neighbouring landscapes and watercourses. Scientific methods for the assessment of environmental impacts and long-term behaviour of post-mining landforms are needed (Hancock, Grabham, Martin, Evans, & Bollhofer, 2006: 104), as emphasised by the following international examples:

- A typical example of a geohazard occurs in the Philippines where abandoned mercury mines have a negative effect on the urban environment of Honda Bay. People were reportedly complaining of unusual symptoms (miscarriages, tooth loss, muscle weakness, paralysis, anaemia, *etc*.), fish had exceeded the recommended total mercury levels, surface water exceeded total mercury standards, soil samples reported exceeding recommended values for total mercury for residential purposes – all this resulted in a overall body burden of mercury among residents in the area (Maramba *et al*., 2006: 136).
- Geohazards give rise to the development of negative perceptions regarding the mining sector in Africa. Mining practices have already caused serious social and environmental impacts in Tanzania. In the region of the Geita Gold mine in Tanzania, houses collapsed as a result of mine-induced explosions, excavation of underground pits and resultant destruction of rocks (Kitula, 2006: 409).
- In Portugal it was reported that abandoned mines gave rise to a higher exposure of cadmium and lead to society. This kind of contamination leads to cancer. Dust from waste piles cause respiratory diseases. Mining sites-enveloped soil contamination reflects negatively on the urban settlements and population resident in the area (Coelho, Silva, Roma-Torres, Costa, Henriques, Teixeira, Gomes, & Mayan, 2007: 400).
- Examples of ‘geohazards’ with a negative impact on urban developments are evident in the Witbank coalfield of South Africa. Board and pillar mining were used as mining method in the early 1900s and was followed by “pillar robbing” until 1946. The roof collapsed with time, leading to void migration and giving rise to surface subsidence, collapse areas and surface tension cracks. This led to flooding of certain areas, as well as a change in the topography and flow of surface water. Due to the artificial influx of oxygen to the mine, the coal in the abandoned mines underwent spontaneous combustion for over 50 years in areas within a 2km range from the nearest urban settlement (Bell, Bullock, Hälbich & Lindsay, 2001: 201; Bell, Bullock & Geldenhuis, 1998).
- Liquefaction of tailing dams may cause the ground to temporarily change to a fluid state and then start to flow, resulting in a collapse. In the case of the Merriespruit, Virginia tailings dam a loss of 17 lives and scores of houses can be blamed on water mismanagement and that a large volume of tailings was in a meta stable state because of ignorance of a suitable tailings dam management system (Fourie, Blight & Papageorgiou, 2001: 707).

These examples clearly indicate that there is a need for a geo-environmental assessment prior to mining-related development. The long-term effect of the specific commodity and related waste products must be evaluated. A minimum distance of the settlement from the ore body has to be determined as outcome from this assessment.

2.1.2 Structural geology

Most of the seismic events recorded are associated with deep-level gold mining of the reefs on the periphery of the Witwatersrand basin. The largest mine-related seismic event ever to occur in South Africa took place on the 9 March 2005 at Stilfontein and registered 5.3 on the local Richter magnitude scale. It had far-reaching socio-economic consequences because the mine was closed down and led to a comprehensive investigation in order to determine the risks to miners, mines, and the public posed by large seismic events in the gold-mining districts (Linzer, Bejaichund, Cichowicz, Durrheim, Goldbach, Kataka, Kijko, Milev, Saunders, Spottiswoode, & Webb, 2006: 419). Minor damages to houses are very common in townships due to deep underground mining activities. Damages to a single house may seem minor, but the total amount spent on remediation of all houses can amount to large sums of money (Van Deventer, 2008: personal communication).

Geological faults within mining areas (with related subsidence) are susceptible to reactivation. This can cause damage to civil engineering structures, residential property, industrial premises, transportation networks and related infrastructures (Culshaw *et al*., 2000).

