Environmental Impact Assessment of Small Scale Resource Exploitation: the case of gold panning in Zhulube Catchment, Limpopo Basin, Zimbabwe

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Abstract

In sub-Saharan Africa most of the population is poverty-stricken and living in the rural areas. These people support their livelihoods by exploiting the natural resources in their vicinity. This study assesses the impacts of one such small-scale natural resource exploitation: gold panning in the Zhulube catchment in the Limpopo basin, Zimbabwe. Environmental impact assessment was done using the pressure-state-impact-response approach. The state was evaluated based on the researcher observation; water quantity was estimated using rainfall and siltation was estimated using two weirs in the catchment together with suspended solids in river water. Water quality was based on chemical water analyses of samples collected from the rivers in the catchment. A survey and informal interviews where carried out to assess the response. The results show small scale resources exploitation in Zhulube catchment have negative impacts on the environment in general and water resources in particular. These activities cause land clearance, erosion, sedimentation and introduction of pollutants among other environmental impacts. The most significant driver of environmental degradation, gold panning, was observed to cause an increase in sediment, an elevation of sulphates entering water bodies and an introduction of the toxic metal mercury into the aquatic environment. Apart from limited enforcement of and compliance with national law, poor resource use practises, a lack of sense of ownership as well as the need to generate livelihoods among users are responsible for the generation of these impacts. It is therefore recommended that illegal forms of small scale resource exploitation such as gold panning should be formalised. Local communities should also be involved in policy making and environmental protection. Furthermore, a continuous and systematic environmental monitoring system should be set up. This system would then act as the basis of decision making in areas of small scale resource exploitation.

Keywords: Gold panning, environmental impact assessment, environmental pressures, small-scale resource exploitation, water quality.

1. Introduction

Since the first Stockholm Conference in 1972 followed by Rio 1992, the Millennium Development Goals and the conference on sustainable development in 2002, environmental protection, together with alleviating poverty and hunger, have gained more attention. Cunningham *et al.* (2005) report that policy makers are becoming aware that eliminating poverty and protecting the environment are interlinked. Furthermore, these authors point out that the poor are both the victims and agents of environmental degradation, forced to meet short term survival needs at the cost of long term sustainability.

Zimbabwe is a subtropical landlocked African country with about 70 percent of it 15 million people living in the rural areas. It has an agro-based economy with most communal rural communities practising rain-fed agriculture (Rockström *et al.*, 2004). The country has one rain season, with periodic droughts. To support their livelihoods the rural population exploits natural resources in the vicinity of their settlements. These activities include small scale mining, irrigated market gardening, wildlife hunting, wood harvesting, wood sculpturing and mat making using tree bucks and reeds.

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It is apparent that small scale resource exploitation is a source of livelihoods to a significant number of people in sub-Saharan Africa (Lombe, 2003); it has the greatest impact in the sustaining of rural economies. In as much as it is a source of livelihoods, it has environmental impacts as well.

Small scale resource exploitation impact studies have been linked mostly to land use changes researches (e.g. Evans *et al.*, 2006; Kloecking and Haberlandt, 2002). Most of these studies have focused on replacement of another land use mainly grassland and forests with agriculture (Joseph, 2002). Kloecking and Harberlandt (2002) envisage that the responses of catchments to changes in land use depend on the reaction of individual sub-basins to changes but in general it will have effects on water availability.

Makoni *et al.* (2004) and Rockström *et al.* (2004) indicate a strong link in water resource use, economic activity (especially rain fed farming) and small scale resource exploitation. Small scale activity can change the landscape without changing the land use at larger scale (Chidumayo, 1997). This suggests that small scale resource exploitation can have effect to water resources by changing the land use locally as well as landscape. Observed effects include increased soil erosion, agro-chemical pollution, degraded water quality and deterioration of freshwater ecosystems (Joseph, 2002).

