CICD Series Vol.1: LARS 2007 Proceedings

2009

CICD Series

Editor

Prof. Dr.-Ing. Gerd Förch,
Universität Siegen,
Centre for International Capacity Development,
Paul-Bonatz-Str. 9-11
57076 Siegen

E-Mail: info@cicd.uni-siegen.de

Printing Printing Office, Universität Siegen, Germany

ISSN: 1868-8578

Preface Volume One

This new publication - CICD Series - has been established to present experiences and results from university engagements in development cooperation which started almost two decades ago at Siegen University, Research Institute for Water and Environment.

CICD stands for Centre of International Capacity Development, a University Siegen research centre established by the Senate in November 2008 at the initiative of senior professors of the departments of architecture, civil engineering, mechanical engineering, electrical engineering and informatics. The aim is to coordinate and support development research and capacity building throughout the university, thereby reflecting the contributions of all disciplines relevant to development cooperation.

The managing director of CICD serves as chief editor of the CICD Series; other individuals or teams may edit the single volumes.

This first volume *Proceedings of Lars 2007 - Lake and Catchment Research* presents the findings of the university component of the technical cooperation project "Assistance to Arba Minch Water Technology Institute - Ethiopia", which lasted from 1989 to 2007. Siegen University was involved in this programme by organising the university cooperation scheme since 1993. The German Government, the Ministry of Economic Cooperation and Development sponsored the project under the Ethio-German development cooperation treaties. It was executed by GTZ - German Development Cooperation.

Lars 2007 stands for the Lake Abaya Research Symposium 2007, which was organised by the two partner Universities in May2007 in Arba Minch; the first one - *Lars 2004* - took place in Addis Ababa in 2004.
Further results of this university cooperation programme are going to be published in the CICD Series with several doctoral dissertations and a compilation of master thesis research.

The Editor

List of Authors and Contact Data

1. Reconstructing Hydrological Drought Using Proxy Data: The Case of Wabi Shebele River Basin

Adane Abebe: Civil Engineering Department, University of Siegen, 57068 Siegen, Germany, adane.abebe@uni-siegen.de,
Gerd Foerch: Civil Engineering Department, University of Siegen, 57068 Siegen, Germany,
Ute Sass-Klassen: Centre for Ecosystem Studies, Wageningen University, the Netherlands

2. Application Of WASIM Distributed Water Balance Simulation Model to the Abbay River Basin

S. Alemayehu: Institute of Water Technology, Arbaminch University, Ethiopia
J. Cullmann: Institute of Hydrology and Meteorology, TU Dresden, Germany
Hans-B. Horlacher: Institute for Hydraulic Engineering and Hydromechanics, TU Dresden, Germany

3. GIS and Remote Sensing Integrated Environmental Impact Assessment of Irrigation Project

Ahmed Amdihun Mahmoud: aamdihun@yahoo.com

4. Comparative Study of the Hydrology and Hydrogeology of Selected Ethio-Kenyan Rift Lakes

Tenalem Ayenew: Addis Ababa University, Department of Earth Sciences, P.O.Box 1176. E-mail: Tenalema@yahoo.com, Addis Ababa, Ethiopia
Robert Becht: International Institute for Geo-Information Sciences and Earth Observation (ITC), Hengelosestraat 99. P.O. Box 6. 7500 AA. Becht@itc.nl. Enschede, The Netherlands

5. Physical and Water Resources Characteristics of the Lakes Abaya and Chamo, including Scenarios and Impacts Extended Abstract

Seleshi Bekele Awulachew: International Water Management Institute, s.bekele@cgiar.org

6. Application of SWAT Model in Mountainous Catchment

B.Z. Birhanu: PhD Candidate, Water Resources Engineering, University of Dar es Salaam, Tanzania, birhanuzem@yahoo.com,
P.M. Ndomba: PhD Candidate, Water Resources Engineering, University of Dar es Salaam,

Tanzania
F.W. Mtalo: Professor, Water Resources Engineering, University of Dar es Salaam, Tanzania

7. Sanitation, IWRM and Food Security, Closing the Loops to Achieve the Targets (Lake Abaya Research Symposium 7th - 11th May 2007)

Patrick Bracken: Consultant for sanitation c/o EIRENE, B.P. 549, Niamey, Republique du Niger

8. Application of SWAT: For assessment of spatial distribution of water resources and analysing the impact of different land management practices on soil erosion in the Upper Awash River Basin watershed

Dilnesaw A. Chekol, Bernhard Tischbein, Helmut Eggers, and Paul Vlek

9. Assessment of Sand Encroachment Using Remote Sensing and GIS, Case Study Dongola Area, Sudan

Dafalla M.S.: Dept. of Soil Science and Environmental Sciences, Faculty of Agriculture, University of Khartoum, Sudan. Presently Institute of Remote Sensing and Photogrammetry, TUD, Germany. Corresponding author
Elhag A.M.H.: Remote Sensing Authority, Sudan
Ibrahim S.I.: Dept. of Soil Science and Environmental Sciences, Faculty of Agriculture, University of Khartoum, Sudan
Doka, M. A.: Dept. of Soil Science and Water Studies, Faculty of Agricultural Studies, Sudan University for Science and Technology-Remote Sensing Authority, Sudan

10. Study of Nitrogen Transformation Lake Victoria

Pascal Emmanuel: University of Dar es Salaam, College of Engineering and Technology, Water Resources Engineering Department P.O Box 35091, Dar es Salaam, Tanzania. Email: pascalemmanuel2000@yahoo.com, Phone: +255745731544
Frederic Mwanuzi and Richard Kimwaga

11. Assistance to Arba Minch Water Technology Institute (AWTI)

Univ.-Prof.Dr.-Ing. Gerd Förch: Civil Engineering Department, University of Siegen, 57068 Siegen, Germany

12. Composition and Distribution of the Surficial Sediment in Lake Abaya

Bogale Gebremariam: Arba Minch University, Ethiopia
Birgitta Schütt: Freie Universität Berlin, Germany

19. Development of Intensity-Duration-Frequency Relationships for gauged and ungauged location of Southern Nations, Nationalities Peoples Region (SNNPR)
Feleke Gerb, Semu Aylew Moges: Arba Minch University, School of Graduate Studies, P.O. Box 21, Arbaminch, Ethiopia telephone: +251-46-8810775; Corresponding author: email: semu_moges_2000@yahoo.com

20. The Use of the Curve Number Method to Determine the Impact of Land Use and Land Cover Changes on the River Flow, A study of the Kihansi River Catchment, Tanzania
S.M.M. Sabai: Lecturer, University College of Lands and Architectural Studies (UCLAS), P. O. Box 35176 Dar es Salaam. Tanzania, Email: mmsabai@yahoo.com
B. Z. Birhanu: PhD Candidate, Water Resources Engineering Department (WRED). Univ. of Dar es Salaam (UDSM)
S. Mkhandi: Senior Lecturer, WRED, UDSM
F.W. Mtalo: Professor, WRED, UDSM
R.K. Kachroo: Professor, WRED, UDSM

21. Climate Change Impact on Lake Ziway Watershed Water Availability, Ethiopia
Lijalem Zeray Abraham: Cologne University of Applied Sciences, Institute for Technology in the Tropics, Contact address: Cologne University of Applied Sciences, Institute for Technology in the Tropics, Betzdorfer, Strasse 2, 50679 Cologne (Deutz), Germany. E-mail: lijalemz@yahoo.com
Jackson Roehrig: Cologne University of Applied Sciences, Institute for Technology in the Tropics
Dilnesaw Alamirew Chekol: University of Bonn, Center for Development Research

Contents

List of Figures

1 Reconstructing Hydrological Drought Using Proxy Data

The Case of Wabi Shebele River Basin

Adane Abebe[1], *Gerd Foerch*[2] *and Ute Sass-Klassen*[3]

1.1 Abstract

In time series analysis a short record data is not much different from none. This problem, often observed on stream flow records in developing countries, is compounded with the unreliability of the data. Inconsistency in measurement and storage exacerbates the quality of retrieved data. Hence, most conclusions drawn from such data suffer a similar unreliability. Signature of water stress can be identified in tree rings. This investigation attempts to explore the potential of this proxy data together with climatic indices for hydrological drought reconstruction in Wabi Shebele river basin, South East Ethiopia. Core and disk samples of tree rings were collected using incremental corer and disk sampler at various sites and from different species in the riparian environment. After multi site disaggregation of the annual events, analysis of hydrological drought is carried out. Any improvement of the reconstructed series due to supplementary attributes from climatic and remotely sensed vegetation characteristics of the catchment is also

[1]Civil Engineering Department,
University of Siegen,
57068 Siegen, Germany
adane.abebe@uni-siegen.de
[2]Civil Engineering Department,
University of Siegen,
57068 Siegen, Germany
[3]Centre for Ecosystem Studies,
Wageningen University
the Netherlands

analysed. The reconstructed series mimics the hydrological drought series established from gauged historical flows well.
Keywords: *Dendrochronology, dendrohydrology, disaggregation, hydrological drought, Wabi Shebele*

1.2 Introduction

The quality of a hydrological prediction is connected at a fundamental level to the quality and length of the hydrometeorological data used both in developing the prediction method (modelling) and during its operational use. The hydrological data collected in developing countries suffer from a number of fallacies: both systematic and instrumental. In certain cases the reliability of data collected may be dubious. It often has missing records. Field assessment of 13 stream gauging stations in Wabi-Shebele basin, Ethiopia, shows that most of the staffs are not properly installed to measure flows, especially during lean years. The inspection of the rating curves at these stations reveals that in certain cases it does not capture the low flows adequately.

Proxy data gives an opportunity to extend data collected through instrumental records to the distant past. Among the various sources of paleoclimatic information available for the last thousand years, tree-ring chronologies have the advantage of being continuous, well replicated, exactly dated to the calendar year, and therefore easily comparable to instrumental records (Fritts 1976).

This paper seeks to reconstruct hydrological drought from riparian tree ring widths and climatic indices in the Wabi-Shebele river basin, East Africa. Nowadays, extreme low flow events are more diligently analysed and given focus to in the emerging field of ecohydrology. However, many of the catchments in developing countries are ungauged; thus, it is difficult to get recorded data on low flows. The hydrologic regime of streamflow drought is of primary consideration in the design of water supply systems, hydroelectric plants, supplemental irrigation scheme, low flow augmentation systems, and others. Statistical techniques dealing with the duration aspects of drought, are reasonably well developed, whereas techniques for severity aspects are less satisfactory and require considerable improvement and refinement (Panu and Sharma, 2002).

1.3 Study Area

The Wabi Shebele river basin, located in East Africa, is a transboundary river basin shared between Ethiopia and Somalia. The part of the river, which is in Ethiopia lies between $4^{o}45$'N to $9^{o}45$'N latitude and $38^{o}45$'E to $45^{o}30$'E longitude, including the closed watershed of the Fafen and the Bio Ado (Figure 1).It springs from the Bale mountain ranges of the Galama and the Ahmar about 4000 m above mean sea level and drains into the Indian ocean crossing Somalia. About 72% of the catchment (202,220 square kilometres) is lying in Ethiopia. The areal distribution of rainfall varies from 271 mm at lower arid portion (Gode) to 1320 mm in the upstream highlands of the basin (Seru).

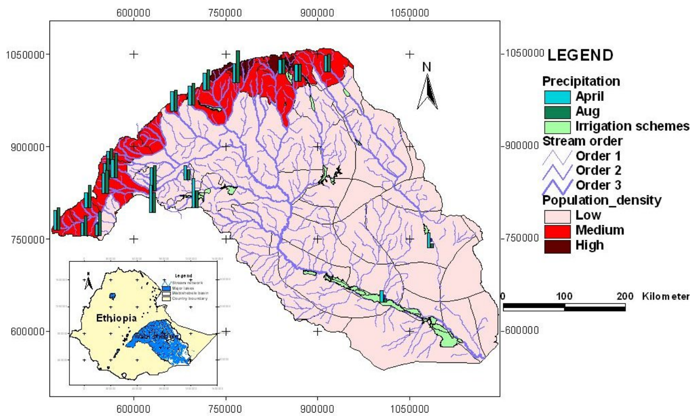


Figure 1.1: Location of the study area and rainfall characteristics in two typical months (in April and August) of the basin.

Both meteorological and hydrological gauging stations are relatively more clustered in the upstream high lands.

1.4 Data and Methodology

If a hydrological drought variable q (e.g. stream flow, ground water level, etc) is truncated at a threshold level q_o, the event of surpluses ($q > q_o$) and deficits ($q < q_o$) would emerge along the time axis (Figure 2). Drought severities are normally expressed in terms of the cumulative shortages (deficit-sums) in sequences of drought variable below a desired demand level. The severity of hydrological drought can be computed as:

$$S = \int_0^d (q_0 - q(t))dt$$

where S is severity of drought, q(t) is the stream flow at time t, and q_0 is the threshold level.

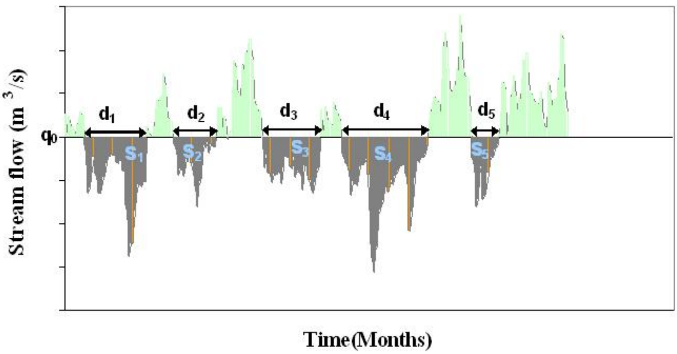


Figure 1.2: Definition sketch of hydrological drought events (q_0=threshold level, S=drought severity, d= drought duration).

In the past, absence of recorded long time streamflow data quite often hindered a reliable drought analysis and an understanding of the phenomenon. In this study proxy data from tree rings and climatic indices are used for simulation and extension of instrumental records. Recent studies show tree rings may be used as proxy for streamflow data (Gedalof, et al 2004).
The presence of old riparian trees belonging to species which have datable rings, is one of the criteria in selection of the trees. Cored and disk samples were

collected from following tree species: *Juniperus procera, Podocarpus falcatus, Acacia tortilis, Eucalyptus globulus, Commiphora monoica, and Erythrina brucei*. 5.15 mm thick wood cores were cored using a 45 cm long Swedish increment borer. A total of 31 increment cores and 17 stem disk samples were collected. All samples were air-dried. The stem disks were sanded until a grit size of 800 and the increment cores were mounted on wooden holders and hand-trimmed with a Stanley knife until the smallest rings were clearly visible. Ring counting gave a first estimate of the tree's age. Tree ring widths were measured with a precision of 0.01 mm along four radii of the stem sections, using LINTAB (RinnTec) measuring station associated with TSAP software platform (Rinn 1996). The time series were visually and statistically cross-dated to obtain mean tree-ring series.
$\bar{I}_t = \frac{\sum_{i=1}^{N}(lnw_t - y_t)_i}{N}$
where I_t is the average tree ring index (value of the master chronology), t stands for the calendar year, w is ring width measurement in 0.01 mm precision, y is the growth trend, simulated by a 30 year cubic spline fitted to remove any age-related trend in the series, i specimen, N stands for the number of specimens available for year t, with N > 5. A logarithmic transformation is made, as shown in equation (2), to obtain a homoscedastic time series.
Most of the samples collected, indicate that the trees were of young age, less than 40 years old. A relatively comparable and long data sample for the Adaba-Dodolla area was obtained from the centre for ecosystems studies at Wageningen University (Couralet et al, 2005). The characteristic feature of the master tree ring series established for the area is explored using plots of periodiogram. The time positions of the predominant frequencies are further revealed using wavelet analysis. In this study continuous wavelet transform (CWT) is used to detect and isolate patterns across temporal scales of the dendrochronologic records. In continuous form, the wavelet transform of a function f(t) is expressed as:

$$Wf_{m,n} = \int f(t)\overline{\Psi}_{m,n}(t)dt, m > 0$$

Where

$$\overline{\Psi}_{m,n}(t) \equiv \frac{1}{\sqrt{m}}\psi(\frac{t-n}{m})$$

represents a family of functions called wavelets. Here, m is a scale parametre, n is a location parametre and $\overline{\psi}_{m,n}(t)$ is the complex conjugate of $\psi_{m,n}(t)$ All sub-

sequent wavelets are rescaled versions of the mother wavelet. The area of each wavelet must sum to zero.Wavelet amplitude decreases as scale m increases. Details of the wavelet transform formulae are described in Smith et al(1998).
There is high correlation between the normalised digital vegetation index (NDVI) and the base flows in Wabi shebele river basin during lean seasons (Adane and Foerch, 2006). Correlations between the temporal NDVI anomalies with El Nino southern oscillation index (ENSO) show that the anomalous conditions over Eastern Africa were a direct result of anomalous warming of sea surface temperatures (SST) in the western equatorial Indian Ocean (WIO) and a lagged response to the warming in the eastern Pacific Ocean (Anyamba et al., 2001). The association between ENSO and droughts in Ethiopia is due to an atmospheric teleconnection or “the linkages over great distance of seemingly disconnected weather anomalies” (Glantz el. al., 1991). Long time series of sea surface temperature anomalies (SSTA) at NINO 3.4 and surface oscillation index (SOI) are obtained from the active archive of NOAA’s Climate Prediction Center (CPC) and are correlated with the master tree ring widths developed at Adaba-Dodolla. Out of the set of tree ring widths measured, a bootstrap sampling analysis was performed to generate more samples with replacement. Then the mean tree ring width was estimated to lie between 1.37 mm and 1.95 mm with significance of 0.05. The frequency of the extreme events and the smaller tree ring widths in the master tree ring series are comparable.

1.5 Results and Discussion

The samples collected from the *Juniperous* and *Podocarpus* species showed distinct concentric rings. Some missing and double rings are noticeable in a few samples. These double rings may be due to the bimodal nature of precipitation in the area. The rings in the species of *Acacia* lack clarity. This may be because of the fact that the Acacia species possesses a relatively high density wood (commonly more than 1.0 g/cm^3) and due to the presence of gum (Gourlay, 1995). In case of the *Eucalyptus* species it was very poorly identifiable. This might be partly explained due to the deep root nature of the eucalyptus species that enables them to reach a more permanent water table and thus making it more insensitive to current rainfall. Characteristics of the tree ring boundaries in the *Commiphora*

and *Erythrina* species could not be verified.
Residual tree rings series is generated for the area that spans a length of 133 years (i.e. 1871-2003). The part of the series, which deals with the very distant past, may be highly influenced by competition at a young age, this is why it is not considered in the latter part of the analysis. Visual inspection of the time series shows that the lowest ring widths at the beginning of the 1980's corresponds with the timing of the devastating drought in the country that claimed many lives and properties. Extreme events have been occurring frequently in the last three decades. The frequency of extreme events and the smaller ring widths (i.e. less than the mean ring width) correspond well (Table 1).

	Climatic signals		Ring width	
Period	El Nino	La Nina	> CI mean	<CI mean
1900-1920	3	6	5	8
1920-1940	2	1	0	12
1940-1960	3	3	3	6
1960-1980	3	5	6	10
1980-2000	9	5	3	16
Total	20	20	17	52

Table 1.1: Frequency of the tree ring width and climatic signals every 20 years. Confidence interval of the mean ring width CI= [1.37, 1.95] with significance of 0.05.

The periodiogram of the residual tree rings series in the area shows predominant cyclicity in a period of about two, three and seven years; the major peak being at around three years. There is a minor cyclicity at a 20 years period. In order to identify the particular years in which this cyclicity are common, a wavelet analysis is performed using morlet wavelet. It shows an increase in frequency in recent years (Figure 1.3).
The individual, linear correlation of the proxy data with the baseflow or streamflow during lean seasons is fairly good. The residual tree ring series at Adaba-Dodolla has a better correlation with the streamflow at Imi in the dry months of January (r=0.53) and February (r=0.35) for the record period of 1975-2000 is significant at 0.05. But the total annual streamflow at the same location is not significantly correlated with the annual tree ring series (r=0.22). The monthly correlation of SSTA and Streamflow at Imi for the period 1981-2000 yielded the

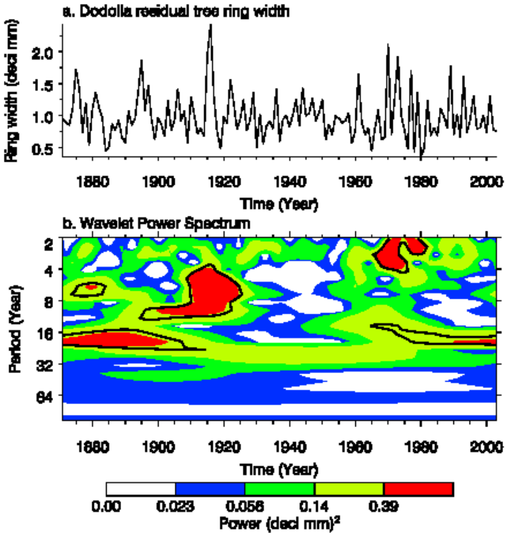


Figure 1.3: Wavelet power spectrums of the master tree ring width series at Dodolla area (Using Morlet wavelet).

highest significant correlations in May of 0.55. The high positive correlation during the belg season may be due to the frequent El Nino events that occurred during this period. During ENSO years, *belg* rains are heavy and the main summer (*kiremt*) rains are reduced (Woldegiorgis, 1996). Thus the upstream portion of the basin tends to receive additional precipitation during the same rainy season as that of the downstream portion (belg). The monthly SSTA (January-March) are significantly correlated to annual streamflow of Imi in the order of r~0.78 for the last two decades. Similarly the monthly SOI has a negative correlation of 0.82 for the same period.

A composite index from the residual tree ring series, SSTA and SOI is developed using singular value decomposition. This index is used to simulate and extend the streamflow records at a downstream location, the Imi gauging station. Extending the short streamflow data with least square regression may not be a good option for extreme events. An underestimation of the variance is seen in linear or log-linear regression techniques and may result in an underestimation of hydrologic extremes (Hirsch, 1982). It is also important to correct for transformational bias when regression analyses use the logarithms of data. Another approach to the least squares method of regression is to use the method of maintenance of variance extension, Type II (MOVE 2) (Hirsch, 1982, Parrett and Johnson, 1994). The simulation shows a correlation of 0.84 for the period 2000-1974, significant at 0.05 (Figure 4). The correlation starts to reduce to 0.65 in the early 1970's.

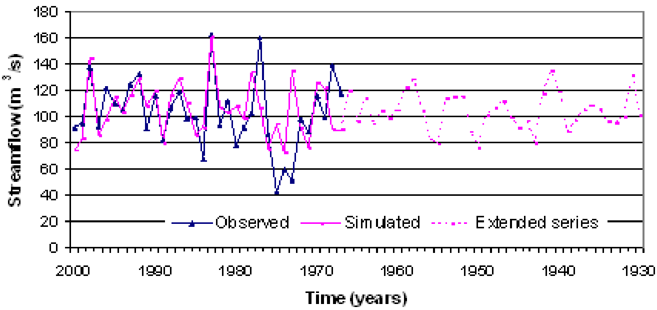


Figure 1.4: Observed and simulated stream flow series (2000-1974) at Imi gauging station and extended series (1974-1930).

The generated long series of annual streamflow is disaggregated to seasonal and then component flows. The essence of disaggregation models is to develop a staging framework [e.g., Santos and Salas, 1992], where flow sequences are generated at a given level of aggregation and then disaggregated into component flows (e.g., seasonal from annual, or monthly from seasonal). The summability of disaggregated flows and their mutual correlation structure (after some transformation) is preserved. Disaggregation is the simulation of the components of a vector of disaggregated variables **X** given (i.e., conditional on) an aggregate variable Z. Statistically, this implies that the joint probability distribution of the flow sequences at the different time periods needs to be preserved. The frequency of hydrological drought severity in the disaggregated series replicates fairly well that of the historical records from instrumental data. Further research from stem disks of old trees from different tree species may offer better evidence.

1.6 Conclusions

The frequency of smaller rings in the residual tree ring series for the Adaba-Dodlla area appears to be increasing in recent years. Extremes of climatic signals may have contributed to smaller ring widths in the region. NDVI can be used as an indicator of the biosphere response to climate variability at a range of time scales. A composite index from proxy data of tree rings and climatic indices (ENSO) is developed. This composite index from the proxy data explains about 70% of the variation in the streamflow at Imi gauging station in the last two and half decades. The frequency of hydrological drought severity in the disaggregated series from the proxy data simulates fairly well that of the historical records from instrumental data. Early wood and late wood ring widths vis-à-vis the seasonality of precipitation signals need to be established.

