Water Practice & Technology Vol 7 No 2
doi:10.2166/wpt.2012.045

A comparative assessment of selected raw water intake systems in Rwanda

I. Nhapi[a,b], A. J. Nshimiyimana[a], U. G. Wali[a], F. O. K. Anyemedu[a] and J. J. Kashaigili[c]

[a] WREM Project, Faculty of Applied Sciences, National University of Rwanda, Box 117 Butare, Rwanda, E-mail: ugwas@yahoo.com; ugarbawali@nur.ac.rw

[b] Dept of Civil Engineering, University of Zimbabwe, Box MP167, Mt. Pleasant, Harare, Zimbabwe

[c] Faculty of Forestry and Nature Conservation, Sokoine University of Agriculture, Box 3003 Morogoro, Tanzania

Abstract

After the genocide of 1994, Rwanda has been struggling to contain urban migration and its pressures on existing facilities. Water supply coverage is low at 76% in urban areas and 68% in rural areas. This implies that huge investments are required to meet the Millennium Development Goals on water supply and sanitation. This study was conducted to assess the existing problems of raw water intake systems at Yanze and Nyabarongo intakes in Kigali; Shyogwe intake in Ruhango District; and Kadahokwa intake in Huye District. The study was in response to high amounts of sediments in raw water which literally clogged the intake systems for a number of days, resulting in erratic water supplies to the residents in the rainy season. The study focused on performance problems of the intake systems, raw water turbidity variations and the assessment of how environmental concerns could be addressed in the design of intake systems in areas of high soil erosion activities. Data was collected through interviews and physical measurements. The study revealed that flooding, intake site selection, erosion, screen clogging, intake protection, high raw water turbidity, inadequacy of raw water supplied to the water treatment plants, and low downstream environmental flows were the main intake problems. The Yanze intake had worst problems with high levels of flooding, erosion, sedimentation, and high raw water turbidity levels. The bank filtration system at Nyabarongo gave the least problems of raw water turbidity. Yanze and Nyabugogo river intakes systems were found to be threatened by decreasing water levels attributed to surrounding upstream landuse activities. It was recommended that proper maintenance of existing structures, landuse management around river intakes, use of well-designed reservoir abstraction systems, increased groundwater abstraction systems (including bank filtration), would greatly improve the performance of intake systems in Rwanda.

Key words: environmental flows, erosion control, intake protection, intake systems, raw water turbidity, Rwanda

INTRODUCTION

Rwanda is a landlocked developing country in East Africa. It is still recovering from the 1994 civil war and genocide in which at least 800,000 people died. The genocide retarded economic growth and devastated the social fabric of the society. The water sector in Rwanda was greatly affected as a number of sector professional were killed or displaced and vital infrastructure destroyed (Twagiramungu 2004). The population of Rwanda has increased rapidly since independence in 1952 reaching about 9 million habitants by 2007 (National Institute of Statistics-Rwanda 2007). Rural to urban migration is estimated at 4.2% per year (Rwanda Wikipedia 2008) with an urbanisation rate of 4.2% per year (CIA World Factbook 2008). Notably, this has resulted in a water supply deficit of >25,000 m³/day in Kigali City by 2007 (Netgroup 2003). There is therefore a challenge in Rwanda on how to improve the water supply systems and ensure adequate and safe water supply to all consumers at an affordable cost.

This study is motivated by the observation that intake systems in Rwanda do not work properly due to different challenges such as design problems, high levels of suspended solids in raw water, erosion problems in upstream catchments, and environmental concerns related to abstraction systems (Electrogaz 2007). This improper functioning of the intake systems implies also the frequent reduction of water supplied to consumers. The main objective of this study was therefore to assess, through case studies, the performance of selected intake systems in Rwanda. Existing data available from the water the utility company, Electricity and Water Supply Agency (EWSA, formerly Electrogaz), was used to assess the level of turbidity variations. For the environmental problems of the intake systems, the study was limited to the ecosystem problems downstream and upstream of the intake structures, environmental flow problems and riverside protection problems. The study focused on intakes from 4 water treatment plants of Kadahokwa, Yanze, Shyogwe and Nyabugogo.

DESCRIPTION OF THE STUDY AREA

Location of study sites

Rwanda covers an area of 26,338 km^2 and shares borders with Uganda in the north, Tanzania in the east, and Burundi to the south, and the Democratic Republic of Congo to the west (Figure 1). Rwanda has *one of* the highest population density in Africa of about 340 inhabitants/km^2. Figure 1 shows the five provinces of Rwanda and location of intake systems covered under this study.

Water treatment systems and details of the study sites

The water abstraction systems commonly used in Rwanda are direct river diversions, river dam or floating type intakes, and bank infiltration intake systems. EWSA, Sher and COFORWA companies deal with abstraction, treatment and distribution of water in urban and rural areas. Other private operators deal only with the management of water supply systems. There are about 847 water supply systems in Rwanda of which 22% are managed by private operators. The water supply coverage in urban areas is estimated at 54%, and 44% in rural areas (MINITERRE 2007). Table 1 shows details of the 16 water treatment plants in the country and shows that, in general, most treatment plants are still operating below their design/installed capacities.

The monthly water production figures for the selected intake systems in this study are given in Figure 2, with Yanze showing to be the largest intake.

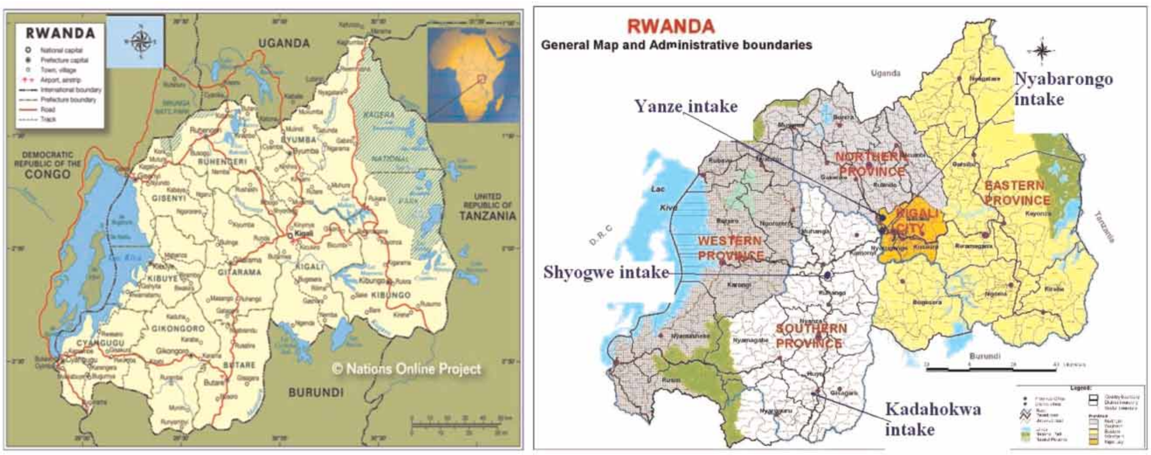

Figure 1 | Map of Rwanda showing (a) neighbouring countries and location of Rwanda in Africa and (b) location of the intake works studied in this report (*Source*: CGIS 2007).

