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Mapping and Evaluation of Pollution in Mine Environments in Southern Africa using GIS and EMS

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Abstract

Während in europäischen Industriestaaten und in den USA sehr viele Untersuchungen zu Umweltbelastungen mit Schadstoffen insbesondere Schwermetallen in Bergbaugebieten durchgeführt wurden, sind aufgrund begrenzter finanzieller Möglichkeiten entsprechende Untersuchungen in Entwicklungsländern eher die Ausnahme. In diesem Kontext sind Untersuchungen in Südafrika und Sambia eine besondere Herausforderung, weil bei der Betrachtung der enormen Flächen die im Einwirkungsbereich der Goldbergbauaktivitäten im Witwatersrandgebiet Südafrikas liegen und der Umweltfolgen des fast hundertjährigen Kupferabbaus in der Copperbelt Sambia viele Parallelen deutlich werden – und weil kaum Untersuchungen zu Ursache-Wirkungsbeziehungen der Schad- und Nährstoffe in diesen Geoökosystemen vorliegen.

Die hier vorgestellten Ergebnisse stammen einerseits aus Fallstudien, die im Rahmen der Aktivitäten von SANTREN (Southern African Network for Training and Research on the Environment) durchgeführt wurden, mit dem Ziel der Entwicklung von Trainingkursen zum Thema "Mining and Environment" für Institutionen und Hochschulen der SADC Region. Andererseits sind sie das Ergebnis der Forschungskooperation zwischen dem Geographischen Institut der Martin-Luther-Universität Halle/Wittenberg und den durch die involvierten Autoren vertretenen Institute.

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In den Untersuchungsgebieten - Copperbelt in Sambia - Kupferbergbau und Carletonville Region Südafrika - Goldbergbau - wurden mittels verschiedener Methoden die Auswirkungen von Tailings und Hütten auf die Umwelt insbesondere die Böden, Pflanzen und Oberflächenwasser untersucht.

Dabei konnte in Sambia im Untersuchungsgebiet Kitwe-Copperbelt erstmalig eine für Sachsen-Anhalt entwickelte GIS basierende Untersuchungsmethodik zur Erstellung des Katasters großräumiger Bodenkontaminationen (KatBo - Zierdt 1996) modifiziert und angewendet werden.

In Carletonville (Untersuchungsgebiet in Südafrika) konnten mittels verschiedener Methoden wie Satelittenbildauswertung, Beprobung von Böden und Oberflächenwasser und Pflanzen die Auswirkungen von Tailings auf die Umwelt untersucht werden. Neben Schwermetallen und Spurenelementen befindet sich im abgebauten Erz eine signifikante Menge Uranerz, deshalb ist es möglich, die Oberflächenradioaktivität zu nutzen, um die Spuren des radioaktiven Niederschlages im Umfeld der Bergbauaktivitäten nachzuweisen. Diese Ergebnisse wurden neben den ermittelten Schwermetallgehalten in Oberflächenböden der Tailings in ein Umweltmanagementsystem eingebaut.

Gleichzeitig konnte für die Region Carletonville mittels Satelittenbildauswertung ein vollständiges Kataster der Tailings erstellt werden.

Diese ersten Untersuchungsergebnisse verdeutlichen die Dringlichkeit weiterer komplexer geoökologischer Untersuchungen um einerseits Migrationspfade und Senken dieser Schadstofflbelastungen in einem typischen Gebiet zu ermitteln und andererseits durch die Implementierung der Erkenntnisse in das Umweltmanagement der Tailings und Hütten die Wirtschaft dieser Länder vor weiteren Umweltschäden zu bewahren.

Dabei erwies sich Nutzung von GIS und Umweltinformationssystemen als hervorragendes Mittel zur Priorisierung des Untersuchungsbedarfes.

1. Introduction

Environmental problems arising from mining have become a major problem within the Southern African Development Community. The present case studies are undertaken as a preliminary investigation into the environmental problems associated with mine dumps in the SADC Region. The Case Studies are some of the activities of the regional Training Network “SANTREN” – Southern African Network for Training and Research on the Environment, in which lecturers and trainers from various universities and training institutions of the SADC Region are involved.

In order to enhance knowledge about mine dumps and to develop and provide high quality training courses for the relevant people in the SADC Region, two case study areas were identified.

1. Copperbelt Area - Zambia – copper mining
2. Carletonville Area – South Africa – gold mining

The studies in these areas were conducted with the help of GIS and EMS.

