

Challenges associated with living in karst environments, such as the historical Cradle of Humankind

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Samevatting

Die unieke geologiese aard van die Wieg-van-die-Mens-Wêrelderfenisgebied (Cradle of Humankind) noord van Krugersdorp, bied sekere uitdagings vir die mense wat daar woon en werk. Hierdie gebied vorm deel van 'n reuse dolomitiese afsetting wat deur verwering, hoofsaaklik deur die werking van water, in 'n tipiese karstlandskap verander is gekenmerk deur grotte, sinkgate, ondergrondse mere en akwifere. Karststelsels bied skuiling aan 'n verskeidenheid organismes soos grotwonende vlêrmuise en grondwaterwonende amfipode. 'n Baie spesifieke ekotoon tussen die suidelike grasveld en noordelike bosveld wat deur 'n unieke versameling silwerblaar plante gekenmerk word kom in hierdie gebied voor. Benewens hierdie belangrike biologiese aspekte, is hierdie gebied wêreldbekend vir sy ongeëwenaarde fossielrykdom. Die onoordeelkundige gebruik van hulpbronne binne hierdie gebied kan onherstelbare skade aan hierdie unieke erfenis berokken. Besoedeling van die grondwater wat die enigste drinkwater in die gebied is, kan ernstige gesondheidsgevaare vir die inwoners van hierdie gebied inhou. 'n Opvoedkundige program oor die bewaring van die karststelsel, gemik op volwassenes sowel as kinders, geletterdes en ongeletterdes wat in hierdie gebied woon en werk kan tot die volhoubare benutting en bewoning van hierdie gebied lei. 'n Kundige bevolking sal ook bewus wees van negatiewe antropogeniese impakte wat die karststelsel vanuit die aangrensende gebiede mag bedreig, en kan met die hulp van die owerhede teen diesulke oortreders optree.

Introduction

One of the largest and oldest karst systems in the world, dominated by 2.2 billion year old dolomite deposits, covers a vast area that from the North West Province, through Gauteng into Mpumalanga and the Limpopo Province. The urban centres in Gauteng and the North West Province are situated

near or on the karst system due to its proximity to the Witwatersrand gold deposits. The demographic development associated with the Witwatersrand gold deposits resulted in it becoming the most densely populated region in South Africa. The resulting human activities such as mining, farming, industrial development and urbanisation have a negative impact on the groundwater, rivers and ecosystems associated with the karst system in the Cradle of Humankind to the north of Krugersdorp.¹

Karst environments are dominated by carbonate rocks such as limestone, dolomite and gypsum. Karst landscapes are characterised by undulating landforms which are produced mainly by the dissolving of the underlying rock by water instead of the usual physical erosive action of water. Karstification occurs when carbonate rocks, which are easily dissolved with weak acids which naturally occur in nature, produce solution cavities, caves and sinkholes. Karst environments are complex and dynamic systems which, in conjunction with the hydrosphere, form an interface or ecotone between surface and groundwater.

The solubility and permeability of karst make it very susceptible to pollution and degradation. These threats do not only pose a danger for humans depending on the water for consumption and irrigation but also for the associated ecosystems in the region. The caves, aquifers and groundwater in the karst provide natural shelters for many species, some of which are extremely vulnerable to disturbance.

The karst environment in Gauteng, North-West and Limpopo Provinces also house some of the most extensive Plio-Pleistocene fossil deposits in the world, resulting in it being declared the Cradle of Humankind World Heritage Site. Degradation of the karst system will impact negatively on these scientifically important sites which have become the hub of tourism activities in these provinces.

Unfortunately many people living in the karst environment are under the impression that there is an unlimited supply of fresh water in the dolomites.

1 For information that reflects an in depth historical view on these areas see, amongst others, ES van Eeden, "Ekonomiese ontwikkeling en die invloed daarvan op Carletonville, 1948-1988: 'n Historiese studie", (PU vir CHO, PhD-proefskrif, 1992); H Hamann, *A town like no other. Randfontein, more than 75 years of history* (Com Printers, Randfontein, 2004); Municipality of Randfontein, *Randfontein, 1929-1950, the spirit of progress* (na, Randfontein, ca 1951); J du Plooy, "Die sosio-kulturele ontwikkeling van Krugersdorp onder munisipale bestuur tot 1993" (PU vir CHO, PhD-proefskrif, 1998); W de Klerk (Red.), *Krugersdorp 100 jaar* (Krugersdorp, Krugersdorp Stadsraad, 1987); A Nieuwoudt, "Die beplanning van die ontwikkelende verspreide stad in die gebied Carletonville, Fochville en Westonaria, 1942-1985" (PU vir CHO, PhD-proefskrif, 1986).

This resource is used for domestic use in most rural households, to water livestock and to irrigate crops. Another common misconception exists that faeces will be broken down by bacteria in the soil and filtered out by the substrate before it reaches the same ground water used for drinking purposes.

Other anthropogenic activities that have a negative impact on karst ecology include the tendency of residents to use caves and sinkholes as rubbish dumps. The removal of indigenous flora, the failure to eradicate alien invaders, the cultivation of exotics plants and the use of insecticides on their crops and flowers have a detrimental effect on the ecology of the area.

In the mission statement of the Cave and Karst Task Force of the IUCN² it is suggested that an environmental education program could be employed in order to promote a better understanding of karst systems. This should be done in order to change peoples' perceptions and attitude towards karst environments. This awareness would empower people to participate in a meaningful way in the conservation of the karst system.

Several acts could be employed with great efficacy to conserve karst systems, this includes the Environment Conservation Act, 1989 (Act 73 of 1989), the National Environment Management: Biodiversity Act (Act 107 of 1998), National Water Act (1998), the Mineral and Petroleum Resources Development Act (2002), the National Environment Management: Protected Areas Act (Act 57 of 2003) and the Biodiversity Act (2004). These acts provide a legal framework in which conservation of the karst system could be enforced.