Table 1 | Details of existing major water treatment plants in Rwanda

Water treatment plant	Date of installation or extension	Installed capacity in m^3/d	2007 production in m^3/d
Cyunyu	1987	1,320	1,208
Gihengeri,Gatoki	1997/2000	3,900	419
Gihira	1987	7,400	4,024
Gihuma	1987	1,930	639
Gisuma	1987/2005	576	531
Kadahokwa	1982/2005	4,450	1,790
Kanyabusage	1986	420	477
Karenge	1976/2008	3,000/12,000	4,000
Mpanga	1984/2006	1,100	800
Muhazi	1986/2004	1,200	898
Mutobo	1987	12,500	2,162
Nyabarongo	2003	3,500	3,000
Nyamabuye	1988	850	792
Rwasaburo	1986	760	529
Shyogwe	in 50′s/2005		No data
Yanze&Wells	1981/1988	30,000	26,106
Total capacity or production		66,166	39,845

Source: Electrogaz 2007.

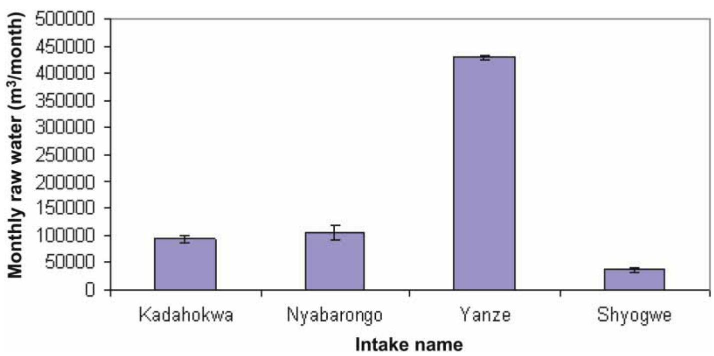

Figure 2 | Average monthly raw water abstractions for the Kadahokwa, Nyabarongo, Yanze and Shyogwe intake systems.

Selection of the study sites

The study sites were selected according to types of intake systems in use, i.e., river diversion, groundwater abstraction or dam abstraction systems. From this criterion, the following sites were chosen:

1. Yanze intake in Kigali City which uses river diversion system;
2. Nyabarongo (also called Nzove) intake in Kigali City which uses a river bank filtration system for abstracting groundwater;
3. Kadahokwa intake in Butare which uses a river diversion system; and
4. Shyogwe intake in Ruhango District which uses a floating intake for dam water abstraction.

Although Yanze and Kadahokwa intakes were using the river diversion intake systems, their designs are quite different, both structurally and operationally. The intake systems are described in detail below.

doi:10.2166/wpt.2012.045

Figure 3 | Yanze water intake up to the treatment plant.

Yanze intake

A greater part of water used in Kigali City is abstracted directly from the Yanze River and treated at the Kimisagara Water Treatment Plant. The intake (Figure 3) is located about 5 km from the centre of Kigali. The Yanze River has a discharge of about 2,500 m^3/h in the rainy season, and 800 m^3/h in the dry season (Electrogaz 2007). There is a 4 m long by 3 m wide and 0.6 m deep screening trough upstream of the intake screen for trapping sand and other floating matter. The flow through this screen is 940 m^3/h, whilst its design capacity is 1,000 m^3/h. The screen channels the water into a pipe of 700 mm diameter which discharges into two pre-sedimentation tanks. The clarified water is gravitated to the Kimisagara water treatment plant through a pipe of 600 mm diameter up to a point called Bwino, where the pipe is divided into four small pipes of 300 mm diameter. Any excess water at the Yanze intake is diverted back into the river. Figure 3 shows how water is abstracted from the Yanze River.

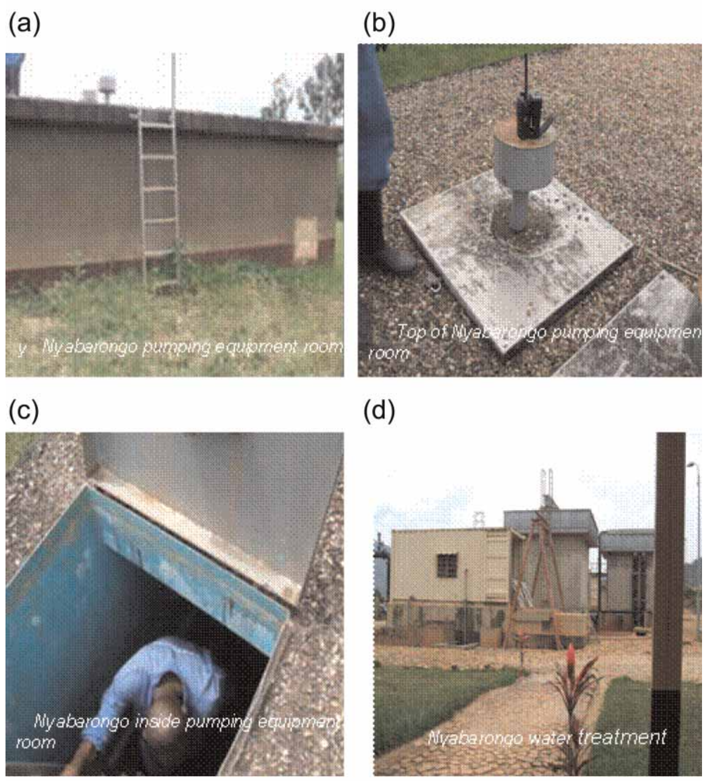

Figure 4 | Nyabarongo water intake up to the treatment plant.

Nyabarongo intake

The Nyabarongo intake is underground groundwater abstraction system consisting of four horizontal drains of 3 m length each. These drains collect the water into 14 m deep wells. The outlets of the drains are located at 10 m from the top of the well. The drains consist of perforated pipes laid on two layers of sand at the bottom and activated carbon at the top. These two materials filter the water before it reaches the pipe and a provision is made for closing the drains when necessary. From the well there are automatic pumps which pump the water to the treatment plant. The top of the intake is sealed. The abstraction capacity is 128–130 m^3/h for the existing intake. The ultimate aim is to produce 40,000 m^3/day upon completion of the new plant and boreholes. The project of installing new boreholes will cover 37 boreholes, nearly 50 m apart, stretching about 1.8 km along the Nyabarongo River. The deepest level is estimated to be 7 m during dry season and to be 3 m during the rainy season. The lowest level is at 1.2 m and it occurs during the rainy season. Figure 6 shows the Nyabarongo intake structures and the treatment plant.