Disturbance of the earth surface can be due to faults, as in the case of the Ellispark Rugby Stadium. In this instance, two different rock units, namely quartzite on the one side of the stadium and shale on the other, with extremely different properties (Hydraulic conductivity and permeability) adjoin each other due to a fault plane. The northern part of the playground was easily saturated and inundated after rain in contrast with the southern part which was well drained quartzite. A difficult and expensive drainage system on the northern side of the venue had to be implemented just prior to the 1995 Rugby World Cup event. Due to the same fault, a filling station had to be rebuilt, because leakage from the fuel reservoirs led to spillage that flowed into the fault and seeped out in the stadium few hundred meters from there. This resulted in a high-risk factor with the potential for an explosion in the stadium (Van Deventer, 2008: personal communication).

Different geophysical methods can be used to characterise the structural geological character and stability prior to urban development. This includes magnetic methods, ground electrical conductivity, ground-penetrating radar, gravity methods and thermal techniques (Culshaw *et al*., 2000).

The regional structural investigation is a very important tool needed prior to strategic regional development planning. The regional geological structure dictates the occurrence of geohazards, stability and characteristics of the ore body of the underlying geology, as well as the mining structure and geological waste and pollutants.

2.1.3 Sinkholes related to dolomite and karts topography

An estimated 2.5 to 3 million people live on dolomites in South Africa. In excess of R1.2 billion of damage to property has been observed to date and in excess of 800 sinkholes have occurred in the Southern Tshwane area alone. This demonstrates that a better understanding of the geology and stability of dolomite area is needed to interrogate the current method of dolomite stability analysis prior to urban development (Trollip, 2006: 1).

There is a strong geological association between the spatial occurrence of dolomite and gold-bearing formations. The acknowledgement of dolomite underlying potential urban developments related to gold-mine activities is important. This spatial relationship requires that urban development related to gold mining must consider the occurrence of dolomite and karst topography during spatial planning.

Urban development on dolomites increases the risk of sinkholes, since interrupted natural surface drainage, increased runoff and leakage from water-bearing utilities can result in concentrated ingress of water into the ground. A classification system, based on the risk of formation sinkholes on dolomite land, has been developed in order to zone the land for appropriate development. Ongoing monitoring and maintenance of water-bearing services, as well as the implementation of precautionary measures relating to drainage and infiltration of surface water are regarded essential for developed areas located on dolomite. Special types of foundations are often needed (De Bruyn & Bell, 2001: 281).

Significant portions (approximately 20%) of densely populated areas in Gauteng, and also the gold-mining districts in the far West Rand and some parts of the North-West Province are located on dolomite. Over the past 40 years, 38 people have died and more than one billion Rand of damage to properties occurred as a result of sinkhole formation. Property values in certain areas have fallen below market trends due to the hazard of sinkholes. Sites for urban development were only investigated on an *ad hoc* basis until 1965, when legislation was passed to regulate land development. It required that each portion of land (in the former Transvaal) earmarked for urbanisation had to be investigated prior to actual development (Trollip, n.d.: online).

The occurrence of sinkholes related to dolomites was enhanced by the regional dewatering of dolomites related to mining activities. After almost 120 years of mining in the Witwatersrand basin, mining has created gigantic, interconnected subterranean warren stretching from Roodepoort in the west to Boksburg in the east, in some places as deep as 3 000 meters (Aucamp, 2000).

2.1.4 Quarrying

Quarrying has a visual impact on the environment. The principle of geomorphic impact of quarrying is the removal of stone with resulting destruction of vegetation and animal habitat. The extent of the effect of quarrying depends on the size, number, type and location of the quarry (Langer, 2001: 8). Accompanying quarrying is noisy. Noise results from earth-moving equipment, processing equipment, and blasting. Another problem is dust. Dust is one of the most visible, invasive, and potentially irritating impacts associated with quarrying, and its visibility often raises concerns that are not directly proportional to its impact on human health and the environment. Dust may occur from excavations, haul roads and blasting, or can be from point sources such as drilling, crushing and screening (Langer, 2001: 11).

2.2 Characterisation of related natural resources

The physical character, long-term capacity, delineation and setting of all natural resources involved with mining activities affect the sustainability of related urban development (Culshaw *et al*., 2000). These natural resources include the water resources (groundwater - surface water interaction), as well as the ore body.

2.2.1 Water resources

The closure of mines and ceasing of pumping may result in the recovery of groundwater levels in the region and leads to flooding of abandoned mine workings (Culshaw *et al*., 2000). This may lead to:

- Mine water penetration into geological faults – contributing to reduction in shear strength and can result in the reactivation of geological movement.
- Pillar deterioration with resulting increases in mine structure collapses.
- Discharging of contaminated groundwater into the surface environment.
- Washing of clay or silt from granular material/natural material and mining related material– causing subsidence (Culshaw *et al*., 2000).

