AN INVESTIGATION OF WATER QUALITY CHARACTERISTICS OF UPPER KAFUBU RIVER IN NDOLA, ZAMBIA

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE
In the Department of Geography

© Phallen Milambo Kamona Nkaka
University of Zambia
November 2000
APPROVAL

THIS DISSERTATION BY Phallen Milambo Kamona Nkaka IS APPROVED AS FULFILLING THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE BY UNIVERSITY OF ZAMBIA.

NAME

Prof. Mwaluko P. Tole

External Examiner

SIGNATURE

Dr. Henry M. Sichingabula

Supervisor and Internal Examiner

Dr. C. Munyati

Internal Examiner

Dissertation Chairperson
DEDICATION

To my beloved husband Nkaka and my daughters Mutale and Tsitsi
ACKNOWLEDGEMENTS

I would like to thank Dr. H. M. Sichingabula who supervised the studentship. His
tireless guidance and support during the whole period of studentship is gratefully
acknowledged. The constructive comments, valuable suggestions and the careful reading
of all drafts and manuscripts are greatly appreciated.

I would like to express my gratitude to the various individuals and organisations
that provided valuable assistance. The Ndola City Council Water and Sewerage
Department provided sediment yield data, laboratory facilities and technical assistance to
the study. Their assistance is very gratefully acknowledged. I thank the Environmental
Council of Zambia (ECZ) for the data provided on industrial effluents discharged into
Upper Kafubu River basin. Permission to use Masaiti Road Bridge Gauging Station was
given by Ndola Water Affairs Department. My appreciation is expressed also to Mr. and
Mrs. Chisala of Water Affairs Hydrological Branch, Kitwe, for the help rendered in the
field measurement of stream discharge. Water Affairs Hydrological section, in Lusaka
provided historical stream discharge and water level data. Special thanks are due to the
National Council for Scientific Research (NCSR) for access to technical reports and other
relevant information on water quality in Zambia.

I also express appreciation to all Indeni drivers who were involved during my
field sample collections, for acting as field assistants during the whole study period.
Special thanks are due to Mr. J. Muyambo, a Mechanic at Indeni who admirably
withstood slippery streambeds in rendering invaluable service as a field assistant, driver
and mechanic. Above all, I thank Mr. F. Zama, the General Manager for Indeni Refinery
and his Maintenance Manager Mr. J. M Nkaka for their individual support by providing
transport, personnel, and laboratory and computer services during my study period.

Various members of UNZA Community gave valuable assistance and include
Geography Department staff, Dr. J. Chikunji, Mathematics Department, DR. S. F. Banda,
Chemistry Department and many others. Messrs. L. Liomba and J. Chalila in the
University of Zambia Cartographic Unit of the Geography Department prepared map
illustrations. The assistance with Computer programming and analysis given by Mr. Kelly
Mulenga (UNZA, Special Education), Dr. C. Munyati (UNZA, Geography Department)
and Mr. B. Zulu of UNZA Computer Center is very gratefully acknowledged.
I thank Mr. F. Mvula, Lusaka Water and Sewerage Company for valuable discussions and advice during the production of this report.

Finally, am heavily indebted to my everlasting friends Charity Musamba (NGO, Zambia), Christine Chikolwa (Gender student), Patricia Bwalya (Veterinary student), Chipo Hamayobe (UNZA, Engineering student), Chileya Mufuzi (Ndola, St. Andrews School), Fiona Musana (Uganda), Henry Francis (Tanzania) and Phineaus Mohajane (South Africa) for their tremendous support and encouragement during my stay at UNZA. Their material support and company need no elaboration whatsoever.