In small scale mining the sought -after mineral ore reacts in distinct way when brought to the surface and comes into contact with air and water, affecting and altering the type of impact that may be expected such operations (Akcil and Koldas, 2006). The set of impacts that any specific mining operation will have on the environment, and especially the aquatic environment, depends on (Ashton *et al.,* 2001):

- The type of rock and ore being mined;
- The type of mining operation and the scale of operations;
- The efficiency and effectiveness of any environmental management systems that are deployed by mine management; and
- The sensitivity of the receiving environment (including scarcity of water).

Crispin (2003) reports that four key areas of impact that mining may have on water systems are: release of metals, acid mine drainage (AMD), siltation and water use.

Gold panning mainly takes the form of surface and shallow underground mining. Mining methods include mainly strip mining and open pit mining; these may drive environmental change of the affected land surface in the following ways (Ashton *et al.,* 2001):

- Changes in topography and surface drainage with the potential for increased soil erosion, long-term compaction, subsidence and reduced agricultural capacity;
- Disturbance and disruption of the natural groundwater regime with the potential for both ground and surface water pollution; and
- Changes in topsoil characteristics with the potential for increased acidity and salt content, development of nutrient deficiencies or imbalances, surface crustiness or desiccation, changes in vegetation cover and land use with the potential for production of atmospheric dust and other pollution.

Zwane *et al.,* (2006) report that gold panners in Zimbabwe generally work less than 50 tonnes of earth per panner per month; this produces the physical effects of the activity. Panners live behind “moonlike” landscapes in potholed environment consisting of piles of waste, abandoned excavations and vast stretches of land (Aryee *et al.,* 2003; Crispin, 2003; Zwane *et al.,* 2006). The reliance on water for mineral concentration results in accelerated evaporation of surface water, drainage of wetlands, erosion and the siltation of rivers and reservoirs (Maponga and Ngorima, 2003). Some small-scale miners use cyanide and mercury in their gold concentration and amalgamation. They put up unplanned mining compounds sited close to water courses, with attendant poor sanitary facilities, resulting in considerable pollution from human waste (Ashton *et al.,* 2001).

Ore and waste stockpiles established on surface commonly contain significant amounts of sulphides and, with the passage of time, heavy metals, sulphates and other pollutants are dissolved and leached out by precipitation into local streams and community water resources. The impact of mineral pollution on an ecosystem may be severe and may result in the total elimination of animal life from the receiving waters (Ravengai *et al.,* 2005).

This study assessed the environmental impacts of small scale resource exploitation especially gold panning in Zhulube catchment, Zimbabwe and evaluated the state of the environment and impacts of the activities on water resources and livelihoods.

2. Methods

2.1 Study area

The Zhulube Catchment in located in the Limpopo Basin which in a benchmark basin under the CGIAR (Consultative Group on International Agricultural Research) challenge program for water and food. It is situated about 120 km southeast of Bulawayo, the second largest city of Zimbabwe; it is part of the Mzingwane catchment as shown in Fig 1.