2. Problems Associated with Gold Mining in South Africa – A Case Study in the Wonderfontein Basin (Far West Rand)

Gold mining activities in South Africa are mainly concentrated in an area known as the Golden Crescent. It is an area stretching from the south east of Johannesburg in the vicinity of Springs, through that city and further west and south west over a distance of approximately 400 kilometres to the south of Welkom.

The gold is contained within the conglomerates of the Witwatersrand Supergroup and the deposits can be dated at approximately 2,800,000 to 2,300,000 years BP (Kent, 1980). The gold bearing reefs also contain minerals such as pyrite, traces of silver and traces of other metals including variable amounts of uranium.

This study will concentrate on a portion of an area known as the West Rand Goldfields. These Goldfields are situated to the west and southwest of Johannesburg and east northeast of Carletonville.

The upper Mooi River drains the present day area, particularly by the so-called Wonderfontein and Loopspruit tributaries. In this study, only problems associated with mines in the Wonderfontein tributary will be discussed.

The gold ore is crushed and the gold and other minerals in the ore are extracted through flotation processes. The resultant slimes are then deposited in built up slime dams. The quality of extraction has improved through the years. In some of the older slime dams the amount of gold still present in the slime is enough to enable the mines to rework the slimes for the recovery of the gold still present. Most of the mines in the area are fairly deep and gold is mined at depths ranging from approximately 1 to 4 km.

Various environmental problems are caused by the mining industry in the study area. The more important problems are associated with the dumping of waste in the form of massive rock dumps and slime dams. Not only are these dumps aesthetically unpleasing but they are also responsible for pollution plumes. Slime dams occupy an area of approximately 25 square kilometres in the Wonderfontein study area.

In order for sidewalls of the dams to be as dry as possible, it was decided by some of the mining companies to locate the slimes dams on the dolomite. This results in a fairly large amount of seepage into the underground aquifer. Not only the original moisture in the slimes, but also infiltrated rainwater can eventually land in the underground water. At present no detailed study is available to quantify the amount of water that eventually lands in the underground aquifer. Some of the slime dams were even constructed over existing sinkholes. In order to try and stabilise these dams, large amounts of slimes are pumped into existing sinkholes.

The next environmental problem caused by the mining activities in the study area is related to the radioactivity issue. As has been mentioned in the introductory paragraph, a significant amount of uranium is present in the ore being mined. Coetzee et al. (1997) had used surface radioactivity to trace radioactive precipitates in the vicinity of mining activities. Their study points to the fact that radioactivity is in fact originating from mining sources and is distributed into the rest of the environment. No quantitative data is obtainable from their report. However, data obtained from the Radioactive Monitoring Committee (1997) shows that there is indeed radioactivity present in samples obtained from localities in the study area.

In summer 1997 surface soil samples were collected to identify the impact from Tailings Dump - Carletonville - Doornfontein Mine Dump on surface soil pollution at several distances from the dump. Samples were taken from the soil surface of ca. 0.25 m² at depths of 0-5 cm. To make sure that the results are comparable, all samples were taken under grassland.

Vegetation parts were removed, and samples were dried and sieved. The applied analytical technique used to determine the total concentration of specific elements in such samples was atomic absorption spectrometry. The analytical results are summarised in Table 1. The measured pH (KCL) in the samples showed that the tailings material was highly acidic with pH 3.3. Since the pH of the natural soils in the area was less acidic, with levels between 4.5 and 5.5, the acidity increased slightly with increasing distances from the edge of the dump, as follows:

- 2.7 up to 4.1 at 500 m distance, and
- 4.5 at 2000 m distance.