Both groundwater and surface water are influenced by mining activity and related structural geological changes. This includes reduced surface runoff and increased groundwater recharge (from 5% average to 50% in the Witbank coal fields). The oxidation of pyrite sulphur, due to the exposure of pyrite (FeS_2), results in the formation of sulphuric acid- a concentrated acid. It results in the production of acid mine drainage and resulting low pH values leads to elevated concentrations of metals associated with sulphide mineralogy (iron, sulphate, copper, mercury, lead, arsenic, antimony, cobalt, zinc, and nickel). This leads to higher TDS (Total Dissolved Solids) values in water and deterioration of water quality in both groundwater and surface water (Bell *et al.,* 1998; Mangena & Brent, 2006: 1072). This water pollution has a very negative effect on urban development, not only on the supply of water as a natural resource, but also on the recreation value of water. The Loskopdam is situated in the catchments effected by the coalfields and is lately reported as the most environmentally affected dam in South Africa due to mining activities. This may eventually lead to the pollution of the entire Olifants River runoff-area in time.

Evaluation of the coal industry on the Resource Impact Indicators (RII) scale indicates that the RII for this water resource group is the highest. The next highest RII is for the mined abiotic resource and land resource group (Mangena & Brent, 2006: 1072). This indicates the need for a detailed geo-environmental assessment prior to the development of urban settlements related to coal mining activities.

At Witwatersrand gold mines, millions of mega litres of groundwater had to be pumped out for decades. After down-scaling in mining activities, much less water was pumped out than previously and the water table is recovering faster than consumption from the surface. Undisturbed, the water table began to rise from the deepest defunct mines into the vast network of tunnels. The old ridge of tumbling waters is coming back to life, but the water is tainted (Aucamp, 2000). The mine-polluted water has high acid levels due to the presence of sulphuric acid. This results in:

- High sulphates: to a level of acutely toxicity.
- Toxic heavy metals dissolved by the acid water.
- Radioactivity in the case of radium and uranium (Aucamp, 2000).

2.2.2 Ore-body: Spatial and compositional characteristics

Possible future changes in the required grade of minerals needs to be considered during the geo-environmental assessment. At Sishen the exploitation and utilisation of lower-grade (<60% Fe) iron ore resources is of crucial importance in ensuring optimal resources utilisation and maintaining of future profit margins by reclassifying waste and ore (Pretorius & Hoffman, 2006).

Urban developments can be trapped between potential new ore exploitation areas, due to poor geo-environmental assessment.

2.3 Characterisation of geological waste and pollutants

The disturbance of geology during mining activities gives rise to an unnatural interaction with the atmosphere. This results in acid mine drainage contaminating water resources and pollution of the atmosphere with negative impact on sustainability.

2.3.1 Waste material

Geological waste undergoes chemical alteration when it comes in contact with the atmosphere and degrades into harmful products (Culshaw *et al.,* 2000). Naturally occurring radioactive material (NORM) are normally accumulated in the geological waste. A typical South African example of this aspect relates to the tailings deposits of gold mines in the Witwatersrand. Large amounts of uranium are brought to the surface by means of gold mining operations. After milling and leaching the remaining ore material (tailings) is deposited as solid-water-mixture (slurry) on 'slimes dams.' It is estimated that an average of 6000 ton of uranium is disposed annually onto slimes dams in South Africa and this counts up to approximately 6 billion ton of tailings produced to date. The slimes dams of the Witwatersrand basin, with a surface of 400 square kilometers, expose about 600 000 ton of U_3O_8 to the biosphere – constituting an environmental problem of extraordinary spatial dimension (Winde & Van der Walt, 2004: 179).

The transport of dissolved uranium from tailings deposits was long neglected. Seepage containing high concentrations of dissolved contaminants migrates from tailings deposits into adjacent aquifers and finally enters adjacent streams. The contaminations of streams by adjacent slimes dams pose a severe risk to the health of people in informal settlements where polluted stream water is often consumed without appropriate treatments. Long term effects on cattle and crop farming and established drinking water supply schemes are also of concern (Winde & Van der Walt, 2004: 179).