Lastly, but not the least, to my beloved family, for their patience and encouragement during the whole period of my study.
ABSTRACT

This study analysed the physico-chemical and bacteriological characteristics of water in the Upper Kafubu River basin in terms of temporal and spatial variations in the period 1991-1999. The effects of urban activities on the physico-chemical and bacteriological regimes of the Kafubu River in Ndola were also assessed. The studied Kafubu River basin is 60 km² in size and originates from the Zambezi-Congo watershed. Analysed data included archival water quality data for sampling stations operated by the Ndola City council, water level and discharge data for Kafubu River, supplied by Water Affairs and rainfall measurements from Ndola Airport rainfall station. These data were supplemented by field measurements in the 1998/1999 season. Six sampling points were located along the whole stretch of the urbanised reach of Upper Kafubu River over distance of about 20 km from Itawa Swamps Railway Bridge in the northeast to Kafubu Dam in the southwest. Physico-chemical characteristics were determined by standard laboratory techniques at Kanini and Indeni laboratories in Ndola. Parameters analysed included temperature, colour, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), turbidity, taste, odour, conductivity, pH, total alkalinity, total hardness, calcium and magnesium hardness, chlorides, and Chemical Oxygen Demand (COD).

The results of analysis showed that, crude and minimally treated municipal and industrial effluents from sewage treatment plants and industries grossly polluted the Upper portion of Kafubu River. This was evidenced by high mineralization of river water such that TDS values averaged between 218.7 to 326.35 ppm, average conductivity (328.0 to 491.88 µmhos/cm), average pH of between 7.2 and 8.96 units, average total alkalinity and hardness of between 152.2 to 259.04 ppm and 133.28 to 294.88 ppm, respectively, were recorded. Trace metal concentrations that included lead (0.035 to 1.58 ppm) zinc (0.03 to 1.0 ppm) and copper (0.02 to 0.34 ppm) with lead exceeding the maximum allowable limit of 0.5 ppm in river water, were observed. Anion and cation transport were highest in the upstream stations at Itawa Swamps and Itawa Dam, which probably resulted from increased chemical decomposition and runoff associated with rain events such that solute transport was more pronounced during wet (November to March) than dry season (April to October). In contrast, the concentration levels of suspended
sediment concentration (SSC), chemical oxygen demand (COD), turbidity, colour, taste and odour were typically highest in the downstream stations (S14 and S15) and were more pronounced during dry season (April to October). Concentration levels of lead, colour, pH, and at times SSC, turbidity, taste and odour were above ECZ (1993) maximum permissible levels for streams receiving wastewaters. The concentration levels of parameters such as TDS, conductivity, total hardness and alkalinity, calcium and magnesium hardness, copper and zinc were relatively high though within permissible levels for an effluent receiving stream used for subsequent production of drinking water. Similarly, the quality of treated water in terms of lead, colour, taste and odour, and at times turbidity, TSS and alkalinity concentration levels at both Itawa and Kafubu water works were above maximum allowable levels. Raw and treated river water in the Upper Kafubu catchment was alkaline and hard throughout the study period.

Organic pollution was evident with high chemical oxygen demand (COD) (39.73 to 65.66 ppm) in river water and also with the occurrence of high number of coliform bacteria (0 to 18 / 100 mls) and the presence of *E. coli* in treated water. The total coliform organisms and *E. coli* were present in most of the treated water samples at both water works indicating that tap water had pathogens which could cause health risks to consumers of this water. This was because chemical additive dosage levels used were insufficient for effective water treatment. Thus, it was deduced that non-continuous granular chlorine additive dosage and the low aluminum sulphate and the copper sulphate dosage, contributed to the presence of coliform bacteria and *E. coli*, excessive colour, and bad taste. The obsolete infrastructure, such as clogged sand filters contributed to the unwholesomeness of tap water especially at Kafubu Water Works.

It is concluded that a combination of temporal, spatial, hydrological and climatological factors control variations in water quality of Upper Kafubu River basin in a complex fashion. Therefore, with more data, multivariate analysis of the aforementioned factors should greatly improve prediction of river quality in Upper Kafubu River basin.
# TABLE OF CONTENTS

Approval ...........................................................................................................(i)

Dedication .....................................................................................................(ii)

Acknowledgements .........................................................................................(iii)

Abstract .........................................................................................................(v)

Table of Contents ...........................................................................................(vii)

List of Tables ..................................................................................................(xi)

List of Figures .................................................................................................(xii)

List of Appendices ...........................................................................................(xvi)