Shyogwe intake

The Shyogwe Dam is supplied by the Rwambanda River. The abstraction is done through a floating intake system. A pipe of 200 mm is used with a system of valves for closing and opening. In addition to the water from the reservoir, other small sources have been used from Karama. Water from this plant is supplied to the Bugesera region. Environmental flows are allowed for downstream ecosystems and the dam is home to a variety of fish and birds. Figure 5 shows some photos of key components of the Shyogwe intake system and the treatment plant. The Shyogwe Dam has a protected foundation, impermeable core and concrete to prevent water from seeping, a sloping embankment of 2 m height, and an overflow channel.

Kadahokwa intake

The Kadahokwa intake is a direct river diversion system. The Kadahokwa water treatment plant started operating in 1983. At the beginning the raw water sources were Nyamasharaza, Kabakene, and Kidogo

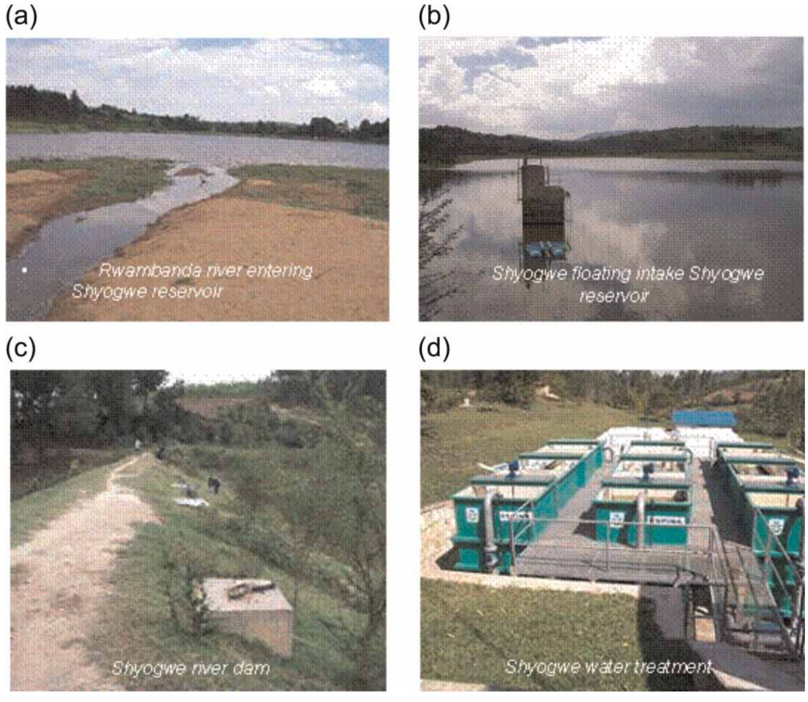

Figure 5 | Photos of key components of the Shyogwe intake system and the treatment plant.

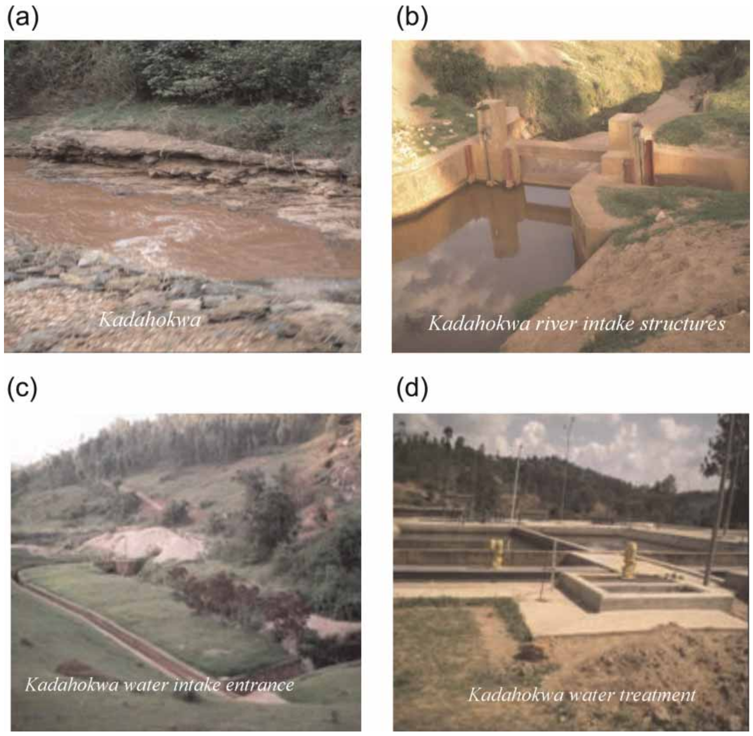

Figure 6 | Kadahokwa intake structures and part of the treatment plant.

Rivers. The discharge was estimated at 65 m^3/h. In 1997, the second intake feeding the same water treatment plant was commissioned and the discharge increased to 504 m^3/h. Raw water reaches the plant by gravity flow. Figure 6 shows the Kadahokwa system from the river to the plant. From the Kadahokwa River, water enters intake structures. Along the intake structures there are gates that can be opened to allow the sands and other settled materials to be diverted back to river.

MATERIALS AND METHODS

Field data collection

The study was carried out from June to November 2007 using close-ended and open-ended questionnaires. Questions were addressed to the water treatment plant chief, chief of operations and maintenance technician, water treatment plant technicians, intake guard, water department officers from EWSA at the intake stations, and the statistics office at the EWSA headquarters. The questions were structured to collect information on problems of intake design, the problems of raw water shortages and turbidity, and problems of environmental management. Photographs were also taken to give an overview of the system and an insight into the localised problems. The raw water quantity and raw water turbidity were monitored by EWSA on an hourly basis.

Data analysis and presentation

The analysis of collected data was based on a scoring system designed for this study. These were 3, 2, 1, 0, and NA, which corresponded to very good, good, fair or moderate, absence or non available, respectively. The average values for each problem were presented in one table for different intake systems. The percentage of occurrence of one problem was then presented for all intakes. This percentage was found by adding the marks for each problem divided by the total marks, and multiplied by 100. After this, each intake was assigned a score in percentage for the analysed problems.

This percentage was found by dividing the total marks obtained for the studied problems. This total mark equalled the number of problems studied times three which is the highest score for each problem. This analysis shows the most problem found at each intake, then for the all analysed intakes. Some photos were also used to reinforce important points in analysing the data.

The data from EWSA on raw water produced and raw water turbidity were also used. These data were analysed by plotting graphs to indicate periods in which the worst and best cases occurred and the standard deviation for a given criteria in a given period. After analysing data separately, the raw water produced and raw water turbidity were analysed together to find out if there was any relationship between them. The discussion was done for different intakes and for different points in terms of intake design performance, raw water quantity and turbidity variations and then in terms of environmental considerations.