1.7 References

Adane A. and Foerch, G. (2006) *Catchment characteristics as predictors of base flow index (BFI) in Wabi-shebele river basin, East Africa. Proceedings of TROPENTAG 2006*, October 11-13, 2006, Bonn, Germany.
Anyamba, A., C. J. Tucker, and J. R. Eastman (2001) *NDVI anomaly patterns over Africa during the 1997/ 98 ENSO warm event. International J. remote sensing*, 2001, vol. 22, no. 10, 1847-1859.
Couralet, C.; Sass-Klaassen, U; Sterck, F.J.; Zuidema, P. (2005) *Combining dendrochronology and matrix modelling in demographic studies: An evaluation for Juniperus procera in Ethiopia, Forest Ecology and Management 216* (2005).
Fritts HC (1976) *Tree rings and climate.* Academic Press, New York.
Gedalof, Z, D.L. Peterson, and N.J. Mantua (2004) *Columbia river flow and drought since 1750*, Journal of the American Water Resources Association (JAWRA) 40(6).
Glantz, M. H., R. W. Katz, and N. Nicholls (1991) Teleconnections *Linking Worldwide Climate Anomalies*. Cambridge: Cambridge University Press.
Gourlay, I.D (1995). *The definition of seasonal growth zones in some African*

acacia species - a review. IAWA Journal, Vol. 16 (4), 1995: 353-359.
Hirsch, Robert M., 1982. *A Comparison of Four Streamflow Record Extension Techniques, Water Resources Research*, Vol. 18, No.4.
Panu, U.S. and Sharma, T.C. (2002) *Challenges in drought research: some perspectives and future directions*. Hydrological Sciences Journal 47.
Parrett, Charles, Dave R. Johnson, 1994. *Estimates of Monthly Streamflow Characteristics and Dominant-Discharge Hydrographs for Selected Sites in the Lower Missouri and Little Missouri River Basins in Montana*, U.S. Geologic Survey Water-Resources Investigation Report 94-4098, Denver, CO.
Rinn, F. (1996): *TSAP (Time series Analysis and Presentation*) Version 3.0. Heidelberg, Germany.
Santos, E.G., and J.D. Salas (1992) *Stepwise disaggregation scheme for synthetic hydrology*, J. Hydarulic Eng., 118 (5), 765-784.
Smith, L.C., D.L. Turcotte and B.L. Isacks (1998) S*tream flow characterization and feature detection using a discrete wavelet transform, Hydrological processes*, Vol. 12, 233-249.
Wolde-Georgis, Tsegaye (1996) El Niño and Drought Early Warning in Ethiopia *Internet Journal for African Studies*. Issue No. 2, March 1997.

2 Application Of WASIM Distributed Water Balance Simulation Model to the Abbay River Basin

S. Alemayehu[1], *J. Cullmann*[2] *and Hans-B. Horlacher*[3]

2.1 Introduction

A proper understanding and modelling of the rainfall-runoff relationship at watershed scale is important for water resources management studies and design activities such as flood control and management and design of various hydraulic structures. The transformation process of rainfall into runoff over a catchment is very complex, highly nonlinear, and exhibits both temporal and spatial variability.

Many rainfall runoff models have been developed by different researchers with various degrees of complexity to simulate this process. These models can be classified, depending on the degree of representation of the underlying physical processes, into three broad categories; namely, black box or system theoretical models, conceptual models and physically-based models. The black box models are data-driven models that normally contain no physically-based input and output transfer functions, and therefore are considered to be purely empirical models. These models have long been very popular because they are generally quickly and easily developed and implemented and mainly avoid the problem of understanding the structure of the inherent processes that take place in the system being modelled. Their low transparency, which results from the inability to interpret their internal workings in a physically meaningful way, is the main drawback of black box models, and these models generally fail to give useful insights into

[1]Institute of Water Technology, Arbaminch University, Ethiopia
[2]Institute of Hydrology and Meteorology, TU Dresden, Germany
[3]Institute for Hydraulic Engineering and Hydromechanics, TU Dresden, Germany

the system under investigation. Physically-based models are knowledge-driven. They are based on detailed descriptions of the system and the processes involved in producing runoff. These models use the basic laws of physics, e.g. equations of mass, energy, and momentum, to describe the movement of water. The resulting system of partial differential equations is then solved numerically at all points (spatially distributed) in a two or a three dimensional grid representation of the catchment.

Conceptual model approaches are a first step from physically-based model approaches towards a more empirical direction. Instead of using the equations of mass, energy, and momentum to describe the process of water movement as is the case in physically-based models, conceptual models a simplified but a plausible conceptual representation of the underlying physics is adopted. These representations frequently involve several inter-linked storages and simplified budgeting procedures that ensure that a complete mass balance is maintained at all times among all the inputs, outputs and inner storage changes. Some examples of conceptual modelling are the Stanford Watershed Model (SWM) (Crawford and Linsley, 1966), the Sacramento soil moisture accounting (SAC-SMA) model (Burnash et al., 1973, 1995), the Xinanjiang Model (Zhao et al., 1980; Zhao, 1992; Zhao and Liu, 1995), the Soil Moisture Accounting and Routing (SMAR) Model (O'Connell et al., 1970; Tan and O'Connor, 1996), the Tank Model (Sugawara, 1961,1995), the Precipitation-Runoff Modelling System (PRMS) (Leavesley et al., 1983), the HBV (Lindstrom et al., 1997), the TOPMODEL (Beven et al., 1995) and HEC-series (US Army Corps of Engineers, Hydrologic Engineering Centre. Their applicability is limited to areas where runoff has been measured for several years and to places where no significant changes in catchment conditions have occurred over the period of simulation since calibrated and not measured model parametres are assumed to remain constant.

The objective of this paper is to assess the applicability of the Wasim-ETH distributed water balance simulation model, in estimating daily runoff from 15 subcatchments in the Abbay River Basin. For this purpose, daily rainfall and temperature data from 38 meteorological stations were used.

2.2 Brief Description of the Watersheds

The area of the Abbay basin is about 200,000 km^2 and the total perimetre is 2440 km. The basin is located in the centre and west of Ethiopia (see figure 1). It lies approximately between latitude 7^{o}45'N and 12^{o}46' N and longitude 34^{o}06'E and 40^{o}00'E, it is generally rectangular in shape, and extending about 400 km from north to south, and about 550 km from east to west. It accounts for almost 17.1% of Ethiopia's land area and about 50% of its total average annual runoff. The Abbay River rises in the centre of the catchments and develops its course in a clockwise spiral in a deep gorge, collecting tributaries along its 922 km length from Lake Tana to the Sudan border. The elevation of the basin ranges from 490 m asl at the Sudan border to 4,230m asl at the summit of mountain Guna. Annual rainfall varies between about 800 mm to 2,220 mm; with a mean of about 1,420 mm. The mean temperature of the basin is 18.5 ^{o}C, with daily mean minimum and maximum temperatures of 11.4 ^{o}C and 25.5 ^{o}C respectively (April 1999, Abbay river Master plan).

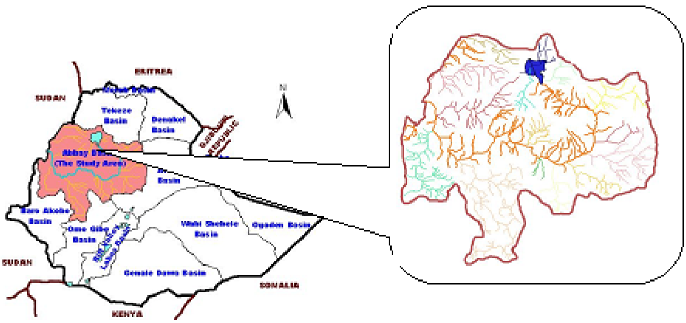


Figure 2.1: Location of the study area. The blue-marked area is Lake Tana (The largest lake in Ethiopia)

2.3 WaSiM-ETH (Topmodel Approach)

WaSiM-ETH is a Water Balance Simulation Model, developed at the Swiss Federal Institute of Technology Zurich. It is a physically-based grid hydrological conceptual model and deals with the possibilities in subdividing the catchment into small sub-catchments, with formats of input and output data and with the structure of the control file. Because of the physical basis of many WaSiM-ETH components the model can generally be applied to various basins in a wide range of environmental conditions all over the world (J. Schulla, 2000). It is recommended to use at least some observed runoff data for the model calibration. In addition, internal data as soil moisture, groundwater tables or snow water equivalents would be of advantage for the calibration process.
Basically, the model has the following components:

1. Interpolation facilities for interpolation of Meteo-data.
2. Evapotranspiration model to compute potential and real evapotranspiration for each grid.
3. Snow accumulation and melt model.
4. Interception model.
5. Infiltration model.
6. Soil model Topmodel approach and Richards equations approaches.
7. Discharge routing model.

Detail description of each component is found in the WaSiM-ETH manual (J. Schulla, 2000).
The hydro-meteorological data, land use and soil data has been prepared as per the format of the WaSiM-ETH through Arc-GIS and Tanalys (topographic analysis, which is a part of Wasim pre-and post processing software tools). The snow accumulation component was disabled, as there is no snow in the study area. Some parametres of the components of the model as the evapotranspiration component, are based on several empirical constants, which are valid for the area where the model is built. Therefore, these empirical constants need to

be checked against the study area, if the study area is different from the place, where this model is built.

2.4 Sensitivity Analysis and Calibration of the Model

A sensitivity analysis of the model for the selected sub-basin of the Abbay River Basin has been done. Sensitivity analyses are considered only for the most important empirical model parametres that have a large possible value range, whose observation is not possible or bear certain difficulties. Mainly, the parametres of the soil model of model version 1 (Topmodel Approach) and evapotranspiration were looked at. Results of the sensitivity analysis show that the recession parametres and the two correction factors are the most sensitive parametres. Precipitation intensity and scaling of capillary rise are the next sensitive parametres. The soil model of model version 1 (Topmodel Approach) is controlled by nine parametres:

- m recession parametre for base flow [m]
- Tkorr correction factor for the transmissivity of soil [-]
- Kkorr correction factor for vertical percolation [-]
- kD single reservoir recession constant for surface runoff [h]
- SHmax maximum storage capacity of the interflow storage [mm]
- kH single reservoir recession constant for interflow [h]
- Pgren precipitation intensity threshold for generating preferential flow into the saturated zone [mmh^{-1}]
- rk scaling of the capillary rise / refilling of soil storage from interflow [0...1]
- cmelt fraction on snowmelt, which is surface runoff [0...1]

There are three options in Wasim to compute potential evapotranspiration, namely the following methods: Penman, Wendling and Hamon. Temperature, relative humidity, wind speed, and sunshine duration is needed to compute potential evapotranspiration using the PENMANN method. Since only rainfall and temperature can be found as a long time series in the study area, the HAMON approach, which requires only temperature to compute potential evapotraspiration, has been chosen for the study area. The empirical constant in the HAMON methods, which is valid for southern Switzerland, has been modified based on the PENMANN method for the study area. The figure below shows the result of potential evapotranspiration of the default empirical constants and the modified constants against the PENMANN.

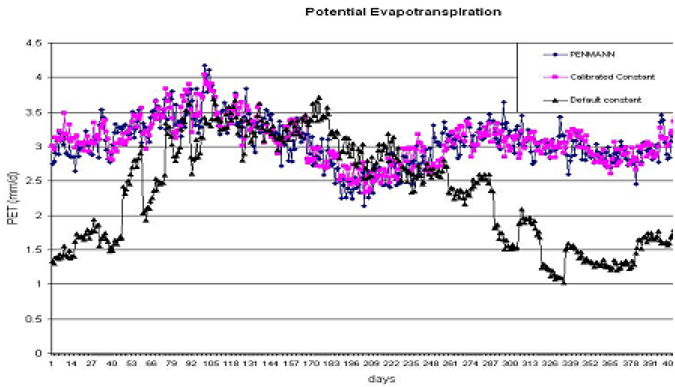


Figure 2.2: Comparison of default empirical constants and calibrated constants for the study area against PENMANN method

The calibration of the model was carried out for the selected sub-basin of the Abbay River Basin by using trial-and-error procedure for the first few runs. The automatic nonlinear parametre estimation method PEST (Doherty et al, 1998) was used to adjust the parametres of a model within individually specified lower and upper bounds, until the sum of squares of residuals between simulated runoff and a complementary set of observed runoffs were the minimum for the final calibration. For all sub-basins concurrent daily rainfall, temperature and runoff from 1995 to 1997 were used for model calibration and the information from 1998 to 1999 was used for model validation (see figure 3). For some areas in the Anger and Dedessa sub-catchment, where long time series of rainfall and temperature are available, the model was validated from 1986 to 1994 and from 1998 to 1999.

Sub-catchment	Catchment area	Model performance		Optimized Wasim soil parameters		
			R^2	m $*10^{-2}$	Tkorr $*10^{-6}$	Kkorr $*10^{3}$
8	168 km^2	Calibration	0.59	1.411	95.87	52.732
		Testing	0.61			
19	202 km^2	Calibration	0.84	16.36	1648	1.5
		Testing	0.78, 0.81			
26	470 km^2	Calibration	0.79	8.93	1	0.001
		Testing	0.73, 0.77			
27	1806 km^2	Calibration	0.77	9.017	1	20.799
		Testing	0.66, 0.70			
35	1664 km^2	Calibration	0.78	5.66	5.762	0.0074
		Testing	0.77, 0.77			
39	1394 km^2	Calibration	0.72	4.2786	6.4948	4.807
		Testing	0.72, 0.80			
59	3431 km^2	Calibration	0.65	5.78	14.9	1.46
		Testing	0.69			
64	524 km^2	Calibration	0.76	4.299	1.6	1
		Testing	0.77			
67	364 km^2	Calibration	0.63	4.567	189.59	4
		Testing	0.70			
78	282 km^2	Calibration	0.76	3.592	4.864	23.13
		Testing	0.73			
82	539 km^2	Calibration	0.79	6.364	32.32	0.8355
		Testing	0.82			
85	322 km^2	Calibration	0.61	8.9147	1	1
		Testing	0.67			
106	573 km^2	Calibration	0.50	4.567	5.927	4.807
		Testing	0.47, 0.66			
116	375 km^2	Calibration	0.79	6.127	134.89	0.01
		Testing	0.74			
131	887 km^2	Calibration	0.67	3.8087	44.915	2.3587
		Testing	0.71			

Model validated from 1998 to 1999
Model validated from 1986 to 1994
Model validated from 1993 to 1994

Table 2.1: Performance of the Wasim-ETH model with its most sensitive optimised soil parametres for the selected sub-catchments.

2.5 Conclusion

A distributed water balance model Wasim-ETH using 90m by 90m grid cells and daily time steps was used to simulate the runoff for 15 sub-catchments in the Abbay River Basin. The R^2 values in table 1 show good simulation results for all sub-catchments in the basin. The model was sensitive to change in the recession constant, correction factor for transmissivity, correction factor for vertical percolation and climatic inputs, mainly precipitation. The rate of evapotranspiration might be important for the recession and low flows, whereas precipitation induces substantially the high flows. The model perfectly simulates the recession and low flow parts of the hydrograph for all sub-catchments. However, it underestimates the peak flow for most sub-catchments, mainly due to the lack of precipitation data points for these sub-catchments. The peak flows for some sub-catchments, having more meteorological stations for precipitation, were simulated satisfactorily.

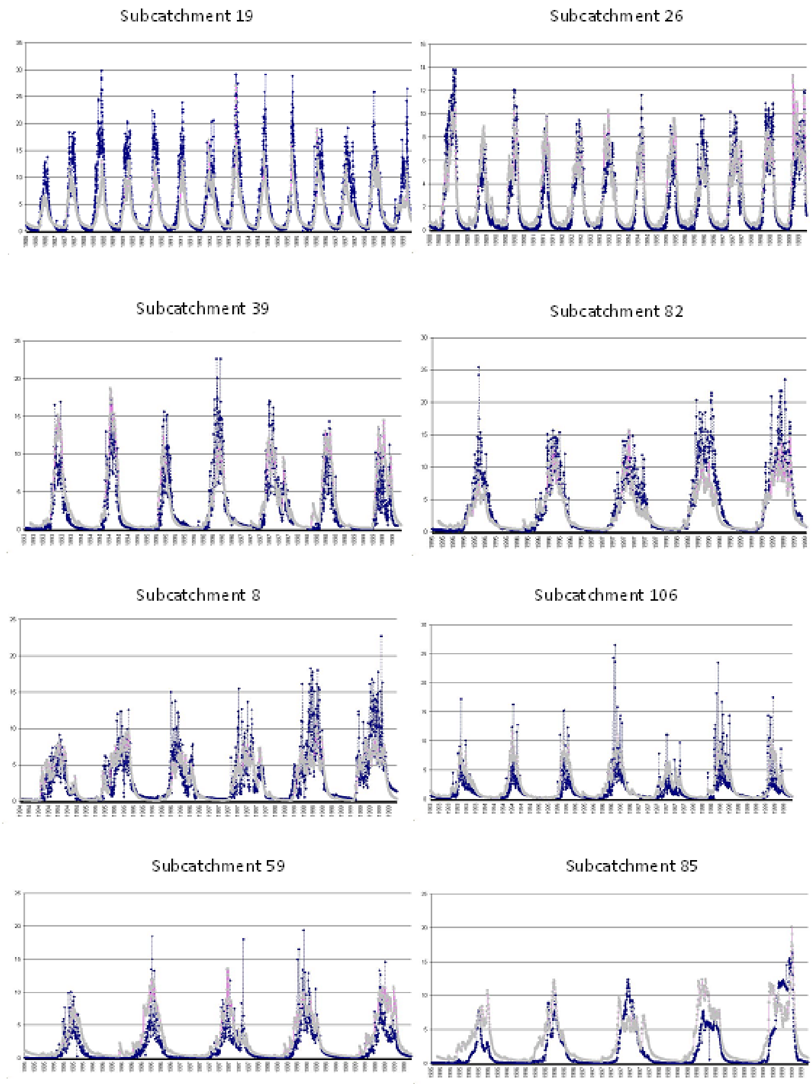


Figure 2.3: Daily runoff (mm/d) for the best and worst Wasim output

3 GIS and Remote Sensing Integrated Environmental Impact Assessment of Irrigation Project

Ahmed Amdihun Mahmoud[1]

3.1 Introduction

The expansion of irrigation schemes in Ethiopia helps to achieve food self-sufficiency and poverty reduction. Irrigation agriculture makes the production more unwavering than rain-fed agriculture. Proper planning and management aided irrigation projects contribute to the growth of national GDP and GNP. It also creates job opportunities for several thousands of people, directly as well as indirectly.
Despite their significances, however, irrigation practices have sometimes an adverse impact on environmental conditions. It is known that human activities have a profound effect on the natural environment and are becoming the main agent of environmental degradation.
Finchaa Valley was one of the few areas in Ethiopia to preserve its natural conditions for years. The topographic set-up made the area inaccessible. In 1975 the valley was selected to be a suitable site by the state farm to produce food and commercial crops. After a few years, the area was again chosen, when the establishment of a sugar factory was planned. Since then many activities were carried out in this area. Some of these activities made an enormously positive contribution, while others had negative effects on the environment.
In Finchaa Valley, in consequence of the establishment of the sugar factory, more pronounced land degradation is observed. There is large scale land clearance (deforestation) carried out by the factory in order to gain new irrigation fields.
In addition, there are many people in- and outside the valley who earn their livelihood from forest and forest products.

[1]aamdihun@yahoo.com

The factory uses agrochemicals like fertilizers, pesticides and herbicides in irrigation fields.The wash away is collected in ditches and then joins the nearby tributary stream. On the other hand, some parts of the liquid waste from the factory spill over the treatment plant and join Finchaa River. The problems emanate from the little attention given to environmental conservation as the main objective is to maximise production and productivity. The cumulative effects of these problems can result in environmental degradation. In Finchaa Valley exists a continuous disturbance on vegetation cover, soil, and water. If the trend continues, an extreme effect on the environment will occur. Thus, it is indispensable to carry out environmental impact assessment (EIA) of the irrigation project in the area.

Environmental Impact Assessment has been recognised as an integral part of the early planning studies of irrigation projects, in order to identify any expected negative impacts and to suggest the necessary actions to curb the problem. In addition, EIA can consider different designed alternatives for the project as an essential step for better decision making. The application of Geographic information system (GIS) and remote sensing can facilitate the study of environmental impact assessment of irrigation projects for a better outcome.

3.2 Result and Discussion

3.2.1 Impacts of the Irrigation Project on Vegetation Cover

In developing countries the attention given to vegetation conservation is less, compared to the need for development. In realising their policies for food self-sufficiency and agricultural productivity, preeminent value is given to irrigation developments, sometimes even at the expense of environmental considerations. Depending on the management system irrigation projects can have both positive as well as negative impacts on vegetation cover. Undoubtedly the expansions of irrigation projects have many advantages. However, in many cases change happens in the natural ecosystem following large scale irrigation developments. Obviously, in order to undertake large scale irrigation projects, the vegetation cover in the area needs to be cleared and different construction activities should be carried out. Natural vegetation as one of the eminent parts of the ecosystem is negatively affected by such development activities. Large scale forest resource degradation can change the natural environment. This in turn puts the sustainability of irrigation projects in question. Conversely, if appropriate consideration is given to vegetation conservation, the forest area can be delineated, and effective afforestation and reforestation can be carried out. For that matter vegetation resource can be maintained around the hills, on vacant and marginally suitable lands. The conservation of natural vegetation can solve the problem of soil erosion, micro climatic disturbances and biodiversity as it balances many of the environmental systems.

Well-planned irrigation schemes have good natural vegetation conservation and management plans. Effective management and proper balancing of these seemingly conflicting issues should be treated wisely. Finchaa Valley in the pre 1975 years was virtually under natural vegetation cover. The tall savanna grasses mixed with short and medium trees predominated the elevation below 1600m.The steep escarpments and the far down stream areas experienced dense vegetation growth. The gallery forests occupied the networks of major rivers and their tributaries. As it is evident from the Multi Spectral Scanner (MSS) satellite image of 1972 there was no apparent human intrusion to the valley. From unstructured interviews conducted with local elders, there were some individuals, who entered the area to collect wild honey from trees and hunters for valour.