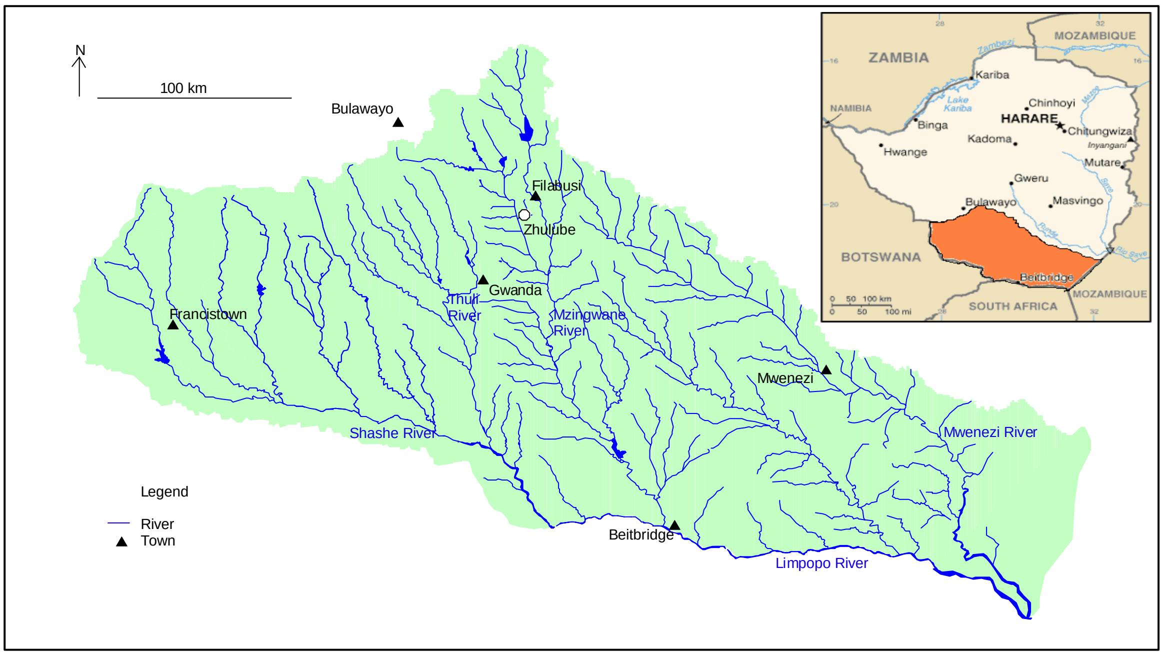

Figure 1. Mzingwane catchment, showing the location of Zhulube catchment. Inset: location in Zimbabwe.

Geologically, most of the catchment is underlain by the Zimbabwe Craton; mafic greenstone, Shamvaian clastics and Archaean granitoid terrain (Ashton *et al.*, 2001, Baglow 1998). The soil types vary from clays and loams in the north to sands soils in the south with stony high ground. The soil types are highly controlled by the underlying geology.

Rainfall in southern Zimbabwe occurs over a limited period of time, and often a large portion of the annual precipitation can fall in a small number of events (Butterworth *et al.*, 1999; de Groen, 2002). The rainfall is erratic, with annual rainfall at Filabusi, an urban centre 2 km north of the catchment, averaging 590 mm/a over the last 70 years but ranging from 250 to 900 mm/a for the same period.

Land ownership in the whole catchment is communal. Land use in the catchment is based partially on the soil types and decisions by the government. The land use of the catchment divided into settlement area, portion for fields and minor built up areas along the Zhulube River with minor grazing land, while along Tshazi River there is mainly range land. Most of the economic activities in this area supports the subsistence lifestyle of most on the inhabitants of the catchment, the most common economic activity being agriculture.

2.2 *Impact Assessment Approach*

The approach used to assess environmental impacts in this project is the pressure state impact response (PSIR) Model. The PSIR model has been in use for some time now and it originated from the Organisation for Economic Co-operation and Development (OECD). Initially it was developed as Pressure-State-Response (PSR) model by the OECD in 1993, to structure its work on environmental policies and reporting (Borja *et al.,* 2006; OECD, 2003). The model considers that human activities exert pressures on the environment and affect its quality and the quantity of natural resources (the state); society responds to these changes through environmental, general economic and sectoral policies and through changes in awareness and behaviour (the response).
The OECD argues that the PSR model highlights these cause-effect relationships, and helps decision makers and the public to see environmental, economic and other issues as interconnected. It thus provides a means of selecting and organising indicators (or state of the environment reports) in a way useful for decision-makers and the public, and of ensuring that nothing important has been overlooked.

2.3 *Data Collection*

Sediment was trapped and measured using two small weirs in the catchment. The weirs where built across tributaries to the Tshazi River with a height of 90 cm and a 20 cm V notch at the centre. The similarity in geology, pedology, vegetation and to some extent geomorphology of the two catchment dammed by the weirs allows a comparison of the two situations. Both weirs where harvested for sediment on the 3rd of January 2007, a month and a half after construction. The harvested sediment was stored and transported in polythene bags. The sediments were weighed for dry weight after oven drying at 105^{o}C for 24 hours.

