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WORLD BANK water — Learning Events

The Zimbabwe Water Forum provides a platform for Government and Development Partners to share international best practices in the water sector between Zimbabwe and other countries. The forum was formed through a partnership between the former Ministry of Water Resources Development and Management (now the Ministry of Environment, Water and Climate), the Multi-Donor Trust Fund and the World Bank and is hosted by the World Bank's Zimbabwe Country Office and the Urban WSS Thematic Group.

Rapid Assessment, Identification, and Characterization of Water Pollution and Source Degradation in Zimbabwe

The Ministry of Environment, Climate and Water, of Zimbabwe is preparing a 'Strategy for Managing Water Quality and Protecting Water Sources' in two phases to support the implementation of its new water policy. The World Bank in partnership with the Analytical Multi-Donor Trust Fund (AMDTF) managed by Michael Webster (Harare) provided funding for Phase 1—an assessment of Zimbabwe's water sources and water quality to support this strategy. Phase 1 developed a methodology for conducting a rapid assessment of water quality in pilot areas using specialized tools and techniques including remote sensing, geographic information systems (GIS) and field sampling to identify pollution hotspots nationwide. Phase 2 will focus on an in-depth assessment of all hotspots across the country. This note summarizes the phase 1 research which was conducted by Amon Murwira, Mhosisi Masocha, Christopher H.D. Magadza, Richard Owen, Tamuka Nhiwatiwa, Maxwell Barson and Hodson Makurira of the University of Zimbabwe under the overall technical supervision of Dr Rafik Hirji, World Bank. Phase 1 was implemented for and with the support of the Environmental Management Agency (EMA) and the Zimbabwe Water Authority (ZINWA), now under the Ministry of Environment, Water and Climate.

Water quality in Zimbabwe

Zimbabwe's freshwater resources include a network of rivers, lakes, wetlands, and groundwater aquifers as well as thousands of small, medium, and large dams and reservoirs; all these sources are critical for supporting healthy communities, economic development, and natural ecosystems. However, the quality and condition of Zimbabwe's surface and groundwater resources are deteriorating. Most surface water and some groundwater resources in Zimbabwe need to be treated before they can be deemed safe for human consumption. The countrywide cholera outbreak of 2008–2009 that claimed over 4,000 lives, as well as the recent typhoid outbreaks in Harare, are clear indications of the real and immediate danger of polluted water. Long-term health hazards are more difficult to trace, but many chemical residues, such as PCBs, DDT, lead, cyanide, mercury, and cadmium, that end up in water sources in Zimbabwe are known to pose serious long-term dangers including cancer and nervous system disorders. The blue-green algae that is increasingly colonizing Zimbabwe's lakes, reservoirs, and rivers poses additional health threats as the microcystins that they produce are known to be carcinogenic.

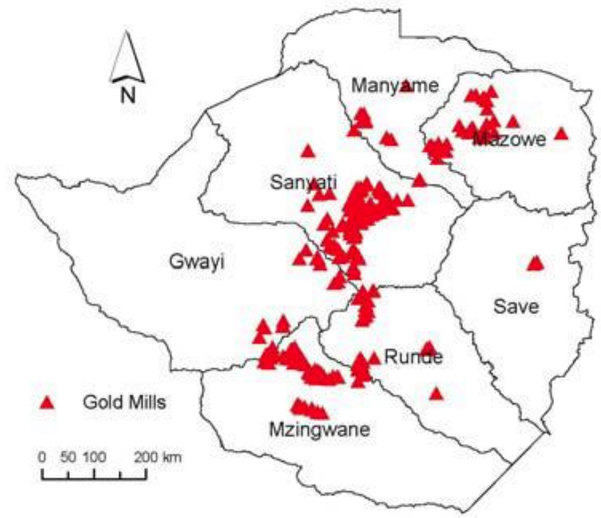
Sources of water pollution

There are many point and nonpoint sources of contamination of Zimbabwe's water. The main point sources are untreated or partially treated municipal wastewater discharge, and discharges from industries and mines. The key nonpoint (or diffuse) sources are inadequate sanitation, frequent sewer outbursts, alluvial mining, urban runoff and agricultural runoff. The most contaminated rivers in the country are in catchments with major urban settlements. Frequent sewer outbursts and the direct discharge of raw or partially treated sewage into waterways contaminate urban water sources; levels of phosphorus in the Marimba river that far exceed statutory limits have been blamed on overflow sewage effluent from Harare treatment plants. Inadequate solid waste disposal in cities also poses a hazard to water sources as unlined open dumps allow contaminants to leach into surface and groundwater. Diffuse runoff from vehicles, as well as urban agriculture and industry, create major challenges to water quality management; in Lake Chivero near Harare, the diffuse source of pollutants are now so numerous that they could maintain the lake in a hyper-eutrophic state even if all direct discharges from wastewater treatment works were brought under control.