RESULTS AND DISCUSSION

Assessment of design-related problems

The occurrence of design-related problems was analysed and the results are shown in Figure 7. A maximum score of 3 was adopted in deriving this graph. The occurrence interval, expressed as a percentage, was found by dividing the sum of scores for each problem by 12 (12 being the number of intake systems studied multiply by 3 (the maximum score)), then multiplying by 100 (to convert it to percentage). Figure 7 shows that the major problems observed are flooding, entrapment of suspended solids on screens, selection of intake structures, weirs, erosion and sedimentation. The level of occurrence in percentages (Figure 8) shows that the intake systems are not well designed because some requirements are not being met in practice. The flood problems accounted for 66% of occurrence especially during rainy season followed by the intake site selection (50%) and screen clogging (50%).

Figure 8 shows the percentage of scoring for each intake. It shows that the Nyabarongo intake performs well, with the least level of problems at 11%. However, the quantity of water abstracted is not sufficient because there is only a single small well which is not accessible for equipment room control during heavy rains. There were plans to increase the number of wells along the Nyabarongo River in order to increase the quantity of water abstracted. About 90% of water used in Kigali City currently comes from the Kimisagara water treatment plant. The Shyogwe intake system was ranked second with a percentage scoring of 22%. For this plant, the water level in the reservoir has dropped drastically because of reduced inflows from the catchment.

The design concept for the Kadahokwa intake appeared good and more elaborate although some elements were missing. This plant was ranked third with the Yanze intake coming last. In order to increase the performance of the Kadahokwa intake, the maintenance of existing infrastructure

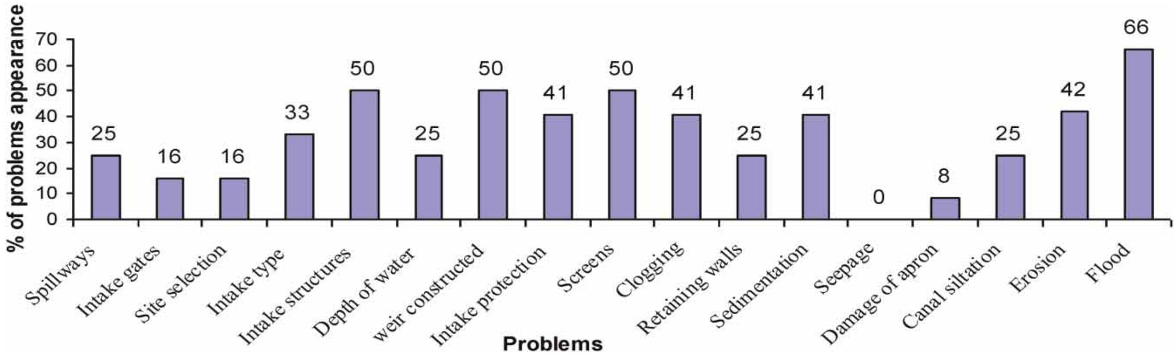

Figure 7 | Design-related problems occurence.

doi:10.2166/wpt.2012.045

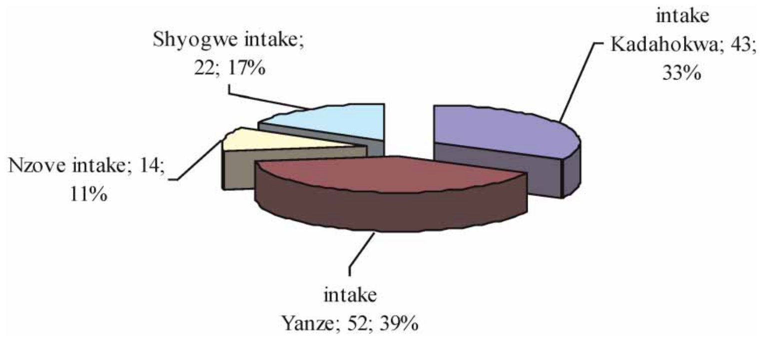

Figure 8 | Percentage of scoring for each intake plant based on design problems.

should be prioritised, followed by the construction of a reservoir or barrage upstream of the intake for the purpose of storage security and settling out of suspended matter. It was observed that the incoming water is laden with sand which is destroying the sediment retaining structures at the intake and is destroying the river channel.

The Yanze intake had the most problems and gets flooded during periods of heavy rains. In many ways the solutions suggested for this intake are similar to those for the Kadahokwa intake. Figure 7 has shown the major problems at the intake works and these are more pronounced at the Yanze intake. Figure 9 shows the sediment deposition and environmental flow problems at the Yanze intake. The sediment deposition problem appears mostly in the rainy season where stones, soils, large pieces of trees and branches, *etc*, come in great amounts and clog the screen and sometimes intake structures are also destroyed. This impacts on the production of treated water as the plant operations are forced to stop until the situation becomes favourable. To solve these problems, there must be an adequate screen to trap all these transported materials and the intake structure design should sufficiently protect against these threats. Besides constructing a dam upstream, catchment protection measures should be adopted to reduce erosion (MINITERE 2007). These measures include terracing, vegetated strips/buffers, cultivation control, zero tillage, etc.

Figure 10(a) shows a typical problem caused by excessive sand loads in the Kadahokwa River. The sand-retaining structures are washed away by the sediment-laden floods and this affects the water treatment operations as the intake structure has to be closed in these circumstances. Figure 10(b) shows a destroyed spillway structure at Shyogwe, which reduces the reservoir storage capacity. This normally occurs in the rainy season and could be reduced by preventive maintenance of spillways and embankments during the dry season.

Figure 9 | Typical problems experienced at intake systems: (a) lack of environmental flow at Yanze intake, and (b) erosion and sediment problems at Yanze.

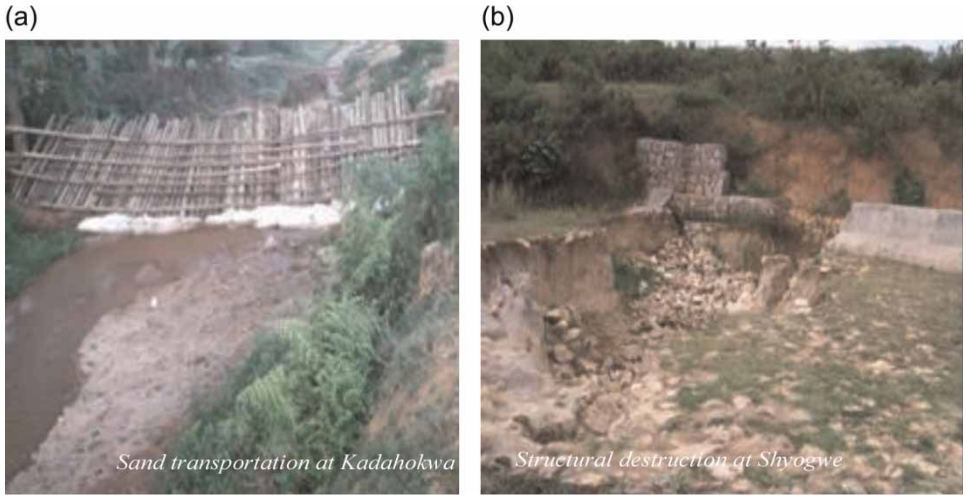

Figure 10 | Typical problems experienced at intake systems: (a) destruction of sand-retaining structure at Kadahokwa and (b) spillway failure at Shyogwe.