Nr.-dir. dist./m	Co	As	Se	Au	Hg	Pb	U	pH KCL
1-SE edge	16	13	25	0,0	0,0	9,1	6,3	2,7
2-SE58	39	5	13	0,1	0,0	19,7	8,2	4,2
3-SE83	37	7	26	0,1	0,0	20,8	4,4	4,1
4-SE110	46	10	26	0,2	3,7	24,4	4,0	4,1
5-SE200	43	7	18	0,1	0,0	19,5	4,7	4,0
6-SE350	31	9	23	0,3	0,0	31,3	3,3	4,1
7-SE400	33	7	22	0,0	0,0	11,9	2,1	4,1
8-SE500	25	5	11	0,1	0,0	8,5	1,9	4,1
1-N edge	4	23	0	0,0	22,9	8,9	2,3	3,6
2-N50	39	9	8	0,2	0,0	16,2	4,7	4,1
3-N100	41	11	20	0,0	0,0	16,3	3,7	4,3
4-N200	38	39	22	0,5	0,0	23,1	15,9	3,9
4a-N200	19	42	9	0,4	0,0	18,3	18,9	3,9
5-N300	44	23	0	0,4	0,0	26,0	15,4	4,0
6-N400	44	14	3	0,7	0,0	12,9	6,6	4,4
7-N500	46	26	0	0,3	0,0	18,5	21,9	4,1
8-N edge	51	208	35	0,6	0,0	55,8	57,2	2,8
9-N1000	54	6	1	0,3	1,2	13,4	31,1	6,4
p3 50-60cm	178	8	0	0,4	0,0	78,5	3,3	4,3
p2 10-30cm	81	10	32	0,8	4,4	31,7	5,2	4,1
p1 0-10cm	12	30	19	0,0	1,1	9,9	12,3	3,3
10-N1500	40	10	31	1,0	0,0	10,0	10,9	7,1
11-N2000	33	3	3	0,0	0,0	20,1	2,0	4,5

Table 1
Surface soil pollution by Doornfontein Mine Dump, Carletonville

An interesting finding was that at the edge of the dump, the concentration of heavy metals like Cr, Co, Ni, As, Pb, Cu, Hg, U and Zn is almost lowest, and highest at 100 m to 200 m distance from the edge of the dump. The minimum level of heavy metals was measured in the dump material itself and often at the edge of the dump. Two possible reasons are assumed. Firstly, it may be the wash out effect of the suspended solids with wind and water erosion. Since the slope of the dump is not re-vegetated, these processes are supported by the special climatic conditions of the tropical climate.

Cd	Zn	Ni	Co	Al	Cu	As	Cr	Pb	Hg
6.5	6-5.5	5.5	5.5	5.5	4.5	4.5-4	4.5-4	4	4

Table 2
Values of pH for a starting mobilisation of heavy metals in soils (Blume. 1992).

Secondly. the very high acidity of this soil samples lowers the mobilisation of heavy metals in soils (Table 2). Toxic heavy metals like As and Hg are washed out into ground and surface water starting from pH 4.5. This is a major risk for human health in the region.

3. Problems Associated with Copper Mining in Zambia -- A Case Study in the Zambian Copperbelt

Mining and smelting in Zambia dates back to A.D. 650 when operations were on a village scale and were replaced by large scale operations in the first half of the 20th century. In 1928, Anglo-American Corporation initiated high level exploration and this was sustained until 1940 when concessions ended. By 1969 a combined production of 720,000 tonnes metal copper from discovered deposits was achieved in the Copperbelt (Watts et al. 1991).

The area of interest encompasses the Nkana Central, Nkana South Orebody (SOB), Mindola, Chambishi and Chibuluma Mines. These mines are located in and around Kitwe, the third largest city, situated some 400-km north of Lusaka, the capital of Zambia. Kitwe and its satellite towns of Kalulushi and Chambishi have a combined population of 490,000 people.

The mines are situated on the north-eastern and south-western sides of the Chambishi-Nkana Basin, which lies to the west of Kafue Anticline. This basin is traversed and drained by streams such as Mwambashi, Kitwe, Mindola, Uchi, Wusakile, Luanshimba, Kamuchanga, Mululu, Kalulushi, Kankashi and Chibuluma which eventually flow into the Kafue River. The is not only the most important river as it supports about 40% of the 9 million people but also the most polluted one in Zambia, mainly due to mining activities in the Zambian Coppebelt in the Upper Kafue and industrial and agricultural activities in the Mazabuka and Kafue towns in the Lower Kafue.

The Nkana Mining Area (ML 3) is some 11217 hectares in extent and is located west of Kitwe, which is situated approximately in the centre of the Zambian Copperbelt. The Nkana Mining Area comprises mainly the South Orebody (SOB), Nkana Central and Mindola Underground Mines.

Metallurgical processing of ores for copper/cobalt extraction has produced, over a period of over 30 years of mining, tailings dams covering a significant surface area. Tailings dumps, most of which are not operational, exist in the Nkana Division area covering a total surface area of 1579.9 ha and contain a total of 224.82 million tonnes of sulphide ore waste.