2.3.2 Dust management

Asbestos mined in Southern Africa for more than a century was marketed around the globe, although owned and operated by British firms. The failure of companies to apply knowledge of the dangers of asbestos resulted in a legacy of disease and environmental pollution (McCulloch, 2003: 230).

Dust usually originates from the mechanical breakdown of larger masses of material through mining actions, stockpiling, transportation and mineral processing operations. Mineral dust is defined as small solid particles originating from the mechanical breakdown of rock and soil, smaller than 75 μm in diameter, which settle out under their own weight, but which may remain suspended for some time. Dust is reported as one of the largest occupational hazards related to the mining industry and has been one of the largest occupational 'killers' (Petavratzi, Kinham, & Lowndes, 2005: 1185). The scale and type of operation and the nature of the original rock determine the particle emission within the mining industry (Petavratzi *et al.,* 2005: 1183).

Air pollution related to mining activity in a broader sense consist of pollutants that consist of particulates, sulphur oxides (Sox), nitrous oxides (NOx), carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds, methane, lead and other hazardous metallic (Mangena & Brent, 2006: 1073).

Dust is sub classified with regard to its environmental, occupational health and physiological effects. Typical human diseases associated with natural material are illustrated in Table 1:

Asbestos related minerals	Asbestosis, lung and related cancer
Mica group minerals	Fibrosis, silicosis
Feldspar, bentonites	Silicosis
Dimension stone	Silicosis, silico-tuberculosis, fibrosis
Limestone, marble, dolomite	Bronchitis, emphysema, calcinations toxicity, dermatitis
Silica, quartz	Silicosis, tuberculosis, fibrosis
Talc	Talcosis
Corrundum	Aliminosis, emphysema
Chromite	Lung cancer
Iron ore	Siderosis, lung cancer
Lead ore	Anaemia, diseases of the central nervous system
Uranium	Excess lung cancer

Table 1: Typical human diseases related to natural material
Source: Banks & Parker, 1998: 65-66

Mineral dust should, therefore, be considered during the design and spatial planning of urban development. The assessment of mineral dust must include modelling of dust by using meteorological data and modelling techniques and algorithms in order to understand the behaviour of the mineral. The model must then represent the physical process of dust generation, transportation and deposition (Petavratzi *et al.,* 2005: 1191). The strategy of monitoring of nearby mining operation needs also to be incorporated in the long term planning of urban development.

The issues related to particulates from mining operation are complex and need collaboration from different scientific disciplines and sectors involved.

2.3.3 Pollutants on the development ground

The amount of households living in informal housing in Johannesburg at and near old goldmine activities increased with 16% during 2001 to 2004. There is however complications with land considered for housing development on contaminated land (Karam & Venter, 2007: 37). As in most gold mining areas, contamination includes the occurrence of radioactive Radon gas resulting from the decay of Uranium. Specific intervention is required to make the area safe for human occupation. This includes the design of houses and foundations, identification of the correct building material, improvement of developer's knowledge regarding radon gas remediation technologies (Karam & Venter, 2007: 43-48).

3. CONCLUSION

The evaluation of the spatial influence of geology on the environment is of critical importance during mining related development. A geo-environmental assessment with focus on the geological setting and aspects is therefore an essential as part of the Environmental Assessments as required by NEMA. It is important to integrate this assessment with the Resource Impact Indicator (RII) done for the related mining activity as the vulnerability of such a community depend on this indicator as reflection of environmental versus economic balances.

The geo-environmental assessment of urban settlements related to mining activity stand therefore within the global debate on sustainability, and the evaluation of the value of development in the mining sector versus the "environmental cost" and concerns.

If not proven that the mining sector have a higher positive impact on society than the environmental cost paid by society, the general perception regarding the mining industry as reflected in the basic premise of the *White paper on the Mineral and Mining policy for South Africa*:

> "that the South Africa mining industry has the capacity to generate wealth and employment opportunity on a large scale", (South Africa, 1998a)
>
> may be misplaced and may enquire further thought (Stillwell *et al.*, 2000: 26).

In this debate, the interaction between geo-environment and town development is of major importance.

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