Laws need only to be enforced when education failed however. The enforcement of laws and punitive measures taken against culprits usually happen only after the damage has already been done. The conservation of karst and karst ecology will be far more effective if the public sector is more aware and knowledgeable about these matters. In the long term it will be far less expensive and more sustainable if the public sector participates spontaneously and voluntarily in karst and karst ecology conservation, rather than to leave it to the understaffed and budget-deficient government departments alone. It is imperative that the conservation and sanitation awareness of the inhabitants of the karst environment be increased. It is also important that the inhabitants

2 International Union for Conservation of Nature and Natural Resources, "Conserving Biodiversity – Cave and Karst Task Force", 2006 (available at [http://www.Karst education/IUCN - World Commission on Protected Areas.htm](http://www.Karst%20education/IUCN%20-%20World%20Commission%20on%20Protected%20Areas.htm) as accessed in April 2006.

of the karst environment be involved in decision making and management of the area.

Impacts of various role players on the karst system

Pollution from mines, industries, certain agricultural activities, and municipal and household waste have a negative impact on karst, karst ecology and water quality. Mismanagement of water resources, poor agricultural practices, mining activities and urbanisation, lead to the degradation of the karst system and resulting habitat loss.

It is necessary, in order to effectively address the degradation of the karst system, to identify the different impacts that various role players have on it. Industrial waste and mining effluent which in most cases emanates from outside the karst system but which has a negative effect on it, need a different approach than municipal, household and agricultural issues within the karst environment. Following this approach, it is possible to distinguish between the threats that come from inside and immediately adjacent to karst environments and those within the larger geographical area in which the karst system is situated, especially the catchment feeding into the surface water and groundwater associated with the karst system.

Negative anthropogenic impacts on the karst system and karst ecology inside karst environments

Urbanisation, household waste management, limestone mining and agricultural activities are the cause of most of the negative impacts on karst systems within the karst environment. Most of these impacts lead to habitat loss on the surface, within the cave environment and the groundwater. The local municipalities, developers, farmers and other entrepreneurs active within the environment would benefit from environmental educational programmes addressing these issues.

Limestone and dolomite mining issues

Limestone and dolomite are used in the cement industry, to neutralise acid soil in agriculture and horticulture and as a flux in the metal industry. Burnt lime is used in the sugar industry, the extraction of gold and uranium and in

water purification³.

Limestone mining started in Gauteng, North-West and Limpopo Provinces more than a century ago when there was a demand for lime which was used in the gold extraction process and in the booming building industry of the Witwatersrand. Limestone and dolomite mining involve the large scale destruction of vast areas of karst deposits. The drainage of the surface, aquifers and ground water was altered due to limestone mining and many cave habitats were destroyed in the process. Mining also altered the structural condition of the karst in many areas the damage to the karst system can be seen in many places including the fossiliferous areas such as Sterkfontein, Wonder Cave, Haasgat, Bolt's Farm and Gladysvale in the Cradle of Humankind World Heritage Site (COHWHS), in Makopane's Valley and at Taung. Little has been done to rehabilitate these hundreds of abandoned mines in the karst environment⁴. There are currently several companies that mine dolomite in the karst environment for the cement industry.

One of the positive results of limestone mining was that fossil deposits were exposed. The scientific community was alerted to the presence of fossils at Taung in North-West Province, Makopane's Valley in Limpopo Province and at Sterkfontein in Gauteng by the mining community.

Urban issues

Local government, developers, landowners and residents in karst environments will benefit from educational programmes which deal with construction, sanitation and the use of water in dolomitic areas, since many misconceptions exist regarding karst systems, groundwater and ecology.

The COHWHS, which falls within the karst system of Gauteng and North-West, houses approximately 700 farms or smallholdings, some with several residences, none of which receives municipal water or is connected to a municipal sewage system. All the households in the COHWHS are therefore dependent on groundwater for drinking, sanitation, irrigation and watering their livestock. The majority of these households also have French drains

3 JEJ Martini and MGC Wilson, "Limestone and Dolomite", MGC Wilson and Anhaeusser (Eds.), *Mineral Resources of South Africa*, (Council for Geoscience of South Africa, 1998); Handbook 16, p. 740.

4 West Rand District Municipality, *Cradle of Humankind World Heritage Site state of the environment report*, Compiled by Strategic Environmental Focus and Bohlweki Environmental, 2005.

for the homestead and pit latrines for the farm labourers, often only tens of meters away from the borehole. All these households have rubbish dumps on their properties in the absence of municipal waste removal services in this region.

A conventional gravitational sewage system would be impractical in the COHWHS due to its karstic nature. The effectiveness of such a system would depend on a series of pump stations in the undulating landscape, which would make it prohibitively expensive. Backflow and clogging will occur with resulting disastrous impacts upon the surface water and groundwater during power failures which have become more prevalent in recent times. This unfortunate reality has led to the situation where the majority of households within the karst environment have to handle their own sewage disposal.

The Department of Public Works strongly advises against the construction of septic tanks, French drains and pit latrines close to boreholes which are used for water abstraction in dolomitic regions.⁵ Pit latrines could be used in low risk areas as long as they are constructed as far as possible from water supplies and permanent structures; they are relocated annually and are constructed in such a way as to exclude storm water. The Department of Public Works also recommends the use of conservancy tanks with low flush volumes and holding tanks with chemical digestion in conjunction with pit latrines. The best alternative to French drains, septic tanks and pit latrines however are package plants and vacuum tanks. Studies conducted in the COHWHS have shown that these alternatives, which are also costly, are used by very few businesses and households. The relocation of pit latrines rarely occur on a regular basis and in most cases the pit latrines and French drains are in close proximity to permanent structures and boreholes, in spite of municipal regulations.

The quality of the groundwater is monitored by the Department of Water Affairs and Forestry on a regular basis by means of samples taken from boreholes within and around the dolomitic regions on the West Rand. In the case where point source pollution can be traced to specific French drains, septic tanks or pit latrines, the landowner will be legally compelled to solve the situation. Unfortunately the traditional system of soak-aways which is adequate in most rural areas does not work effectively in karst environments

⁵ Department of Public Works, Report PW344, "Appropriate development of infrastructure on dolomites: Guidelines for consultants", 2003.

due to the permeability of dolomite. Bacteria associated with faeces such as faecal coliforms, *Salmonella* and *Clostridium* have been found in the groundwater exposed in Sterkfontein Caves and Koelenhof Cave in the COHWS in 2005.⁶

Most rural households in the karst environment have at least one rubbish dump on the property where rubbish is customarily burned. Household waste, carcasses, empty agrochemical containers are disposed of in this way. Many cases have been observed where residents have turned caves and sinkholes into rubbish dumps. Both these legal and illegal actions have serious implications for the conservation of karst, karst ecosystems and water quality.