In summer 1997 surface soil samples were collected to identify the impact of pollution by Tailings Dump 52 and Tailings Dump 60 on surface soil at several distances from the dumps. Samples were taken from the soil surface of about 0.25 m^2 at depths of 0 to 5 cm. To make sure that the results were comparable, all samples were taken under grassland.

Vegetation parts were removed, and samples dried and sieved. The applied analytical technique used to determine the total concentration of specific elements in such samples was atomic absorption spectrometry. The analytical results are summarised in Table 3 (next page). The measured pH (KCL) in the samples showed that the tailings material was alkaline with pH 7.2 - 8.3. Since the pH of the natural soils in the area was quite acidic, with levels between 4.1 and 5.5 (Chirwa and Sichinga, 1996) the acidity increased with increasing distances from the edge of the dump.

An interesting finding is that in our case the concentration of copper heavy metals like Cu, Co, Ni, As, Pb and Zn is almost highest of 100 m distance from the edge of the dump. The minimum level of heavy metals was measured in the dump material itself and often at the edge of the dump. A possible reason may be the washout effect of the suspended solids with wind and water erosion. Since the slope of the dump is not revegetated, these processes are supported by the special climatic conditions of the tropical climate. Since in the Copperbelt these dumps are often situated in the flood plains of the river basin, there are high inputs of suspended solids like toxic heavy metals into the streams. The increase in siltation processes is a known fact of environmental degradation due to water erosion of mine dumps since there are sensitive land uses, such as townships, in the impact area the effect on human health should be considered in further investigations.

distance in m	Pb in ppm	Cu in ppm	As in ppm	Ni in ppm	Zn in ppm	Co in ppm	pH KCL
TD52	6	3380	13	19	26	405	8,3
N	77	14436	22	29	152	983	6,8
N50	50	9372	60	42	269	1722	7,5
N100	87	21433	24	25	105	454	5,7
W	20	3255	15	21	55	530	7,4
W50	60	13392	26	32	119	797	6,6
W100	45	10294	16	22	80	519	6,7
S	12	3094	9	19	38	332	7,4
S50	45	9245	17	27	134	664	6,7
S100	32	9045	11	22	66	389	6,4
TD60	0	3437	3	14	4	147	7,2
S	16	3185	4	20	41	316	6,9
S50	missing	missing	missing	missing	missing	missing	5,2
S100	44	7339	13	61	84	286	4,0
W50	9	1332	5	54	29	74	5,3
W100	434	11833	20	50	1312	631	4,2
N	6	1627	4	63	24	333	6,3
N50	7	1402	5	83	20	122	5,1
N100	13	1935	5	92	30	115	4,9
reference soi	10	885	3	16	16	33	4,2

Table 3
Surface soil pollution, tailings due to tailings, Kitwe

4. Environmental Management Information System - a Tool for Sustainable Development of Mine Dumps

Wide areas of the SADC countries are affected by environmental pollution detrimental to industrial and agricultural use as well as to the quality of nature and landscape.

The sources of contamination are industrial facilities and waste sites as well as traffic, dumps and a diversity of other sources of hazardous substances. Chemicals used in agriculture contributed heavily to soil pollution. The highest environmental risks are caused by toxic metals, PAH, pesticides and nitrates.

Along with the development of the economies in the SADC countries, there is an increase in demands for environmental protection, especially in the mining areas. There appears to be growing confrontation among citizen groups, governmental agencies and members of the mining industry. The degree of conflict and its nature usually depends on the current land use and the estimated consequences of proposed disturbances.

The conflict has centred on the following issues: destruction of landscape, degradation of the visual environment, disturbance of watercourses, destruction of agricultural and forest lands, damage to recreational lands, noise pollution, truck traffic, sedimentation and erosion, land subsidence, vibration from blasting and air blasts, air pollution, water pollution, soil pollution.

These impact processes require a proper study in order to appreciate the extent of environmental degradation. This understanding is necessary to be able to formulate a more appropriate environment management programme. Using GIS as a tool in this study, it was possible to create a complete survey of mine dumps in the case study areas.

The main aim of this project is to develop training material and modules in environmental analysis, methods of identification and evaluation of environmental impacts within a GIS-based environmental management system. In this regard, the experience with the KatBo GIS System, which was developed and used for monitoring and studying environmental problems related to copper mining activities of the Mansfeld Region in East Germany, has been integrated in the project.

