Elements of Groundwater Pollution and Protection in a Karst Environment of Lusaka.

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INTRODUCTION

Lusaka lies in an area of folded Precambrian metamorphic rocks. These include a variety of lithologies: marbles (both calcite and dolomite), schists, quartzites and gneisses, the dominating geological characteristics of the area being provided by the thick and extensive marbles (Fig 1). The carbonate rocks of the Lusaka area are commonly referred to as limestone and dolomite; but they are all crystalline metamorphic rocks and the correct name is marble (D.& B. Turner, in Williams 1986). The extensive occurence of marble has given rise to karst conditions.

Karst conditions are probably the most unfavorable geologic media considering vulnerability of the aquifers to different kinds of pollution and their low self-purification capabilities. Enourmous uncontrolled emission of a wide spectrum of pollutants coming mainly from unsewered urban settlements and also from industry and various activities of man is particularly reflected negatively on the karst environment and its groundwater resources. In the case of Lusaka, this is emphasized by a complete absence of regional urban development plans considering the natural integrity of water districts. On the other hand, karst groundwater is not "completely lost" , therefore strict measures should be taken by Lusaka City Council.

DEFINING AND CLASSIFICATION OF SOURCES OF POLLUTION

The first step in the process of groundwater protection is defining the sources of pollution. Besides general division based on areal spread of pollution (i.e. division into point and nonpoint pollution), the sources of pollution are divided into the following according to their origin: natural, rural and urban. Based on duration, all sources of pollution also could be divided into temporal and permanent.

Natural sources of pollution are constituted by erosion of natural material. It is particulary important in boundary areas between karstified and nonkarstified terrains where heavy rain torrents coming from clastic or magmatic rocks (in case of Lusaka it is mainly schists) usually cause a rapid increase of turbity at wells. The process of physical and chemical disintegration of carbonate rocks during karstification also produce turbity after washout of deposited terra rossa and clay material from fissures and karst cavities.

Closely related to the turbidity of karst groundwaters is the content of bacteria. The presence of humic acids and suspended particles in groundwater increses the time of survival of bacteria, which is, especially in highly karstified aquifers, usually longer than the travel time of the groundwater between the recharge surface and point (surface) of discharge.
Another source of karst groundwater pollution can be organic matter that originates from plant and animal remains and of course groundwaters close to ore deposits act as natural pollutants of karst aquifer.

Rural pollutants characterize agricultural areas around Lusaka. These are mainly represented by animal wastes from livestock and fertilizers. Concentrations of pecticides and herbicides in the groundwater of Lusaka have not been evaluated.

The biggest source of contaminants is nitrogen fertilizers. High values of nitrate (Table 1) indicates that this aspect of pollution comes from agricultural sector. Also boreholes in the farming areas gives high contents of nitrate (very rarely less than 15 mg/l).

The group of *urban pollutants* is the largest, and have the most dangerous consequences on karst environment. It includes:
- Communal waste water (sewege)
- Industrial waste water
- Waste disposal
- Traffic wastes
- Precipitation

Organic chemicals and heavy metals, which have contaminated a groundwater (Table 1 and 2), come mainly from previously listed sources.

GROUNDWATER QUALITY ANALYSIS

The groundwater quality data include analyses from 19 boreholes. 152 samples were analysed for ammonia, nitrate, nitrite, chloride and sulphite. Concentrations of Cd, Cr, Cu, Fe, Mn, Ni, Zn were determined from 68 samples; As and Se from 53; Al from 47 and Hg from 23.

Unpolluted groundwater contains *ammonia* usually less than 0.1 mgl^{-1}. Median concentration of ammonia in Lusaka groundwater 0.4 mgl^{-1} is clear indication of organic pollution, such as leaching from pit latrines, domestic sewage and industrial waste. There is small increase in ammonia concentration with heavy rains. This can be explained by leaching effect of the rains on all surface deposits of sewage and waste.

