Anthropogenic pollution characteristics and impacts on shallow groundwater in a peri-urban settlement in Kampala, Uganda and solutions for prevention

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Introduction

Kampala, the capital city of Uganda like many cities in Sub-Saharan Africa has the majority of its population (60%) residing in peri-urban areas. These areas are densely populated, located in valleys with a high water table and lack basic social infrastructural services. The use of shallow groundwater for domestic consumption is a common practice in Kampala's informal settlements. About 36% of the population in the peri-urban settlements and slums within the city draws shallow groundwater from protected springs and 11% from unprotected springs. The quality of the shallow groundwater is a major concern due to the poor environmental sanitation in these areas.

This study was undertaken to characterize the potential anthropogenic pollutant sources in a typical Kampala peri-urban settlement, analyse impacts on the shallow groundwater quality and propose solutions for pollution mitigation.

Case Study Area

Bwaise III Parish is located in the northern part of Kampala approximately 4 km from the city centre (Fig.1) covers an area of 57ha.

Low-lying area with a high water table (<0.5-1.5m) in most of the areas. Largely unplanned with lack of basic services, poor road access and deplorable housing (Fig.2).

Has one of the highest population growth rates in Kampala District with an annual average rate of 9.6% (more than twice the city's average annual growth rate of 3.7%) and a population density of about 27,000 pers/km^2.

Fig 1. Kampala District Map showing the location of Bwaise III Parish

Fig 2. An overview of the dense deplorable housing in part of Bwaise III Parish

Materials and Methods

- Field surveys and consultations were undertaken to identify and locate pollution sources, and assess the environmental sanitation of the area.
- 16 monitoring wells (code named MW1 to MW16) were installed (up to 2m depth) in two zones of the study area. Water quality monitoring was carried out over a period of 19 months during 2003-04 from these wells and one protected spring to ascertain the seasonal variation.
- Rainwater samples were collected near the Faculty of Technology, Makerere University (about 1.5km from the study area) to ascertain the quality. Wastewater samples were collected from three selected secondary drains within the area.
- Field *in-situ* measurements of temperature, pH, electrical conductivity and dissolved oxygen using field meters and, wastewater flow and spring discharge rates.
- Water and wastewater sample analysis at the Public Health and Environmental Engineering Laboratory (Faculty of Technology, Makerere University) according to APHA/ AWWA standard methods for water and wastewater analysis.

Results and Discussion

Pollutant source characteristics

The identified anthropogenic pollution sources for shallow groundwater in the area are presented in Fig.3.

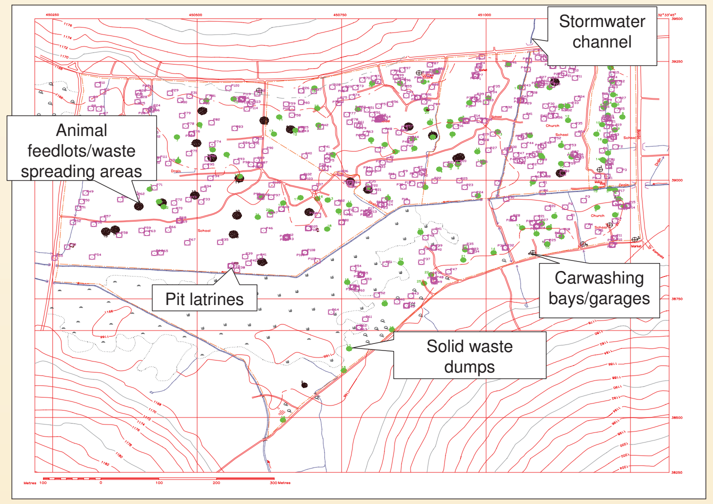

Figure 3. Anthropogenic pollution source types in Bwaise III Parish

The major pollutant sources were excreta disposal facilities (pit latrines), solid waste dumps and grey/storm water discharged into unlined drains in that order (Fig. 4).