In informal high-density suburbs, poor sanitation is an even greater source of groundwater contamination. Pit latrines are usually the only available toilet facilities in these communities, and poorly lined pits allow bacteria to seep into groundwater sources. Research in the semi-formal settlement of Epworth (near Harare) reported significantly elevated levels of coliform bacteria in groundwater samples collected from shallow wells and boreholes, with the highest levels of coliforms (> 10,000 cfu) from areas with a high density of pit latrines.

Zimbabwe's rich mineral resources are an important source of wealth for the country, but their exploitation is also a major contributor to water pollution. The economic crisis in Zimbabwe saw the closure of many of the big mines that used sophisticated extraction technology and the proliferation of small-scale, informal, mining operations, which lack the technical skills and equipment to control pollution. In the numerous small gold mines across the country, as much as 30 percent of the mercury used to process gold quartz can leach into soils and streams, posing a serious health hazard to communities and ecosystems close to these operations. Groundwater is particularly at risk, as the abandoned tailings and open shafts are expected to leach sulphuric acid into the groundwater for generations.

Distribution of gold mills in Zimbabwe



The treatment and disposal of industrial effluent is also a major factor contributing to the deterioration of surface-water quality in the country. While most industries are connected to sewerage reticulation, several industries discharge directly into public waters, causing high levels of heavy metals in rivers downstream. The growing number of backyard industries in urban centers is particularly problematic because their activities are largely unmonitored, and pollution regulations are therefore difficult to enforce. A great deal of the diffuse pollution from cities is created by runoff from these small-scale industries.

Zimbabwe's commercial agriculture, especially sugar production and tobacco farming, depends on high inputs of fertilizers and pesticides, making agricultural runoff a major source of non-point source pollution; high levels of nitrogen have been measured in the lower reaches of the Sanyati River, and phosphorus loading has been reported in Lake Kariba. High nutrient levels caused by fertilizer runoff have contributed to the eutrophication of lakes and rivers, allowing invasive weeds and algae to infest Zimbabwe's waterways. The blue-green algal bloom in lakes is toxic and can pose a substantial health risk for communities using affected water for drinking, irrigation, and recreation.

Land use changes (for example, settlement expansion, urbanization, and the conversion of wetlands and vegetated areas to cropland) that reduce vegetation cover in catchments are also a major source of water quality degradation. The removal of vegetation cover and the subsequent erosion of topsoil results in increased run-off and decreased groundwater recharge. With less fresh water entering the aquifer, the remaining groundwater becomes more saline with time.

Methodology used in Phase 1

Although numerous studies have shown that Zimbabwe's surface and groundwater quality is deteriorating, there is not enough information available to systematically define the scale and severity of the problem in terms of the location, rate, or causes of this decline. This information is critical to guide decision-makers about the best steps to take to protect and manage water quality and control pollution. The primary objective of the first phase of Zimbabwe's Strategy to Manage Water Quality (reported here) was to develop practical methods to assess the quality of Zimbabwe's water rapidly and efficiently through the use of satellite imagery, GIS, and selective field sampling.

Recent developments in remote sensing technology make it possible to monitor and map the dynamics of surface water and catchment areas throughout the year. In this study, the Modified Normalised Difference Water Index (MNDWI) was applied on Landsat 8 imagery over Zimbabwe between April 19, 2013 and May 30, 2013 to map surface water bodies in catchments covered by the Landsat scene. This spectral index is based on the fundamental idea that water absorbs energy at near-infrared and shortwave infrared (SWIR) wavelengths: MNDWI values greater than 0 indicate water while MNDWI values below 0 indicate non-water features. The condition of catchments was evaluated through the use of the Normalised Difference Vegetation Index (NDVI) which also uses spectral analysis of Landsat imagery to determine the amount of groundcover present in a given catchment with the underlying premise that, holding other factors constant, the better protected the catchment the higher the vegetation cover and the higher its mean NDVI value. In order to relate the condition of catchments to the quality of water sources, 89 sites were also directly sampled for key water quality indexes including chlorophyll-a, turbidity, total nitrogen, total phosphorus, and suspended solids. These techniques were empirical in that they modelled relations between spectral bands and measured water quality parameters and then used these statistically derived relationships to estimate water quality over a larger area.