The first intrusion into the valley was successfully made by the state farm in 1975. It is estimated that since this event the state farm has cleared about 3,500 hectares of land (vegetation). The 1986 TM image reveals that some parts of the eastern and western banks of Finchaa River were occupied with several food and commercial crops. Even then the most part of the valley was under a natural vegetation cover. The construction of the road dawn the escarpment made the forest resources accessible and vulnerable for human interference. This opened up a new episode for the forest resource exploitation. Still to the present day Finchaa Valley is considered as an ideal site for hard wood and bamboo forests used for fire wood and construction activities. The beginning of the 1990s can be considered as the second turning point in the forest history of the area. In these years Finchaa Valley was selected as the most suitable site for sugar cane plantation and industrial development. In the meantime, the state farm abandoned the farm and handed the area over to Finchaa Sugar Factory. In 1991 the Finchaa sugar project started extensive mechanised vegetation clearance. Of the three ma-

jor companies that carried out the feasibility study, none considered any single buffer area for natural vegetation conservation. Almost all attention was on sugar cane production and strategies for expansion. Accordingly, the west bank of Finchaa River was considered more suitable and fertile, thus about 8,064.88 hectares are at present under sugar cane plantation (See fig 4.3). The factory neglected the east bank until the recent years. This year vegetation clearance and land preparation has been taking place on the eastern bank. The total area of 7,108 hectares is expected to be irrigated. Despite the fact that the expansion escalates the industrial productivity, it further aggravates the problem of deforestation in the valley. From the visual image interpretation, it is evident that a change in land cover is taking place. Some features like the vegetation biomass are diminishing, while some others like Finchaa Lake have increased in size. Even though there is large scale vegetation clearance, efforts are made by the factory to plant trees on unused areas. Until now the Finchaa sugar factory under forestry department planted 600 hectares of land in the afforestation programme. One of the tree species which is preferred for accessibility reasons, is the eucalyptus tree. Currently, the department is planning to cover 2,200 hectares of land under the reforestation and afforestation programmes. However, this amount is marginal, with respect to the vegetation clearance, that has been taking place for many years in the area. In comparison to the vegetation, which has been cleared, the present afforestation programme reclaims not more than 7.5 percent of the land under irrigation. Even if the future goal of the department was attained, it would reclaim only about 27.3 percent of the present land under irrigation. At the time 13,000 hectares of land is irrigated; if only 2,200 hectares of land is under forest cover, it means that less than 17 percent of the cleared land is revitalised.
The irrigated field has increased a lot. In 1997/98 about 932.27 hectares of land were harvested and after eight years it has increased by more than seven times. Accordingly, the vegetation cover has retreated at a same or even higher rate.
Deforestation is the major problem in the Finchaa Valley area. The large scale vegetation clearances by the factory together with individuals earning a livelihood from forest products are destroying the vegetation resource. Forest fire is one of the critical causes for the vegetation degradation. In addition to the naturally instigated fire, the factory and some individuals play a significant role in triggering the problem. The fire escaping from the frequent cane burning by

the factory and irresponsible action by individuals, who are looking for timber, charcoal, fire wood, wild honey, construction wood and others, exacerbate the obliteration.
The Normalized Difference Vegetation Index (NDVI) is calculated from reflectance and measured in the visible and near infrared channels from satellite-based remote sensing. NDVI shows the temporal and spatial change of vegetation cover. The difference between two images is calculated by finding the difference between each pixel and the subsequent generation of a new image based on the result. The NDVI Analysis of the 1972 MSS image of Finchaa Valley area reveals that there is more vegetation biomass in the study area (NDVI>0) compared to the later years.
The Normalized Vegetation Index of 2000 image shows less vegetation biomass compared to the 1972 image. The expansion of cultivated areas, bare lands and built up areas are apparent in the NDVI analysis. These areas appeared as deep red and NDVI < 0.0. This means that many areas which were formerly under vegetation cover, were turned up into human-made features.
The NDVI analysis reveals that the mean and standard deviation of the 1972, 1986 and 2000 images has been decreasing. This could indicate the rate of vegetation cover destruction. Generally, the Visual image interpretation and the Normalized vegetation index results confirm that the vegetation biomass of the Finchaa Valley area has been diminishing. This condition can be explained with help of three major factors, which are the following: the expansion of agricultural lands, growing settlement areas and large scale deforestation that has been taking place for many years. The present trend still indicates that the deforestation will continue to the virgin lands. By taking the aspiration of the factory for expansion into consideration, large effort should be made in afforestation and reforestation projects. Strict measures should be taken to stop illegal forest resource exploitation and the frequent fires. Afforestation and reforestation activities should not be considered as a superfluous activity. Beyond harmonising many of the natural systems they can serve as means to solve many problems as soil erosion, hot weather conditions, degradation of biodiversity, fire wood and wood product requirements and many others.

3.2.2 Impacts of the Irrigation Project on Soil

Soil is one of the most decisive natural resources. It has been supporting the increasing number of life on our planet earth. Nowadays, the large population increases the demand for food, this in turn puts forth full-size pressure on land / soil resource. Areas formerly considered as marginal, are currently being cultivated. The demand for big yield created enthusiasm to look for alternative means. One of these is getting bigger yield through customary agricultural practices like irrigation systems, use of fertilizers, pesticides, herbicides and many other agricultural inputs.

Irrigation schemes, next to their positive contributions, have many shortcomings on the physical and chemical properties of soil in particular and the environment in general. The FAO repository document mentioned some of the adverse impacts of irrigation schemes on soils that include salinisation, alkalisation, water logging, soil pollution and soil acidification. There are two dominant soil types in the project area; these are the Luvisols and Vertisols. Luvisols cover 75 percent of the irrigated land. These soils are partly made of alluvial and colluvial materials from the surrounding escarpments. Luvisols have limited fertility and agricultural suitability. Water logging is not a vital problem in the area as the factory is using a over head sprinkler irrigation system. This consecutively evades the problem of salinisation. In order to maximise production, the agro-chemicals have been used in the irrigation fields. The most common ones are fertilizers, pesticides and herbicides. The two commonly applied fertilizers are Urea and Dap. The brief summery of the total amount of agro-chemicals is presented in table 4.1. (Indicated in Appendix 4)

The use of fertilizers, pesticides and herbicides has been increased in an alarming rate with the expansion of irrigation. The use of large scale agro-chemicals alter the physical and chemical properties of the soil which can damage the soil quality and beneficial organisms.

In order to see whether there is change in the soil physico-chemical properties of the dominant Luvisols in the irrigated fields samples are collected and analysed. Luvisols are preferred for analysis because 75 percent of the irrigation is carried out in this soil. The samples are taken from three sites in three layers. The first site is the non-irrigated field that is without human interference. The second site is a ploughed but not yet planted field. In this site none of the agricultural inputs

are applied. The third site is the irrigated field, where the agricultural inputs have been used. In each of the three sites soil samples from three spots are collected and mixed to form only one composite soil sample. The three layers are the top layer (0-30 cm), the middle layer (30-60 cm) and the bottom layer (60-90cm). In total, nine samples were investigated and the result is presented under 4.2.1 and 4.2.2. The three spots are believed to show the possible positive and / or negative impacts of irrigation scheme on the physical and chemical properties of the soil. In addition, the comparative results of samples from cultivated but not planted and non-irrigated spots can reveal whether the change is due to human intervention or natural causes. The soil sample from vegetation cover area is supposed to reveal the natural properties of the Luvisols in the area. Thus, the site selection for soil samples is intentional and carried out in a manner that the impacts of irrigation on the physical and chemical properties of the soil is visible.
The laboratory result of the soil analysis illustrated that the total sand content of Luvisols decreases with increasing soil depth in all sampled layers. The silt content of the soil from vegetated areas is higher. This might be the case due to the lesser amount of erosion in vegetated areas, compared to the cultivated areas. The clay content of the soil in ploughed and vegetated areas increases with the increasing depth. Unlike the non-irrigated fields, the clay content of soil from the irrigated site is higher in 30-60 cm depth. This could be the case due to the excess water that dissolves soluble minerals and percolates down. On its way it accumulates the insoluble clay in this horizon. Generally, the texture classes of the Luvisols in all locations range from sand clay loam (SCL) to clay (C). Such soils are known to be suitable for irrigated cane plantation with cautious soil management. The soils in all the three spots of the three layers are found to be acidic. The pH is less than 5.6. The investigation reveals that there are perceptible pH differences between irrigated and non-irrigated soil. The average pH value of the soil in the irrigated area is 5.3, whereas in the vegetation area the value is 4.6. This shows that the soil in the vegetation cover site is more acidic than the soil in the irrigated field. Theoretically, the fertilizers, pesticides and herbicides which have been applied to the cane fields seem to increase the pH of the soil. But the result shows that the soil in the irrigation field is less acidic than in the vegetation area. Three main reasons can explain this result. Firstly, the surplus water use in the irrigated areas can wash the chemicals vertically and

laterally. Secondly, cultivation by itself can alter the inherent pH of the soil by exposing the soil. Finally, the respective composition of the soil forming parent material can be different in the sample sites.

The normal soil chemical properties can be altered by natural and human-made factors. Industrial toxic wastes, hazardous chemicals, agricultural malpractices and inputs, and many others constitute the human factors. Alternatively due to some natural processes in the system, there may be alteration of soil chemical properties. In this respect the physico-climatic conditions play a key role in changing the chemical properties of the soil. As illustrated in table 4.4, the average amount of chemical elements in the three sample areas is different. The amount of exchangeable bases (Exch. Na, K, Ca and Mg) varies with increasing depth. Generally speaking, the amount of potassium, calcium and magnesium decreases with increasing depth, while sodium increases with depth. Exchangeable calcium and sodium is higher in the irrigation and cultivated but not planted fields, than in the vegetated areas. The total percentage of nitrogen is higher in the irrigation field. The available phosphorous is extremely high in the top layer of the irrigation site. These higher amounts are due to the fertilizers (Urea and DAP), which have been used in the irrigated areas. The organic carbon is found in higher quantity in the vegetated area. The soil samples from the vegetation area are found to be more acidic, than these from the irrigation fields. This is mainly due to the high organic content in the vegetated areas. Then again, the less acidic nature of the soil in the irrigated area is related to the exposure and excess water use in the irrigation fields. In addition, the acidic nature of the soils in the vegetation areas shows that the soil in the area is naturally acidic and that human intervention minimises the soil acidity.

Generally, the analysis of the three soil samples indicates that there is alteration of some soil physical and chemical properties as a result of the irrigation scheme. The level of alteration hardly results in full-sized soil pollution at this level. However, the cumulative impact could escalate to soil quality degradation. Thus, there are signs of soil pollution in the irrigated areas. There are several reasons which can explain this condition for example application of agro-chemicals.

3.2.3 Impacts of Irrigation Project on Water Quality

In the study area the Finchaa and Amerti-Nashe rivers form the main drainage system. Both rivers join the Abay River in the far down stream area. The irrigation field and the Finchaa sugar factory are situated within the networks of the Finchaa river system. Both rely on this river to meet their water requirements. Finchaa River is diverted to cane fields near the power house in the upstream area through concrete canals. At present the west bank canals run for about 44 kilometres. Water from the canal is pumped to irrigation fields, and finally sprinklers shower the water to the growing cane. The extra water from cane fields flows to the nearby ditches and joins one of the nearest tributary streams.

On the other hand the industrial wastewater is taken to the treatment plant which is situated to the east of the factory. The factory uses a rock filtration treatment method. However, some instruments of the treatment are nonfunctional. The wastewater coming from the factory overflows due to these broken parts and two stream-sized crude wastewater flows to Finchaa River. These direct leakages, together with the agro-chemicals from irrigation fields, indisputably alter the physico-chemical properties of the water. This phenomenon affects particularly the living organisms in water and the environment in general. Again, Finchaa River as one of the tributaries of Abay River crosses the boundaries of Sudan and Egypt. Any water quality problem in this place causes dispute with these countries. Thus, strict water quality control works should be carried out in and around the industrial and agricultural sites.

The physical and chemical properties of water characterise the water quality. These properties are susceptible for change. The addition of toxic wastes to the surface or sub-surface water alters the normal composition. The pH, for instance, is a sensitive and decisive factor for the survival of living organisms in water. On experimental lakes in Northwest Ontario, Schindler (1988) finds out that due to change of pH from 5.4 to 5.1, the number of species in the lake at pH 5.1 was over all 30 percent lower than in the pre-acidification years. In order to asses the impacts of the agro-chemicals and industrial wastes, water samples from the upstream and downstream areas are taken and analysed (Indicated under Appendix 5). The upstream area refers to the water near the power house where the water does not get in contact with water from irrigation and industrial waste sites. The downstream region comprises the water after it mixes up with water from streams

in the irrigated and industrial waste sites.
In order to increase the result accuracy, water samples were not taken from the irrigation ditches and direct industrial wastewater. Instead, the mixed downstream water was preferred, to avoid inaccuracies and exaggerated results. The physical properties of water like pH, EC, odour and colour are found to be different in the upstream and downstream areas. The pH and EC are lower in the upstream water compared to the downstream water. This could be due to differences in the chemical constituents in these two sites. The colour differences are also discernable.
The results of the water chemical analysis also indicate that some elements are found in a higher quantity in the downstream than in the upstream water (indicated under appendix 5).
As it is evident from Figure 5.3, almost all of the inspected elements are found to be higher in the downstream water. This could be due to two major reasons. Firstly, the extra water washed the agro-chemicals from irrigated fields and joins the river. The second main reason is the liquid waste from the industry and the urban areas that directly or indirectly drains to surface or subsurface water. These two cases comprise the point and non-point sources for the pollution. The industrial wastewater escaping from the treatment plant forms the point source pollution while the agro-chemicals from irrigation field cover the non-point source for the pollution.
In an effort to alleviate the problem of water pollution the point and non-point sources should be given priority. The contribution of wastewater from the industry can be addressed by continuous follow-up and maintenance of the treatment plant. Again, it is advisable to replace the treatment plant with modern and effective instruments and methods. And the problem of non-point source can be mitigated by avoiding the direct contact of the excess water from irrigation ditches and metropolitan wastes with the river and tributary streams. This is possible by creating a buffer around Finchaa and Amerti-Nashe Rivers and major tributaries (see figure 5.4).
The buffered zone needs to be covered with vegetation to enhance soil and plant litter filtration and purification. Alternatively, the extra water from the irrigation field can be collected in an artificial reservoir and treated before it discharges to the main rivers.
Generally, the water samples from Finchaa River indicate a water quality differ-

ence between the upstream and downstream area. This shows that, to a greater or lesser extent, there is water pollution in the river. The discrepancy in the physico-chemical properties of water is supposed to be from the industrial wastes, agro-chemicals from irrigation fields and to a lesser extent metropolitan wastes forming the point and non-point sources.

3.2.4 Health Conditions in the Post Development Years of the Irrigation project

There is no recorded health status data before the establishment of the Finchaa sugar factory as there was no settlement in the valley. However, during unstructured interviews, conducted with local inhabitants, some persons asserted that the area had been affected by epidemics even before the arrival of the state farm. The interviewee sited the problem as one of the impeding factors for the omission of permanent settlement inside the valley in the former years.

Booker international agriculture Ltd. (1977), involved in the feasibility study for the Finchaa sugar project, affirmed that the Malaria and Tsetse fly exist in the valley. The company added that this could be a challenge for the project workers and residents of the valley. Currently, there is one health centre in the valley and some recorded case-information is available. Accordingly, the intestinal and malaria cases have increased from 1992 onwards. According to the informal interviews made with the staff of the health centre, three possible rationales can explain this scenario. Firstly, the water used for drinking is pumped from the canal with diminutive treatment. Secondly, the expansion of irrigation can facilitate the spread of malaria as well as access to unclean water. Finally, the population explosion in a short period of time may inflate the proportion of patients compared to the early years.

Malaria has been the top health problem in the last twelve years. The fluctuating weather conditions, together with the expansion of irrigated fields and ditches, could be the factors behind the problem. The fluctuation in malaria case records arises from the inconsistent use of anti-malaria chemical sprays and expansion of irrigated lands. The second and third top health threats are Guardia and Ascaries. These intestinal problems in most cases are water born diseases, that can be related with unhygienic water use for drinking. The haphazard increment of intestinal parasite and malaria case records can be due to natural- or human-made

reasons. On the one hand, the natural set up of the valley and the climatic conditions can facilitate the birth and growth of pathogenic organisms in the area. On the other hand, human interference has changed some of the existing natural systems. In other words, the expansion of human-made environments results in alteration and degradation of the natural ecosystem.
These environmental modifications create a fertile ground for some insects and pathogenic organisms that give birth to the spread of diseases. The classical example here is the expansion of irrigation and increasing malaria case records.
As it is evident from the analysis that malaria cases are increasing with the expansion of irrigation fields. At the beginning few malaria cases were seen in the valley. For 1992 and 1993 there was no recorded malaria cases data available in the health centre. But for the consecutive two years fewer malaria cases were recorded. From 1995 until 1997 a large number of malaria cases was observed (indicated under appendix 3). In these years extensive sugar cane plantation was carried out in the valley. The lag time between the highest malaria case and the expansion of irrigation could be due to the time taken for reproduction and stages of development in the human body.
In general there is no health data available on the pre-irrigation development years of the valley. Since 1992 malaria and intestinal parasite case records have increased. Conversely, the health facility given in the valley has improved profoundly since 1992. The positive relationship between malaria cases and the expansion of irrigation fields was determined. The intestinal health threats are also interlinked with unclean drinking water. Well-organised preventive and controlling measures should be implemented as the health cases are interrelated with workers' productivity.

3.2.5 Conclusions

In order to illustrate the possible environmental impacts of irrigation projects some parametres were selected. Some of the geographic information system and remote sensing techniques were also used. Accordingly, it is observed that the natural environment in Finchaa Valley has been modified due to agricultural and industrial developments since 1975. Following this modification, the irrigation project has both positive as well as negative impacts on the environment.
Due to the positive contributions the project opened up large scale job opportuni-

ties for many thousands of people. It has also many socio-economic benefits for the valley and the surrounding people. In addition, Finchaa sugar factory plays a key role to address the current sugar demand in a local market. There are also many efforts to exploit the byproducts of the factory for other extra purposes like using ethanol for fuel. The project has also an important role for the growth of national GDP and GNP.

On the other hand, the attention given to natural resource conservation is less than for economic purposes and this has been devastating some of the environmental components. There has been large scale vegetation clearance taking place in the study area. The NDVI image analysis of the 1972 MSS and the 2000 ETM images shows that the vegetation biomass is diminishing. The intensification of agricultural and industrial developments together with population explosion are the major reasons for the decrement. The large scale deforestation has been destroying vegetation and wild life resources in particular and biodiversity in general. There are efforts made by the Finchaa sugar factory to rehabilitate the forest resource. But the amount and rate of deforestation on the one side, and the reforestation and afforestation projects on the other side, are incomparable in any measure.

In addition, deforestation facilitates the progress of runoff and accelerates erosion. Accordingly, soil erosion is a critical problem in the project area. The active erosion, beyond taking the fertile top soil, is changing some of the potentially irrigable lands into Bad Lands. In some areas are gullies that extend up to 30 m. The topographic setup and the human-induced factors are responsible for the active erosion in the area. The steep slope in the escarpments surrounding the valley promotes greater runoff. The road construction and the frequent maintenance down the valley made the soil ready for erosion.

The physical and chemical analysis of the soil samples taken from the irrigated field, the cultivated but not yet planted site and the vegetation cover area are found to be different. The total sand content of Luvisols decreases with increasing soil depth in all sampled layers, whereas the clay content increases with depth. The exchangeable bases are higher in the irrigated and cultivated area than in the vegetation cover area. Relatively large quantities of organic carbon, nitrogen and phosphorous are found in the irrigation fields, especially in the upper layer (0-30cm). The use of agro-chemicals in the irrigation fields is supposed to contribute to this result. In general, some of the physical and chemical properties of the soil in the irrigated and non-irrigated sites are found to be different. This shows that, to a lesser or greater extent, there is soil contamination that could lead to full-size soil pollution. The result of water samples from upstream and downstream areas indicates that the physico-chemical properties are different in these two areas. The downstream water contains more chemical substances than the upstream water. The point and non-point sources contribute to the pollution. The point source comprises the industrial wastewater that escapes from the treatment plant and joins the river. The non-point sources involve the use of agro-chemicals (fertilizers, pesticides and herbicides) and the metropolitan wastes that join the tributary streams. Thus, based on the water samples inspected, it can be said that there is water pollution emanating from poor industrial waste water treatment and the leftovers of the agro-chemicals used in the irrigation fields. In most cases climate is the reflection of the natural environment. Any system disturbance on the environment can affect the climatic conditions. The analysis of the 22 years rainfall, temperature and humidity data can not meaningfully imply any climatic change as a result of the irrigation project. This is due to the sluggish and unpredictable nature of climatic anomalies. It is reasonable, however, to say that there are imperceptible changes following the environmental degradation. Still, it is open for further specific and detailed works to see the impacts of irrigation on the local climate. Case records of Malaria and some water born diseases have been increasing after the opening of the Finchaa irrigation scheme. There is a positive correlation between malaria case records and expansion of irrigation fields. Although the health care facilities have improved tremendously, the number of patients increased greatly. This shows that a lot of attention is given to disease control rather than to its prevention. The environmental modifications and the diminutive prevention measures contribute to the large number of malaria and water born diseases case records. Generally, despite of its positive consequences, the irrigation project in the Finchaa Valley area has a negative impact on the environmental components. Especially on the vegetation cover, soil quality, water quality and partly on some health conditions. But this does not, in any way, mean that the problems outweigh the benefits of the factory and that the problems are out of control. The degradation ranges from the early to the moderate stage and is even not difficult to address and alleviate. The possible solutions are much easier and cheaper in this moderate stage of the environmental degradation. But undoubtedly, if the current trend continues, the problem would become more complex and difficult to reclaim. Thus, urgent attention should be given to the environmental rehabilitation and conservation.

4 Comparative study of the hydrology and hydrogeology of selected Ethio-Kenyan rift lakes

Tenalem Ayenew[1] *and Robert Becht*[2]

The Ethio-Kenyan Rift (EKR) has many things in common with regard to geological and hydrogeological setting. One of the remarkable similarly is the existence of a series of lakes filling volcano-tectonic depressions separated by volcanic hills in the floor of the rift. The major input to the lakes comes from highland rainfall generating perennial and seasonal flows in the form of rivers and surface runoff. Groundwater recharged by direct rainfall is also vital to many lakes. These lakes are highly variable in their geomorphic and morphometric setting and their hydrochemical and isotope composition controlled by the input and output conditions of the various components of the hydrologic cycle.

The EKR lakes are being used for various purposes and increasingly play vital role in the lives of millions of people. The region has become industrially significant as a consequence of development of flower and horticultural production, soda extraction, tourist industries and other human activities around the shores of the lakes. This trend is expected to rise steadily. For long time water abstraction from the lakes and tributary rivers preceded without the basic understanding of the complex nature of the hydrological system and the fragile rift ecosystem. In the quest for improved understanding of the East African rift lakes this study has been conducted both in Ethiopia and Kenya. The study starts from the comprehensive assessment of the regional hydrology and hydrogeology with relevant magnitudes of time and thereafter zooming in to the catchment scale processes. Five Ethiopian lakes (Awassa, Shala, Abiyata, Langano and Ziway) and three Kenyan lakes (Naivasha, Elementaita, Nakuru) are selected (Fig. 1)

[1] Addis Ababa University, Department of Earth Sciences, P.O.Box 1176. E-mail: Tenalema@yahoo.com, Addis Ababa, Ethiopia

[2] International Institute for Geo-information Sciences and Earth Observation (ITC), Hengelosestraat 99. P.O. Box 6. 7500 AA. Becht@itc.nl. Enschede, The Netherlands

on the basis of their similarity in geomorphological and hydrogeological setting within the broad East African Rift system. Given the complexity of the rift geology, the scantiness and doubtful quality of the available hydrogeological data, a clear picture of the rift hydrodynamics cannot be achieved easily by classical methods alone. Therefore, the integrated converging evidence approach has been applied using both conventional hydrogeological field investigations, hydrometeorological and hydrogeological data analysis supported by remotely sensed spectral satellite data under GIS environment and hydrological modeling. Ancillary information on isotopes and hydrochemistry has helped in understanding the subsurface link of the lakes.

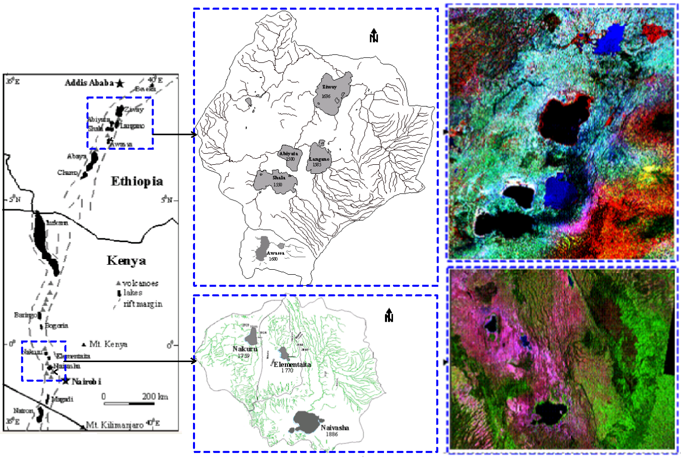


Figure 4.1: Location map (with enhanced TM image window)

The movement of groundwater is heavily dependent upon regional and local geology. TM images (1987, 1989, 1999, 2003) and panchromatic aerial photographs (1965,1967) at the scale of 1:50,000 were used to assess the spatial variability of lake sizes and detection of the various hydrogeological structures. Data on lake levels and river discharge and other meteorological variables were available since the early 1960s for most lakes. In addition to the study of the role of rift faults in the hydrodynamics, the understanding of the flow system has been approached either solely or principally using piezometric levels as the determinant for the flow pattern of groundwater. In connection with this comprehensive piezometric survey was carried out to reconstruct the regional groundwater contours. In some catchments detailed hydrological modeling has been done.

The result is presented by providing the wide picture of the hydrology and hydrogeology of the respective regions quantitatively and in illustrative and comparative manner by emphasizing on the broad topics of lake levels; water balance, isotopic and hydrochemical signature analysis, lake-groundwater interactions and the complicated hydrogeological aspects of the rift and adjacent highlands.