The surface water samples were collected as shown in figure 2, sampling points of the second survey are similar to those of the first survey. The two surveys were conducted five weeks apart, with the first survey, at the beginning of the rain season. Samples were collected after a storm on the previous day with initial samples being collected while there was flow and those collected later in the day being collected in pools. All sample bottles were made of polythene, they were rinsed with the river water to be sample twice before the sample was collected. They were collected manually by the researcher and no preservation could be done to the samples.

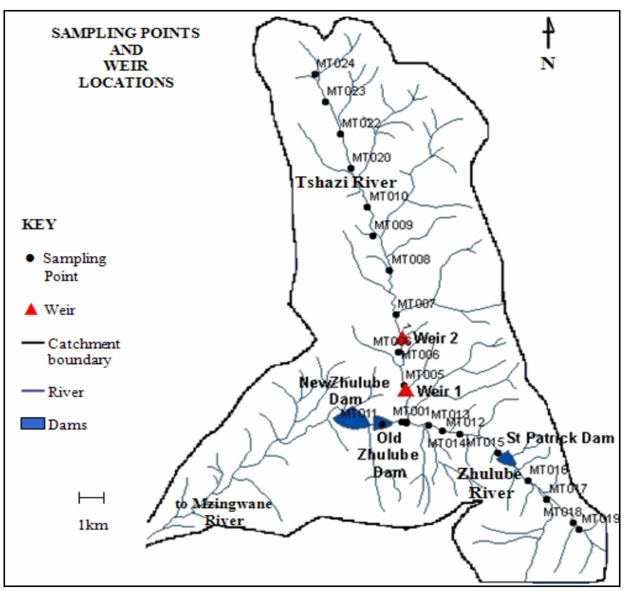

Figure 2. Location of sampling points and weirs.

The samples where analysed for conductivity, temperature and pH using HANNA field devices, while total dissolved and suspended solids where determined gravitationally. Spectro-photometric methods where used to analyse for phosphates and nitrates with titration for hardness and chloride based on Standard Methods (1995) and the Standard Association of Zimbabwe methods. Cations and metals where determined using atomic absorption spectro-photometry (AAS) using two machines namely the Perkin Elmer ASS 3110 and the Solaar 95, graphite furnace and auto-sampler AAS machine. The samples for AAS where digested with nitric acid before analysis. Statistical analysis of the results was done using Microsoft Excel and Statistical Package for Social Scientists (SPSS). Comparisons are made with the World Health Organisation (WHO) drinking water standards (WHO, 2004), South African domestic use water standards (London *et al.*, 2005) and Zimbabwean effluent discharge standards.

A survey was carried out with the two authorities and eight agencies involved in environmental protection of the area. The survey form was given and explained to the head of the agency or authority. Respondents were given up to 3 weeks to fill out the survey form after which it was collected. Long term residents of the area and farmers, in particular were questioned informally for information on historic developments of the activity and their perception on the state of the environment in the future if gold panning was to be left in operation.

3. Results and Discussion

3.1 Rainfall

A total of five rain gauges were used. The average total rainfall received in the catchment over the three months of observation was 157mm. This represents the rainfall received in the first half of the rainfall season. Based on this total rainfall the area is semi-arid with a projected total rainfall at the end of the season between 300 and 500mm.

3.2 Water Quality

Table 3 shows average results for pH, conductivity and hardness. pH increases in the second survey can be explained by the different climatic conditions during sampling. As the rainy season progresses more carbonate material is expected, leading to the increase in pH. The pH range (6.5 – 8.0) reported minimises the effects of acid mine drainage (Akcil and Koldas, 2006). The amount of dissolved solids (TDS) reflects the natural variations in various water bodies and major environmental factors (Chapman, 1996). Although the values of TDS found in the two rivers during the sampling campaigns lie in the ranges of values commonly found in streams and rivers (Bartram and Balance, 1996), the levels are consistently higher in the Tshazi River than the Zhulube river.