Assessment of raw water shortage and raw water turbidity problems

Problems related to water demand and raw water quality

Table 2 shows an assessment of the problems relating to water demand and raw water quality observed in this study. Figure 11 was plotted using the data from the Table 2. It shows the quantitative level of problems. It shows that there are high water shortages and high turbidity problems at Yanze intake and these problems are least at the Nyabarongo intake. Table 2 shows that people complain much about water shortages than about the problems of raw water turbidity.

Turbidity at Yanze intake

In many cases, full data on abstractions were not available from the treatment plants or the EWSA headquarters. Figure 12 was plotted using the turbidity data from EWSA for the period June 2005 to October 2007 and it shows that periods of higher turbidity values correspond with periods of low abstractions.

Turbidity and abstraction values for Kadahokwa intake

The monthly average turbidity for the raw water at the Kadahokwa intake for the period January 2006 to September 2007 are shown in Figure 13(a). The results show that the highest turbidity value at Kadahokwa occurred in November. Using the raw water abstraction data obtained from the

Table 2 | Assessment of raw water shortage and raw water turbidity problems at the four intake systems studied based on a defined scoring system

Criteria	Kadahokwa intake	Yanze intake	Nyabarongo intake	Shyogwe intake	% of problems appearance
Complaints about shortage of water	2	2	3	2	75
Problems of turbidity of raw water	2	3	1	1	58
Score%	66	83	66	50	

Key: 3. Very good or higher, enough 2. Good or high 1. Pass, or not enough 0. Absent.

doi:10.2166/wpt.2012.045

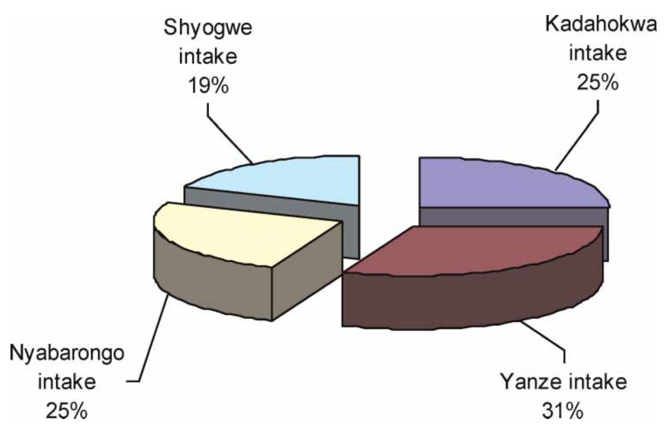

Figure 11 | Assessment results for raw water shortages and raw water turbidity problems for the 4 intake systems studied shown as percentage of occurrence at each plant.

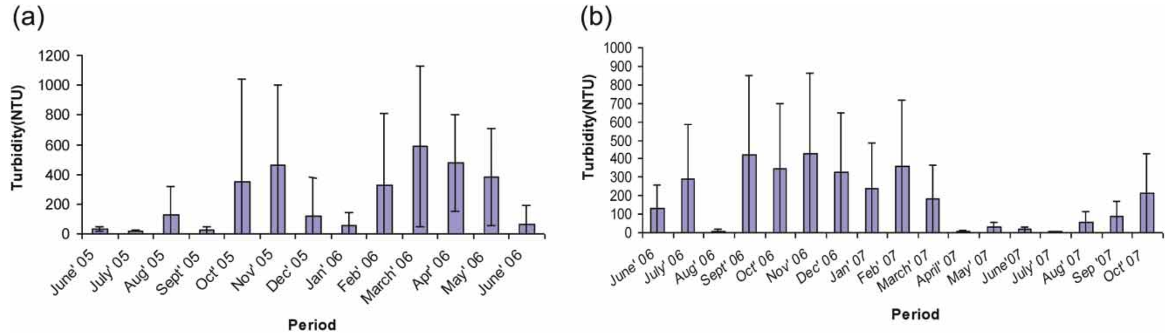

Figure 12 | Average raw water turbidity at Yanze Intake based on data from EWSA (a) period June 2005–June 2006 and (b) period June 2006–October 2007.

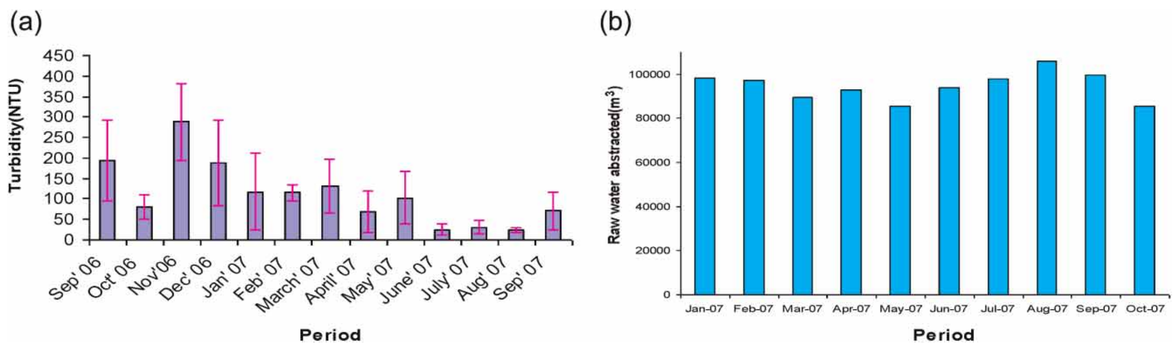

Figure 13 | Monthly variations in (a) raw water turbidity and (b) abstractions from the Kadahokwa Intake for the periods shown.

Kadahokwa water treatment plant, Figure 13(b) was plotted for the period of January 2007 to October 2007.