The lake level record shows extreme fluctuations over half a century,whereas the Ethiopian case is more dramatic than the Kenyian one. Despite, long-term pumping of the Kenyan lakes for horticultural development, the reduction in size is minimal. This signals that the lake level changes that took place in Ethiopia may dominantly be natural rather than anthropogenic, with the exception of lakes Abiyata and Ziway. The Kenyan lakes remained more or less stable until the mid 1980s. However, in the 1990s there is slight decline in level. This is more pronounced for lake Naivasha, which is the freshest lake being used for local irrigation, mainly horticulture and floriculture.

Table 1 summarizes the long-term water balance of the lakes estimated on the basis of long-term average monthly hydrometeorological data. The groundwater flow component was estimated using a simple spreadsheet hydrological and groundwater flow model. The result shows that rainfall, river discharges, and evaporation play very important roles in most open lakes. Groundwater plays also a vital role in the hydrodynamics and existence of the lakes, particularly in closed basins. It is evident that terminal lakes are more dominated by groundwater; either in the form of outflow as in the case of Naivasha and Awassa or inflow as in the case of Shala, Abiyata, Nakuru and Elmentaita.

From hydrogeological maps and groundwater contours established from piezometric survey, it is evident that the groundwater - lake relation is strongly controlled by the density and orientation of the rift and marginal faults. In this regard

Water budget	Nakuru	Elementaita	Naivasha	Abiyata	Langano	Shala	Ziway	Awassa
Precipitation	31.8	16.4	93.9	113	186	232	323	79.7
Stream inflow	16.6	11	217.4	245	212	185	704	78.6
Groundwater inflow	24	15.7		26.8	135.4	364	80.6	18.2
Total inflow	72.4	43.1	311.3	384.8	533.4	781	1107.6	176.5
evaporation	72.1	36	256.3	372	463	781	890	135.5
Groundwater outflow			56	1.2	18.9			30.6
Abstraction		4.1		13			49	
River outflow					46		173	
Total outflow	72.1	40.1	312.3	386.2	527.9	781	1112	166.1
Residual	0.3	3	1.6	-1.4	5.4	0	-4.4	10.5
(Groundwater inflow/total inflow)*100	33.1	36.4	18.5	7	25.4	46.6	7.3	9.6

Table 4.1: Long-term annual water balance of the lakes (in million cubic meter)

the Ethio-Kenyan rift has astonishing similarity. The groundwater contours follow more or less the shape of the topographic contours in large parts of the region, except in the rift where groundwater is diverted following the direction of axial faults preferentially. In many cases the form of the water table appears to be a subdued replica of the land surface. In the Ethiopian rift groundwater flows towards the center of the basin ultimately converging to the lowest elevation of the lakes Shala, Abiyata and Langano. Owing to the presence of volcanic intrusions local water divides exist at different elevations. Groundwater flow modeling revealed that Lake Shala gets the largest net groundwater flux and Abiyata the lowest,whereas Lake Ziway gets moderate inflow. Groundwater migrates towards the south to Abiyata and Langano following the N-S and NE-SW trending faults. Ziway and Abiyata have a strong hydraulic link. Lake Shala remains terminal from both surface water and groundwater perspective. This result reasonably agrees with the hydrochemical and isotope studies that have been made. Total inflow from the southern adjacent Awassa Basin to the study area has also been quantified. Apart from this flow, all evidences indicate that inflow across the basin in other areas or substantial outflow from the basin is not evident.
In the Kenyan rift the groundwater flow pattern is less complicated. Flow of groundwater often follows the topographic slope. Axial groundwater flow is not as dominant as in the Ethiopian rift. The terminal lake Naivasha looses substantial amount of water to the surrounding aquifer and, ultimately, to the lakes situated at a lower position in almost all directions. Nevertheless, it resembles

Lake Awassa in many features as they are both situated at the culmination of the local rift floor and the leakage is multi-directional. Some groundwater inflows occur from the flanks of the rift valley towards the lakes Nakuru and Elmentat, but not dominantly following preferential path as the Ethiopian lakes.

On a regional scale, the evidence suggests that the major axial faults divert substantial amounts of groundwater in the rift valley/interfluves system, that come from elevated recharge areas to low lying discharge areas.The flow occurs both laterally and longitudinally. Always the longitudinal flows dominate and govern the interconnection of the lakes. The structure of the rift valley and in particular the major marginal and the grid faulting on the rift floor have a substantial effect on the groundwater flow system. The high hydraulic gradient developed across the Ethiopian rift favors the emergence of various springs and seepage zones that supply substantial groundwater to the majority of lakes, which in the Kenyan case is subdued.

The most important result in this study is the elaboration of the intricate nature of the subsurface hydrology of the rift and the much greater role of groundwater in the water balance most lakes. This signifies the importance of hydrogeological studies with particular reference to the movement and occurrence of groundwater and its relation with subsurface hydraulically interconnected nested lakes. The attempt to establish a water management plan of these lakes without accounting the groundwater fluxes will certainly lead to erroneous water use practice.

5 Abaya-Chamo Lakes Physical and Water Resources Characteristics, including Scenarios and Impacts

Extended Abstract

Seleshi Bekele Awulachew[1]

5.1 Introduction

Prior to 2000, until the GTZ supported research project has constituted a number of sponsored Ph.D. studies and research programs at Arba Minch University that have produced results, little information was available regarding the water resources systems of Abaya and Chamo Lakes which are found in Southern Rift Valley Region of Ethiopia. Some of the key challenges of the basin are:

- Increased population and insufficient developed resources to support the rapidly increasing population
- Inadequate agricultural food production
- Limited use of water for irrigation, arbitrary use of potential & poor management practice in the existing irrigation schemes
- Overuse of forests as firewood while hydropower and other alternative energy sources are not developed
- Severe erosion, loss of soil, loss of land due to combined effects of deforestation, overgrazing and poor-tillage
- Degradation of river bed and bank, transportation in rivers and hence deposition of sediment in the lakes

[1]International Water Management Institute s.bekele@cgiar.org

- Inadequate clean water supply, improper sanitation and as a result poor health status of inhabitants of the region
- Flooding of areas adjacent to the rivers, loss of possessions and damage of infrastructure
- Potentially receding lake volume and size
- Production of toxic substances in the lake such as blooming of algae
- Literally non-existent coordinated water resources research efforts in tackling the problems of the basin

Against this background and the investigation of various characteristics of the lakes systems, this paper discusses the following issues, based on the Ph.D. research results of the author:

- GIS based watershed characterization of the watersheds of the Abaya and Chamo lakes
- Information on understanding the physical and morphological characteristics of the two lakes
- Hydrological information and generation of time series data for gauged and ungauged watersheds based on modelling
- Water balance model of the two lakes, development of scenarios and evaluation of impacts

5.2 GIS based watershed characterizations

The study basin for which the model was developed and tested is found in southern part of Ethiopia. Figure 1 shows the location on the Ethiopian map and the particular major basin which is the rift valley basin in which the study area drainage system is found. The study drainage system, although a sub-basin of rift valley lakes basin, is considered as Abaya-Chamo Basin (ACB) and constitutes 3 medium rivers and a number of small and ephemeral rivers. In addition it constitutes 2 Lakes which are interconnected through surface overflow. The rivers are draining into the two Lakes from surrounding relatively large slopes of rift valley escarpments.

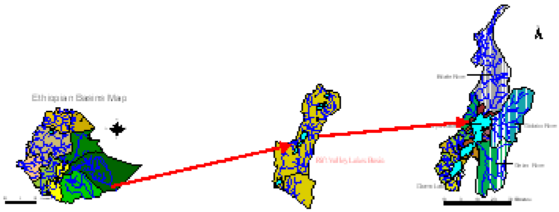


Figure 5.1: Abaya-Chamo Basin Location on Ethiopian and Rift Valley Drainage Map with Major Rivers

As a result of the GIS and digital terrain model based analysis using Arc View, Auto-CAD and WMS softwares, the total area of ACB including the lakes and their islands is found to be 18,599.8Km^2. Summaries are provided in Table 1, for further details see Awulachew (2001).

No.	**Sub-Basin**	**Total Area in Km^2**
1	Abaya Drainage Area Excluding	15219.62
2	including	1108.9
3	Chamo Drainage Area Excluding and Abaya Contribution	1942.65
4		328.63
5	**Total**	**18599.8**

Table 5.1: Sample output of the drainage information system is provided for Bilate Lake sub-basin (Northern part of the ACB), which is showing sub-basins definitions based on sub-drainage characterizations.

5.3 Physical and Morphological Characteristics of the Two Lakes

A six months bathymetry survey was undertaken on the Abaya and Chamo Lake and the resulting morphomoteric characteristics derived as a result. The background lake map has been digitised and surveyed data has also been developed as digital values. The digital values have been interpolated and grids of the elevation

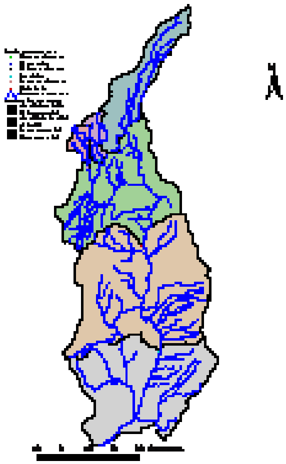


Figure 5.2: Bilate Sub-basin

surface have been generated. Elevation area and elevation volume curves (capacity curves) of the two lakes, which can describe the water resources capacity of the lakes body, have been developed from the digital values. This component has enabled understanding of the lakes in terms of size, characteristics, capacity, vulnerability due to various factors, etc. Figure 3 provides the derived contour maps of the two lakes.

5.4 Hydrological Data Analysis and Modelling

A monthly water balance model, known as MOWBAL, which can be used to generate runoff based on few parameters, is developed. The model in this study uses variables of rainfall and evaporation as an input and runoff as an output on a monthly basis. In the model, 2 optimized calibration parameters and 6 conceptual functional parameters are employed. The model is particularly useful for

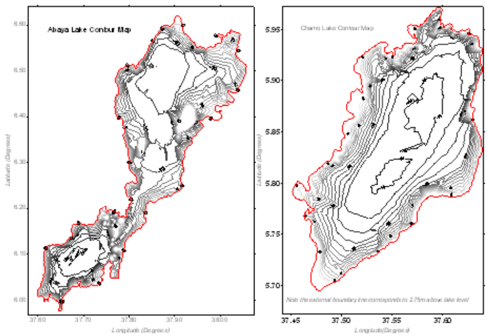


Figure 5.3: Abaya Lake Contour (left=a) Chamo Lake contour (right=b)

simulating runoff in cases of limited hydro-meteorological and physical data, and where climatic conditions lead to low or large rainfall variations, like in temperate or semi-arid regions respectively. The model is used to simulate the runoff of 8 sub-catchments of the Abaya and Chamo Lakes drainage basins of Ethiopia. The results of both calibration and validation show that the model performs acceptably well and can be used to generate runoff for similar catchments like the study area considered. The developed model is successfully applied to generate runoff datac for the ungauged areas to further study the water balance of these remotely situated natural lake systems where data is limited.
Data of the ACB for gauged sites were used to calibrate and validate results. Figure 4 and 5 show such results for Alaba-Kulito station and they indicate good performance.
The development of the model has enabled to extend hydrological data for gauged basins, and also helped estimation of such data for ungauged sites and development of a water balance model of the Lakes.

5.5 Water Balance Model of the Two Lakes, Scenarios and Impacts

In this component, modelling of the water balance components and the impact of water use, sediment transport and deposition are highlighted. In order to be able

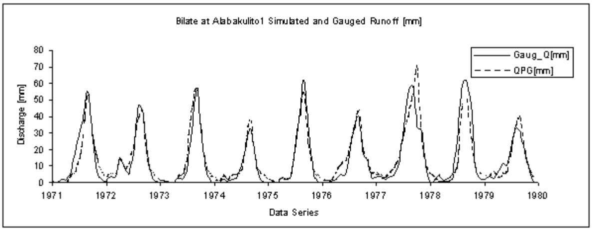


Figure 5.4: Alab-Kulito gauged and simulated runoff plot in the calibration

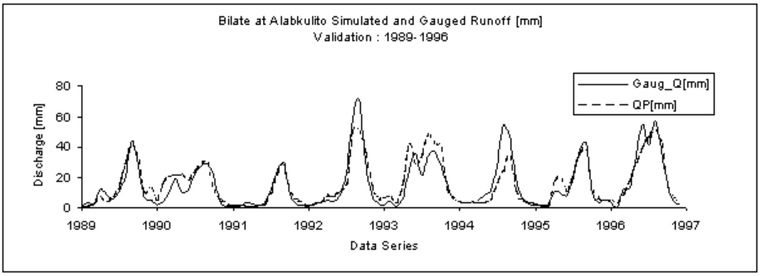


Figure 5.5: Alab-Kulito gauged and simulated runoff plot in the validation periods

to develop the water balance model, the various outputs discussed in the previous section and not reported in this paper such as watersheds of the lakes system, morphometry of the lakes, rainfall-runoff model. These information systems have been integrated to model the water balance of the lakes which simulates the water level.
The structure of the model that was used for this study is shown in Figure 6.
The program for water balance, named LAKEBAL, has been developed and the modelling process constitutes three stages:

- Pre-processing of input data and selection of model parameters
- Simulation and computation of water balance components by executing the simulation program

- Post processing of output from simulation result

The figure shows the sources of various components of the input data elements and their interaction in the modelling process.

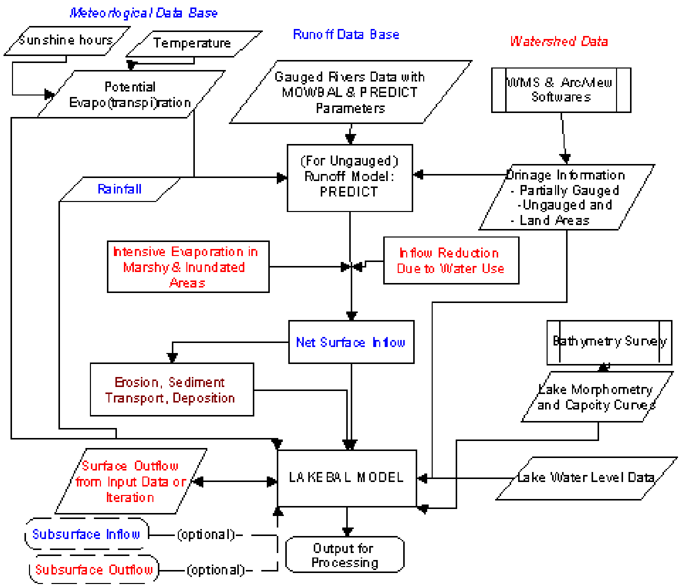


Figure 5.6: Data input elements and interaction of various elements in LAKEBAL model

The results generated by this model are found in Awualchew (2001). Based on the simulations result and the computation of life expectancies, it is found that sediment inflow and deposition are the most detrimental factors for the two lakes, not the development impacts.
Keywords:*Bathymetry survey, capacity curves, GIS, life expectancy, MOWBAL rainfall-runoff model, LAKEBAL water balance model, scenarios, impacts.*

6 Application Of Swat Model For Mountainous Catchment

B.Z. Birhanu [1], *P.M. Ndomba* [2] *and F.W. Mtalo* [3]

6.1 Abstract

A GIS based hydrologic model, SWAT (Soil and Water Assessment Tool) was applied for modeling the WeruWeru catchment at the foot slopes of Mt. Kilimanjaro in Northern Tanzania. The catchment has an approximate drainage area of 101 km^2 and a mean annual precipitation between 1500mm and 3000mm. The water balance modeling was performed on annual and monthly bases using spatial and temporal data.

A statistical weather generator file WXGEN was prepared for ten years to generate climatic data and fill in gaps in the measured records of climatic data. Various GIS data preprocessor modules involving watershed delineation, input map characterization and processing, stream and outlet definition, the computation of the geomorphic parameters, and characterization of the landuse/land cover and soil were developed in the course of modeling. Surface runoff computation was done using Soil Conservation Service-Curve Number (SCS-CN) method; and Muskingum routing method was used for flow routing.

The Rainfall-Runoff modeling was based on a long term global water balance simulation for 15 years (1972-1986) and temporal calibration technique. The Nash and Sutcliff efficiency criterion (R^2) and the Index of Volumetric Fit (IVF) were adopted for the measure of efficiency of the performance of the model. An R^2 of 82% and 59% was obtained during calibration and verification periods respectively.

[1]PhD Candidate, Water Resources Engineering, University of Dar es Salaam, Tanzania, birhanuzem@yahoo.com

[2]PhD Candidate, Water Resources Engineering, University of Dar es Salaam, Tanzania

[3]Professor, Water Resources Engineering, University of Dar es Salaam, Tanzania

The predicted mean daily stream flow was found to be $1.92\mathrm{m}^3/s$ exactly as observed during the water balance simulation. Besides, modeling result gave a total annual water yield of 597.1mm, from which the annual surface water component was 155.8mm and that of the base flow component was 441.4mm in the long term simulation period with IVF unity. While demonstrating that the catchment is rich in ground water sources as a result of high magnitude of precipitation and good water retention capacity, this study shows that SWAT model can be a potential monitoring tool for watersheds in mountainous catchments.

6.2 Introduction

Kilimanjaro mountain catchments are located in Northern Tanzania driving their water from the slopes of Mt. Kilimanjaro. These catchments are heavily populated and as a result water has become a limiting factor for life and development. Various hydrological studies have been conducted using different hydrologic models to simulate the catchments hydrology. For example, the use of a modified conceptual HBV model (Rinde, 1999) by Rohr (2003) to simulate Charongo, Ngomberi and 1DD1 catchments in the southern slopes of Mt. Kilimanjaro, and the use of a semi distributed hydrologic modeling system (HEC-HMS) by Moges (2003) to simulate the 1DD1 catchment are a few worth mentioning. The limitations applying these hydrologic models were also discussed by these studies. In Mt. Kilimanjaro catchments, the interaction between precipitation, evapotranspiration, surface runoff, infiltration and spring discharge on the mountain slopes and the low-lying plains has been reported as complex by Rohr (2003). These components are all important and considerable factors in the local hydrological cycles (Rohr, 2003). The uncertainty in catchment hydrology can be solved with the use of hydrologic models by customizing to the region of interest. For example, in their study of sediment yield modeling for ungauged catchments in Tanzania, Ndomba *et al.* (2005) recommended to customize the SWAT model in the local area for improved watershed management.
In recent years, SWAT model developed by Arnold *et al.* (1998) has gained international acceptance as a robust interdisciplinary watershed modelling. SWAT is currently applied worldwide and considered as a versatile model that can be used to integrate multiple environmental processes, which support more effec-

tive watershed management and the development of better informed policy decision (Gassman *et al.*, 2005). But little have been published on the applicability of SWAT model in the tropical catchments particularly in East Africa and Nile basin. In Tanzanian catchments, for example, there are few research studies using SWAT model (Birhanu, 2005; Ndomba *et al.*, 2005) which recommended further testing/customizing SWAT model for different climatic conditions. Thus this study examines the applicability of SWAT model for modeling mountainous catchments, focusing on WeruWeru catchment in the Kilimanjaro region of Northern Tanzania.

6.3 Description of the study area

The catchment is located between 37.25^{o}E - 37.33^{o}E and 3.08^{o}S -3.16^o S with an approximate drainage area of 101 km^2. The minimum and maximum ground elevations in the catchment are 2001 and 4177 meters a.m.s.l respectively, and the region receives heavy rains of about 1500mm-3000mm annually. Forest, bush land and scattered cropland are the main landuse/land cover forming (84.91%) of the area, other land covers are open woodland and scattered bushland (13.21%), and snow (1.89%). Sandy loam and loam soils are the dominant soil types in the area, according to the classification by Pauw (1984). The catchment was gauged from 1969 to 1986 and the gauge was re-sited making the rating curve unreliable then after. There are no meteorological stations in the study area, thus stations in the nearby area as shown in figure 1 were used.

6.4 Methodology

SWAT is a physically based hydrologic model and requires physically based data (Jacobs and Srinivasan, 2005). Obtaining physically based data for hydrologic modelling is often difficult, even in developed countries where data of high quality are generally collected and analyzed (Jacobs and Srinivasan, 2005). In this study various input data were collected from different sources: climatic input data were collected from meteorological office for neighboring stations outside the catchment. These include daily precipitation, maximum/minimum air temperature, wind speed, and relative humidity. Spatial input data used are topog-

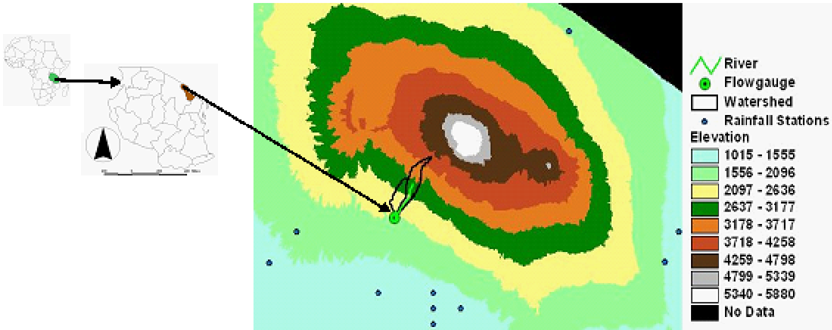


Figure 6.1: Map of WeruWeru catchment, including the location of the used meteorological stations

raphy landuse/landcover, and Soil. Digital Elevation Model (DEM) data was sourced from the US Geological Survey's (USGS, 2006) public domain geographic data base HYDRO1K, the landuse and soil data were obtained from the Institute of Resource Assessment (IRA) based at the University of Dar es Salaam (UDSM). Further, the database incorporated into the SWAT model was used for reclassifying the landuse and soil data. The input data were prepared to the required format for an input to the SWAT model. A statistical weather generator file WXGEN (Sharply and Williams, 1990) was prepared for ten years in order to generate climatic data and fill in gaps in the missing records from climatic data obtained from Moshi airport station (0973004).

The hydrologic modeling using SWAT was based on the application of the Graphical User Interface (GUI) of AVSWAT2000 (DI Lizio, 2002) which after being loaded is embedded into ArcView, and tools are accessed through pull down menus and other controls which are introduced in the various ArcView GUI and custom dialogs. The watershed and sub watershed boundaries, drainage networks, slope, soil series and text maps were generated under the GUI of AVSWAT2000. Various GIS data preprocessor modules which involve watershed delineation, input map characterization and processing, stream and outlet defini-

tion, the computation of the geomorphic parameters, and characterization of the landuse/landcover and soil were developed in the course of modeling the catchment. Interactions between surface flow and subsurface flow in SWAT are based on a linked surface-subsurface flow model developed by Arnold et al. (1993). The simulation option of the rainfall runoff modeling was performed based on previous experience and modelling techniques published by various researchers (Birhanu, 2005; Ndomba, *et al.*, 2005; Val Leiw *et al.*, 2005; Ndomba, 2007). These include using a curve number method for calculating the surface runoff (SCS, 1972), a first-order Markov Chain and a skewed normal distribution to determine rainfall distribution, computing potential evapotranspiration using Penman Monteith method, and Muskingum routing method for routing water through the channel networks. An automated base flow separation technique based on master recession curves developed by Arnold *et al.* (1995a) was used to separate the observed flow components into surface and base flow. This technique was successfully used by Arnold and Allen (1999) for estimating base flow and annual ground water recharge from stream flow hydrographs.
In this study, calibration and validation procedure presented in the SWAT user manual was followed (Neitsch *et al.*, 2002). Calibration for water balance and stream flow was first done for average annual conditions. Once the run was calibrated for annual conditions, we shifted to the monthly records to fine-tune the calibration. Parameters used for model calibration were the Curve Number (CN2), threshold depth of water in the shallow aquifer for water moving into the soil zones (REVAPMN), threshold depth of water for percolation to occur (GW_REVAP), soil available water capacity (SOL_AWC), baseflow alpha factor (ALPHA_BF), and number of days of ground water delay (GW_DELAY). Calibration and verification was performed for the selected periods. The objective functions used to test the model performance were the Nash and Sutcliff efficiency criteria (R^2) and the Index of Volumetric Fit (IVF).

6.5 Results and Discussions

Data for the first three years (1969-1972) were used as a warm-up period for the model setup, and calibration was done for 15 years (1972 to1986). The calibration results for the surface and ground water components of the total water yield are shown in Table 1 and Figure 2, with an IVF unity (100%). The observed daily average flow for the simulation period is 1.92m$^3/s$, and the simulated result from the model is 1.92m$^3/s$, which shows good agreement of the water balance simulation in the long term bases.