By implementing the research results in the management system of tailing dumps to minimise environmental damages, it is possible to protect the economy of the affected country. Using GIS and EMS (Environmental Management Systems) it is possible to evaluate and prioritise necessary mitigation measures.

What is an Environmental Management Information System?

1. This is a relatively new system with methods for classifying the nature and extent of pollution sources. The ultimate goal of the system is to devise the methods needed to record and interpret environmental pollution on a regional scale.
2. The system provides all its users with a user friendly, proven database that includes information on methods, sites, analytical results and quick reference for available problem solving information (e.g. sources, subjects, etc.).
3. All available data is filed in a register, which is flexible since it is updateable and upgradeable to accommodate new information.
4. It is a tool with which to identify all possible anthropogenic factors associated with each pollution source in order to isolate it from those factors which are particularly relevant and related to the spread of the pollution away from the source.
5. The system is also a cost-effective tool which enables its users (the company as well as other relevant agencies) to gather a regional (but also site-specific) overview of all environmental problems. It also provides the user with a tool with which to determine the true source of the pollution. Groundwater, soil and air pollution can therefore be mapped and traced back to its original source.

The SYSTEM will provide a tool to:

- Test, check and prove assessments
- Create programs for the investigation of all contaminated sites and provide standards for contractors
- Assess the present as well as the possible future value and use of sites
- Produce a co-ordinated system for administration

How are MINE DUMPS integrated in the SYSTEM ?

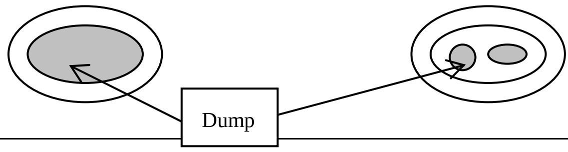
Input Criteria	Anthropogenic Criteria	Natural Criteria
	Type of Mine Dumps: Large Dumps (>1 ha) Dumps from Small Scale Mining	Relief Vegetation Soil Type
Data Source	Data Collection ZCCM Topographical Maps / Aerophotos Field Mapping Environmental Agency	Data Collection
Migration of Pollutants	**Large Dumps**: Wind Erosion - Pollution with heavy metals **Dumps from Small Scale Mining**: High contents of ore in the surrounds of the dump ➢ Often situated in agricultural areas ➢ Short distances between different dumps	
Identification of the impact area from the edge of the dump	Large Dumps: The pollution impact from large dumps can be predicted at 500 m from the edge of the dump. Dumps from Small Scale Mining: the areas of this dumps will be mapped as small scale mine dump fields with a maximum impact area from the edge up to 250 m .	
Manual for implementing in a GIS	Large Dumps: Dumps from Small Scale Mining: 	
Risk Assessment	Reference concentration of heavy metals (Cu) in soils in the Kitwe Area - Copperbelt Zambia Large dumps: 0-10 m 15000 ppm 10-100 m 10000 ppm 100-500 m 1000 ppm	

Figure 1
Overview of phases to inventorise environmental impact zones of mine dumps

Several phases to inventorise environmental impact zones of mine dumps are shown in figure 1 above.

5. Conclusions

Along with the development of the economies of SADC countries, there is an increase in demands for environmental protection. Often only poor data collection is provided for environmental impact assessment. There is therefore a gap to be filled by complete regional environmental information.

Based on the wide range of reasons for providing environmental impact assessment studies and the future requirements to protect wider areas from environmental destruction, there is a need to implement special training in the SADC Region for creating EIAMS (Environment Impact Assessment Management Systems).

As an attempt to fill this need, SANTREN initiated a pilot study entitled Creating an Environment Impact Assessment Management System for the copper-mining region in Zambia.

The vision of the study is to implement the system in universities, training institutions and government agencies in the SADC Region to enhance the quality of management of the environment.

The merits of the system include participation by a multidisciplinary network of independent research institutions in its creation.

There is a challenge for the region to create a unique environmental management system in an area of millions of square kilometres. Using similar tools, the system may be used to support decision making for multinational projects.

It is clear from the above discussion that there are indeed several environmental problems in the study areas due to mining activities (past and present). If the studied area is compared to the total area where gold mining occurs in South Africa and the whole Copperbelt of Zambia, then one realises that the extent of the problems is potentially much larger. Solutions to these problems can only be achieved through concerted research efforts.

The results of this work are to be assimilated into training modules. The experience of national as well as that of international agencies concerned with such environmental problems is indeed of prime importance.

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