Turbidity and abstraction values for Nyabarongo intake

Figure 14 shows the turbidity and raw water abstraction trends at the Nyabarongo intake for the period October 2006 to October 2007. The graphs show that the high turbidity values occurred in November and March, which are normally high rainfall months in Rwanda. It is also clear from Figure 14(b) that the monthly raw water produced is high in April and May, and the lowest values

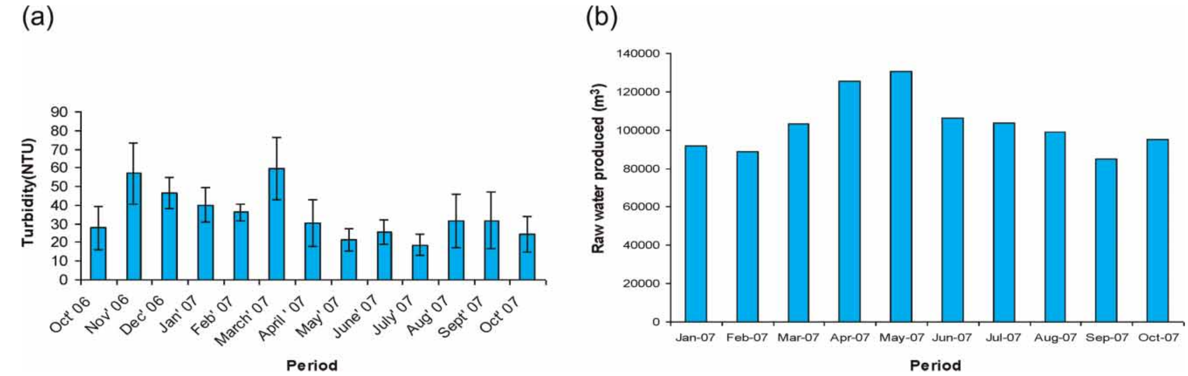

Figure 14 | Monthly variations in (a) raw water turbidity and (b) abstractions from the Nyabarongo Intake for the periods shown.

are found in February and September. This graph does not have error bars because there were no daily records at the treatment plant. The data used were found in monthly reports sent to the EWSA headquarters.

Turbidity and abstraction values for Shyogwe intake

There were very little data for the Shyogwe intake system and the dam had been damaged and not working well by the time this research was completed. The data that were available were for the years before 2003 only. These data were used to produce the graph in Figure 15(a) on the Shyogwe raw water turbidity in 2003 since it is the latest year for which the data were available. Figure 15 (b) shows the amount of water abstracted at Shyogwe in the year 2003. In general, the water produced at this intake was not changing very much.

Turbidity and abstraction values for all intakes

Figure 16 shows the general view of how turbidity varies for the different sites studied. To have a combined view of how raw water turbidity varies for different intakes, the turbidity values for Shyogwe intake had to be moved from 2003 to the 2005–7 period where data for other plants do exist.

Figure 16 shows that Yanze had highest values and highest variations of turbidity whilst Nyabarongo had the least turbidity and nominal variations. The raw water turbidity in general is high during the rainy season, especially in September, November and March, and is lowest in the drier month of August. Further analysis was conducted to investigate the relationship between raw water turbidity and the quantity of raw water abstracted. Figure 17 shows that at Yanze intake, which supplies Kimisagara water treatment plant, the water abstracted is highest when the turbidity is

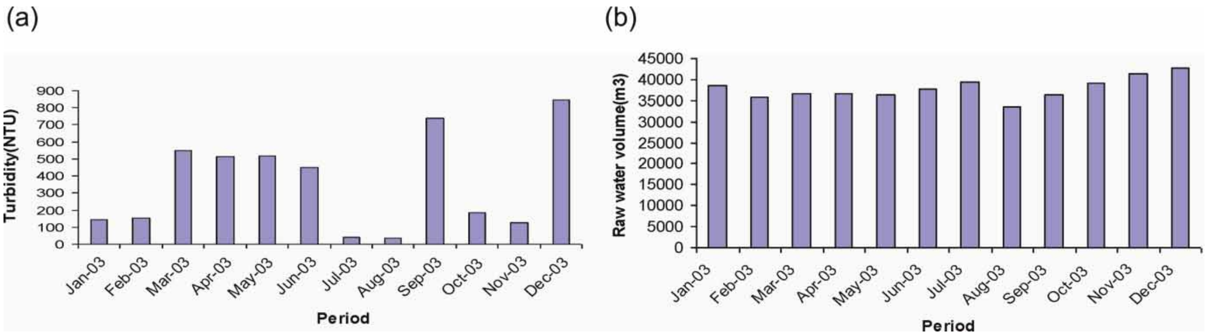

Figure 15 | Monthly variations in (a) raw water turbidity and (b) abstractions from the Shyogwe Intake for the periods shown.

doi:10.2166/wpt.2012.045

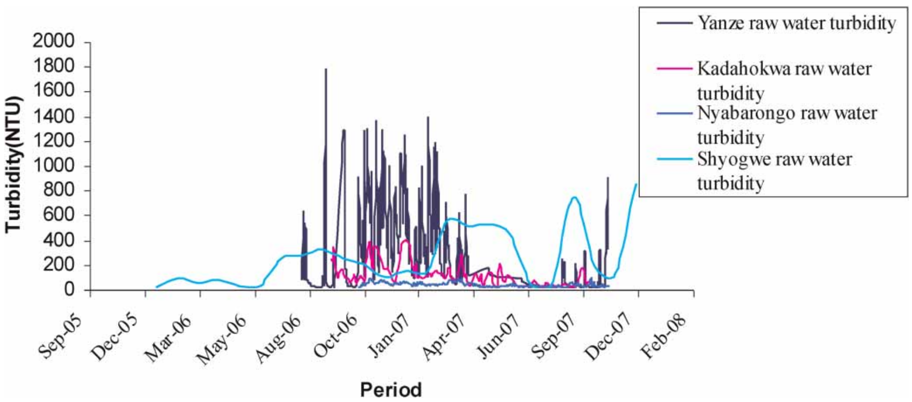

Figure 16 | Raw water turbidity graphs for different intake sites based on data from EWSA.