	TOTAL WATER YIELD(mm)	BASE FLOW(mm)	SURFACE FLOW(mm)
Observed	597.2	438.4	158.8
Simulated	597.1	441.4	155.8

Table 6.1: Long-term average annual volumes calibration results

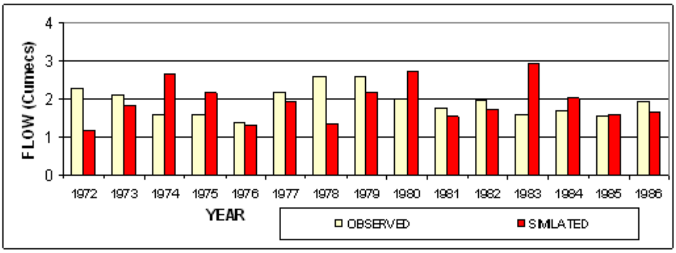
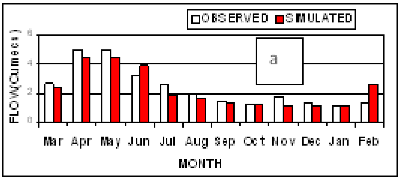


Figure 6.2: Long term average annual simulation results (Jan 1972-Dec 1986)

As shown in Table1 the model overestimated the base flow and underestimated the surface flow with the same magnitude (0.5% of the total water yield). One would note that the discrepancy didn't produce a significant change in the overall simulated water balance (597.1mm), which is an equivalent figure as the total observed water balance (597.2mm).
The trend followed by the observed and simulated average daily flow for the year is promising as shown in Figure 2 as merely the flow was over-estimated during 1974, 1980, and 1983. Close examination of the data reveals that rainfall records during these periods were high particularly in the rainy seasons (April 1974, May 1980 and May 1983). So the flow data during these periods are not accuryte as they were not correctly recorded.for the reason that in case of gauging

station floods nobody goes out to the station to take measurements. After the water balance was well simulated in the long-term simulation period, a seasonal calibration and verification on a monthly basis was done in the wet years of the data series. The calibration period was from March 1979 to February 1980 as shown in Figure 3.The Nash and Sutcliff efficiency criteria (R^2) is 82 %. A validation period is between March 1982 and February 1983 with an R^2 59 %, which implies that the predicted monthly flow data is in close agreement with the observed flow values in the validation period.



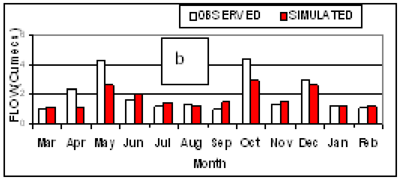


Figure 6.3: (a) Temporal calibration (March 1979 -Feb1980) and (b) Verification (March 1982-Feb 1983)

In addition to surface and base flow components, SWAT derived average annual basin outputs in mm. These are: Actual Evapotranspiration (AE =536), Potential Evapotranspiration (PE=1274), lateral soil flow (49) and ground water from shallow aquifer (393). Rohr (2003) used Morton's complementary relationship to calculate the AE for Charongo (21km^2) and Ngomberi (52km^2) catchments in the southern slopes of Mt. Kilimanjaro and reported an AE of 597mm and 783mm respectively. Besides, the magnitude of infiltration (ground water recharge) computed by the water balance was reported as 291mm and 510mm respectively for these two catchments (Rohr, 2003). Thus, the authors of this research believe that the outputs from SWAT are reasonably comparable to other catchment study in the same geographical area.

6.6 Conclusions

The predicted mean daily stream flow was found to be $1.92\text{m}^3/s$, exactly as much as observed during the water balance simulation. Besides, modeling result gave a total annual water yield of 597.1mm, from which the annual surface water component was 155.8mm and that of the base flow component was 441.4mm in the long term simulation period with IVF unity. While demonstrating the catchment is rich in ground water sources as a result of high magnitude of precipitation and good water retention capacity, this study shows that SWAT model can be a potential monitoring tool for watersheds in mountainous catchments of the tropical regions.

6.7 References

Birhanu, B.Z (2005). *Application of SWAT model in simulating the available water resources in Pangani river basin upstream of NYM reservoir. A case study of 1DD1 catchment*. M.Sc Thesis, University of Dar es Salaam, Tanzania, 2005.

Arnold, J.G., P. M. Allen, and G. Bernhardt (1993). A *comprehensive surface ground water flow model*. Journal of Hydrology. 142:47-69.

Arnold, J.G., P. M. Allen, R. S. Muttiah, and G. Bernhardt (1995a). *Automated base flow separation and recession analysis techniques. Ground water* 33(6): 1010-1018.

Arnold, J.G., and P. M. Allen (1999). *Automated methods for estimating base flow and ground water recharge from streamflow records.* J. of. Amer. Water Res. Assoc. 35(2):411-424.

Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams (1998). *Large area hydrologic modelling and assessment part I: Model development*. J. of Amer. Water Res. Assoc. 34(1): 73:89.

DI Luzio, M., Srinivasan R., and Arnold, J. G. (2002). *ArcView Interface for SWAT2000 User's Guide. Backland Research and Extension Center, Temple, Texas BRC Report 02-07*. Published 2002 by Texas Water Resources Institute, College Station, Texas. TWRI Report TR-193.

Gassman, W.P., M.R. Reyes., C.H. Green and J.G. Arnold (2005). *SWAT peer-reviewed literature: A review, Proceedings of the 3rd International SWAT confer-*

ence, Zurich, 2005.
Jacobs, J.H., and R. Srinivasan (2005). *Application of SWAT in developing countries using readily available data. Proceedings of the 3rd International SWAT conference*, Zurich, 2005.
Moges, S.A. (2003). *Development of a decision support system for Pangani river basin*. PhD Thesis (University of Dar es Salaam, Tanzania, 2003).
Neitsch, S.L, Arnold, J.G., Kiniry, J.R., Williams, J.R., King, K.W. (2002). *Soil and Water Assessment Tool, Theoretical Documentation and user's manual*, Version 2000.
Ndomba, P.M., F.W. Mtalo and A. Killingtveit (2005). *The Suitability of SWAT model in sediment yield modelling for ungauged catchments: A case study of Simiyu river basin catchments, Tanzania. Proceedings of the 3rd International SWAT conference*, Zurich, 2005.
Ndomba, P.M. (2007). *Modelling of Erosion Processes and Reservoir Sedimentation in the Pangani River basin, Upstream of NYM Reservoir*. A draft PhD Thesis submitted for examination at the University of Dar es Salaam.
Rinde, T. (1999). *Landpine: A hydrologic model for describing the influence of landuse on changes in runoff*. Trondheim: SINTEF Bygg og miljoteknikk.
Rohr, P.C. (2003). *A hydrological study concerning the southern slopes of Mt. Kilimanjaro, Tanzania*. Dr. Ing.- Thesis 2003:39, Norwegian University of Science and Technology.
Sharpley, A.N. and Williams, eds. (1990) *EPIC Erosion Productivity Impact Calculator,1. model documentation*. U.S Department of Agriculture, Agricultural Research Service, ARS-8.

7 Sanitation, IWRM and Food Security

Closing the Loops to Achieve the Targets (Lake Abaya Research Symposium 7th - 11th May 2007)

Patrick Bracken[1]

7.1 The sanitation crisis

The worldwide problems of a decreasing quality and quantity of fresh water resources are becoming continuously serious. Thus, we now face a severe world water crisis that will affect us all. Developing countries and countries with an emerging market economy in particular have already begun to be affected by the effects of this crisis, thereby mostly suffering from a decrease in fresh water availability, from sanitation related diseases and a damaged environment, and will suffer further as the competition for resources intensifies. It was against this backdrop that the member states of the United Nations adopted the Millennium Developments Goals (MDGs) that aim to ensure an improved accessibility to basic requirements such as primary education, health care, food security, and the protection of biodiversity. According to the most recent assessment of the Joint Monitoring Programme (JMP) for the water supply and sanitation Millennium Development Goals (MDGs), 1.1 billion people are currently without access to a safe water supply and 2.6 billion have no access to basic sanitation (WHO / UNICEF 2005).
With particular regard to water supply and sanitation provision, the MDG was set to halve the share of people without sustainable access to safe drinking water and basic sanitation by 2015, with 1990 taken as the baseline year. A midterm review of progress towards achieving these goals by the JMP in 2004 concluded that "the world was on track to meet the drinking water target" even though large parts of

[1]Consultant for sanitation c/o EIRENE, B.P. 549, Niamey, Republique du Niger

Sub-Saharan Africa lag quite far behind (WHO / UNESCO 2004). Progress towards the sanitation target has been considerably slower, prompting the United Nations to declare 2008 the International Year for Sanitation (IYS). In order to achieve the target of sanitation, an estimated 1.6 billion people will have to gain access to sanitation systems - over 500 000 people per day, every day until 2015 - and will still leave almost 800 million people without any access at all(WHO / UNICEF 2006). The reasons for the lag in sanitation are numerous. A major obstacle is that sanitation rarely benefits from the political attention of other issues despite its key importance on all sectors. Political will has been lacking when it comes to placing sanitation high on the international development agenda. This, for example, has pushed it into the shadow of water supply projects and sorely limited innovation in the sector, ensuring a continuation of conventional approaches in addressing the problem. Conventional approaches, however, are not providing suitable solutions. Centralised wastewater treatment systems have confirmed to be too expensive to construct, operate and maintain even in industrialised nations, with unofficial World Bank figures placing the number of functioning wastewater treatment plants in developing countries as low as 25%.This has a correspondingly huge impact on the available water resources. Globally, pit latrines are viewed as *the* low cost option, yet they pollute groundwater and consequently result in volumes of faecal sludge that are often dumped without treatment. This discharge leads to further pollution of available water resources and a loss of the nutrient and organic resources they contain.
This slow progress on sanitation is entailing terrible deficits. Diarrhoea, resulting from a lack of sanitation and faecal contamination of drinking water, alone results in the deaths of over 1.8 million children under 5 every year - 4 900 children per day, 5 times more deaths than caused by HIV / AIDS. Diarrhoea kills more people than malaria or tuberculosis and is only one of the many diseases associated with poor sanitation and the resulting contamination of drinking water (UNDP 2006). This daily catastrophe has not only an unspeakable human sacrifice, but has an even broader impact. The development of children is impaired through repeated illnesses, preventing them from reaching their potential. Productive working days for adults are dropping away and human dignity is demeaned by the humiliation of open defecation. The lack of sanitation is keeping people locked within the poverty trap.

Thus, sanitation is not only relevant to the MDG 7 - Ensuring environmental sustainability (under which it has been identified as a target) - but it also makes major contributions to other MDGs, most notably MDG 4: Reducing child mortality and MDG 1: Eradicating extreme poverty and hunger.

7.2 The soil crisis

Whilst billions are caught in the trap of poverty, displayed in poor health and poor nutrition as a result of no sanitation, another process is at work that further undermines the livelihoods of millions, particularly the poorest. Soils in all parts of the world are being depleted from their nutrients.
In Sub-Saharan Africa, for example, average sanitation coverage is the lowest for any region on the planet, with a rate of 36%. At the same time, in this region, 85% of all arable land was losing an average of 30kg of nutrients per hectare/year with 40% losing up to 60 kg per hectare in the period of 2002 to 2004. These nutrients have an average estimated annual value of four billion dollars (Morin 2006). In 2003, 19 million tons of cereals were imported into the Sub-Saharan area with a value of 3.8 billion dollars.
If water is recognised as being essential for survival, fertile soil should be seen as the basis for living. This basis is currently in the process of degrading, requiring increased amounts of chemical fertiliser in order to support soil fertility and ensure continued harvests to feed increasing populations. In 2004, farmers around the world used 135 million tons of mineral fertiliser, with a market value of about 40 billion dollars, to replace the nutrients which were lost in the soil. So as to produce these fertilisers, significant energy consumption is necessary as is the use of non-renewable resources. Current estimates point out that for the essential nutrient phosphorus, reserves will be exhausted in approximately 60 to 130 years at the present rate of consumption.

7.3 Where do the nutrients go?

The current situation is therefore quite perilous. Competition for fresh water resources is increasing, and available reserves often are damaged through contamination by excreta or wastewater. Water related diseases are major causes of death and can seriously weaken populations and aggravate conditions such as malnutrition. The food that is necessary to feed these populations is becoming increasingly difficult to produce as soil quality decreases with nutrient losses, requiring increased chemical agricultural inputs.

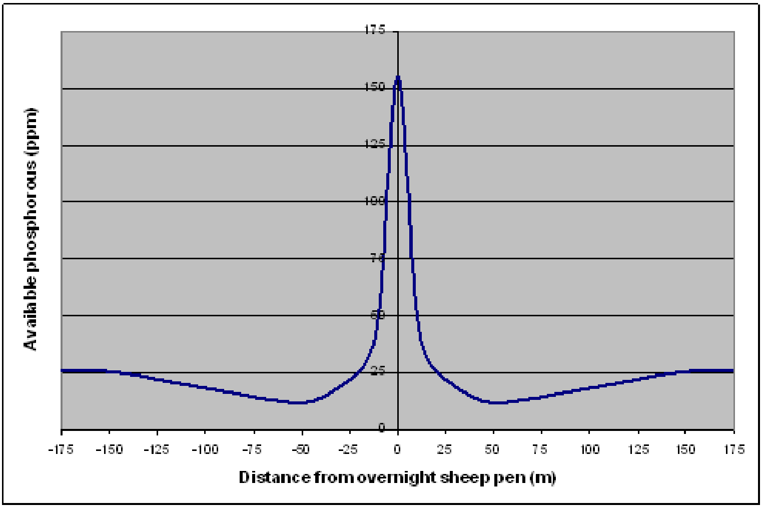


Figure 7.1: The content of soluble phosphorous in soil as a function of distance from an overnight sheep pen (data: Blair 1983)

There is however a synergy between these problems that may prove to be vital in developing sustainable solutions to water resources management, sanitation provision and agriculture. A clue to this synergy can be seen by considering figure 1 which shows the variation of soluble phosphorous in the soil in a field where sheep graze by day and are penned in at night, with the distance 0m representing the pen. The grazing sheep amass nutrients such as nitrogen, potassium and phosphorus while eating, which is then excreted during the night. This results in a dramatic redistribution of the nutrient concentrations within the soil, and produces the resultant peak in soluble phosphorous concentrations. A similar situation occurs in any area where there is a plant nutrient concentration resulting

from the import of food to a particular area, whether being a household, village, town or city. Adults generally have no necessity for these nutrients and therefore they leave the body via urine and faeces.
These nutrients have caused serious problems within wastewater, resulting in the eutrophication of water bodies. This happens when the wastewater is discharged into water bodies or expensive tertiary treatment steps to eliminate the nutrients are required. However, this nutrient elimination step is only the latest addition in the development of conventional wastewater management systems and as such it is not available ubiquitously.

7.4 Conventional approaches to sanitation

Current conventional approaches to wastewater management and sanitation fall in the category of either waterborne or dry systems. In both cases, the system design is based on the premise that excreta are a dangerous waste and that waste should be disposed of. Moreover, it also assumes that the environment can safely assimilate this waste. Unfortunately, with increasing population densities this assumption is in most cases no longer valid and experience and statistics show that such conventional approaches are unable to have a significant impact on the sanitary backlog.
Starting with the very rudimentary consideration that conventional systems can be financed, it quickly becomes clear that choosing conventional systems to cover the sanitary backlog aimed for in the MDGs will result in failure. According to a World Bank estimate from 2003, over 25 billion US dollars per year will be needed until 2015 if the goal of providing sanitary infrastructure is to be reached. Another aspect is that once these conventional systems have been put in place they will have to be operated and maintained. Clearly, for most developing countries, even if they were to receive sewage networks and treatment plants or latrines free of charge, the cost of operating and maintaining the entire system would ensue to be financially impossible. This is highlighted by a recent statistic from the World Bank Water Week stating that $3/4$ of all the wastewater treatment plants which were built in developing countries either do not function correctly or do not function at all. The problems of financing the construction and maintenance of conventional centralised sanitation systems are, however, not exclusively lim-

ited to developing countries. Industrialised nations also face huge problems in the maintenance and operation of their sewer systems and treatment plants. Of 540 major cities in Europe, only 79 have advanced tertiary sewage treatment, 223 have secondary treatment, 72 have incomplete primary treatment and 168 of those cities that discharge their wastewater have no or an unknown form of treatment of their wastewater (EcoSanRes, 2002).

- Unsatisfactory purification or uncontrolled discharge of more than 90
- Pollution of water bodies by organics, nutrients, hazardous substances, pathogens, pharmaceutical residues, hormones, etc.
- Unacceptable health risks and spread of disease
- Severe environmental damage and eutrophication of the water cycle
- Consumption of precious water for transport of waste
- High investment, energy, operating and maintenance costs
- Frequent subsidisation of prosperous areas, and neglect of poor settlements
- Loss of valuable nutrients and trace elements contained in excrement through their discharge into water bodies
- Impoverishment of agricultural soils, and increased dependence on chemical fertilisers
- Predominance of combined central systems, resulting in problems with contaminated sewage sludge
- Linear end-of-pipe technology

While figure 2 highlights some of the other serious disadvantages of conventional waterborne and dry wastewater disposal systems, the most fundamental problem of all is that they do not facilitate the reuse of the water, organics and macro and micro nutrients contained in the wastewater. This leads to a linear flow of nutrients from agriculture via humans to recipient water bodies, misusing them as a

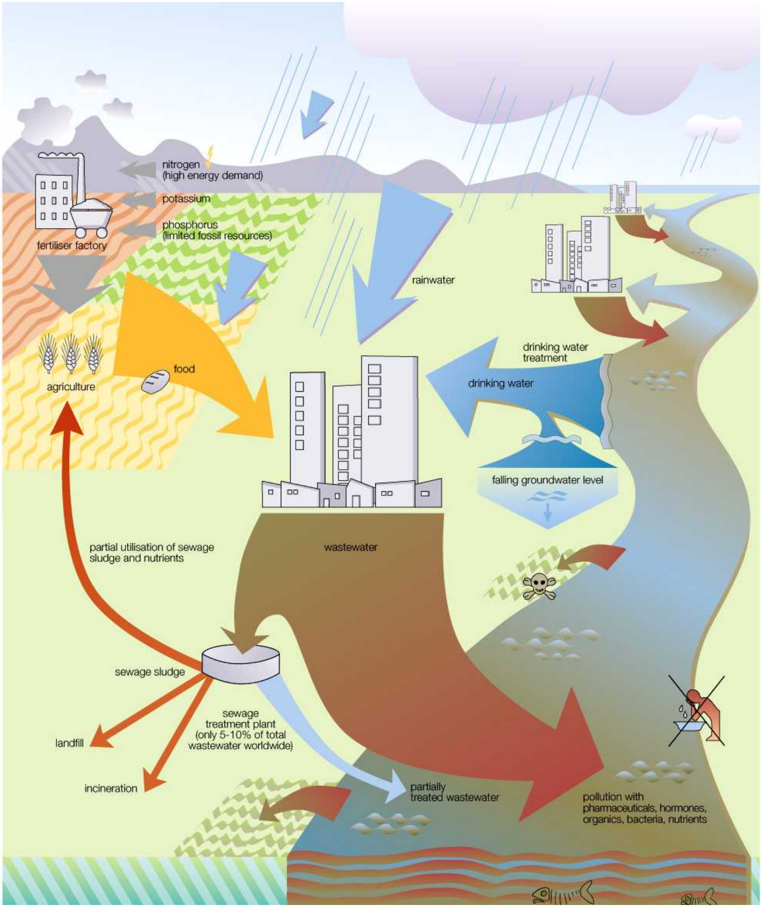


Figure 7.2: The disadvantages of the conventional approach to sanitation

sink for our waste. Even if sewage sludge is used in agriculture, only a very small share of those nutrients contained in the excrement is reintroduced into the living soil layer. The greater share is either destroyed in the treatment process (e.g. by

nitrogen elimination) or enters the water cycle, where it pollutes the environment and causes the eutrophication of lakes and rivers. The use of sewage sludge from central wastewater systems is also frequently restricted as it contains high concentrations of heavy metals and other hazardous substances, due to the mixing of domestic wastewater with industrial wastewater and storm-water runoff from streets. The failure of returning the nutrients to the soil has led directly to decreasing soil fertility.
In short, our conventional wastewater systems are largely linear end-of-pipe systems where drinking water is misused to transport what is seen as waste into the water cycle, thus causing environmental damage and hygienic hazards, and contributing to the water crisis. They were developed under false premises and at a time when resource efficiency was not a consideration.

7.5 Ecological sanitation - an alternative

The modern misconception that human excreta are wastes with no useful purpose has resulted in the end-of-pipe sanitary systems that we have today. In nature, however, there is no waste. All products of living things are used as raw materials by others as part of a cycle. Considering the environmental damage, the health risks, and the worsening water crisis, resulting from our present sanitary practices, a revolutionary rethinking is urgently needed if we are to correct this misconception. A new paradigm is required in sanitation, based on ecosystem approaches and the closure of material flow cycles rather than on linear, expensive and energy intensive technologies. This paradigm must recognise the resource value of safely treated human excreta and water from households.
Ecological sanitation represents this urgently needed new holistic paradigm in sanitation. It is based on an overall view of material flows as part of an ecologically and economically sustainable wastewater management system which is tailored to the needs of the users and to the respective local conditions. It does not favour a specific sanitation technology, but is rather a new philosophy in handling substances that have so far been simply considered as wastewater and water-carried waste for disposal. Ecological sanitation introduces the concept of sustainability and integrated, ecosystem oriented water and natural resources management to sanitation.

The basic principle of “ecosan” is to close the nutrient loop between sanitation and agriculture, with the following objectives:

- providing affordable, safe and appropriate sanitary systems
- reducing the health risks related to sanitation, contaminated water and waste
- improving the quality of surface and groundwater
- improving soil fertility
- optimising the management of nutrients and water resources

Closing the loop enables the recovery of organics, macro and micro nutrients, water, and energy contained in household wastewater and organic waste and their subsequent productive reuse - after adequate treatment - in agriculture. An essential step in this cycle is the appropriate treatment and handling of the materials throughout the entire process, from collection through to reuse, ensuring that a series of barriers are erected that will reduce the risk of feaco-oral disease transmission to acceptable limits, thus providing comprehensive protection of the human health.
“Ecosan” systems restore a balance between the quantity of nutrients which are excreted by one person in one year and that are required to produce their food. Therefore, it can conserve limited resources, preserve soil fertility and safeguard a long-term food security. Closing local nutrient cycles by recovering and using the nitrogen, phosphorous, potassium, micro nutrients and organic components contained in excrement is consequently not only important since it helps minimising the energy and resource intensive production of mineral fertilisers. It also makes such agricultural inputs available even to the poorest farmers in developing countries that are often engaged in subsistence farming.