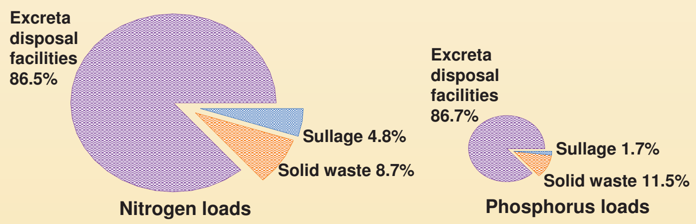

Figure 4. Annual nutrient load contribution from the major pollutant sources

- >80% of the pit latrines are of the traditional unimproved type (Fig. 5) and do not meet the basic criteria of hygiene and accessibility to the children and disabled persons.
- Polythene bags ("flying toilets") and spaces around the house are used for excreta disposal especially by the children.
- Open dumping is a major form of solid waste disposal in the area (Fig. 5 & 6). Approximately 9000kg/d of solid waste is generated which previous studies show is 80-90% biodegradable, 0.4% metal, 2.5% plastics and polyethylene bags, 1.1% wood wastes, 1.7% paper and 7.4% others.

Figure 5. Typical raised pit latrine in the area. Note solid waste dump in the foreground

Figure 6. Sullage/storm water drain in the area with solid waste dumping on the drain bank.

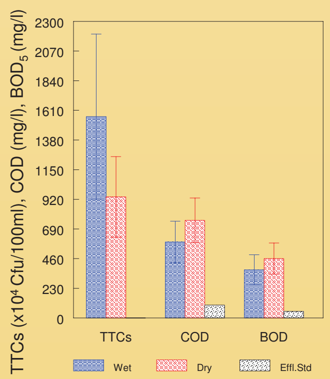

Figure 7. Seasonal variation of grey/storm water quality

- Most households do not use water-borne sanitation. Grey water is directly disposed of into unlined grey/storm water drains and open spaces (Fig.5).
- Drains operate as combined sewers with high chemical oxygen demand (COD), biochemical oxygen demand (BOD$_5$) and thermotolerant coliform (TTC) values above national effluent discharge standards (Fig. 7).

Shallow groundwater quality - anthropogenic pollution impacts

- Shallow groundwater quality varies with season. During the rains, quality deteriorates in terms of the bacteriological and organic content (Fig. 8).
- The shallow groundwater has up to 779 mg/l of nitrates, 370 mg/l of Total kjedahl nitrogen, 126E3 cfu/100ml of TTCs, 154E3 cfu/100ml of Faecal streptococci and 13 mg/l of total phosphorus.
- Contamination of the shallow groundwater in the area is widespread and is linked to the multiple pollutant sources (Fig. 3).

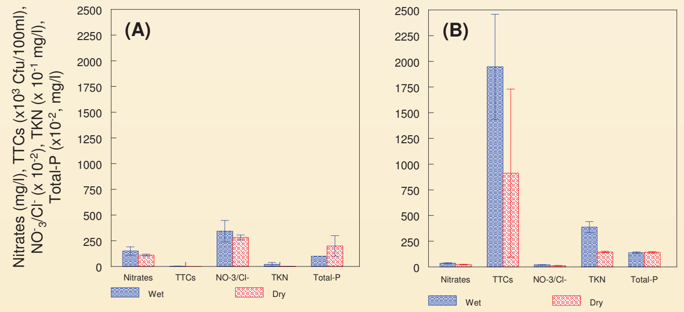

Figure 8. (A) Protected spring and (B) Monitoring well (16no.) water quality variation with season (average values ± Standard error bars)

- The groundwater has high microbial contamination above national and WHO drinking water standards.
- The spring discharge exhibits relatively lower contaminant values than the wells (Fig.8). This may be due to the highly pervious shallow vadose zone associated with the wells. The latter is suggested by the strong positive correlation between the short rains and water table depths at most of the well locations (Table 1).
- A low positive correlation between the spring discharge and short rains (r=0.356, P=0.042) suggests
  - hardly any mix between the "old" and "new" water from rainfall infiltration in this system
  - spring is primarily fed by base flow from a high storage aquifer. Hence the potential pollutant sources of this water source lie within a wider catchment extending outside Bwaise III Parish.