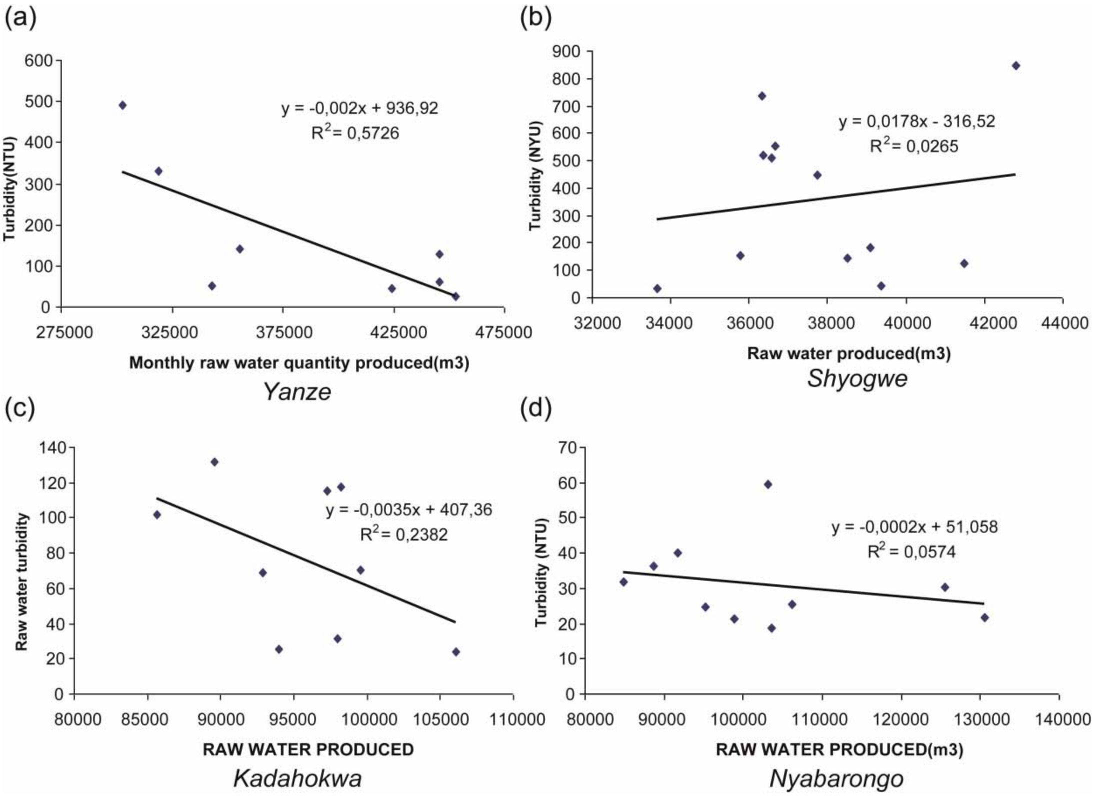

Figure 17 | Comparative assessment of the correlationship of tubidity and raw water abstracted for the four studied intake systems.

lowest. The correlation, however, is not very strong. The other river diversion system, Kadahokwa, was next in the extend of correlation (R2 = 0.2382), whilst for Shyogwe and Nyabarongo there was virtually no correlation at all.

From Figure 17 it can be concluded that the raw water turbidity was, to some extent, affecting raw water production at the intakes using river diversion systems (Kadahokwa and Yanze). This was corroborated by personnel on site. The Shyogwe system uses a dam abstraction system and did not show considerable effect. The turbidity problems were lowest at the Nyabarongo intake because the type of intake used (river bank or infiltration intake system) is not much affected by the rainfall since the water is filtered as it passes through the soil.

doi:10.2166/wpt.2012.045

Assessment of environmental problems

Table 3 shows results of the assessment done for environmental-related issues. The table indicates the environmental problems occurrence and scores using the same principle as described in Section 3.1. For an example, for Yanze we have: $3+2+2=7$, and then 7 is divided by 9 to give a total score as percentage of 77%.

Using the data from Table 3, Figure 18 was also plotted, showing the environmental problems occurrence for different sites.

This study revealed that the environmental concerns are not given due respect as evidenced by the bad design of some intakes systems or the lack of control and maintenance of intake systems. This is seen by the lack of environmental flows downstream of the Yanze and Kadahokwa intake systems (Figure 18). The problem has been exacerbated by the increased population in different parts of Rwanda leading to increased demand for water. In an attempt to meet increased water demand, a large volume of water is increasingly being abstracted from the rivers. As a consequence, the ecosystems and other environmental needs are threatened. This therefore calls for regulatory mechanisms to modify the intake systems so as to balance water that must be abstracted and the flow for the environmental needs. Erosion could be substantially reduced by planting trees and grasses at the intake sites and upstream in the catchment. This study shows a greater need to introduce catchment protection measures and to evaluate how the catchments are responding to these measures. These measures include landuse prohibitions for areas of high erosion potential, terracing, buffer strips, regulated choice of plants in sensitive areas, better planting and soil conservation measures, etc.

Table 3 | Assessment of environment-related problems at the four intake systems studied based on a defined scoring system

Problems	Kadahokwa intake	Yanze intake	Nyabarongo intake	Shyogwe intake	% of problems appearance
Problems of ecosystems like fish up and downstream	2	3	0	1	50
Problems of environmental flow downstream the intake	1	2	1	1	41
Problems of riverbank protection	1	2	0	0	25
Score (%)	44	77	11	22	

Key: 3. Very good or higher, enough; 2. Good or high; 1. Pass, or not enough; 0. Absence.

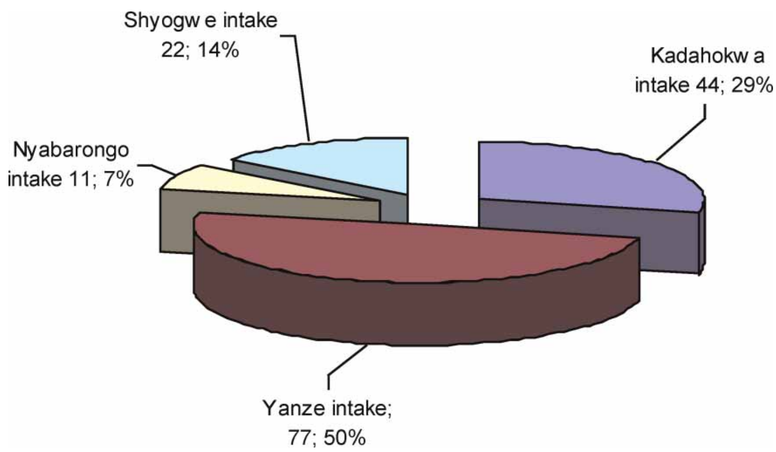

Figure 18 | Percentage of environmental problems for different sites.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following are the conclusions from this study:

(i) The performances of intake systems studied in this paper were not as per desired level. Most of the intakes were not correctly designed and the design considerations were largely not adhered to.
(ii) The intake activities have negative impacts on surrounding ecosystems and neighbouring people especially those downstream. At Yanze Intake the river water flows reduce considerably during the dry season, with abstractions threatening the health of downstream ecosystem as there will be virtually no environmental flows.
(iii) The quality of raw water is poor especially for river direct intake systems. The raw water turbidity is high. Some of the intake systems are flooded and clogged with suspended and floating materials; pointing to deficiencies in their designs. At times the water treatment processes are suspended because the incoming raw water is too turbid to be treated. Moreover, there are no measures in place to divert excess sediments at river diversion intakes and all eroded materials go direct to the intake especially in the rainy season.

Recommendations

From our observations, we make the following recommendations:

(i) There must be several wells of the same type or boreholes along Nyabarongo River to increase the quantity of water supplied to meet current demand.
(ii) Measures are required to control upstream erosion through best management practices. Such practices include conservation tillage, residue management, grassed waterways, terraces, conservation buffers, crop rotations, contour farming, planting trees, entrapment and removal of sand and stones from the river bed, etc.
(iii) The construction of dams to reduce turbidity by sedimentation and also to ensure security of storage is highly recommended for the systems using river diversion systems (Yanze and Kadahokwa).
(iv) All abstractions need to be regulated by prescribing a suitable method for determining environmental flow requirements in Rwanda.
(v) The design of future intake installations should ensure good sediment control and energy dissipation.