**CHAPTER 1: INTRODUCTION** ......................................................................1

1.1 Introduction .................................................................................................1

1.2 Background to the Study ............................................................................3

1.3 Research Objectives ....................................................................................4

1.4 Scope ............................................................................................................4

**CHAPTER 2: LITERATURE REVIEW** ..........................................................8

2.1 Introduction ................................................................................................8

2.2 Water Quality at Global Level ..................................................................8

2.3 Quality of Zambian River Waters ...............................................................10

2.3.1 Water Quality Characteristics in the Kafue River Basin ......................12

2.4 Water Pollution Control Standards in Zambia .........................................16

2.5 Legal Framework for Commercial Utilities in Zambia .........................17

**CHAPTER 3: THE STUDY AREA** ...............................................................19

3.1 Location and Size ......................................................................................19

3.1.1 Topography ........................................................................................19

3.1.2 Geology ................................................................................................21

3.1.3 Climate ..................................................................................................23

3.4 Hydrology ..................................................................................................23

3.2 Vegetation and Landuse ..........................................................................24

**CHAPTER 4: METHODOLOGY** .................................................................26
4.1 Introduction..................................................................................................................26
4.2 Types and Sources of Secondary Data........................................................................26
4.3 Primary Data Collection...............................................................................................27
4.3.1 Water Levels and Discharge Measurements...............................................................27
4.3.2 Field Observations and Water Sample Collection......................................................28
4.4.1 Sampling Points.........................................................................................................29
4.4.1.1 Itawa Swamps Station (ST1)..................................................................................29
4.4.1.2 Itawa Dam Station (ST2).......................................................................................32
4.4.1.3 Itawa Water Works Station (ST3)..........................................................................32
4.4.1.4 Kanini Station (ST4).............................................................................................34
4.4.1.5 Kafubu Dam Station (ST5)....................................................................................34
4.4.1.6 Kafubu Water Works Station (ST6).......................................................................34
4.5 On-Site Sampling Procedure.........................................................................................37
4.6 Water Quality Determination.......................................................................................37
4.6.1 Measurements of Physical Parameters.....................................................................38
4.6.1.1 Temperature, Colour, Turbidity and Conductivity..................................................38
4.6.1.2 Total Suspended Solids (TSS) and Total Dissolved Solids (TDS).........................39
4.6.2 Measurements of Chemical parameters..................................................................39
4.6.2.1 pH, Chemical Oxygen Demand (COD), Magnesium hardness
(CaCO₃), Calcium hardness (CaCO₃), Total hardness,
Total Alkalinity, and chlorides......................................................................................39
4.6.3 Trace Metals.............................................................................................................40
4.7 Quantitative Analysis Methods....................................................................................40
4.8 Limitations....................................................................................................................41

CHAPTER 5: RESULTS AND ANALYSIS........................................................................42
5.1 The Hydrological Regime of Kafubu River..................................................................42
5.1.1 Stream Hydrograph and Hyetograph Characteristics..............................................44
5.2 River Water Quality.....................................................................................................46
5.2.1 Physical Characteristics of River Water....................................................................49
5.2.1.1 Temperature.......................................................................................................49
5.2.1.2 Total Suspended Solids (TSS)............................................................................50
5.2.1.3 Total Dissolved Solids (TDS)............................................................................52
5.2.1.4 Conductivity ................................................................. 55
5.2.1.5 Turbidity and Colour of Water ........................................... 56
5.2.2 Chemical Characteristics of River Water ................................. 59
5.2.2.1 pH ............................................................................. 59
5.2.2.2 Total Alkalinity ............................................................ 60
5.2.2.3 Calcium, Magnesium and Total Hardness .............................. 63
5.2.2.4 COD and Chlorides ....................................................... 63
5.2.3 Trace Metal Concentrations in Raw River Water ....................... 66
5.3 Treated (tap) Water Quality Characteristics ................................. 70
5.3.1 Physico-Chemical Characteristics of Treated Water .................... 70
5.3.2 Bacteriological Characteristic of Drinking Water ....................... 79
5.4 Quality of Wastewaters Discharged into the Kafubu River ................ 82
5.4.1 Municipal Wastewaters ..................................................... 82
5.4.2 Characteristics of Industrial Wastewaters ................................. 88
5.4.2.1 Treatment of Industrial Wastewaters at Zambezi Paper Mills Limited ................................................................. 90
5.4.2.2 Treatment of Industrial Wastewaters at Textile Mills ................ 91
5.4.2.3 Treatment of Industrial Wastewaters at Lever Brothers Zambia Limited ................................................................. 93
5.4.2.4 Treatment of Industrial Wastewaters at Colgate Palmolive Zambia Limited ................................................................. 94
5.4.2.5 Treatment of Industrial Wastewaters at Zambia Oxygen Limited (ZAMOX) ................................................................. 94
5.4.2.6 Treatment of Industrial Wastewaters at Lyons Brooke Bond Zambia Limited ................................................................. 95
5.4.2.7 Treatment of Industrial Wastewaters at Ndola Lime Mine Area ................................................................. 96