The West Rand is experiencing rapid urbanisation which, together with mining poses the biggest immediate threats to karst ecology in the karst environment. Agricultural land in karst environments is being subdivided and developed for residential settlements including high-density housing. There is also an increase of informal settlements in the area. The increase of residents in the area place enormous strain on the existing infrastructure including waste disposal, water supply and effluent management.

Urbanisation is also accompanied by the destruction of the natural fauna and flora of the area with the resultant habitat loss. The fragmentation and degradation of habitats due to urbanisation threaten the indigenous animal populations. Urbanisation goes hand in hand with the reduction in the number and diversity of insects that can be utilised by bats⁷. Urbanisation is also accompanied by the introduction of decorative alien species and the use of fertilisers and pesticides to ensure their growth. The removal of indigenous organisms, the introduction of aliens and the use of agrochemicals contribute to the wholesale destruction of the natural ecology of that area.

Urbanisation is also characterised by the alteration of the natural run-off due to the canalising of streams, drying of wetlands, paving and road construction. The compaction of the soil and paving causes impermeability of the surface which in turn causes localised desertification and flooding. These alterations have a detrimental effect on the natural recharging of the groundwater

6 S van Tonder; JF Durand and S Taylor, "Aspects of the general histology of the gastrointestinal tract, and the use of microbiology and molecular techniques in determining the GIT contents of cave dwelling amphipods" (Proceedings, 15th Entomological Congress of the Entomological Society of Southern Africa, Rhodes University, Grahamstown, 2005), pp. 88-89.

7 JF Geggie and MB Fenton, "A comparison of foraging by *Eptesicus fuscus* (Chiroptera: Vespertilionidae) in urban and rural environments", *Canadian Journal of Zoology*, 63, 1985, pp. 263-266.

and surface hydrology with the resultant negative impact on the associated ecosystems and water quality. In karst systems this alteration in run-off often results in sinkholes forming in places where there is an unnatural abundance of water.

Previous studies have shown that urbanisation has a negative effect on groundwater and cave environments.⁸ In the well known case of the Blesbokspruit on the East Rand the water quality was seriously impacted upon by industrial waste, mine effluent and sewage effluent. The resulting eutrophic water had high concentrations of sulphate, phosphate, nitrite/nitrate, ammonia and heavy metals.⁹ Daily thousands of cubic metres of treated sewage and industrial effluent are released from the Percy Steward municipal sewage works near Krugersdorp into the Blougatspruit, a tributary of the Blaauwbankspruit.¹⁰ Similarly landfills threaten the water quality and ecology in karst environments. Studies have shown that a plume of pollutants emanates from landfills into the groundwater¹¹. The increase of sewage and waste production which accompanies urbanisation would only further contribute to the degradation of the local karst system.

Farming issues

Farming activities on the West Rand include agriculture, horticulture and animal husbandry. Agrochemicals such as pesticides and fertiliser are used as a rule on the West Rand. The leaching of agrochemicals into the soil, surface streams and groundwater has a major negative impact on the ecology and invariably leads to habitat loss and the death of organisms.

The topography of the West Rand makes it more suitable for grain crops, whereas the rocky surfaces and thin soil covering found in the Tarlton and COHWHS areas are better suited for horticulture and orchards. Animal

8 TE Pride, MJ Harvey, AE Ogden and WP Smith, "Water quality and benthic community structure of caves receiving urban runoff", *NSS Bulletin*, 53, 1988, p. 15; JR Reddell and WR Elliott, "The impact of urbanization on endemic cave fauna in Travis and Williamson counties, Texas" (National Speleological Society, NSS Convention, 1994, Abstracts), p. 49.

9 C Haskins, "Blesbokspruit, South Africa, Information sheet for the site designated to the List of Wetlands of International Importance in terms of the Convention on Wetlands of International Importance especially as Waterfowl Habitat, South African Wetlands Conservation Programme, Gauteng Nature Conservation" (available at http://www.ext.grida.no/soesa/nsoer/resource/wetland/blesbokspruit_ris.htm as accessed in April 2006).

10 M Fourie, "A rising acid tide", *Johannesburg Mail & Guardian*, 12 April 2005.

11 JA Cherry, "Migration of contaminants in groundwater at a landfill: A case study", *Journal for Hydrology*, 13(1, 2), 1993, pp. 1-198.

husbandry in the karst environment in Gauteng differs generally from that in North-West. In North-West free ranging cattle grazing in natural veld are a common sight, whereas piggeries, chicken batteries and feedlots are the norm in Gauteng. Feed is imported to sustain these animals in Gauteng because of the scarcity of veld, and water is freely available via the surface streams and boreholes. The result is that far more effluent is produced per surface area on a feedlot than on a conventional farm with free ranging cattle. The same situation applies to other high-density animal husbandry enterprises such as piggeries, chicken batteries and trout farms where the effluent is flushed directly into the rivers in the COHWHS.¹²

The Mogale City municipal regulations stipulate that smallholdings may not be subdivided into portions smaller than two hectares and that there may not be more than two households per smallholding. This regulation is *inter alia* to minimise the impact of sewage on the karst system. Any of these high-density animal production enterprises produce orders of times more sewage than an average household on the same area would. If the subdivision under two hectares in the COHWHS is not allowed by the municipality *inter alia* because of the negative impact of the sewage on the environment and the contamination of the ground water, animal husbandry should also be curbed in the region for the same reason.

The use of pesticides is a very dangerous activity in and around the karst environments. Pesticides and fertiliser are commonly used to increase production on farms but in the karst environment these substances enter the groundwater much faster than in other regions. This has serious consequences for human and animal health because the chemically active insecticides could enter the groundwater before enough time has elapsed for it to break down in less dangerous components. Pesticides and other agrochemicals enter the groundwater through surface runoff and infiltration when it rains and accidental spillage.¹³

The use of insecticides in the karst environment is in direct conflict with the conservation of karst ecosystems. Both bat and aquatic invertebrate populations are threatened by the use of insecticides in the karst environment

12 S van Staden, "A case study on the use of habitat assessments and biological indices for the management of recreational stream fisheries" (MSc Dissertation, RAU, Johannesburg, 2003).