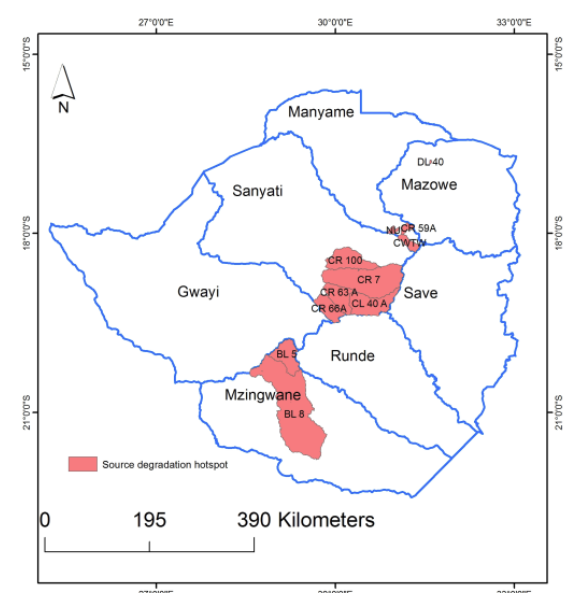
Two contrasting reservoirs—Lake Chivero and Mazvikadei dam—were chosen as sites for more intensive sampling to test the accuracy of remote sensing for assessing water quality in water supply reservoirs. Water samples from 80 sites within these reservoirs were sampled for the most important proxies of surface water quality: chlorophyll-a concentrations, water transparency (measured with a Secchi disk), and turbidity. High chlorophyll-a concentrations are an indication of high nutrient levels that may originate from sewage and fertilizers, and transparency and turbidity measure the physical quality of water that can be altered by land degradation, soil erosion, and alluvial mining. These measurements were then paired with the spectral bands derived from Landsat satellite imagery, and regression equations were computed to determine the relationship between the two analytical categories.

To evaluate the condition of groundwater in Zimbabwe, a GIS-based expert system was used to generate a groundwater vulnerability map. This mapping technique uses rankings from 0.1 to 1.0 on key variables—including rainfall, geology, soil, topographic wetness index, vegetation cover, and land use—that affect groundwater's vulnerability to contamination. For example, in areas with more rainfall, surface pollutants are more likely to enter groundwater through seepage and are therefore ranked 1.0 on the rainfall variable. Similarly, more permeable aquifers are more vulnerable to contamination and are given a high ranking on the geology variable. These rankings are added together and normalized to compute overall vulnerability scores from .01 to 1.0 with .01 being the least vulnerable and 1.0 the most vulnerable. This vulnerability map can be overlaid with a demographic map and a map that shows the contaminant hotspots, to create a map that shows the risk posed to the public by deteriorating groundwater quality. In order to validate the results of groundwater vulnerability mapping, 22 groundwater samples were collected from boreholes or wells.

Results of Phase 1 research

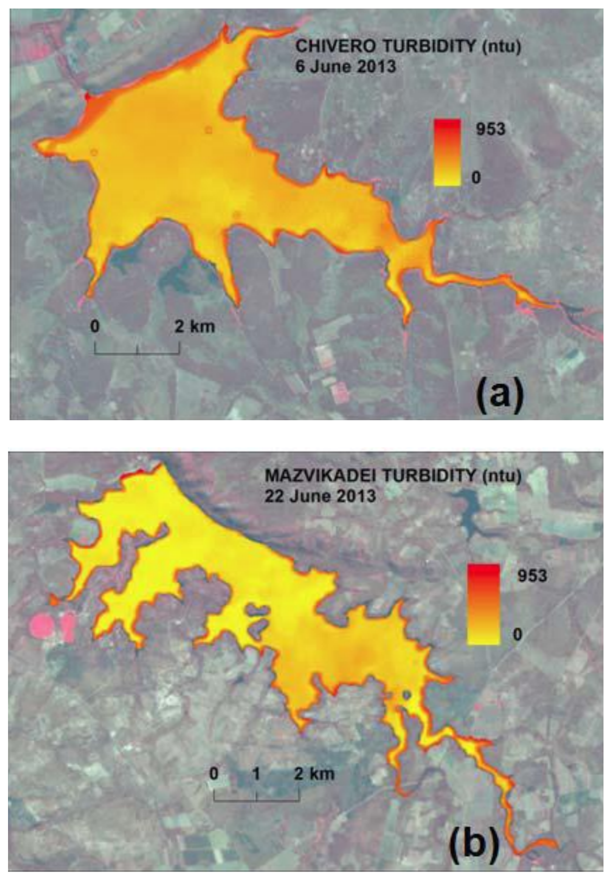
The results of phase 1 of this project confirmed that the use of satellite imagery and GIS is a quick way to assess the quality of water at a fraction of the cost of traditional methods. The MNDWI calculated from Landsat images proved useful for detecting and mapping surface water in Zimbabwe; in the Runde catchment, for example, the MNDWI was able to detect all dams, as well as tailing dams and wetlands. This satellite-based technique is much faster and more efficient than traditional mapping and can be used for monitoring the extent of changes in the quality of surface water bodies throughout the year in all catchments. Vegetation density—as measured from satellite images using the NDVI—was found to be inversely correlated to physical measures of water turbidity, and the application of the equations derived from this relationship was successful in identifying source degradation "hotspots" in the Mzingwane, Sanyati, and Manyame catchments.