CHAPTER 6: DISCUSSION, INTERPRETATION AND IMPLICATIONS ......... 97
6.1. Introduction ........................................................................... 97
6.2 Seasonal Characteristics of River Water Quality .............................. 99
6.2.1 Wet Season ....................................................................... 99
LIST OF TABLES

Table 5.1: Wet Season Physico-chemical Characteristics of raw
River water in the Upper Kafubu River (1998)..........................47

Table 5.2: Dry Season Physico-chemical characteristics of raw River Water in the
Upper Kafubu River (1998)..................................................48

Table 5.3: Temperature Variations in Raw and Treated Water in
The Upper Kafubu River Basin in Ndola (°c)............................50

Table 5.4: Total Dissolved Loads in the Upper Kafubu River Basin, Ndola........53

Table 5.5: Physico-chemical Characteristics of Treated
Water at Itawa and Kafubu Water Works in the Wet Season..........71

Table 5.6: Physico-chemical Characteristics of Treated Water
at Itawa and Kafubu Water Works in the Dry Season.................72

Table 5.7: Coliform Bacteria, Taste, Odour, and Appearance of
Water in relation to Residual Chlorine Concentration
Levels at Itawa and Kafubu Water Works and their

Table 5.8: Percentage of Occurrence of Total Coliforms and E. coli
in Treated water works and their Distribution Systems in Relation to
Residual Chlorine Concentrations (1991/98) .............................81

Table 5.9: Results of Laboratory analysis for Sewage Effluents
Collected at Sewage Outflows in Ndola....................................83

Table 5.10: Mean values of Percentage Removal of Sewage Works
in Ndola .............................................................................88

Table 5.11: Listing of Major Industries in Ndola: their Products,
Potential Pollutants to Kafubu Aquatic Environment and
Pre-treatment Processes..........................................................89

Table 6.1: Regression Equations for Estimating Trace Metal Concentrations
From River Discharge...............................................................108

Table 6.2: Results of t-test on the Effectiveness of Itawa and Kafubu
Water Treatment Plants.........................................................120
LIST OF FIGURES

Figure 1.1 Location Map of Ndola in Zambia ........................................2

Figure 3.1 Map Showing the Topography and Drainage Network of
Upper Kafubu River Basin ..................................................................20

Figure 3.2 Map Showing the Geology of the Upper Kafubu River Basin........22

Figure 4.1 Map Showing the Water Sampling Stations along Kafubu
River in Relation to Major Economic Activities in Ndola Town..............30

Figure 4.2 Kafubu River at Itawa (a) Itawa Swamps (ST1),
(b) Itawa Dambo, a Low Earth Dam Providing Raw River
to Itawa Water Works ........................................................................31

Figure 4.3 Itawa Water Works Sampling Station for Raw and Treated
Water (a) Intake point from Itawa Dam (ST2) and (b) tap Water
Within the water Works (ST3) .............................................................33

Figure 4.4 Kafubu River at Kanini Foot-Bridge (a) Kanini Sewage Works
on the Western bank of Kafubu River (b) Kanini
Foot-Bridge (ST4) ................................................................................35