13 JE Conrad, C Colvin, O Sililo, A Görgens, J Weaver & C Reinhardt, "Assessment of the impact of agricultural practices on the quality of groundwater resources in South Africa", Water Research Commission Report No. 64/1/99 (WRC, Pretoria, 1999).

and adjacent areas. Organic farming provides sustainable alternatives to commercial insecticides and fertilisers. The largest tomato producer in the world, ZZ2 near Mooketsi in the Limpopo Province, has proved that it is possible to farm successfully both from an economic and ecological perspective by returning to organic farming methods. These methods prevent salinisation caused by the overuse of artificial fertilisers and the decimation of the ecology caused by the use of pesticides. In addition organic farming has much fewer side effects compared to conventional farming methods.¹⁴

The over-abstraction of groundwater for irrigation has a detrimental effect on the structure of the dolomite as well as the ecological habitats associated with the groundwater and surface area. The situation has deteriorated to such a degree in the Magaliesburg District that the Magalies River has stopped flowing and the adjacent riparian zones have dried out. The big farmers in the district abstract all the available water by means of larger pumps and deeper boreholes. The boreholes of the small farmers in the area can not reach down to the lowered water table and water has to be brought in from outside the region for household drinking purposes. The small farmers in the area can not farm anymore because they cannot irrigate their crops or water their animals. Similarly Malone's Eye in the Tarlton area has dried up in 2005 for the first time in recorded history, coinciding with record levels of abstraction of groundwater in that area. Dolines and sinkholes form frequently when over-abstraction of groundwater occurs and the roofs above solution cavities cave in.¹⁵ The lowering of the water table would cause the aridification of caves, which in turn would make the cave unusable to humidity-dependent bats and aquatic organisms such as amphipods, flatworms and micro-organisms.¹⁶

The clearance of the natural vegetation for farming has a similar negative effect on the ecology as urbanisation. The replacement of the natural vegetation with alien vegetation, ploughing and the compaction of surfaces contribute to changes in permeability, run-off patterns and ultimately the recharge of the groundwater. The karst environment in North-West and Gauteng is characterised by a variety of habitats, including streams, vleis, grassland and hills, which support a distinct floral ecotone between the northern Bushveld

14 T van Zyl, Director ZZ2, Mooketsi, 2007. Personal communication.

15 RJ Kleywegt and DR Pike, "Surface subsidence and sinkholes caused by lowering of the dolomitic water-table on the Far West Rand Gold Field of South Africa", *Annals of the Geological Survey of South Africa*, 16, 1992.

16 JF Durand, "The threats to karst ecology in the Cradle of Humankind World Heritage Site. Flows from the past: a trans-disciplinary conference on the history of water in Africa", (Proceedings, Zoology Conference, University of North-West, Vanderbijlpark Campus, 8-10 December 2004), p.10.

and southern Grassland Biomes¹⁷. The removal of the natural vegetation, which contains several endemic species, causes irreparable damage to this unique ecotone and habitat loss. This in turn has a detrimental impact on a variety of vulnerable animal species, especially those that live in cave and aquatic systems.¹⁸ Introduced invaders compete with indigenous vegetation and in many instances use more water than the indigenous plants.

The grassland in the karst environment has adapted over millions of years to naturally occurring veld fires which have subsequently played an important role in maintaining this vegetation type. Urbanisation and the type of farming that occurs in Gauteng and parts of North-West excludes conservation of this ecotone by means of burning. In the absence of natural veld fires, bush encroachment takes place as the succession from grassland to savannah takes place in the areas which have not been cleared for urban development or farming.¹⁹ The change in vegetation has a profound effect on the species composition of the area, drainage patterns and the recharge rate of the groundwater.

Negative anthropogenic impacts on the karst system and karst ecology from outside the karst environment

Pollution, habitat loss and the mismanagement of the catchment feeding the surface streams and groundwater of the karst environment threaten the integrity of the karst system, karst ecology and aquatic systems. The pollution emanating from the gold and uranium mines in Gauteng and North West Province overshadows all the other threats due to the magnitude and the duration of this threat. Not only does it have a negative impact on the water quality of the whole catchment, but also the quality of the sediment and soil and all the associated ecosystems on and below the surface. Pollution from industries and landfills outside the karst environment enters rivers, groundwater and wetlands which drain into the karst environment.²⁰

17 A Krige, "Floristic study of the Silver Vegetation of Kalkheuveld West in the Cradle of Humankind World Heritage Site, North West Province, South Africa", Botany Honours Research Report, University of Pretoria, 2004.

18 S van Staden, "A case study on the use of habitat assessments and biological indices...".

19 GJ Bredenkamp; F. Spada and E Kazmierczak, "On the origin of northern and southern hemisphere grasslands", *Plant Ecology* 163, 2002, pp. 209-229.

20 JF Durand, "The threats to karst ecology in the Cradle of Humankind World Heritage Site..." (Proceedings, Zoology Conference, 2004), p.10.

The gold and uranium mines of the Witwatersrand Group are situated in the quartzites underlying the dolomites of the Malmani Subgroup. These mines have to be dewatered in order to allow mining to take place.²¹ In the 1960's sinkholes started to form over a large area in the Carltonville District in North-West Province due to the massive abstraction of groundwater from these mines.²² The water has been, and still is in the case of active mines, pumped into adjacent river systems. This activity has had a adverse effect on the natural flow of surface streams as well as the groundwater.²³ The pumping of megalitres of mine effluent into surface streams may alter the natural flow of water within the catchment irrevocably as was the case in the Blesbokspruit on the East Rand. This river system changed from a meandering non-perennial stream without reeds to a permanent reed-containing eutrophic wetland.²⁴

The biggest concern involving gold and uranium mining is the associated pollution emanating from these mines.²⁵ Mining involves bringing rocks which are kilometres below the surface of the earth to the surface to be crushed and treated with an array of chemicals to extract the gold and uranium it contains. During mining pyrite (FeS₂), a natural sulphur-rich component of the quartzite, is exposed to water and oxygen resulting in the formation of sulphuric acid which reacts chemically with the silt, gravel and exposed rock. This results in the release and mobilisation of the heavy metals contained in the silt, gravel and rock. The effluent run-off from the slimes dumps, tailings and rock dumps of gold and uranium mines which enters the catchment typically contains acid and heavy metals. Eventually these pollutants reach the groundwater. In the past slimes dumps were built on the karst itself

21 DJ Morgan and AB Brink, "The far West Rand dolomites", (Proceedings, International Conference on Ground Water Technology, Johannesburg, South Africa, 1981), pp. 554-573; DW Warwick, IJ Brackley, RJ Connelly and G Campbell, "The dewatering of dolomite by deep mining in the West Rand, South Africa", (Proceedings, B Wilson, "2nd Conference on Sinkholes and Environmental Impacts of Karst, 1987" (Beck, Wilson, Orlando, USA), pp. 349-358.