Source degradation hotspots based on equations derived from NDVI and measures of water turbidity



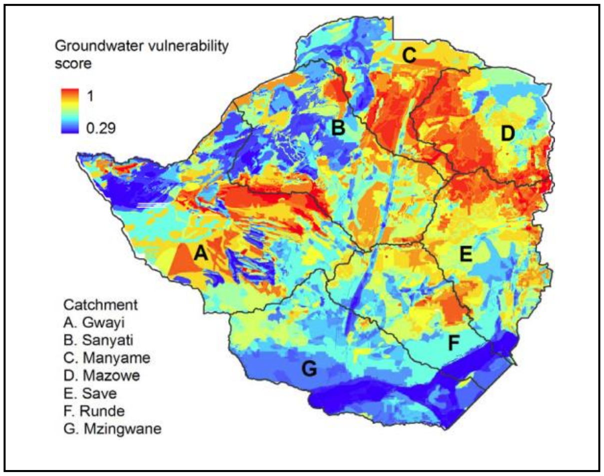
The water quality in reservoirs was also amenable to rapid assessment through the use of satellite imagery. Statistical correlations (using pairwise Pearson correlation analysis) between spectral bands derived from Landsat images and water quality measured in field samples (chlorophyll-a concentrations, Secchi disk depth, and turbidity) allowed the researchers to create maps of water quality for the test reservoirs of Lake Chivero and Mazvikadei Dam. Overall, Lake Chivero was more contaminated than Mazvikadei Dam with higher chlorophyll-a concentrations and turbidity, and less transparency.

Maps of spatial variations in turbidity in (a) Chivero and (b) Mazvikadei



Groundwater vulnerability maps paired with groundwater sampling showed that most microbiologically contaminated samples were drawn from areas with high vulnerability scores, mostly in catchments with large amounts of urban sewerage. All 13 samples tested were found to contain coliforms, six tested positive for e. coli, and four were found to be contaminated with salmonella. Although sampling was uneven and not fully representative of the overall groundwater conditions, it is clear that a variety of activities including industry, mining, solid waste disposal, commercial agriculture, and urbanization are major threats to the quality of groundwater in Zimbabwe.

Aquifer vulnerability map of Zimbabwe produced using a GIS-based expert system



Recommendations for Phase 2 research

Phase 1 of the water quality strategy demonstrated that the use of satellite imagery, GIS, and field sampling was an effective, rapid, and inexpensive way to assess water quality in Zimbabwe. But this methodology has two key limitations that will need to be addressed in the design of Phase 2. First, the approach used in this analysis was empirical; it used the statistical relationship between spectral bands in satellite imagery and variables measured in field samples to estimate overall water quality. Although this approach works well for the analysis of similar bodies of water, these statistical relationships cannot be applied to surface water with different ranges of water column constituents. Second, these results apply only to Landsat 8 derived imagery and would need to be recalculated if new sensors were used. Models that use the underlying physics of the spectral properties of a water column—such as atmospheric and underwater light processes—to estimate water constituents are less sensitive to sensor, chronological, and geographic differences and require fewer in-situ data. The long-term water quality monitoring and assessment systems needed in Zimbabwe, to be developed in Phase 2 of the strategy, should rely on these physical approaches.

Phase 2 should also include an in-depth assessment of the quality of selected high-priority surface and groundwater bodies to be identified by EMA and ZINWA. It will also be critical to train staff, create a water quality database, and develop strategies for controlling pollution and protecting water sources. These approaches should be accompanied by a review of the policy, legal, and institutional aspects—as well as the economics and financing—of water-quality management.

The Zimbabwe Water Forum Policy Notes Series

Between 2011 and 2013, at the request of the Government of Zimbabwe, through the Ministry of Water Resources Development and Management, and with support from the Zimbabwe Analytical Multi-Donor Trust Fund, the World Bank has undertaken a series of analytical studies and technical assistance in the water and sanitation sector. These studies are captured in the Zimbabwe Water Forum Policy Note Series. The task team leader for the studies is Michael Webster, Sr. Water and Sanitation Specialist in Harare (mwebster@worldbank.org) with support from Priscilla Mutikani (pmutikani@worldbank.org). All notes have been edited by Rolfe Eberhard and Hilary Gopnik.

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