Table 3: Average values for pH, dissolved solids and hardness.

Parameter/River(Survey)	**Tshazi River**		**Zhulube River**	
	1st Survey	**2nd Survey**	**1st Survey**	**2nd Survey**
pH ($^{-}$)	7.06	7.79	6.94	7.56
Hardness (mg $CaCO_3$/l)	55	79	36	33
Total dissolved solids (mg/l)	685.50	1101.25	497.50	834.38
Number of samples	8	10	8	9

The Piper diagram of the first survey shows that the geology of the two rivers is different. The cation triangle shows clearly that water in the catchment comes in contact with igneous rocks, with the Tshazi sub-catchment having on average higher magnesium concentrations since it is in a greenstone area while the Zhulube sub-catchment has more sodium and potassium because of underlying granitic rocks.

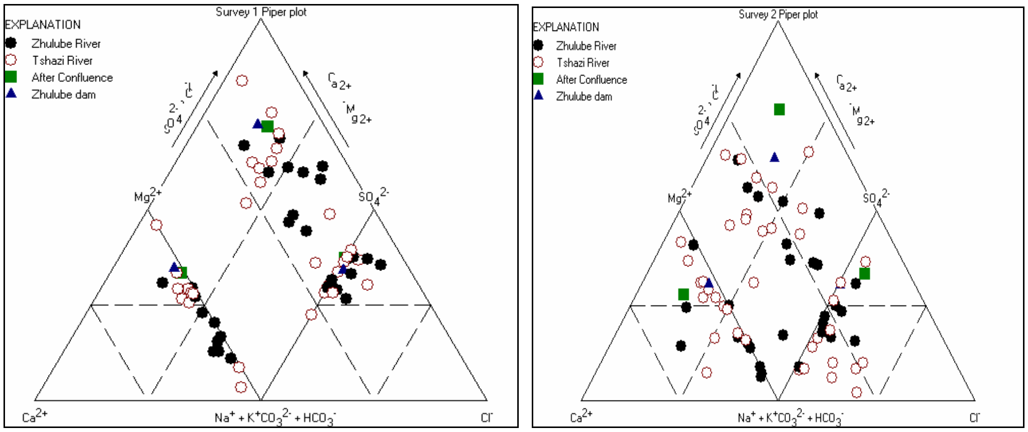

Figure 4. Piper diagrams for water samples of both surveys.

The difference in the cations gives these two rivers different water types. Zhulube River has got sodic water while Tshazi River has calc-magnesian water with permanent hardness. It can be seen that water in the river after the confluence and therefore in the Zhulube dam is dominated by permanent hardness expressed through calcium and magnesium sulphates and chlorides. Permanent hardness will have effects on the quality of the water; some effects of hardness included affecting the taste and the washing efficiency of soaps are significantly reduced (Hounslow, 1995). Hardness is also suspected to increase chances of kidney stones (WHO, 2006). It has effects on aquatic life, especially the life forms which lays legs and which have permeable skin, causing swelling (due to high osmotic pressure).

Nutrients were also assessed in the water samples collected from Zhulube catchment. Of interest were the three primary macronutrients, phosphorous, potassium and nitrogen, value in the sub-catchments are shown in table 4.

Table 4. Mean values of nitrates and phosphate as determined in water samples for the two rivers.

Parameter/River(Survey)	**Tshazi River**		**Zhulube River**	
	1st Survey	**2nd Survey**	**1st Survey**	**2nd Survey**
Nitrates (mg NO_3-N/L)	1.4	1.57	2.38	2.34
Phosphate (mg PO_4-P/L)	0.3	0.05	0.06	0.1
Number of samples	8	10	8	9

Both nitrates and phosphates measured in the water samples are less that the amount for drinking water in Zimbabwe and within the WHO drinking water standards.