22 RJ Kleywegt and DR Pike, "Surface subsidence and sinkholes...", *Annals of the Geological Survey of South Africa*, 16, 1992.

23 JFEnslin, RJ Kleywegt, JHT Beukes and JF Gordon-Welsh, "Artificial recharge of dolomitic ground-water compartments in the Far West Rand Gold Fields of South Africa", Geological Survey of South Africa, Report 0249, 1976; W. Dreybrodt, "Principles of early development of karst conduits under natural and man-made conditions revealed by mathematical analysis of numerical models", *Water Resources Research*, 32, 1996, pp. 2923-2935.

24 C Haskins, "Blesbokspruit, South Africa..." (available at http://www.ext.grida.no/soesa/nsoer/resource/wetland/blesbokspruit_ris.htm as accessed in April 2006.

25 RJ Kleywegt, "Memorandum oor die moontlike gevaar wat geskep word deur water vanaf die Western Areas Gold Mining Co. Ltd.", *Geological Survey of South Africa*, Technical Report No. 0141, 1977; H Coetzee, F Winde and PW Wade, "An assessment of sources, pathways, mechanisms and risks of current and potential future pollution of water and sediments in gold-mining areas of the Wonderfontein spruit catchment", *Water Research Commission*, Report No. 1214/06, 2006.

because it was found to be more stable due to the fact that the water drained directly into the karst system below with the result that the slimes dump were more stable.

After the closure of many of the mines on the West Rand this situation has deteriorated even further. The dewatering of the mines along the Witwatersrand has caused many springs after which Braamfontein, Doornfontein, Sterkfontein, Randfontein etc. were named, to dry up. After a few years of closure, the groundwater has returned to its original level and the springs which have been dry for almost a century are flowing again, but now decanting toxic acid mine effluent instead of potable water. The first known incident occurred when mine effluent started to emanate from one of the abandoned mine shafts of Harmony Gold Mine (Pty) Ltd (Randfontein Operations). Afterwards a borehole upstream from Tweelopiespruit started to decant and then two dry springs started to issue mine effluent in the Krugersdorp Game Reserve.²⁶ At the time the report was written between 7 and 15 megalitres of water decanted daily into the tributaries that feed into the Tweelopiespruit joining the Crocodile River. Mine effluent is currently issuing from 15 active and 29 closed gold mines in the northern part of the Vaal Barrage catchment which is the main water supply for Gauteng.

AMD threatens the structural stability of the dolomites and calcites of the karst system. Due to the solubility of carbonate rocks, large scale karstification can be expected in the areas affected by AMD.²⁷ Several by-products of gold mining cause the pollution of the soil, groundwater and surface streams and the destruction of the associated ecosystems. The pollutants include AMD, cyanide, sulphates and heavy metals - some of which are radioactive on top of being toxic. AMD leads to the decimation of aquatic ecosystems.²⁸

Cyanide is used to extract gold. Although there are strict regulations concerning the use of cyanide, spillages do occur which cause cyanide to be released accidentally into the environment. Cyanide is a toxin that damages the nervous, cardiovascular and respiratory systems of organisms that ingest or

26 M Fourie, "A rising acid tide", *Johannesburg Mail & Guardian*, 12 April 2005.

27 FDI Hodgson, BH Usher, R Scott et al, "Prediction techniques and preventative measures relating to the post-operational impact of underground mines on the quality and quantity of groundwater resources", *Water Research Commission*, Report No. 699/1/01, 2001; CJU Swart, AR James, RJ Kleywegt and EJ Stoch, "The future of the dolomitic springs after mine closure on the Far West Rand, Gauteng, RSA", *Environmental Geology* 44(7), 2003, pp. 751-770.

28 SS Roback and JW Richardson, "The effects of acid-mine drainage on aquatic insects", *Proc. Acad. Nat. Sci. Phil.* 121, 1969, pp. 81-99; S Jooste and C Thirion, "An ecological risk assessment for a South African acid mine drainage", *Water Science and Technology*, 39(10-11), 1999, pp. 297-303.

inhale it.²⁹ Cyanide poses a great threat to the ecology and human health.³⁰

Mine effluent emanating from the gold mines contains metals including manganese, aluminum, iron, nickel, zinc, cobalt, copper, lead, radium, thorium and uranium.³¹ There is incontrovertible evidence that all of these metals may be toxic and even fatal, depending on the concentration and duration of exposure to them.³² Several of these elements such as uranium, thorium, radium and certain isotopes of lead, are in addition to being extremely toxic, also radioactive.³³ The absorption of these metals may cause necrosis, tumours, cancer and the general impairment of the neurological, cardiovascular, urogenital and digestive systems.³⁴ These metals are found not

29 Agency for Toxic Substances and Disease Registry (ATSDR), *Toxicological profile for cyanide* (US Department of Health and Human Services, Atlanta, 1993).

30 D Albersworth, *Poisoned profits: Cyanide heap leach mining and its impact on the environment* (Washington, D.C., USA, 1992); H Marquardt and SG Schäfer, "Lehrbuch der Toxikologie", *BE Wissenschafts -Verlag* (Mannheim, Deutschland, 1994), pp. 555-558; F Korte and F Coulston, "From single-substance evaluation to ecological process concept: The dilemma of processing gold with cyanide", *Ecotoxicology and Environmental Safety*, 32, 1995, pp. 96-101.

31 AJA Venter, "Assessment of the effects of gold-mine effluent on the natural aquatic environment" (PhD Thesis, RAU, Johannesburg, 1995).

32 MJ Smith and AG Heath, "Acute toxicity of copper, chromate, zinc and cyanide to freshwater fish: Effect of different temperatures", *Bulletin of Environmental Contamination and Toxicology*, 22, 1979, pp. 113-119; AJA Venter, "Assessment of the effects of gold-mine effluent ..."; A Adendorff, "Effects of mining activities on selected aquatic organisms" (PhD Thesis, Rand Afrikaans University, Johannesburg, 1977); S Jooste and C Thirion, "An ecological risk assessment for a South African acid mine drainage", *Water Science and Technology*, 39(10-11), 1999, pp. 297-303.