Nitrate concentration in natural levels, which seldom exceed 0.1 mgl^{-1} NO_3-N, may be enhanced by municipal and industrial wastewaters, including leachetes from waste disposal sites and landfills. In Lusaka area median concentration of nitrate exceeds 10 mgl^{-1} and can reach up to 160 mgl^{-1}. This gives rise to great concern as undoubtely heavy chemical contamination is accompaning the chemical pollution. In 87% of samples NO_3-N concentration exceeds WHO-s limit.

A few high *nitrite* concentrations can be indicative of industrial effluents.

Higher *chloride* concentrations occur near unsewered settlements (mainly southern and south-western compounds of Lusaka). As chloride is frequently associated with sewege, it is often incorporated into assesments as an indication of possible faecal contamination in groundwater.

Sulphate concentration in natural waters are usually between 2 and 80 mgl^{-1}. Industrial discharges and atmospheric precipitation can possibly add significant amount of sulphate to groundwater.

Metals

Generally, trace amounts of metals are always present in groundwaters from the weathering of rocks and soil. In addition, industrial wastewater discharge is the major source of metals into groundwater (as mining activity have possible greatest influence in the other urban areas of Zambia). Significant amounts of metals also enter surface waters from atmospheric deposition (e.g. lead).

Water pollution by heavy metals resulting from anthropogenic impact is serious threat to human health. This situation is aggravated by the lack of natural elimination process for metals.

High iron concentration is an important groundwater quality issue in Lusaka. This situation is made worse by the corrosion of ferrous well linings and pump components. Lead, widely used as an additive in petroleum for automobiles and is emitted to the atmosphere in exhaust. Concentrations of Cd, As, Ni, and Cu can also give us great cocern about groundwater quality in Lusaka.

CONCLUSIONS

Several studies have proofed that the underground water in the karst aquifer in Lusaka is polluted. According present study 70-80% of wells are chemically contaminated. During last 15 years there is also clear trend of increasing groundwater pollution. The natural purification capacity of the aquifer is very limited due to the aquifer characteristics. Once pollutants have reached the water table only a certain amount of dilution can take place. Means for water quality improvement by treatment are limited. Biological pollution can be met by chlorination. Chemically contaminated water however is costly to be treated and toxic substances cannot be removed without implementation of complex and extremely costly treatment processes.

40% of water supply of Lusaka is from groundwater sources. Public health demands the implementation of measures to ensure good drinking water quality. Effective groundwater protection will ensure the preservation of an important public asset.

Protection measures should include:

- Continuous monitoring of the physical, chemical and biological characteristics of groundwater.
- Removal of all sources of pollution from the karstic depressions and prohibiting a use of natural depressions and collapses as dumping sites.
- Establishing the Groundwater Protection Areas as this was recommended 1978 by German study for Lusaka City Council.
- Stop spreading the unsewered urban settlements to the south and south-west of Lusaka.

TABLE 1. Concentrations of selected Lusaka ground water variables (mg/l)

	Min	Max	Med	WHO's allowable limit	Percentage of samples exceeding WHO's limit
Ammonia	0.1	3	0.4	0.5	36%
Nitrate as N	2	160	12	10	87%
Nitrite as N	not detect.	3	0.9	1.0*	8%
Chloride	15	290	85	250	17%
Sulphate	38	520	340	400	9%

* Allowable limit in Canada

TABLE 2. Contents of selected elements in Lusaka ground water (in ppm).

	Number of samples	Min	Max	Med	WHO's limit	Percentage of samples exceeding WHO's limit
Al	47	0.00	0.200	0.100	0.200	-
Cd	68	0.00	0.008	0.004	0.005	12%
Cr	68	0.00	0.045	0.009	0.050	-
Cu	68	0.00	1.500	0.200	1.000	4%
Fe	68	0.01	3.300	0.270	0.300	54%
Hg	23	0.00	0.001	0.0005 (?)	0.001	-
Mn	68	0.00	0.003	0.005	0.100	-
Ni	68	0.00	0.140	0.028	0.050	32%
Pb	68	0.00	0.100	0.067	0.050	47%
Zn	68	0.00	5.000	3.500	5.000	-
As	53	0.00	0.080	0.038	0.050	11%
Se	53	0.00	0.006	0.002	0.010	-