Table 1 Correlations of the water table depths[1] with short rains (48hr) at the monitoring well locations

MW ID	Pearson correlation coefficient	Sig. (2 tailed)
1	0.608**	0.000
2	0.317 *	0.049
3	0.852 **	0.000
4	0.534 **	0.001
5	0.364	0.052
6	0.581**	0.000
7	0.490**	0.002
8	0.531**	0.001
9	0.480**	0.003
10	0.555	0.096
11	0.589	0.057
12	0.606*	0.048
13	0.618*	0.043
14	0.524	0.098
15	0.494	0.122
16	0.684*	0.029

** Significant at the 0.01 level

* Significant at the 0.05 level (2-tailed)

[1] Water table depths varied between 1.19 to 0.22m below ground level. The positive values are indicative of a risen WT above ground level and occurred during flooding.

The latter, could possibly explain the occurrence of high nitrate concentrations in the spring discharge irrespective of season (Fig.8) suggesting continuous contamination from pit latrines in the up gradient areas.

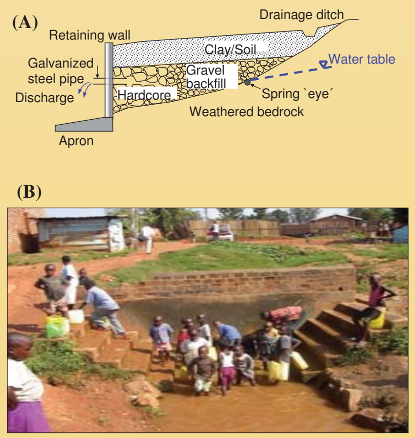

Figure 9. (A) Typical protected spring design (schematic);

(B) Protected spring within the study area. Note the damaged spring protection wall and loss of drainage ditch, which contribute to direct entry of surface contaminants into the spring backfill during the rains

- The increased microbial contamination of the spring discharge following rains (Fig.8) is a result of the poor maintenance of the spring protection structure with loss of the drainage ditch and damage of the wall around the spring "roof" (Fig. 9).
- Poor protection leads to ingress of contaminated surface waters (probably containing faecal matter) into the spring discharge via the sides of the damaged protection wall and "roof" of the spring.

Solutions for prevention

Excreta disposal systems

Ecological sanitation toilets should be piloted in the area especially at household level (e.g. Fig. 10)

These have the advantage of

- space economy
- resource recovery and,
- minimal impact on the environment including groundwater protection

Figure 10 Ecosan toilet in a peri-urban area, Kampala (KCC Ecosan Project)

However, successful operation is very much dependent on continuous sensitization of the community on the operational aspects of these systems as well as a support mechanism for reusing of the materials as appropriate.

Solid waste

- Community participation should be encouraged so as to improve solid waste collection and disposal in the area
- With more than 80% of the solid waste generated in the area being organic, composting is a plausible solution to obtain manure that can be used in gardens (Fig. 11).
- Direct use of food (banana) peelings as animal feed should be encouraged.

Figure 11 Compost Pile (GTZ, Kenya)

Grey water and storm water drainage

- Lining of drains should be encouraged and dumping of garbage in all drains should be prohibited
- Natural wetlands receiving these wastewaters should be gazetted and encroachment restricted.
- Rainwater harvesting should be encouraged
- Low cost decentralized wastewater treatment systems such as waste stabilisation ponds, constructed wetlands (reed bed filters) where land is available.
- Direct application to a garden or container field (Fig. 12)

Figure 12 Planted Grey water garden (GTZ, Mali)

Conclusions

- There is widespread contamination of shallow groundwater in Bwaise III mainly from excreta disposal systems, solid waste dumps and grey water.
- The highly permeable and shallow vadose zone in the area offers limited attenuation of contaminants especially during the rains.
- The operational spring in the area must be re-protected to safe guard communities' health. In view of the high nitrate concentrations, consideration should be given to provision of piped water and encouraging communities to harvest rainwater.
- Proposed solutions necessitate community participation, institutional support and collaboration with existing non-governmental organisations (NGOs), Community based organisations (CBOs) and or development partners.