33 A Durakovic, Medical effects of internal contamination with uranium, *Croatian Medical Journal* 40(1), 1999, pp. 49-66; JB Hursh, NF Neuman, T Toribara, H Wilson & C Waterhouse, "Oral ingestion of uranium by man", *Health Physics* 17(4), 1969, pp. 619-621.

34 SP Zhu, QY Hu and MY Lun, "Studies on reproductive toxicity of enriched uranium [abstract]", *Chun Hoa Yu Fang* (China), 28(4), 1994, pp. 219-222; DE Jackson, "On the pharmacological action of uranium", *American Journal of Physiology*, 26, 1910, pp. 381-395; K Conrad, J Mehlhorn, K Luthre *et al.*, "Systemic lupus erythematosus after heavy exposure to quartz dust in uranium mines: clinical and serological characteristics", *Lupus* 5, 1996, pp. 62-69; X Baur, HP Rihs, P Altmeyer *et al.*, "Systemic sclerosis in German uranium miners under special consideration of antibody subsets and HLA Class II alleles", *Respiration* 63, 1996, pp. 368-375; R Zaire, CS Griffin, PJ Simpson *et al.*, "Analysis of lymphocytes from uranium mine workers in Namibia for chromosomal damage using fluorescence in situ hybridization", *Mutation Research/Genetic Toxicology* 371, 1996, pp. 109-117; R Zaire, M Notter, W Riedel *et al.*, "Unexpected rates of chromosomal instabilities and alterations of hormone levels in Namibian uranium miners", *Radiation Research*, 147, 1997, pp. 579-584; J Bigu, "Theoretical considerations regarding the migration of 22Rn and 220Rn from uranium and thorium bearing underground environments", *Health Physics*, 67, 1994, pp. 60-64; EM Shanahan, D Peterson, D Roxby *et al.*, "Mutation rates at the glycoporphin A and HPRT loci in uranium miners exposed to radon progeny", *Occupational and Environmental Medicine* 53, 1996, pp. 439-444; GS Wilkinson, SK Tynning, MS Legator *et al.*, "Monitoring populations for DNA repair deficiency and for cancer susceptibility", *Environmental Health Perspectives*, 104 Suppl. 3, 1996, pp. 579-584.

only in the water but also in the sediments of rivers and wetlands and have a serious negative impact on these aquatic systems.³⁵

The role of education and legislation in the protection of karst systems and karst ecology

Legislation

There is strong legal framework in place to protect the soil and water quality and biodiversity as well as to insure the public health in the karst environment. There is also adequate legislature to control farming, industrial and mining activities in and around karst environments. The only shortfalls are the failure of implementing an integrated approach to conserve of karst and karst ecology as well as the lack of enforcement of these laws.

The absence of an integrated approach can be seen in the confusion that exists around the prioritisation of legislature – for instance do property rights outweigh the Biodiversity Act? Does the right to produce food for a living by means of conventional farming methods, which includes the use of pesticides, outweigh the Biodiversity Act? Should arable land containing endemic species belonging to a unique ecotone be cleared? Should farms be rehabilitated to conserve this unique heritage? Should high-density animal husbandry be allowed in a karst system where people are dependent on groundwater for drinking purposes? Do the rights of mining companies responsible for the destruction of the ecology outweigh the rights of people to clean water as the Constitution of South Africa clearly state? Every household within the COHWHS has soak-away sewage disposal systems while using borehole water for drinking purposes in direct contravention of Mogale City regulations and recommendations from the Department of Public Works. Simultaneously Mogale City releases the wastewater runoff of the Percy Steward Sewage Works into a tributary of the Blaaubankspruit which is the main water supply of many households in the COHWHS.

The enforcement of legislation is another major problem not only in the karst environment, but in many other arenas in South Africa. The enforcement

35 F Winde and IJ van der Walt, “The significance of groundwater-stream interactions and fluctuating stream chemistry on waterborne uranium contamination of streams – a case study from a gold mining site in South Africa”, *Journal of Hydrology* 297, 2004, pp. 178-196; H Coetzee, F Winde and PW Wade, “An assessment of sources, pathways, mechanisms and risks of current and potential future pollution...”, Water Research Commission, Report No. 1214/06, 2006; E Tempelhoff, “Gif in die water. *Beeld*, 31 Julie 2007, p. 1.

of environmental health legislation depends firstly on the availability of environmental health officers and secondly these environmental health officers in turn depend on the Department of Justice to penalise offenders. The Department of Justice is bogged down under more pressing matters such the escalation of violent crimes in South Africa and environmental offences have to take second priority. The rate for the successful prosecution of offenders is therefore disappointingly low.

The approach of the Mogale City Local Municipality is commendable otherwise. According to their Integrated Development Plan³⁶ the conservation of environmental stability, which includes resource protection, ecological conservation and pollution prevention, is one of its key priorities. The approach of this municipality is to protect the natural resources of the region, such as the water, caves, flora and fauna and land by promoting sustainable development. These natural resources are protected on the one hand by the enforcement of legislature and decision support tools such as the Management Framework and State of the Environment Report, but on the other by awareness programmes such as environmental awareness, park development, waste management, nature conservation and water conservation.³⁷

Unfortunately the threats to karst, karst ecology, groundwater and human health in this region are of such magnitude that local government can not solve all these problems and manage this region alone. The confusion around legal priority in addition to the ineffective enforcement of legislation should be resolved at the highest level. The health of millions of people and the conservation of unique ecosystems are at risk.

It would be naïve to think that the attitude of multi-national corporations, mining houses and industries through environmental will change through educational programmes. The only possible route through which the negative impacts caused by the industries under their control can be minimised or halted is through the consistent and constant enforcement of legislation. Local, Provincial and National Government Agencies such as the Department of Environmental Affairs and Tourism, the Gauteng Department of Agriculture, Conservation and Environment, and the Mogale City Local Municipality, must monitor the emissions and effluent emanating from these industries and mines, environmental studies have to be done and warnings, warrants

³⁶ Mogale City Local Municipality, "Mogale City Local Municipality Integrated Health Sector Plan for the Integrated Development Plan", 2002.

³⁷ Mogale City Local Municipality, "Environmental Management Framework", 2003.

and fines have to be issued.