Arsenic, copper and lead were within the standards while nickel and mercury were above, rendering the water unsafe for domestic use. The standard for nickel in the WHO standard is 0.07mg/L but in the entire campaign, for both rivers, an average value of 0.14mg/L was found. This value was found in water samples in both surveys and in both rivers. This implies that the value can not be attributed to any exploitation activity since it is the same in both rivers, thus rather can only be regarded as background value

The distribution of mercury in the catchment is shown in figure 5. The figure shows that there is a higher concentration of mercury in river water in the Tshazi River in both campaigns. The value in Zhulube is also higher than all the three standards used, but is consistent in the two campaigns. The highest values in the Tshazi River are associated with area of gold panning especially the processing of the ores. Mercury is used to recover gold from ore minerals by the process of amalgamation (Love, 2002) hence the high values in waters of Tshazi River (see Fig. 5) can be attributed to the processing of gold which is widespread along the river. Mercury is more stable in sediments and in air (Boese-O'Reilly *et al.*, 2004), therefore the values in water samples are taken as an indicator which show that there is probably more mercury in the catchment in other forms. The occurrence of mercury in this river accentuated findings and reports that mercury is a major pollutant associated with gold panning in Zimbabwe (Ashton *et al.*, 2001; Zwane *et al.*, 2006) and elsewhere (Hinton *et al.*, 2003; Kambey *et al.*, 2001; Ramírez-Requelme *et al.*, 2002).

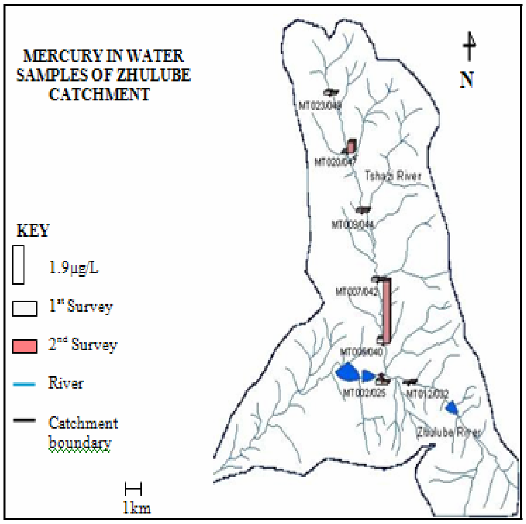

Figure 5. Levels of mercury in Zhulube catchment.

3.3 Sediments

Sediment levels in the Tshazi River are nearly twice as high as those of the Zhulube River (table 5).

Table 5. Means and standard deviations of total suspended solids in the two rivers in mg/L.

River	Survey 1	Survey 2
Tshazi River	479 ±109 (n=11)	973 ±181 (n=11)
Zhulube River	268 ±83 (n=9)	366 ±121 (n=10)

Although there is an increase in the two rivers in the second survey, in general the increase in the Tshazi catchment is greater than that in the Zhulube catchment. It was observed that from the onset of the rainy season panning activities increase due to the availability of water. The increase in suspended sediment in Tshazi is therefore mainly attributed to this activity. In comparison with water standards for effluent discharge, both rivers have most of their values in the red class, which means they far exceed Zimbabwean safe water standards.

The values for suspended sediment for the Tshazi River are above those of Zhulube River. This is despite the fact that the Zhulube River sub-catchment contains most of the settlement and human activities and under normal circumstances it will generate more erosion than the other river, hence more suspended sediments (and TDS) would be expected (Evans *et al.*, 2006). The only human activity in Tshazi River which can contribute to such elevated levels is gold panning. The high values in the Tshazi River can be explained by the excavations made by panners; such activities increase the rate of weathering and susceptibility to erosion (Castro and Sanchez, 2003; Shoko and Love, 2005; Zwane *et al.*, 2006). Despite being lower than in the Tshazi River, suspended sediments levels in the Zhulube River are above the standards set for domestic use in South Africa and effluent discharge for safe water in Zimbabwe. Gold panning alone therefore cannot be singled out as the major source of dissolved solids and sediment downstream of this catchment. It was observed that such a high yield in the other river can be attributed to:

- Pre-existing geomorphology along the river, which has gullies that promote high rates of erosion (Dondofema and Mhizha, 2007; Ngwenya *et al.*, 2006).