- Improvement of health by minimising the introduction of pathogens from human excrement into the water cycle
- Promotion of recycling by safe, hygienic recovery and use of nutrients, organics, trace elements, water and energy

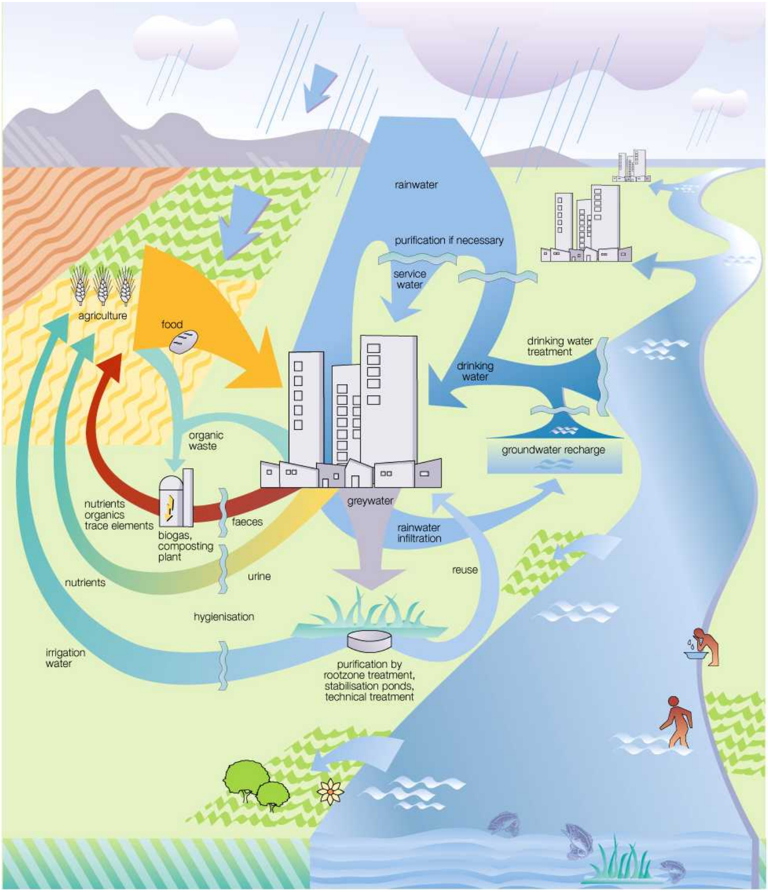


Figure 7.3: The advantages of ecological sanitation

- Resource conservation, through lower water consumption, substitution of chemical fertilisers and minimisation of water pollution
- Preference for modular, decentralised partial-flow systems for more appro-

priate cost-efficient solutions

- Possibility to integrate on-plot systems into houses, increasing user comfort, and security for women and girls
- Contributes to the preservation of soil fertility
- Improvement of agricultural productivity and hence contributes to food security
- Promotion of a holistic, interdisciplinary approach (hygiene, water supply and sanitation, resource conservation, environmental protection, urban planning, agriculture, irrigation, food security, small-business promotion,)
- Material-flow cycle instead of disposal

As ecological sanitation does not prescribe a particular technical solution, but rather tailors sanitary systems to fit the needs of social, economic and environmental sustainability in a given context, a wide range of technologies can be used in ecological sanitation systems. These range from quite simple low-tech systems to sophisticated high-tech solutions. This flexibility in the choice of system technologies makes eco-sanitation suitable for all countries around the world - not only in industrialised nations, but also in developing and emerging countries.
The paper concludes with an illustration of how ecological sanitation can be used as an implementation tool for the concepts of IWRM (see figure 3).

7.6 References

Blair, G.J. 1983. *The phosphorous cycle in Australian agriculture*, in Costin and Williams pp 92-111.
Brown, A.D. 2003. *Feed or feedback: Agriculture, Population Dynamics and the State of the Planet*, International Books Utrecht, the Netherlands.
EcoSanRes, 2002. *The Sanitation Crisis.* Digitally available at:http: //www.ecosanres.org/
Werner, C. and Bracken, P. 2004. *Ecological Sanitation - respecting the needs of developing and emerging countries.*

WHO/UNICEF JMP (World Health Organization and United Nations Children's Fund Joint Monitoring Programme for Water Supply and Sanitation), 2004, *Meeting the MDG drinking water and sanitation target: A mid-term assessment of progress,* World Health Organisation, Geneva, Switzerland.

WHO/UNICEF JMP (World Health Organization and United Nations Children's Fund Joint Monitoring Programme for Water Supply and Sanitation), 2006, *Meeting the MDG drinking water and sanitation target: the urban and rural challenge of the decade.* World Health Organisation, Geneva, Switzerland.

UNDP (United Nations Development Programme), 2006, Human Development Report 2006 - Beyond Scarcity : Power, Poverty and the Global Water Crisis. UNDP, New York, USA.

8 Application of SWAT

For assessment of spatial distribution of water resources and analysing the impact of different land management practices on soil erosion in the Upper Awash River Basin watershed

Dilnesaw A. Chekol, Bernhard Tischbein, Helmut Eggers, and Paul Vlek

8.1 Background and Objective

As a result of fast growing population rates and an increasing resource and industrial development, water is becoming a very scarce and valuable resource. Because of the scarcity of water and its quality related problems, the capabilities of some countries to supply their population with water and to satisfy their future water need for the economic and environmental need are already affected. In a country sustainable development is possible if the water resources of a country are managed and utilized properly. Proper utilisation of water resources requires knowledge and a basic understanding of the hydrologic system and the processes influencing them both spatially and temporally.
A comprehensive understanding of hydrologic processes in the watersheds is a prerequisite for successful watershed management and environmental restoration. A hydrologic cycle is a complex system, because of the spatial and temporal heterogeneity in soils properties, vegetation and land use practices. As a result, mathematic models and geospatial analysis tools are required in order to study hydrologic processes and hydrologic responses to land use and climatic changes. Hence, assessing the spatial distribution of water resources and analysing the impact of different land management practices on hydrologic response and soil erosion in the Upper Awash River Basin watershed will give information for effective watershed management.
This study had the following objectives: (1) to assess the spatial distribution of

water resources in the study area and (2) to evaluate the impact of different land management practices on hydrology and soil erosion.

8.2 Methodology

8.3 Study Area

This research was undertaken on the upper part of the Awash River Basin in Ethiopia, which lies upstream of the Koka Dam and is located between latitudes of 8^o16' and 9^o 18' and longitudes of 37^o 57' and 39^o17'. It covers about 7240 km^2.

8.4 Model Description

In order to assess the spatial distribution of water resources and sedimentation, one needs to use a physically-based distributed model. For this study, the SWAT model was selected because of its ability to characterise complex watershed representations by explicitly accounting for spatial variability of soils, rainfall distribution, and vegetation heterogeneity. Moreover, it is able to show the effects of different land management practices on surface runoff and sediment yield as well as to characterise surface runoff and sediment yield producing mechanisms. SWAT is a watershed model which was developed to quantify the impact of land management practices in large watersheds (Arnold et al., 1998). SWAT was devised to predict the impact of land management practices on water, sediment and agricultural chemical yields in large watersheds with varying soils, land use and management conditions over long periods of time. The model simulates eight major components: hydrology, weather, erosion and sediment transport, soil temperature, crop growth, nutrients, pesticides, and agricultural management (Neitsch et al.2002). Major hydrologic processes that can be simulated by the model include evapotranspiration (ET), surface runoff, infiltration, percolation, shallow aquifer and deep aquifer flow, and channel routing (Arnold et al., 1998). SWAT uses the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975) to estimate soil erosion and sediment caused by rainfall and

runoff. Sediment yield prediction is improved since runoff is a function of antecedent moisture conditions as well as rainfall energy.
Spatial datasets that were used in this study included Digital Elevation Model (DEM), soil, land use and land cover, daily weather, daily discharge, and daily suspended sediment load.

8.5 Calibration and Validation: Stream flow and suspended sediment

Calibration is the process by which a model is adjusted to match some observed data more precisely. Calibration greatly improves the accuracy of a model. Model validation is the process of rerunning the simulation by using a different time series for input data, without changing any parameter values which may have been adjusted during calibration. Validation can also occur during the same time period as calibration, but at a different spatial location.
In this study, the SWAT model was first calibrated and validated using observed stream flow at the Hombole station. After that, the SWAT model was calibrated and validated using measured suspended sediment load at this station.
Three methods for goodness-of-fit measures of model predictions were employed during the calibration and validation periods. These three numerical model performance measures are the percent difference (D), coefficient of determination (r^2 coefficient) and the Nash-Suttcliffe simulation efficiency (E_NS) (Nash and Suttcliffe, 1970).
SWAT developers in Santhi et. al., (2001) assumed an acceptable calibration for hydrology at a D<15%, r^2 >0.6 and ENS >0.5. These values were, in this study, also considered as adequate statistical values for acceptable calibration.

8.6 Spatial Evaluation of different land management practices

Farming activities in the upper catchment of the Awash Basin are changing very rapidly because of the population pressure. In order to see the effects of these changes on water quantity and sedimentation, it is necessary to develop and test different possible land management scenarios. These scenarios are briefly described in table 1.

Scenario	Description
Sc-1	Existing conventional tillage system (with Ethiopian *maresha*) without conservation measures
Sc-2	Conservation agriculture
Sc-3	Parallel Terraces: Assume the slope length is reduced by 25%.
Sc-4	Parallel Terraces: Assume the slope length is reduced by 50%.
Sc-5	Parallel Terraces: Assume the slope length is reduced by 75% .
Sc-6	Ploughing on contour (P=0.9)[(a)]
Sc-7	Strip Cultivation (P=0.8)[(b)]
Sc-8	Combination of Conservation agriculture and Parallel Terraces: that assumes the slope length is reduced by 25%, the conservation practice factor reflects a high sedimentation factor
Sc-9	Afforstation: Areas with slope higher than 15%
[(a) and (b)] These factors were defined for Ethiopia by Hurni (1985)	

Table 8.1: Summary of conservation measures and best management practices scenarios for Upper Awash Basin.

8.7 Results and Discussions

8.8 Calibration and Validation

The Hombole watershed was delineated into 27 sub-watersheds by the model with a suggested flow accumulation threshold of 15900 ha, which were further divided into 160 HRUs. Each HRU was determined by the multiple hydrologic response unit option of 2% land use cover the sub-watershed area and 5% soil class cover over the land use area, which was found to be optimal for the study area. Simulated flow and sediment load at the Hombole gauging station was compared with the observed flow and measured sediment load.

In order to conduct calibration processes one has to find out the sensitive parameters by applying sensitivity analysis. Results of the sensitivity analysis showed that the most sensitive parameters for the SWAT model in the Hombole sub-watershed are curve number (CN2), available water capacity (SOL_AWC), average slope steepness (SLOPE), saturated hydraulic conductivity (sol_k), soil evaporation compensation factor (ESCO), and soil depth (sol_z). These parameters were used for the calibration of the model.

8.9 Calibration and validation for stream flow

Simulations runs were conducted on a daily basis to compare the modelling output with the measured daily discharge. Discharge data from January 1, 1989, to December 31, 1992, were used for calibration. Simulation results from January 1, 1989, to December 31, 1992, were used for the evaluation of parameter calibrations.
The calibration greatly improved the agreement between measured and simulated daily, weekly and monthly flows. As can be seen in table 2, all three numerical model performance measures are in the acceptable rang meaning that the SWAT model accurately tracked the measured flows. These results confirm SWAT's ability to predict realistic flows.
After the calibration processes, SWAT was validated using flow data from a different time period at the Hombole gauging station from January 1, 1993, to December 31, 1998. As already done for the calibration, the three goodness-of-fit measures were calculated for the validation, as well.

Watersheds		Simulation Period	E, (The Nash-Sutcliffe model efficiencies)		
			daily	weekly	monthly
Hombole	Calibration	1989-1992	0.78	0.85	0.87
	Validation	1993-1998	0.66	0.75	0.79
		Simulation Period	D (%)(Deviation of mean discharge)		
			Daily	weekly	monthly
Hombole	Calibration	1989-1992	-3.22	-3.25	-3.3
	Validation	1993-1998	1.53	1.53	1.49
		Simulation Period	r^2 coefficient		
			daily	weekly	monthly
Hombole	Calibration	1989-1992	0.78	0.85	0.87
	Validation	1993-1998	0.68	0.76	0.79

Table 8.2: SWAT model calibration and validation statistics for daily, weekly and monthly stream flow comparison at Hombole station.

The graphical representation of measured and simulated flows matched well for both calibration and validation periods (Figure 1). The calculated value of the goodness-of-fit measures for validation processes are shown in table 2 and all values are also arranged in the acceptable range.

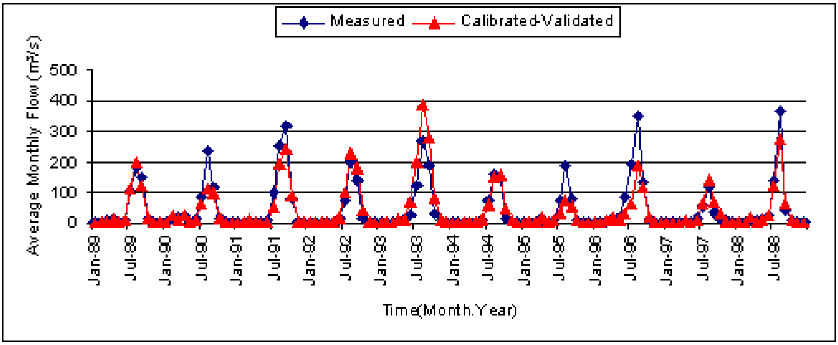


Figure 8.1: Comparison of observed monthly discharge with simulated monthly discharge using SWAT calibrated parameters as well as validated parameters at Hombole.

8.10 Calibration and validation for suspended sediment load

SWAT model calibration and validation for monthly sediment yield were conducted after the model was calibrated and validated for the stream flow at the Hombole station. The calibration and validation period were for the period 1997 to 1998 and, respectively, for the period 1999 to 2000. Model performance evaluation statistics for simulating monthly sediment yield at the Hombole gauging station for calibration and for validation are given in table 3. From these results it can be inferred that the SWAT model was found to simulate agreeably on a monthly basis of sediment yield.

Watersheds		Simulation Period	Monthly Average		
			r^2	E_r	D (%)
Hombole	Calibration	1997-1998	0.82	0.76	16
	Validation	1999-2000	0.73	0.65	15

Table 8.3: SWAT model calibration and validation statistics for monthly sediment yield comparison at Hombole station.

SWAT model results revealed that the base flow is an important component of the total discharge within the study area and is usually greater than the surface runoff. The percentaged contributions of surface runoff and base flow to the total water yield in the study area are 16.8% and 53% respectively. The runoff coefficient was calculated based upon the simulated results and constitutes 17.9%. Because SWAT is a distributed model, it is possible to perceive a model output as it varies across the basin. Figures 2a and 2b depict the variability of surface runoff and, accordingly, the base flow across the basin.

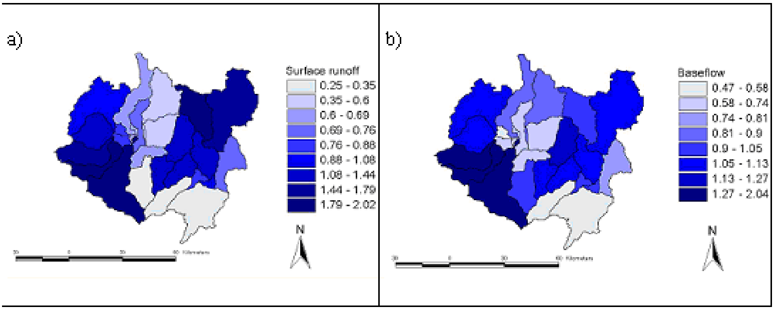


Figure 8.2: Surface runoff as a fraction of the basin average (a) and baseflow as a fraction of the basin average (b) as simulated by SWAT for the Hombole watershed, derived from a 10-year (1991-2000) simulation.

8.11 Spatial Distribution of Sediment Sources Hotspot Area

In this study the SWAT model, which was calibrated and validated for hydrology and sediment at the Hombole station, was used so as to identify hot sediment sources within the Hombole sub-watersheds and simulate the effect of management/conservation measures on water and sediment yield in the Upper Awash River watershed. The spatial variability of the erosion rate was identified and represented in figure 3. Based on this result, potential areas of intervention were prioritised and nine management/conservation measurement scenarios were de-

veloped and simulated by SWAT model in order to evaluate the most suitable management/conservation measures within the Upper Awash basin.
SWAT simulated annual sediment yields for the Hombole sub-watershed for the years 1983-2000. They ranged from 8 to 46 tons/ha/yr with an eighteen-year average of 21.5 tons/ha/yr. The average annual sediment yield which was predicted by the model was used to generate sediment source maps (figure 3).

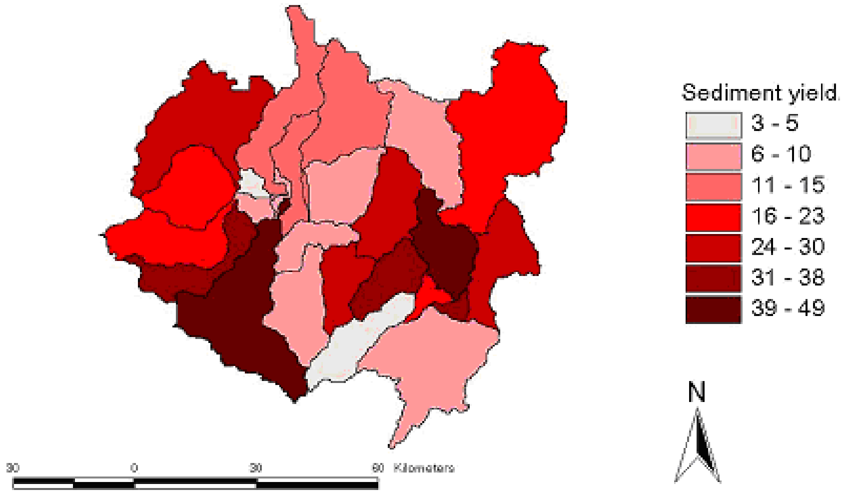


Figure 8.3: A spatial map of the watershed showing a SWAT simulated annual sediment yield in stream flow for individual sub-basins. Sediment yields presented are in t/ha/y.

The model results show that the Upper Awash River Basin with existing condition generates 21.5 t/ha/y of an average annual sediment yield (figure 3).
Hurni (1983) has conducted a research to estimate the rates of soil formation for Ethiopia. The range of the tolerable soil loss level for various agro-ecological zones of Ethiopia was obtained from 2 to 18 t/ha/y (Hurni, 1985). The actual annual soil loss rate in the study area exceeds the maximum tolerable soil loss

rate of 18t/ha/y. This fact shows how soil erosion is a serious threat for the study area.
Simulation was performed for each scenario after altering the respective USLE_P for the HRUs with the corresponding conservation measures and management practices. Water and sediment yields were compared to the result of the baseline scenario's simulation. Sediment loss reductions relative to the base scenario due to conservation practices are listed in table 4.

Scenarios	Percentage Change (Sediment)	Percentage Change (Water yield)	Percentage Change (Surface runoff)	Percentage Change (Lateral flow)	Percentage Change (Baseflow)
Sc-1	0	0	0	0	0
Sc-2	-41	1	-23	0	11
Sc-3	-14	-2	0	27	-7
Sc-4	-59	4	-23	85	3
Sc-5	-72	11	-25	215	-7
Sc-6	-10	-3	0	0	-5
Sc-7	-20	-3	0	0	-5
Sc-8	-49	2	-23	31	8
Sc-9	-11	-4	13	24	-16

Table 8.4: Estimated reductions in water flow and sediment loss from agricultural sub-basins due to conservation structures and best management practices as compared to the baseline scenario.

The effective measures in removing sediment from the water that exits the watershed are arranged in their effectiveness. These are Sc-5 (72% reduction and the value is 6.09 t/ha/y), Sc-4 (59% reduction and the value is 8.88 t/ha/y), Sc-8 (49% reduction and the value is 10.95 t/ha/y), Sc-2 (41% reduction and the value is 12.66 t/ha/y), Sc-7 (20% reduction and the value is 17.2 t/ha/y), Sc-3 (14% reduction and the value is 18.55 t/ha/y), Sc-9 (11% reduction and the value is 19.1 t/ha/y) and Sc-6 (10% reduction and the value is 19.36 t/ha/y
It was observed that simulated annual water yields at the outlet of the Hombole station were increased by implementation of Sc-2, Sc-4, Sc-5 and Sc-8 by 1%, 4%, 11% and 2% respectively (see table 4). But other scenarios, like Sc-3, Sc-6, Sc-7 and Sc-9 resulted in the reduction of simulated annual water yield at the Hombole station by 2%, 3%, 3% and correspondingly 4%. In general, the impact of all scenarios, except for Sc-5, on the simulated stream flow at the outlets of

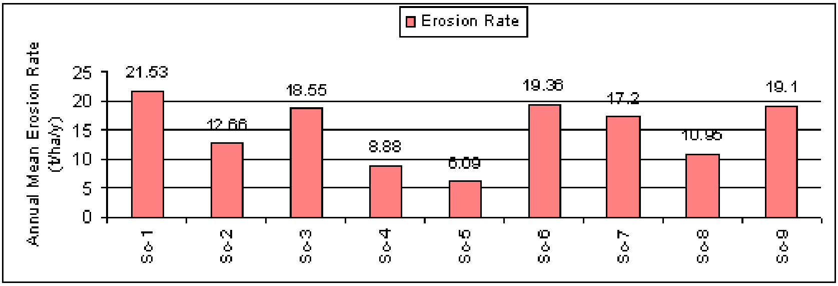


Figure 8.4: Simulated average annual sediment yield for each scenario at Hombole station.

the studied watersheds was negligible. The highest effect was observed in Sc-5 due to the influence of the runoff parameter, which is induced as a result of slope length reduction by 75%.

8.12 Conclusion and Recommendation

The SWAT model was examined for its applicability with regard to the assessment of water resources in the Upper Awash Watershed. The study showed that the model can produce reliable estimates of daily, weekly and monthly discharge and also monthly sediment yield with relatively high Nash-Sutcliffe model efficiencies. Results demonstrated that SWAT is a capable modelling tool in order to analyse hydrologic processes and water resources planning and management in the Upper Awash River Basin using the set of optimized parameters.
Different soil conservation scenarios were tested with respect to the sediment yield. The results of the simulations were utilised to illustrate the potential reduction in sediment yield that could be expected by various management/conservation measures.
Successful tackling of soil erosion and sedimentation problems depends to a large extent on the understanding of the sources, transport and fate of sediments within watersheds, and evaluating the outcome(s) of a certain management action on the system's water quality. This study showed that SWAT is a useful tool for

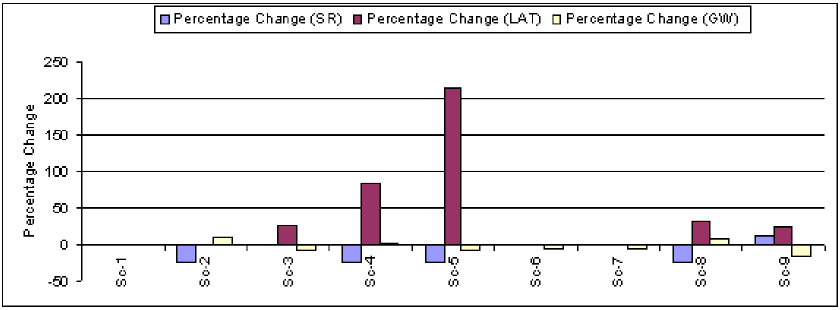


Figure 8.5: Percentage change in simulated average annual water yield components (surface runoff, lateral flow and base flow) for each scenario compared with the baseline scenario.

evaluating the outcome(s) of a certain management action on water quality of the system.

Results of the simulation show that land management/conservation measures in a watershed scale can result in a reduction of sediment yield. This reduction occurred at the Hombole station by about 10-72%. The simulation, using parallel terraces with the reduction of slope length by 75%, gave the highest reduction in sediment yield which is 6.09t/ha/y. Moreover, this measure shows its capability of the conservation of water resources by provoking the highest increment in water yield by 11%. A comparison of these management/conservation measure scenarios revealed that the implementation of these soil conservation measures would significantly reduce sediment yields at the outlets of the watershed.

8.13 References

Arnold,J.G., Sirinivasan,R., Muttiah, R.S, Williams, J.R. (1998). *Large area hydrologic modelling and assessment, Part 1: Model development.* Journal of the American water resources association, 34(1).

Hurni, H. (1983). *Soil Formation Rates in Ethiopia* Ethiopian High lands Reclamation Study, December 1983.

Hurni, H. (1985). *Soil conservation manual for Ethiopia*. Ministry of Agriculture. Addis Abeba, Ethiopía.
Nash, J. and Sutcliffe, J. (1970) *River flow forecasting through conceptual models part 1 - adiscussion of principles*. Journal of Hydrology, 10, 282-290.
Neitsch, S.L., J.G. Arnold, J.R. Kiniry, R. Srinivasan, and J.R. Williams. (2002). *Soil and Water Assessment Tool User's Manual*, Version 2000.
Santhi, C., J.G. Arnold, J.R. Williams, W.A Dugas, R. Srinivasan, and L.M. Hauck, (2001). *Validation of the SWAT model on a large river basin with point and nonpoint sources*: Journal of the American Water Resources Association 37(5): 1169-1188.
Williams, J.R. (1975). *Sediment-yield prediction with universal equation using runoff energy factor*. p. 244-252. In Present and prospective technology for predicting sediment yield and sources: Proceedings of the sediment yield workshop, USDA Sedimentation Lab., Oxford, MS, November 28- 30, 1972. ARS-S-40.

Successful tackling of soil erosion and sedimentation problems depends to a large extent on the understanding of the sources, transport and fate of sediments within watersheds, and evaluating the outcome(s) of a certain management action on water quality of the system. This study showed that SWAT is a useful tool for evaluating the outcome(s) of a certain management action on water quality of the system.