Ultimately the mines and industries must be legally compelled to comply with health and environmental regulations which include the Environmental Conservation Act, 1989 (Act 73 of 1989), the National Environmental Management Act (Act 107 of 1998), and local by-laws. Mines must also comply with Environmental Management Program Reports (EMPR's). It seems however that very little is done to enforce these laws. The rapid deterioration of karst environments should convince government it has become imperative to weigh the short-term benefits of appeasing industrialists, developers and mine managers by allowing them to continue with actions that have a long term negative impact on the environment.

In the introduction to the State of the Environment Report of Mogale City³⁸ it is stated that: "The State of Environment Report has been compiled to assist the Gauteng Provincial Government, specifically the Gauteng Department of Agriculture, Conservation and Environment and other decision-makers to make informed decisions about our environment. The Gauteng Provincial Government will use the information presented in this report to assist in achieving sustainable development."

The responsibilities of the Department of Agriculture, Conservation and Environment are carried out in terms of 13 major national laws which include: Environment Conservation Act, 1989 (Act 73 of 1989), the National Environment Management Biodiversity Act (Act 107 of 1998), the National Environment Management: Biodiversity Act (Act 107 of 1998), the National Environment Management: Protected Areas Act (Act 57 of 2003), the National Water Act (Act 36 of 1998), and the World Heritage Convention Act (Act 49 of 1999). All these acts are applicable and relevant to the karst environment and associated ecosystems.

Although these acts and local government regulations conform to international best practice, there are many practices in the karst environment that are in direct contravention of these laws. Legislation is only as effective as the will to enforce it.

³⁸ Mogale City Local Municipality, "State of the Environment Report", 2003.

Education

Present legislation provides a legal framework within which the impacts on karst systems and karst ecology can be monitored and measures can be taken against transgressors. These laws and regulations cover the aspects which impact karst, karst ecology and human health (geology and mining, pollution, biodiversity, agriculture, water quality and sanitation). It is clear however that since the negative impacts on karst systems and karst ecology still continue, legislation alone is not sufficient.

In spite of the extensive municipal regulations that exist to regulate the actions of residents and other people which may have a negative impact on the natural resources within Mogale City Local Municipal boundaries, the majority of respondents were unaware of the regulations about subdivision of property, building, sanitation and water quality.

In most of the cases these impacts can be minimised if people were better informed and their attitude towards karst and karst ecology changed. Mogale City Local Municipality³⁹ and the Water Research Commission⁴⁰ have drawn up guidelines for pollution control, the erection of buildings, the placement of package plants, water quality conservation and sanitation in karstic regions. The publication of the Department of Public Works⁴¹ includes extensive guidelines for the development of infrastructure on dolomites. The guidelines include a list of practices that should be avoided when designing infrastructure on dolomitic land, as well as stipulations on the designs and materials used for construction.

In more recent legislation a clause is often included that public education on that particular matter should be promoted. In the World Heritage Convention Act (Act 49 of 1999) for example it is stated “that community well-being and empowerment must be promoted through cultural and natural heritage education, the raising of cultural and natural heritage awareness, the sharing of knowledge and experience and other appropriate means”. In the Mogale City Local Municipality Waste Water Sector Plan it is stated that they aim to “disseminate information about sanitation and wastewater management”.⁴²

39 Mogale City Local Municipality, “Integrated Development Plan 2002-2006”, 2002.

40 Water Research Commission, “Sanitation research strategy”, December 2003. <http://www.wrc.org.za/downloads/special%20publications/SanitationResearchStrategyFinal1.pdf>.

41 Department of Public Works, Report PW344, “Appropriate development of infrastructure on dolomites: Guidelines for consultants”, 2003.

42 Mogale City Local Municipality, “Mogale City Local Municipality Integrated Health Sector Plan for the Integrated Development Plan”, 2002.

In the Mogale City Local Municipality State of the Environment Report⁴³ “What can you do?” section is included in each chapter. Some of the advice pertaining to the conservation of karst systems, groundwater and associated ecology include the following:

- Harvest storm water on your property and use it for irrigation purposes. Ensure that there are soft permeable surfaces on the property.
- Plant indigenous species, which do not have large water requirements, in the garden.
- Only flush the toilet if necessary (place a brick in the cistern and save water).
- Install 2-system flush toilets.
- Rather have a quick shower than a deep bath, it uses less water.
- Use water from the kitchen/bathroom to water the garden.

On the conservation of rivers and wetlands the following advice is included:

- Conserve the existing natural water resources (e.g. the wetlands and rivers) by supporting wetland/river clean-ups as well as initiating and taking part in rehabilitation/management programmes in your area.
- Take part in the Working for Water (WfW) and Land Care Programmes, which eradicate alien vegetation from water resources.
- Conserve the natural water systems in your community.

On nature conservation in general:

- Take part in the establishment of secondary industries, which are linked to the eradication of alien vegetation (e.g. furniture making woodlots). This supports the principle of sustainable development.
- Support local reserves and conservation areas.
- Plant indigenous trees in your garden.
- Familiarise yourself with regard to the Red Data species in your area and take part in the protection of these species and their habitats.
- Be aware of alien invasive species and assist your local authority in removing these species.

⁴³ Mogale City Local Municipality, “State of the Environment Report”, 2003.

On environmental education:

- Take part in environmental education programmes.
- Local schools should assist in managing reserves administered by the MCLM.
- Attend education programmes regarding river and wetland conservation.

On nature conservation legislation and public participation:

- Report unlawful discharge of effluent by industry, business and/or the mining sector to the local health department.
- Owners of land on ridges can protect their properties through formal legislation.
- Communities can form conservancies to protect and manage ridges in their neighbourhoods. The public should play a watchdog role by objecting to development proposals on ridges, bringing insensitive development proposals to the attention of local media and requesting that their local councils implement the policy fully (Urban Green File, 7(4), Sept/Oct 2002).

In the World Heritage Convention Act (Act 49 of 1999), which is applicable to the COHWHS, it is stated “that community well-being and empowerment must be promoted through cultural and natural heritage education, the raising of cultural and natural heritage awareness, the sharing of knowledge and experience and other appropriate means”.

There seems to be consensus amongst regulatory bodies which govern the karst environment, nature conservation and water that the public has to be educated about these matters and that they have to take part in the conservation of these resources. At this stage no forum or communication channel has been identified to disseminate information or to communicate effectively with the public however.