ACKNOWLEDGEMENTS

The authors are very grateful to Nuffic for sponsoring this study through the WREM Project, a collaborative capacity building project between the National University of Rwanda and the UNESCO-IHE Institute for Water Education. We would also like to acknowledge the kindly cooperation and assistance given by EWSA during this research.

REFERENCES

Acreman, M. C. 2001 Ethical aspects of water and ecosystems. *Water Policy Journal* **3** (3), 257–265.
Acreman, M. C. & Dunbar, M. J. 2004 Methods of environmental flow setting. *Hydrology and Earth System Sciences*.

Baruth Edouard, E. 2004 *Water Treatment Plants, Design and Control*. 4th edn., American society civil engineering, American water works associations, McGraw-Hill.

Birdie, G. S. & Ram Chandra 1996 *Irrigation Engineering (Including Water Power Engineering)*. Dhanpat Rai and sons.

California Bay-Delta Authority & Bay, Delta Public Advisory Committee 2005 Water Plan Update 2005, volume 2.

Center for Watershed Protection 2000 Design of infiltration practices.

Ebrahim, M. 2000 water supply and sanitation sector assessment, part II.

Electrogaz-KIMISAGARA 2007 *Raw Water Daily Data Records*. Kigali, Rwanda.

Electrogaz-NYABARONGO 2007 *Raw Water Daily Data Records*. Kigali, Rwanda.

Electrogaz-KADAHOKWA 2007 *Raw Water Records and Monthly Reports*. Butare, Rwanda.

Electrogaz-SHYOGWE 2007 *Raw Water Records and Monthly Reports*. Kigali, Rwanda.

Electrogaz-WATER DEPARTMENTS 2007 *Statistics and Budget Management*. Kigali, Rwanda.

Electrogaz-ARCHIVES DEPARTMENT 2007 *Raw Water Data Monthly Report*. Kigali, Rwanda.

EPA 1987 *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources*. Washington, D.C.

EPA 1991 *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources*. Washington, D.C.

EPA 1991a Manual of Individual and Non-Public Water Supply Systems.

EPA 1995 *EPA/State Joint Guidance on Sanitary Surveys*. Developed as a cooperative effort between the EPA and the Association of State Drinking Water Administrators. Washington, D.C.

EPA 1996 *Ultraviolet Light Disinfection Technology In Drinking Water Application - An Overview*. Office of Water, Washington, D.C. EPA 811-R-96-002.

EPA 1997b Drinking Water Inspector's Field Guide for Use When Conducting a Sanitary Survey of a Small Surface Water System.

EPA 1997c *State Source Water Assessment and Protection Programs*. Office of Water, Washington, D.C. EPA 816-R-97-009.

EPA 1998b Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program. EPA/625/6-91/027, revised August 1998.

EPA, ASCE, and AWWA 1996 *Technology Transfer Handbook – Management of Water Treatment Plant Residuals*. Office of Research and Development, Washington, D.C. EPA/625/R-95/008.

François, b. & Maarten, B. 2003 *Linking Technology Choice with Operation and Maintenance in the Context of Community Water Supply and Sanitation*. World Health Organization and IRC, Water and Sanitation Centre, Geneva, Switzerland.

GLUMRB (Great Lakes Upper Mississippi River Board). 1997 Recommended Standards for Waterworks. (Also known as the Ten State Standards).

Government of Rwanda 2004 *Sectorial Policy on Water and Sanitation*. Ministry of lands, environment, forest, water and mines, Kigali, Rwanda.

Government of Rwanda 2005 *Water and Sanitation Department, Technical Assistance on the Preparation of National Water Resources Management*. Ministry of lands, environment, forest, water and mines.

IRC 2002 International Water and Sanitation Centre, Small community Water Supplies.

Leonovich, P. M. & Fedorovich, A. 1994 *Guide for the Design of Surface Water Intake, Water Intake Structure for Surface Water Source*. Byelorussian Agricultural academy, Gorki, Russia.

Mahdi, M. Al-Kaisi, Mark, Hanna & Mark, Licht 2003 *Soil Erosion and Water Quality*. Iowa State University Extension, USDA Natural Resources Conservation Service through Cooperative Agreement No. 74-6114-0-2.

Margaret, A. Novicki Improving Africa's water supply; special initiative seeks greater access for farmers and the poor. *From Africa Recovery* **11#2** (October 1997), 22.

Ministry of Health, New Zealand Public health Risk management plan guide, Surface Water Abstraction, Rivers, Streams and Infiltration Galleries, Version 1, Ref P1, June 2001. http://www.moh.govt.nz.

Ministry of infrastructures 2004 *Market Survey of Urban Energy and Water Use*. Kigali, Rwanda.

Ministry of lands, environment, forest, water and mines, MINITERRE 2007 *Private Operators Water Supply Systems Managers*. Kigali, Rwanda.

Muna, M. O., Sylviran, K., Abdel, A. A., Asfaw, A., Zelalem, H. & Aden, A. 2005 *Design and Operation of Diversion Systems*. Nile Basin Capacity Building Network, River structures, research cluster.

Netgroup 2003 *Electrogaz - Loss Reduction Assessment and Strategy, Electrogaz Request for Budget Support 2005–2007*. Kigali, Rwanda.

UK Parliamentary Office of Science and Technology balancing water supply and environment, number 256, February 2006.

Peter, L. Watson, Joseph, Gadek, Eyob, Defere & Catherine 2000 *Assessment of Resource Flows in Water Supply and Sanitation Sector*. Ethiopia.

South Africa Ministry of Water and Livestock Development 2003 Building Capacity to Implement an Environmental Flow Programme in Tanzania. World Bank Netherlands Water Partnership Program - Environmental Flow Allocation Window, IUCN-The World Conservation Union - Water and Nature Initiative, Centre for Ecology and Hydrology, Wallingford, UK, Southern Waters, Cape Town, South Africa, University of Cape Town.

TWAGIRAMUNGU F. 2004 *Water Sector and Sanitation Policy, Draft, Ministry – Draft, Kigali, Rwanda*. Ministry of Land, Environment, Forest, Water and Natural Resources.

United Nations World 2007 Water Development Report 'Water for people Water for life' 102.

U.S. Department of State 2007 *Consular Information Sheet*. Bureau of Consular Affairs, Washington, DC 20520.

Yalin, W. A., Odgaard, J. & Melville 1996 Sediment control at water intake. *Journal of Hydraulic Engineering* **122** (6), 353–356.