9 Assessment of Sand Encroachment Using Remote Sensing and GIS

Case Study Dongola Area, Sudan

Dafalla M.S.[1], *Elhag A.M.H.*[2], *Ibrahim S.I.*[3] *and Doka, M. A.*[4]

9.1 Abstract

Desertification is land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including climatic variations and human activities (UNCCD, 1994). The major desertification processes are wind erosion, water erosion, denudation of vegetation cover while the other minor ones include salinization, sodicity and compaction of the soil. The Sudanese Desert Encroachment Control and Rehabilitation Programme (DECARP, 1976) concluded that

> it appears that no one single factor causes desertification. Obviously, it is a combination of factors, involving fragile ecosystem developed under harsh and fluctuating climate, and man's activities, some of which are increased in an irreversible magnitude by weather fluctuations, especially periodic drought.

Sand encroachment is one of the main problems threatening the agricultural production in some parts of the Sudan and in particular the northern state. Wind and water erosion are the major environmental hazards. An understanding of the extent of wind and water erosion on various field surfaces is essential for the

[1]Dept. of Soil Science and Environmental Sciences, Faculty of Agriculture, University of Khartoum, Sudan. Presently Institute of Remote Sensing and Photogrammetry, TUD, Germany. Corresponding author.

[2]Remote Sensing Authority, Sudan.

[3]Dept. of Soil Science and Environmental Sciences, Faculty of Agriculture, University of Khartoum, Sudan.

[4]Dept. of Soil Science and Water Studies, Faculty of Agricultural Studies, Sudan University for Science and Technology-Remote Sensing Authority, Sudan.

selection of appropriate control and preventive measures against land degradation. Furthermore, there is a need to know the appropriate field conditions prior to making any attempts to reduce wind and water erosion to permissible levels. Salih (1996) stated that sand moves from north to south at an alarming rate, and under those conditions 13 Sudanese states out of the 26 are affected by land degradation. He further postulated that sand and sand dunes in the areas between latitudes 10^o and 18^o N had originated from the weathering products of the basement complex, Nubian Sandstone together with alluvial deposit. Eltigani (1996) and Awad and Drag (2004) agreed with Salih (1996) findings and concluded that the northern state is one of these 13 states in the Sudan affected by desertification.
Remote sensing can be defined as the science of collection, processing and interpretation of images and related data, obtained from aircraft and satellites, which record the interaction between matter and electromagnetic radiation (Sabins, 1997). In the Sudan the use of remote sensing technology is a cost- and time-effective way for surveying natural resources. Starting from 1971 remote sensing has been used in natural resources surveys of specific areas chosen by the Food and Agricultural Organization (FAO) for testing the possible utilization of remote sensing for surveying, mapping, planning and developing natural resources. Lampery (1975) studied vegetation change in the Sudan and concluded that the desert was then moving southwards with a rate of 5-6 km per year. He attributed this spread of desertification to misuse of land by people. However, Hellden (1978, 1988) showed that there was no systematic desert encroachment and criticized the findings of Lampery (1975) as misinterpretations resulting from his application of the vegetation map of Jackson and Harrison (1958), which depended mainly on the 100mm rainfall isohyets. Hellden (1978, 1988) stated that vegetation recovered during the rainy season.
The flow of the river Nile is affected by the joining flow of the Blue Nile, White Nile and Atbara River (Abdel Salam, 2001). River Nile course is affected by bank erosion especially at the meandering sites and sedimentation of suspended material in form of islands and flood plains.
This study aims to assess sand encroachment in Dongla area for the period 1961 to 200 with emphasis on its effect on productive lands and River Nile course. Satellite imageries and GIS techniques were used.
Dongla area is located in the Northern State, Sudan (Fig.1) . It is characterized

by a desert climate with very low and irregular rainfall, very hot summers and cool winters. The wind blows most of year in a north to south direction. The population of area is estimated as 291,630 (Sudan Statistics, 1993). The area is generally a broad peneplain with few scattered mountains along the banks of the River Nile. The soils in the northern state are categorized into three major types: Entisols which are the dominant soils of the active flood plain that receive annual alluvium deposits, Aridisols which are the soils of the high terrace that had not been flooded for a long time and accordingly have shown limited horizon development and the miscellaneous soil types (desert soils) which are mainly sandy soils mixed with other miscellaneous land types. Agriculture is practiced mainly on small areas of the *Gerf* soils (Entisols), but these highly productive soils are currently seriously threatened by sand encroachment.
Landsat images acquired for this area are MSS Landsat (188/47) 1972, TM Landsat (175/47) 1996 and TM Landsat (175/47) 2000. Aerial photos for years 1961 and 2002 were scanned and used in digital forms in the rest of the study. The field work was conducted during the period 29/5/2004 to 11/6/2004 aided by Garmin 12 XL GPS.
Global and linear enhancement was conducted, in addition to radiometric and geometric corrections for the geo-referenced images using ground control points and first order transformation with an error of <94 1.0 pixel.
Supervised and unsupervised digital classifications were used based on visual interpretation and the field work. Areas and percentage of the areas affected by sand in each year were determined, and then post-classification change detection approach based on map calculation was applied to determine the dynamic of change in sand encroachment.
Visual interpretation showed that sand moved from eastern, western and north western parts of the study area towards the River Nile and Dongola town area. Sand movement is affected by the dominant direction of the prevailing wind in both summer and winter season. In summer the dominant one is the southwesterly wind which steered the sand towards the west bank of the river and away from the eastern one. While in winter the dominant wind is the northeastern one which steers sand toward the eastern bank of the river and away from the western bank.
The area covered by sand dunes increased from 51.2 km^2 to 61.2 km^2 during

the period between 1976 and 1996. However, it decreased to 35.1 km^2 in 2000. Moreover, the aerial photos interpretation confirmed the increased pattern of sand dunes for the period between years 1961 to 2002. The apparent decrease of the area covered by sand could be explained by a corresponding increase of the area covered by gravel plus fine and/or coarse sand. This result indicated that the sand dunes were active and shifted from one place to another affected by the direction of the prevailing wind exposing the underlying gravel and sand. This suggests that the increase in the area covered by gravel plus coarse and/or fine sand could be used as indicator to land degradation in Dongla area. However the outstriking phenomenon was the appearance of sand dunes on the eastern bank of the River Nile. This sand could have been moved either in suspension from the western part of the River Nile or through sheeting or bouncing from the north or the north-eastern part of the study area. However, the increase of area covered by sand dunes could be attributed to the expansion of agricultural activities near to urban areas possibly coupled with climatic variations. These finding agreed with Salih (1996) Eltigani (1996) and Awad and Drag (2004) who found that sand encroachment was a real problem in the northern state of the Sudan.

9.2 River Nile Course

The Nile River course showed a consistent stable pattern. The changes in the River Nile course could be due to water erosion along one bank and deposition on the other bank particularly on curvatures due to the meanderings of the Nile. This was confirmed by an increase of island areas. However, the year 2000 witnessed an increase in the area covered by River Nile course. This could be attributed to the exceptionally high flood during that year in which either islands and/or active terraces of the Nile were covered by flood water. Figures show that sand dunes in addition to sandy soil covered a large area along the Nile river course, in addition to islands. This was clearly observed in the satellite images of 1996 and 2000 and aerial photo of 2002.

It is obvious that sand encroachment threatens the River Nile course and the highly productive areas. These findings were supported with the finding of Abdel Salam (2001). This situation will certainly endanger the livelihood of local inhabitants of the area and can lead to more losses of fertile soils of the first terraces of the River Nile (Gerf soils).

9.3 Conclusion and Recommendations

Sand encroachment threatens the highly productive agricultural land and settlements in Dongola area. This will endanger the livelihood of inhabitants in this area. Therefore there is a critical need for adoptions of certain measurements to face this problem such as:

- Adoption of strategies for sand dunes stabilization through plantation of shelter belts to retard sand movement.
- Construction of the proposed canal starting from Marawi dam at the eastern side of the River Nile up to Dongola province.
- Adoption of optimal land uses that are suitable for these vulnerable areas.
- Improve the awareness of the inhabitants about this problem.
- Conduction of research aiming towards understanding the origin of encroaching sand and creation of new methods to prevent sand encroachments.

10 Study of Nitrogen Transformation Lake Victoria

Pascal Emmanuel[1], *Frederic Mwanuzi and Richard Kimwaga*

10.1 Integrated Water Resources Management For oral presentation

10.2 Abstract

This study was aimed at identifying the sources and sinks of nitrogen in Lake Victoria. Spatial and temporal variations of nitrogen were studied by use of Arcview GIS and Microsoft Excel.
Results show that high amount of nitrogen are found in the lake areas subjected to high municipal and industrial loading. For urban centres, municipal loading (1777kg/day) outweighs industrial loading (654kg/day) as TN. The quality conditions of the lake were found to be deteriorating particularly during the rainy season. Thus, runoff from agricultural activities and wet atmospheric deposition must be contributing nitrogen in the lake. With time, this situation might affect species biodiversity through changing lake characteristics.
This situation calls for immediate mitigation measures that include: public awareness, use of proper sanitary and wastewater treatment facilities, cleaner production technology, compliance to effluent standards, and improvement of agricultural practices.
This study is highly valuable as it provides nitrogen pollution inventories, which can accelerate environmental compliance, make informed decisions, and identify opportunities for nitrogenous waste minimization and cleaner production.

[1]University of Dar es Salaam, College of Engineering and Technology, Water Resources Engineering Department P.O Box 35091, Dar es Salaam, Tanzania. Email: pascalemmanuel2000@yahoo.com Phone: +255745731544

10.3 Introduction

It has been observed that nutrients discharge into the Lake Victoria is increasingly becoming a serious problem (Rutagemwa et al, 2005). This can be observed through the problem of eutrophication. The previous studies on nutrient loadings into the lake as well as their ultimate effects of eutrophication revealed that, there are high levels of nitrogen in both near and offshore areas of the lake. In addition, there is no uniform distribution of nitrogen both within area and time (Rutagemwa et al, 2005).

> The eutrophication effect of Lake Victoria is anticipated to be arising from the increased inflow of nutrients. Stimulated by these and other nutrients, increase in algal growth, and the shift in its composition towards domination by blue-green algae, has caused deoxygenation of the lake water, increased sickness for humans and animals drawing water from the lake, clogging of water intake filters, and increased chemical treatment costs for urban centers. Aside from the near-total loss of the deepwater species, the deoxygenation of the lake's bottom waters now poses a constant threat, even to fish in shallower portions of the lake, as periodic upwelling of hypoxic water causes massive fish kills. The increased nutrient loads have also spurred the water hyacinths infestations (World Bank, 1996).

Lake Victoria environmental management project has established a database on nutrient distribution spatially [area and depth] and temporal. Nitrogen transformation is not well established. Therefore, this study focused on the determination of spatial and temporal variation of nitrogen as well as identifying the processes governing its variation in this lake. The identified sources and sinks of nitrogen were used to initiate the establishment of management strategies regarding nitrogenous pollution of Lake Victoria.

10.4 Methodology

The Study area was a segment of Lake Victoria covering an area of about 35720 km^2, with a maximum depth of 73m, mean depth of 40m, and a volume of about

1,429km^3. It lies between latitude 01^o and 03'S and longitude 31^o 51.5' and 33^o 54.7'E.

For the purpose of this study only the Tanzanian part of the lake was considered. The study area was divided in two main zones namely the open waters herein referred to as pelagic zone (P) and the near shore areas herein referred to as the littoral zone (L). This classification is based on the depths with the pelagic area having depths greater than 15 metres and the littoral area having depth less than 15 metres. All 18 pelagic and 11 littoral stations were considered for the purpose of this work.

Each of the stations was located in such a way it fell on a transect joining the Ugandan or Kenyan stations of the harmonized monitoring network. This is meant to examine the temperature profiles along and across the lake at a number of instants in time. This can illustrate for example the variations from north to south and east to west at any one instant. See the figure 1 below:

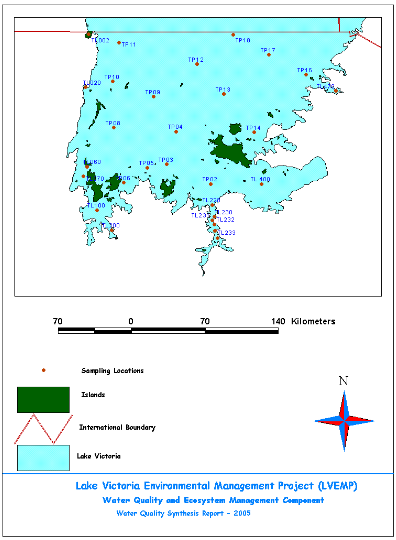


Figure 10.1: Monitoring Stations in Lake Victoria, ŚTanzaniaŠ (Source: LVEMP, 2005)

The data used for this study were obtained from LVEMP (Lake Victoria Environmental Management Project) database. Both chemical and physical water parameters for the lake were extracted from the same database. After database study, the useful information were extracted; off course these were whole about spatial (depth and location) and temporal (time) variation of nitrogen for all stations.
Likely processes for nitrogen transformation for all points were identified. Some forms of nitrogen such as NO3, NO2, NH3 and IN as shown in the conceptual diagram of nitrogen cycle were discussed.
The variations of nitrogen with depth and time were analyzed by the use of Excel. Only spatial variation of nitrogen was analyzed by the use of ArcView GIS. Other transformation processes of nitrogen in the lake were identified through modeling by the use of Stella II software. Finally, the comparison was made between the inputs and outputs of nitrogen in the lake.
The following passage further illustrates the methodology used for specific objectives:

1. **Spatial and temporal variation of nitrogen**
   The variation of nitrogen with depth were performed by the use of Excel software while Arcview GIS software was used to process data for the spatial variations of nitrogen for the Tanzanian part of Lake Victoria.

2. **Mass Balance analysis by comparing inflow and outflow nitrogen in Lake Victoria**
   Calculations and estimations of the inputs, outputs and accumulation were performed as follows:

- **Inputs:** these were established from the observed data of the river catchments for the respective months of the year. Data analysis was done by the use of Excel program and dilution equation was also involved in order to calculate the combined initial concentration from different rivers. The equation was: $C_0 = (Q_1C_1 + Q_2C_2 + (\dots)Q_nC_n)/(Q1 + Q2(\dots)Qn)$; Where C_0=initial concentration of the combined discharge of all river catchments was found to be1.497mg/l. Q_1, Q_2 up to Q_n=Discharge of the respective river catchments (m^3/s) and C_1, C_2, up to C_n=Nitrogen concentrations from the sub-catchments (mg/l)

- **Outputs:** data analysis was also done by the use of Excel, where average values of nitrogen were determined at every sampling station, integrated with depth, by considering different forms of nitrogen and on monthly basis.

- **Accumulation:** This was done through comparing the input and output values of nitrogen in the lake.

10.5 Results and Discussion of Findings

10.5.1 Spatial Variation of Nitrogen in Lake Victoria

Under spatial variation of nitrogen in the lake, all monitoring stations were considered for the purpose of calculating the average values of different forms of nitrogen.
Its summary is as shown in four different figures below:
Note: *The average values of nitrogen in the lake at 0.5m for the all period of monitoring activities (i.e. from year 2000-2005) were calculated for the respective sampling stations. The data were processed by the use of Arcview GIS; the results are as shown in different figures below; followed by their discussions at the end.*
The four figures 2-5 show that higher concentrations of nitrogen were observed in the Southern-East part of Lake Victoria.
The spatial variations of nitrogen shown above might be due to unequal effluent discharges into the lake from the catchments. And also it might be due to unequal distribution of population on the lake catchments area. This is because, anthropogenic activities are expected to increase and so do the nutrient loading in the lake, since agricultural intensity is a function of population growth.
The evidence can be revealed by figure 6 below:

Mwanza urban centre demonstrates both largest industrial and municipal loads followed by Mara and Kagera. This is due to the fact that Mwanza is an area of high population and it has many industries of different categories compared to Mara and Kagera.

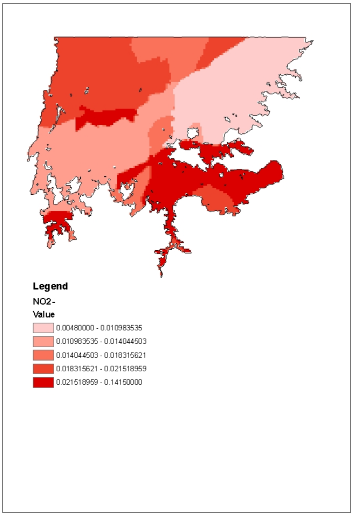


Figure 10.2: Spatial variation of Nitrite Nitrogen in the lake

10.5.2 Temporal (Monthly) Variation of Nitrogen in Lake Victoria

When monthly nitrogen variation is compared to that of rainfall, the two cases are similar as heavy and short rain periods are directly related to high amounts of nitrogen measured in the lake.
This confirms earlier findings that a lot of nutrients are introduced in the lake during the wet seasons of the year from the lake catchments due non-point sources of pollution which are atmospheric deposition as well as precipitation and land runoff through rivers from agricultural activities (LVEMP, 2002 and Tamatamah, 2002).

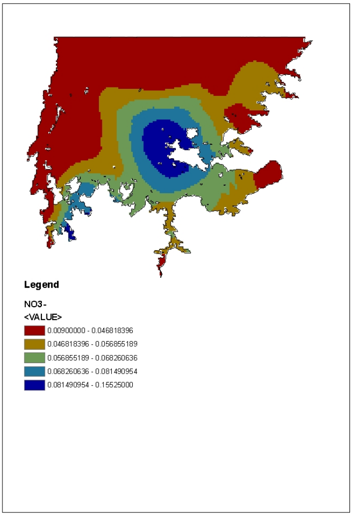


Figure 10.3: Spatial Variation of Nitrate Nitrogen in the Lake

10.5.3 Mass Balance through Comparing the Inflow and Outflow Nitrogen in the Lake.

The input and output values of nitrogen in the lake are as shown on figure 8 below:

Figure 8 indicates that due to a great difference between the inputs and outputs resulting in very high accumulation of nitrogen in the lake, we could have expected the effects of eutrophication of the lake; and that is what is happening for three decades now. And hence we need to put much emphasis in controlling possible sources of nitrogen loadings in the lake.

But, within the same figure 8 above, input nitrogen concentration in the months of January, May, August, November and December were found to be less than

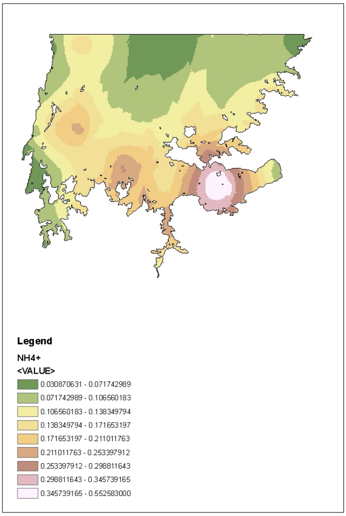


Figure 10.4: Spatial Variation of Ammonia Nitrogen in the Lake

output nitrogen measured in Lake Victoria. This might be caused by the process of resuspension of nitrogen in the burial sediments of the lake in these respective months. This confirms earlier observation by LVEMP (2005) that total mixing occurs in July to August in Lake Victoria and according to Fish (1957) and Newell (1960), complete mixing occurs in December to January for some stations causing resuspension of bottom sediments. Also Talling (1964) observed that in periods of February to May there is the development of deep thermocline that causes more suspended particles to be held by warm water.

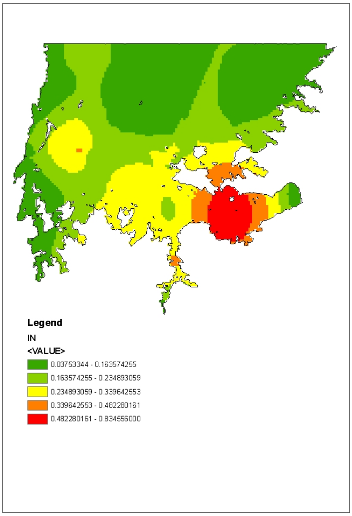


Figure 10.5: Spatial Variation of Inorganic Nitrogen in the Lake

10.5.4 Suggested Management Strategies of Lake Victoria

The notion that prevention is better than cure is in most cases considered and proven as the best option in the sense that it is the least expensive approach. This may prove to be the best and a long term rewarding approach towards ecological restoration of Lake Victoria.

Reduction of nutrient loads from point sources (industrial and domestic pollution) may be realized through improvement of the existing production processes, introduction of recycling of waste streams and application of the "end of pipe technology" such as treatment of effluents streams before discharging them into Lake Victoria.

Non-point nutrient sources to Lake Victoria (run-off and atmospheric deposition)

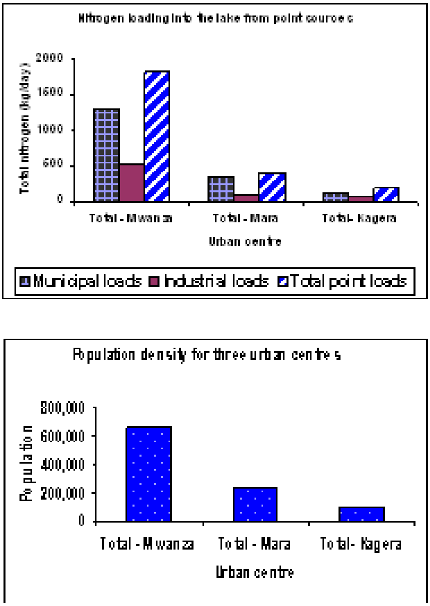
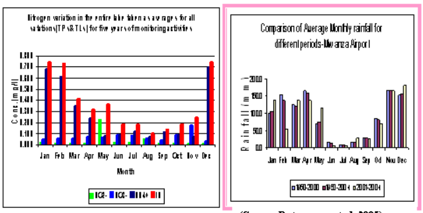


Figure 10.6: Comparison of total nitrogen from point sources and population density for three Tanzanian urban centres of the lake



(Source: Rutagemwa et al; 2005)

Figure 10.7: Variation of nitrogen with time as averages for both littoral and pelagic stations and in comparison with rainfall data

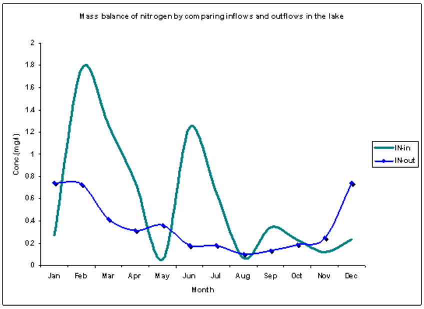


Figure 10.8: Accumulation as a result of differences between inputs and outputs of inorganic nitrogen (IN) in the lake with seasons of the year

may be checked through improvement of agricultural practices in the catchments area of the lake. Possible changes in agricultural practices include reduced and controlled use of artificial fertilizers and animal manure particularly on fields adjacent to the lake ecosystems.

Soil conservation, afforestation efforts and policies to control forest fires are among some best land management approaches to be strengthened in the catchments area of the lake in endeavours to reduce the nutrient loading to the lake. Utilization of the rice husks in the production of cement (Lema, 1995) can reduce the piling up (a solid waste problem) and burning of the same.

Enhanced management efforts of the lake should also include creation and maintenance of buffer zones (transition zones) between human settlements and the lake. These (the littoral and the supra-littoral zones) play an important role as filters and as nesting and spawning areas for fish and other aquatic organisms. The potential of wetlands to filter the incoming pollutants (especially nutrients) should be appreciated by maintaining their filtering efficiency by avoiding the prevailing habit of indigenous people to cultivate the wetlands.

Introduction of economic incentives by the government can also be aimed at waste reduction in the industrial sector. These may include increasing taxes on pesticides and fertilizers as well as production-tax rebates to encourage clean technologies, environmentally friendly activities, introduction of the ”polluter

pays" principle and attachment of the value to the lake itself.
The last, but probably the worth taking approach is that of human-resource development, which is a major constraint to proper planning, development and management of water resources, specifically Lake Victoria. Mass mobilization in the form of education and training programs on the importance of Lake Victoria pollution control efforts need be established and those existing to be strengthened.