- The beginning of the rainy season during which huge amounts of sediments are generated from the bare fields and yards in the sub-catchment.
- Natural yield in sediments due to differences in geology and soils in the two sub-catchments.

Values for trapped sediments are shown in table 6.

Table 6. Weight of sediment harvested in the weirs

Weir	Fresh weight (kg)	Dry weight (kg)	Catchment Area (km^2)	kg/km^2
1	76.33	63.20	0.500	126.40
2	43.94	34.00	0.125	272.00

The results would have been more representative if the catchments were of the same size. It was noticed that water reached the weir in the bigger catchment (weir 1) only after heavy storms (above 20 mm) while for weir 2 even rainfall events of less than 10 mm produced runoff which reached the weir, hence the value for weir 2 is higher because even small storms generated some sediment while there was no significant difference in the amount of rainfall in the two sub-catchments.

One possible factor is catchment size: it has been shown that runoff coefficients generally decline with catchment size in the Mzingwane catchment (Love *et al.*, in press) and proportionally lower discharge could result in proportionally lower sediment load in the larger catchment. Size of the catchments also meant that during heavy storms more discharge passed through weir 1. It was noted that high amounts of discharge are able to reactivate previously deposited sediment and since sediment was gathered after a number of storm events, some sediment was lost. In the river with panning there are holes and damming sites before the weir. These act as sediment traps before the material gets to the weir. The above implies that the amount of material at the weir is, therefore, not totally representative of the material generated. Although the amounts of sediments harvested are elevated they are not representative of the sought after measure of sedimentation.

3.4 Pressure State Impact Response Study

The state of the environment and water quality in the Zhulube catchment can be partly explained by natural controls such as geology and climate. Besides these natural controls of water quality, a number of pressures can be imposed on river systems by anthropogenic activities. In relation to water resources four broad groups of pressures were identified by Borja *et al*. (2006). These groups are: 1) pollution, which is mainly from discharges into rivers; 2) alteration of hydrological regime by water abstraction and flow regulation; 3) changes in morphology; and 4) biology. Biology focuses on changes in biodiversity and was not assessed in this project. The same classification was used in this project but narrowed down due to the size of the catchment under study and pressures in the catchment as assessed are shown in table 7.

Table 7. Assessment of pressure levels of relevant pressures in the Zhulube catchment. Key: -, without; *, Low; **, Moderate; ***, high. (after method of Borja *et al.,* 2006)

Pressures	Tshazi River	Zhulube River
Sediments	***	**
Nutrients	-	*
Water abstraction	**	-
Heavy metals	*	-
Channel morphology	***	**
Hardness	***	*

These pressures are generated by drivers in the catchment. Drivers indicate those anthropogenic activities which impose pressures on resources (OECD, 2003), i.e. water resources. In the Zhulube Catchment three major drivers where identified. First, gold panning is a significant driver especially along Tshazi River. Second, another relevant driver in the catchment is agriculture. Agriculture encompasses smallholder crop production and animal husbandry practised in the catchment. Third, population is also a pressure; this is the general increase in population, causing more demands on the environment. Table 8 gives the level of influence of the drivers in the catchment. High levels of influence imply that the driver significantly contributes to the pressure while low indicate minimal contribution.