Alternative avenues of communication than the State Gazette and a few poorly advertised public meetings should be explored. The majority of respondents supported the suggestion that information should be disseminated by means of a web site or booklets and flyers informing them on karst and karst ecology, rather than government directives or workshops.

Conclusions

It is important to keep in mind that the present land use, water supply, effluent and waste management and conservation of the karst environment generally fall within the delimitations of the existing legal framework. Unfortunately this is not enough and far more should be done to conserve this area and its unique resources.

Environmental education will also play a positive role in the curbing of the negative impact the farming, industrial and mining industries have on the karst environment by raising the environmental awareness of the general public. People will benefit greatly from knowing what the causes and effects of environmental pollution and degradation will be and how it will affect their lives. It is also imperative that the public be informed about their rights to a healthy environment. In spite of the Bill of Rights in the Constitution of the Republic of South Africa, Section 24, 1996, spelling out these rights, the public is generally unaware of these rights or their implications. The public is generally also ignorant about which governing bodies to complain to or what channels to follow when their rights are impinged upon. The community would benefit greatly from workshops, TV Programmes, websites and blogs, flyers and booklets which explain the public's environmental rights and an introduction to the different governmental and municipal departments' functions.

Web sites or blogs should be set up to inform the residents and operators working and living in the karst environment. The web sites could be utilised with great utility by including more than mere factoids. The web sites should at least include the acts and directives governing the conservation of karst, karst ecology, aquatic habitats and biodiversity, guidelines on rehabilitation of the ecology within the COHWHS, guidelines to sanitation and health, guidelines to sustainable farming on dolomite and guidelines on construction on dolomite. There should be downloadable and printable building plans, interesting school projects and contact details and links to the web sites of conservation societies.

The poorer section of the community would rarely have access to the internet, except maybe through schools and libraries, and may be reached through flyers and booklets. It is crucial to communicate effectively with the farm labourers living and working in the karst environment because they are often the permanent residents while the owners are often absent. Unfortunately due

to the fact that approximately 40% of the adult population of South Africa is illiterate and literacy is dropping even amongst learners, an alternative avenue of communication should be sought.

Even though the respondents were reluctant to attend workshops, it should be mentioned that only white adults responded to the questionnaire. The public sector obviously consists of more than that. I am convinced that farm labourers would be amenable to attending a workshop during work hours and learners attending workshops during school hours, especially if the content matter was presented in a digestible, interesting and entertaining manner. There is an added benefit to presenting workshops; namely providing an opportunity to distribute booklets and flyers.

Workshops for learners should be held at schools during school hours and the content can easily be linked with the existing curriculum which already includes topics on ecology, conservation, sustainable development and health. Experts in permaculture, karst ecology, geology, palaeontology and nature conservation could visit the school with slide shows, Powerpoint presentations or lead a school outing to an organic farm, sewage plant, cave system, river or museum in and around the karst environment in stead of expecting the teacher to present the workshop.

Special workshops on the benefit of organic farming should be held for the farming sector. Organic farming methods are gradually becoming more popular in South Africa. Compost should replace fertiliser and biological control should replace insecticides. It is crucial that farmers should be made aware of the unsustainability of the current orthodox farming methods, which were in the first place designed for non-karst environments. The farming community should also be compelled to take part in clean-up operations on their farms, including the caves and sinkholes on their properties. The farmers should also be responsible for the clearing of alien vegetation on their farms especially along the riparian zones adjacent to the rivers and wetlands on their properties.

The objectives of the conservation of karst environments can also benefit greatly from the establishment of a community forum. It has become evident from interviews done with land owners and tenants living and operating in the karst environment in Gauteng that they feel that they were excluded from the decision-making process with regard to the developments in the COHWHS. Most respondents did not know which government department was involved

with the declaration and development of the COHWHS in spite of the fact that the Gauteng Department of Agriculture, Conservation, Environment and Land Affairs has held several public participation meetings in the area.

The community forum would serve two purposes: it would create a forum where residents, workers and decision makers could voice their opinions and where information could be gathered. Secondly, it could become a vehicle which would legally empower the residents of karst environment and by means of which they could engage with government, developers, industrialists and mines.

Parastatals and local, regional and national government agencies such as Nature Conservation, Department of Public Works, the Health Department, Mogale City Local Municipality, Department of Water Affairs and Forestry, Water Research Commission, Council for Geoscience and the CSIR should also be involved in educational programmes in the karst environment. The community forum could act as the organiser of educational programmes and invite researchers from these institutions to present workshops or lectures on matters of importance to the residents and operators in the karst environment. The establishment of a community forum will open a new and direct channel of communication between government and parastatals and the community through which legislative directives can be passed on to the interested and affected parties. This more transparent and inclusive alternative will provide the local community the opportunity to discuss the government directives and will lessen the suspicion and animosity of the residents towards government.

Similarly developers and environmental consultants could access the community by means of the community forum to inform them about public meetings and planned developments in and around the karst environment. The community forum would be the ideal communication vehicle through which residents can be reached to allay their fears and apprehension about conservation and development. The possibilities are endless – the community forum can arrange community days, lectures, educational tours, river clean-up picnics, eradication of alien species and fundraising events for conservation projects in the region. The money generated by the forum could be used to fund clean-up operations, tree planting days, alien species eradication programmes, permaculture programmes for schools, environmental educational workshops and conservation projects.

There are several NGO's that have an interest in the conservation of karst environments and the associated ecology which will readily cooperate with such a community forum. These organisations include:

- The Gauteng and Northern Regions Bat Interest Group (GNORBIG).
- The South African Society for Amateur Palaeontologists.
- The Geological Society of South Africa.
- Speleological societies.
- Hiking clubs.
- Tree and succulent societies.
- Bird and wildlife societies.

It is important that the operations of such a community forum should be kept democratic and transparent, and to avoid becoming a vehicle for covert political or economic manipulation. For this reason it is important to select individuals and organisations to cooperate with which primarily have the conservation of natural resources and education at heart. The election process should be democratic and membership of cooperating organisations should therefore be open to any member of the public that subscribes to their respective constitutions. Ideally members of the community should join these organisations which would provide the opportunity for the exchange of ideas and transfer of knowledge to take place. This will contribute to the increase of subject knowledge in the region and would empower residents to make informed decisions about their environment, conservation, rehabilitation, health issues and sustainable development.