Figure 4.5 Kafubu Water Works Sampling Stations (a) Intake point from Kafubu
Dam into the Water Treatment Plant (ST5), (b) Tap Water (ST6)
Located within Kafubu Water Treatment Plant ......................................36

Figure 5.1 Hydrological (a) and Rainfall (b) Regimes of Kafubu River in
Ndola in the period 1997-1998, respectively ........................................43
Figure 5.2  Plot of hyetograph and hydrograph for Kafubu River 1993-1998.................45

Figure 5.3  Temporal Variations in Sediment Concentration Levels in
Raw River Water in Upper Kafubu Catchment (a) TSS
(ST1) and (ST4), (b) TDS (ST1) and (ST4), (c) TSS (ST2) and (ST5),
and TDS (ST2 and (ST5) .................................................................51

Figure 5.4  Relationship between estimated Discharge and measured total dissolved
load at (a) Itawa Swamps (ST1) and (b) Kanini (ST4), 1998, Ndola.................54

Figure 5.5  Temporal Variations in Conductivity Concentration levels
in Kafubu River Water at (a) Itawa Swamps (ST1) and
Kanini (ST4), and (b) Itawa (ST2) and Kafubu (ST5) Dams.........................57

Figure 5.6  Turbidity and Colour Units in Raw River Water in Upper Kafubu
Catchment (a) Turbidity (ST1) and (ST4), (b) Colour Units (ST1)
and (ST4), (c) Turbidity (ST2 and ST5) (d) Colour Units
(ST2) and (ST5) .................................................................................58

Figure 5.7  Temporal Variations in pH Units in River Water at (a) Itawa
Swamps (ST1) and Kanini (ST4), (b) Itawa (ST2) and
Kafubu (ST5) Dams .................................................................61

Figure 5.8  Temporal Variations in Total Alkalinity Concentration Levels
in Raw River Water at Itawa Swamps (ST1) and Kanini
(ST4) Itawa (ST2) and Kafubu (ST5) Dams ........................................62

Figure 5.9  Temporal Variations in Concentration Levels of (a) Total Hardness,
(b) Calcium Hardness, (c) Magnesium Hardness, (d) Total Hardness,
(e) Calcium Hardness and (f) Magnesium Hardness in Raw River
Water in Upper Kafubu Catchment ..................................................64

xiii
Figure 5.10  Temporal Variations in COD Concentration Levels in Raw River Water at
(a) Itawa Swamps (ST1) and Kanini (ST4), (b) Itawa (ST2)
(b) and Kafubu (ST5) Dams ................................................................. 65

Figure 5.11  Temporal Variations in Concentration Levels of Chlorides in Raw
River Water at (a) Itawa Swamps (ST1) and Kanini (ST4), (b) Itawa
(ST2) and Kafubu (ST5) Dams ............................................................... 67

Figure 5.12  Temporal Variations in Concentration Levels of (a) Lead, (b) Copper
(c) Zinc in Raw River Water in the Upper Kafubu River Basin .......... 69

Figure 5.13  Temporal Variations in Concentration Levels of (a) Colour
(b) Total Suspended Solids and (c) Total Dissolved Solids
in Drinking Water at Itawa and Kafubu Water Works ......................... 73

Figure 5.14  Temporal Variations in Concentration Levels of (a) Turbidity,
(c) Conductivity (c) Chlorides, and (d) pH in Drinking Water at
(d) Itawa and Kafubu Water Works ...................................................... 75

Figure 5.15  Temporal Variations in Concentration Levels of (a) Total
Alkalinity and (b) Total Hardness in Treated Water at
Itawa and Kafubu Water Works ......................................................... 77

Figure 5.16  Temporal Variations in Concentration Levels of (a) Lead, (b) Copper
and (c) Zinc in Drinking Water at Itawa and Kafubu water works .......... 78

Figure 5.17  Graphs Showing TSS, SDS, and Conductivity Concentration
Levels in effluents from (a) Old Kanini (b) New Kanini