Table 8. Level of influence of the main drivers on the relevant pressures in the Zhulube catchment. Key: *** High; ** Moderate; * Low. (after method of Borja *et al.*, 2006)

Pressures	Drivers		
	Gold panning	Agriculture	Population
Sediments	***	**	*
Nutrients		*	
water abstraction	**		*
Heavy metals	***		
Morphology	***	**	*
Hardness	**		

The analysis shows that small scale resource exploitation has some negative impacts on the environment. In the Zhulube catchment, the significant small scale resource exploitation activities with impact on water resources are gold panning and agriculture. The most considerable impact is the generation of sediment which causes siltation of dams and rivers which is rampant in the Limpopo basin (Mhizha, *in press*). In addition, these activities also alter the hydrological regimes in the basin and morphological properties of rivers.

3.5 Management Options

The general approach to enable gold panning management was to permit it in order to regulate it (Zwane *et al.*, 2006). The Environmental Management and the Water Acts create a framework for environmental protection, and institutions for the implementation and monitoring. In common with most developing countries, legislation is clearly written but is difficult to implement mainly due to lack of capacity and resources.

A number of institutions are found at the local level in the Zhulube catchment to implement environmental protection monitoring, they are also responsible for formulating and directing national policies at local level. Most of the institutions are ill-equipped with lack of proper manpower and instrumentation. This problem is widespread (Maponga and Ngorima, 2003; Shoko and Love, 2005; Zwane *et al.*, 2006). In addition, there are numerous institutions which are not well coordinated; centralisation of efforts may increase resources and efficiency of operations (Zwane *et al.*, 2006).

Crispin (2003) argued that the only way to eradicate small scale mining is to create other livelihood generating activities; besides that there is need to have trade-offs with environmental protection. Hinton *et al.*, (2003) argue that sustainable development can be applied to small scale mining; this can the realised by realisation of net benefit by the panners from the inception of activity to post production. Key to this process is formalisation of the activities and creating a code of conduct in the activities, especially with regards to environmental protection.

The involvement of the local community including the person active in panning could improve environment protection (Hinton *et al.*, 2003). In such instances capacity building should not only focus on authorities and agencies of environmental protection but rather on the local community. Such a wide spread of capacity can initiate the principle of subsidiarity which is crucial in environment protection (Cunningham *et al.*, 2005). Management and monitoring structures should be established at village level. Other advantages of local participation include lower policing costs and a strong sense of ownership and belonging by the local communities (Shoko and Love, 2005).

Formalisation of small scale mining and other types of resource exploitation would also go a long way to reduce environmental impacts; clean technologies will significantly reduce impacts on water resources. One of the major pollutants being produced in this system is mercury. Cleaner production techniques have been reported world-wide (Babut, *et al.,* 2003; Ghose, 2003; Hinton *et al.,* 2003), which can be used in the purification of gold to reduce its impacts on the workers and the environment.

4. Conclusions

- Small scale resource exploitations, represented in this case by gold panning and agriculture, are significant drivers causing environmental change and generating negative impacts on the environment.
- Negative impacts generated by gold panning on water resources are the generation of sediment, the elevation of sulphates entering water bodies causing permanent hardness of water and introduction of the toxic metal mercury.
- Agriculture and population growth also impose negative impacts on water resources especially by generating sediments. Population growth injects need for other types of resource exploitation like brick making and sand harvesting, which also have negative impacts on the environment.
- A combination of factors may be responsible for the generation of these impacts. These include the need to generate livelihoods, poor resource use practises and lack of sense of ownership among users.
- There is limited if any environmental monitoring as well as systematic water quality monitoring in the Zhulube catchment. As a results there is lack of paucity of data, which should form the basis of decision making.
- The research established that there is a clear national legislation framework for environmental management but is not being applied at the local level. This is mainly due to lack of capacity and resources of local authorities and agencies.
- Also noted is the lack of involvement of local communities in policy making and environmental protection. Some of their significant forms of income hence livelihoods are illegal. This generates more negative impacts on the environment than if the activities are formalised and ways to reduce impacts and cleaner technologies are discussed and made available.

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