10.6 Conclusions

From this study the following conclusions can be drawn:

- Spatial variation of nitrogen in the lake is directly linked to the extent of pollution discharges from municipalities, industries and agricultural activities
- Seasonal variation of nitrogen in the lake is directly related to rainfall intensity in the catchments; thus, a lot of nitrogen is contributed in the lake via runoffs from agricultural areas and wet atmospheric deposition
- Resuspension of bottom sediments due to complete mixing of the lake also contribute nitrogen in the same lake

Therefore, there is no way you can control nitrogenous pollution of Lake Victoria without focusing directly on the sources of nutrients from which it emanates. And the way forward toward sustainable management of Lake Victoria is therefore according to the suggested management strategies suggested above.

10.7 Recommendations

The following were recommended:

- There should be a research on phosphorus transformation in the same lake so that a common conclusion can be drawn concerning nutrients
- Study of the extent of lake pollution due to other chemical parameters
- Lastly, there should be improvement on the monitoring program by LVEMP to make sure that all daily data are made available in their database.

11 Assistance to Arba Minch Water Technology Institute (AWTI)

Uni.-Prof.Dr.-Ing. Gerd Förch[1]

11.1 A Brief History of German Project Support and its Impacts on the Ethiopian and German Partners

1979-1990 Training of Water Works Personnel within the Context of the Programme "Water Supply for 83 Towns" (BMZ, executed by GTZ/RODECO)
Training of water works personnel was done at the beginning at the "Provisional Arba Minch Training Centre" for the Ethiopian Water Resources Authority (EWRA) and the Urban Water and Sewerage Authority (UWSA) who were partner for the programme. The training centre was originally under the legal authority of the Ministry of Agriculture. Starting from 1986 the training measures (plumbers, mechanics, electricians, technical managers) were organised at the Arba Minch Water Technology Institute (AWTI), which was under the legal authority of the Ethiopian Water Resources Commission.
1986 Establishment of the Arba Minch Water Technology Institute by the Ethiopian Water Resources Commission
The establishment of AWTI was supported with major contributions by the European Commission, the German Government, the Government of the Soviet Union (establishment of workshops; water, hydraulic and geotechnical laboratories etc) and other donors.
Arba Minch was just a rural town of about 30.000 inhabitants with a young textile factory as the main employer. AWTI accommodated some 300 students;

[1] Civil Engineering Department,
University of Siegen,
57068 Siegen, Germany

programmes offered were on technician and diploma level.
1989 Start of Assistance to AWTI Project (BMZ, executed by GTZ / RODECO)
The German Government supported the Ethiopian Water sector since the late seventies as a key donor; this project is the follow-up of earlier support for the training of waterworks personnel rendered by the German Technical Cooperation GTZ; two German experts were seconded (until 1994).
02/92 Project Evaluation Mission conducted by a team of experts (U Siegen/U Munich) to re-start the German project support after the change of Government.
92 The first student from U Siegen spent his time at AWTI on an extended field research (DAAD sponsored) for his BSc thesis. A Draft of the **Appropriate Research Programme** (a result formulated in the log frame of the project) was prepared and endorsed; topics were related to the immediate environment of the institute (Lake and catchment research). First graduates from a degree programme (BSc Water Resources Engineering) left AWTI.
93 A first contract was signed between GTZ and U Siegen for sponsoring exchange of staff and students (start of the **Twinning Activities** as stipulated in the log frame of the project).
94 Support of the hydraulic laboratory with **research equipment** (U Siegen); Implementation of Infrastructure (Water Quality Laboratory, Library) and training of technicians (workshops) was terminated (implemented by RODECO).
95 5 students from U Siegen spent several months for their **field studies** at AWTI. A formal **University Cooperation Agreement** was signed between AWTI and U Siegen. The first **PhD** student started his studies on Water Resources Assessment in Lake Abaya Chamo Basin in Germany (TU Dresden/U Siegen).
A second PhD student (from Addis Ababa University) joined the research group in Dresden on medium hybrid (hydro) power schemes in the same and neighbouring basins.
96 Design of **AWTI Water Journal** completed. The GTZ Contract with U Siegen was renewed and expanded with TU Dresden as second partner. The **Integrated Water Resources Development Programme** was started for enhancing research capacity of AWTI in cooperation with U Siegen and TU Dresden. A Planning Workshop was held at AWTI for enhancing project implementation.
96-98 Two German **visiting lecturers** worked at AWTI (irrigation and geotechnical engineering) (CIM financed) to support the teaching activities.

97 The **1st AWTI Symposium** on Sustainable Water Resources Development was held and established a series of annual national conferences in water resources research.
The **10th Anniversary of AWTI** was honoured by the official visit from the **German Ambassador** and the Registrar of **U Siegen**.
98 Four AWTI lecturers were selected for their **MSc studies** at Rourkee University in India.
99 **New Departments** in Civil, Mechanical and Electrical Engineering started offering diploma and degree level courses.
2000 3 AWTI lecturers went to Germany for their **PhD studies** on sediment transport and water quality in the tributaries to Lake Abaya (TU Dresden/U Siegen).
2001 Seleshi Bekele Awulachew graduated as the **first** AWTI lecturer with a **PhD degree** from a **German University** (TU Dresden). A detailed **GTZ Project Evaluation** was conducted by experts from U Leipzig and the Federal Institute of Water Resources (BFG), Koblenz, resulting in an immediate **change of the project concept** with a focus on starting master programmes, supporting PhD research and initiating staff research.
Expansion of **hydrological and meteorological network** started for sustainable lake and catchment research.
2002 Field **research on soil erosion risk** assessment in Bilate River Catchment started by a German PhD student (U Siegen/FU Berlin) **International Field Course** on Watershed Management organised by U Siegen, U Trier and AWTI for an international and interdisciplinary group of students (DAAD sponsored). One AWTI lecturer started his **PhD Research on Lake Abaya** (FU Berlin). **Two Master's Programmes** started in **Irrigation and Drainage; and Hydraulic and Hydropower Engineering**.
DAAD Alumni Meeting on Natural Resource Management, AAU, supported by U Siegen and attended by Alumni from Ethiopia.
One PhD graduate with expertise in irrigation engineering (Rostock University, DAAD sponsored) joined AWTI.
Expansion Programme of AWTI started and AWTI grew to have 4 faculties and one graduate school.
Extensive field research conducted on Lake Abaya of a German Master student (U Trier).

2003 International Field Course on Watershed Management organised by FU Berlin, U Siegen and AWTI (DAAD sponsored). Last project phase started with focus on development of research potential in the water sector; the financial agreement between GTZ and AWTI for more flexibility in project implementation on the side of AWTI was signed. Joined Lake Research (DFG sponsored) was started by researchers from U Siegen and FU Berlin, with the support from AWTI on lake sediments. Project finding missions (U Siegen) were conducted to Kenya and Tanzania (sponsored by DAAD) for regional networking. DAAD Alumni Seminars were attended at the universities in Jimma and Awasa (U Siegen).

12 Composition and Distribution of the Surficial Sediment in Lake Abaya

Bogale Gebremariam[1], Birgitta Schütt[2] and Gerd Förch[3]

12.1 Extended Abstract

Four major units of surficial sediment deposits of Lake Abaya were recognized: (1) silty-sand; (2) clayey-sandy-silt; (3) sandy-silty-clay; and (4) silty-clay. These divisions are based on in situ visual inspection of the fresh samples used in this study. Most of the sediments of Lake Abaya consist of silty clay; pure sand rarely lies at the mouth of main rivers and near shore; yet most sand also contains silt and clay in significant amount. The distribution pattern is basically simple with a natural sorting of sediment units reflecting the different energy-regimes of the lake. Samples from near the mouth of the major rivers as well as exposed shallow regions parallel to the shorelines are characterized by high sand contents.
In shallow areas, particularly in the northernmost of the lake at Bilate River delta, the sand silt deposit extends southward. Marked increase in the sand population of samples taken near the mouth of major tributaries and the narrow passage between Gidicho Island and the east shoreline in the north basin suggests a possible higher energy environment. Regions of highest energy in the lake occur around the periphery of the lake in the nearshore zone. This zone predominates in the northern and eastern shores of the lake and is absent from regions with hilly surrounding topography. The bulk of the remainder of the lake is composed of sediment with high fine fraction which indicates the main depositional basin and part of the nearshore zones. These zones representing decreasing energy from

[1]Arba Minch University, Ethiopia
[2]Freie Universität Berlin, Germany
[3]Universität Siegen, Germany

nearshore to offshore environment verified by the textural characteristics.
The basin sediments are composed of fine grained, soft, sandy-silty-clay, and black, greyly black, grey, to reddish brown in colour. Near the shore line the sediment colour is dark grey to black except the water-sediment interface. A thin oxidized microzone of reddish brown, varying in thickness was observed at the surface of all mud samples. The black grey colour dominates near the east shores of the northern part of the south basin and the north basin, whereas the grey to brown colour is present near the west shore. The reddish brown clay at the most top surface of the recent mud increases towards the centre and south. This increasing reddish brown clay at the top suggests that the fine materials derived mainly from suspension are deposited at the low energy zones. The coarsening of the grain sizes can be observed by the decrease of the reddish brown at the most top of the water sediment interface and the darkening of the underlying light grey and brown to black grey and black onshore.
The sediments of Lake Abaya contain variable amounts of quartz, feldspar (essentially sanidine and andesine), clay minerals, calcite, and organic and carbonate carbons, with possible traces of hematite, magnetite, pyrite and hornblende in some samples. Hematite and magnetite were often detected in several samples. The presence and absence of these different minerals is a clear function of location.
The quartz content is found to be within the range of <1 to 40 percent. With respect to quartz concentrations in surfical sediments the lake basin is partitioned geographically. Percent content of quartz is high (> 20 percent) in the areas close to the mouths of the major rivers entering the lake in the north basin, except Shope River where the quartz fraction settled in the flat flood plain before reaching the lake. The influence of major streams in the distribution of sediment in the north basin is illustrated by the fact that sediments of the quartz fraction carried significant distance from the river mouth by flow current before its setting. The general trend for horizontal distribution of quartz minerals is decrease to the centre of the main basins and from north to the south. The main depositional zone of sediments in the north basin contain quartz content in the range of 5 to 10 percent, whereas the south basin has less than 5 percent in the majority of samples both from onshore and offshore. Considering the quartz population in Lake Abaya, it is convenient to define the north end as the area of high concentration and the

south end as the area of low concentration.
One of the most abundant constituent mineral in Lake Abaya sediments is feldspar. Lake Abaya sediments contain substantial quantities of feldspar ranging from 3 to 76 percent (the overall ratio of feldspar is about 28 percent). All surficial sediments collected from Lake Abaya contain feldspar. However, there is considerable variability: relatively high concentrations associated with nearshore sediments and stream deltas where the winnowing (erosion) action of waves or currents is not effective in preventing deposition of feldspar rich inputs. The distribution of feldspar followed nearly similar patterns in both north and south basins. Highest feldspar contents (more than 60 percent) are observed along the west and north shorelines near the mouths of major tributaries and the lower feldspar contents occur around the centre of the main basins. The distribution structure at the area of the narrow connection of the north and south basins corresponds approximately with that of the nearshore zones. Samples taken from the station close to the shoreline but within the influence of cliffs or hilly surrounds have lower feldspar content. The general feldspar concentration is less than 20 percent in the main basin, whereas the distribution in the north basin being slightly more variable than in the south basin.
Clay minerals are the most abundant mineral fractions in Lake Abaya sediments, ranging from 6 to 96 percent with a mean of 61 percent. Relatively low concentration of clay minerals is associated with nearshore sediments and stream deltas where the winnowing action of waves or currents is effective enough in preventing deposition of fines. Sediments with less than 25 percent of clay (hence mostly sandy) are restricted to the west shoreline and northernmost part close to the mouth of major rivers. Clay minerals show the expected general distribution pattern, with relatively low values in nearshore sediments increasing to maximum concentration at the centres of the main basins. Further noticeable patterns in clay distribution are: (1) increasing clay concentration in the nearshore sediments collected from stations surrounded by cliffs or hills; (2) generally low clay concentration at the narrow bottleneck transition and narrow passage between the largest Gidicho Island and east shore; and (3) a southward increasing tendency.
Most samples contain only small quantities of calcite; the amount ranges from less than 1 to 24 percent. Similar distribution patterns are observed in the north and south basins. Calcite is relatively more abundant in the shoreline than in the

main basins sediment samples of both north and south basins. No general trend is observable, but higher calcite values occur around narrow passages such as the area of bottleneck connection and to the east of Gidicho Island. Similar amounts of calcite values are observed in the west shoreline of south basin.
Organic carbon is generally low throughout the lake ranging from less than 1 up to 16 percent. Few values of organic carbon exceed 3 percent and most of them contain between 0.5 and 1.0 percent in both south and north basins. The highest organic carbon content was observed in the delta of Gelana River. Organic matter is more evenly distributed in the main basin and high organic carbon contents are confined to nearshore zones. The organic carbon distributions suggest that organic muds settled more rapidly close to the input points. A decline in organic carbon to the west is observed around the area of narrow bottleneck transition. Sediments from the western part of the narrow transition were mostly depleted of organic carbon. A marked difference is apparent between the organic sediment distribution in the sediment samples from deltas of the eastern and western major tributaries. Sediment samples from the deltas of eastern major tributaries showed higher relative abundance of organic carbon. Similar amounts were observed in the northern part of the south basin.
The carbonate carbon percentage is generally low throughout the lake ranging from 0 to 3 percent. No general trends are observable but higher carbonate carbon values occur along the eastern shoreline and in the bottleneck connection in the middle. Few values of carbon exceed 1 percent and most of the sediments in Lake Abaya contain less than 0.5 percent carbonate carbon. The sediments of the narrows have increased carbonate carbon ratios. From x-ray diffraction results, all the carbonates appear to be in the form of calcium carbonate with no siderite or dolomite, resulting in parallel distribution pattern with calcite.
Trace minerals detected by X-ray diffraction are principally hematite, magnetite, pyrite and hornblende. Widespread traces of hematite occurred in surficial sediments of Lake Abaya. The general distribution pattern shows increasing tendency southwards. The amount of hematite observed in the north basin is mainly less than 2 percent with occasional occurrence between 2 - 4 percent. It is observed that hematite is an important constituent of samples from the south basin. The distribution in the south basin does not have obvious pattern except for an increase towards the centre of the basin.

The distribution of magnetite in the surficial sediments of Lake Abaya is quite variable over the lake basin; an increasing tendency towards the mouth of main streams in the western side is evident. It is interesting to note that the maximum concentration is observed at the deepest sampling site in the south basin. Similarly, increasing concentration in the north basin was observed around the deepest zone. Another feature of magnetite distribution is that most of the samples from south basin are found to have more amounts of magnetite than the counterpart samples from the north basin.

The pattern of spatial variability for concentration of pyrite has some similarity with that of hornblende. Both minerals were detected rarely and showed no obvious trend in both south and north basins. Pyrite was identified in more samples from the south basin than from the north basin. The concentration of hornblende also exhibited similar but less pronounced patterns. Larger concentration of pyrite and hornblende are found in the south basin surficial sediments than in surficial sediments of the north basin. The largest pyrite occurrence was found near the Hare and Amesa deltas. Like pyrite, the largest concentration of hornblende was also found in the Hare Delta. On the other hand, pyrite concentrations were substantially smaller (less than 5 percent) than the percentage detected for hornblende (5 to 13 percent).

The textural trends observed in Lake Abaya assist the interpretation of the transport and deposition of sediments as a function of increasing or decreasing energy regimes due to wave and current activity. The general pattern of textural distribution characteristics of the lake sediments shows a dependence on different energy regimes. It suggests that relatively higher energy regimes exist in the northern due to stronger lacustrine currents and wave activities.

The strong current near shore zone will have considerable importance for the dispersal of any effluents near shore. Southward and offshore and into the central basin of bottom water flow is indicated by increase in suspended sediment concentration at station further south in the north basin. Major tributaries are expected to cause appreciable horizontal currents in the offshore direction at the vicinity of river mouths, particularly near the bottom. Since onshore winds are stronger than offshore wind, currents at the bottom and surface layers are quite strong and opposite in direction than in the case of offshore winds when suspended sediments are transported away from the river by the large currents. In

general, much of the river sediments would be deposited when the weak offshore wind causes insignificant bottom shear stress. These sediments, however, can later be resuspended, owing to the presence of strong onshore wind, and can be transported offshore by the strong currents near the bottom layer. It is, therefore, apparent that repeated accumulation, erosion, and transport results in the long-term transport of sediment from river to the deep portion of the basin.
It has been shown that decreasing percentages of sand (feldspar + quartz) are negatively correlated with increasing percentages of clay in Lake Abaya bottom sediments. In addition, the concentration of sand decreases and the concentration of clay increases with increasing depth. These mineralogical trends are due to hydrodynamic sorting by high-energy conditions at shallow proximal areas and declining energy as water depths increase at deep distal portions. The rapid energy decrease at stream mouths appears to allow deposition of high amounts of the sand and silt. As the energy level further decreasesout into the lake, clay particles begin to flocculate and the floccules are deposited alongside the remaining sand and slit. Any major trends in mineralogy compositions at deltas of major tributaries are likely to reflect source variation. Thus this investigation recognizes that mineral sorting trends of lake deposits, containing large amounts of detrital origins, might be used in interpretation of circulation and sediment transport patterns in shallow lake basins.

12.2 Reference

Alvarez, L. G., and S. E. Jones (2002). Factors influencing suspended sediment flux in the upper Gulf of California, *Estuarine, Coastal and Shelf Science*, 54, 747-759.
Baudo, R., and M. Beltrami (2001). Chemical composition of Lake Orta sediments, *Journal of Limnology*, 60(2), 213-236.
Bäuerle, E., D. Ollinger, and J. Ilmberg (1998). Some meteorological, hydrological, and hydrodynamical aspects of Upper Lake Constance, *Archiv für Hydrobiologie Special Issues, Advances in Limnology*, 53, 31-83.
Beletsky, D., S. H. Saylor, and D. J. Schwab (1999). Mean circulation in the Great Lakes, *Journal of Great Lakes Research*, 25(1), 78-93.
Bennett, J. R. (1974). On the dynamics of wind-driven lake currents, *Journal of*

Physical Oceanography, 4(3), 400-414.
Biggs, R. B. (1970). Sources and distribution of suspended sediment in Northern Chesapeake Bay, *Marine Geology*, 9, 187-201.
Blanton, J. O., and L. P. Atkinson (1983). Transport and fate of river discharge on the continental shelf of the southeastern United States, *Journal of Geophysical Research*, 88(C8), 4730-4738.
Blumberg, S., and B. Schütt (2006). Spatial distribution of lake sediments in the Lake Abaya bottleneck, Zbl. *Geol. Paläont. Teil I, 1/2*, 113 - 128.
Bordovskiy, O. K. (1965a). Source of organic matter in marine basins, *Marine Geology*, 3, 5-31.
Bordovskiy, O. K. (1965b). Accumulation of organic matter in bottom sediments, *Marine Geology*, 3, 33-82.
Carmack, E. C., C. B. J. Gray, C. H. Pharo, and R. J. Daley (1979). Importance of lake-river interaction on seasonal patterns in the general circulation of Kamloops Lake, British Colombia, *Limnology and Oceanography*, 24(4), 634-644.
Csanady, G. T. (1967). Large-scale motion in the Great Lakes, *Journal of Geophysical Research*, 72(16), 4151-4161.
Davis, M. B., and M. S. Ford (1982). Sediment focusing in Mirror Lake, New Hampshire, *Limnology and Oceanography*, 27(1), 137-150.
Douglas, R. W., and B. Rippey (2000). The random redistribution of sediment by wind in a lake, *Limnology and Oceanography*, 45(3), 686-694.
Fong, D. A., and M. T. Stacey (2003). Horizontal dispersion of a near bed coastal plume, *Journal of Fluid Mechanics*, 489, 239-267.
Fong, D. A., and W. R. Geyer (2002). The alongshore transport of freshwater in a surface-trapped river plume, *Journal of Physical Oceanography*, 32(3), 957-972.
Fukuda M. K., and W. Lick (1980). The entrainment of cohesive sediments in freshwater, *Journal of Geophysical Research*, 85(C5), 2813-2824.
Garvine, R. W., and J. D. Monk (1974). Frontal structure of a river plume, *Journal of Geophysical Research*, 79(5), 2251-2259.
Gebremariam, B., B. Schütt, and G. Förch (2004). Recent monitoring of suspended sediment stress, bulk water quality parameters and meteorological forcing on Lake Abaya, *Lake Abaya Research Symposium proceedings* - 2004, 11-20.
Grancini, G., and B. Cescon (1973). Dispersal processes of freshwaters in the Po River coastal area, *Limnology and Oceanography*, 18(5), 705-710.

Grant, W. D, and O. S. Madsen (1979). Combined wave and current interaction with a rough bottom, *Journal of Geophysical Research*, 84(C4), 1797-1807.
Håkanson, L. (1981). On lake bottom dynamics-the energy-topography factor, *Canadian Journal of Earth Sciences*, 18, 899-909.
Håkanson, L. (1977). The influence of wind, fetch, and water depth on the distribution of sediments in Lake Vänern, Sweden, *Canadian Journal of Earth Sciences*, 14, 397-412.
Hawley, N., and B. M. Lesht (1992). Sediment resuspension in Lake St. Clair, *Limnology and Oceanography*, 37(8), 1720-1737.
Hilton, J., and M. M. Gibbs (1984). The horizontal distribution of major elements and organic matter in the sediment of Esthwaite Water, England, *Chemical Geology*, 47(1-2), 57-83.
Hilton, J., J. P. Lishman, and P. V. Allen (1986). The dominant processes of sediment distribution and focusing in a small, eutrophic, monomictic lake, *Limnology and Oceanography*, 31(1), 125-133.
Hilton, J. (1985). A conceptual framework for predicting the occurrence of sediment focusing and sediment redistribution in small lakes, *Limnology and Oceanography*, 30(6), 1131-1143.
Holmes, P. W. (1968). Sedimentary studies of late quaternary material in Windermere Lake (Great Britain), *Sedimentary Geology*, 2, 201-224.
Horowitz, A. (1974). The geochemistry of sediments from the Northern Reykjanes Ridge and the Iceland-Faroes Ridge, *Marine Geology*, 17(2), 103-122.
Jacobs, S. J. (1974). On wind-driven lake circulation, *Journal of Physical Oceanography*, 4(3), 392-399.
Jellison, R., R. F. Anderson, J. M. Melack, and D. Heil (1996). Organic matter accumulation in sediments of hypersaline Mono Lake during a period of changing salinity, *Limnology and Oceanography*, 41(7), 1539-1544.
Jeong, J., and S. D. McDowell (2003). Characterization and transport of contaminated sediments in the southern central Lake Superior, *Journal of Minerals and Materials Characterization and Engineering*, 2(2), 111-135.
Johns, W. D., R. E. Grim, and W. F. Bradley (1954). Quantitative estimates of clay minerals by diffraction methods, *Journal of Sedimentary Petrology*, 24(4), 242-251.
Jones, B. F., and C. J. Bowser (1978). The mineralogy and related chemistry

of lake sediments. In: Lerman, A. (ed.), *Lakes: Chemistry, Geology, Physics*. Springer-Verlag, New York, 179-235.
Kennedy, S. K., and N. D. Smith (1977). The relationship between carbonate mineralogy and grain size in two alpine lakes, *Journal of Sedimentary Petrology*, 47(1), 411-418.
Krause, J., B. Schütt, and S. Thiemann (2004). Hare River catchment - Landscape character of a drainage basin in the southern Ethiopia Rift Valley. In: Wenclawiak, B., and S. Wilnewski (eds). *Sedimentary Studies in Tropics and Subtropics*, Weiterbildung in Siegen, 14, 16-40.
Largier, J. L. (1993). Estuarine fronts: How important are they? *Estuaries*, 16(1), 1-11.
Lawrence, G. A., K. I. Ashley, and Yonemitsu (1995). Natural dispersion in a small lake, *Limnology and Oceanography*, 40(8), 1519-1526.
Lesht, B. M., and N. Hawley (1987). Near-bottom currents and suspended sediment concentration in southeastern Lake Michigan. *Journal of Great Lakes Research*, 13(3), 375-386.
Lonsdale, P., and J. B. Southard (1974). Experimental erosion of North Pacific red clay, *Marine Geology*, 17, M51-M60.
Luettich, R. A., Jr., D. R. F. Harleman, and L. Somlyòdy (1990). Dynamic behaviour of suspended sediment concentrations in a shallow lake perturbed by episodic wind events, *Limnology and Oceanography*, 35(5), 1050-1067.
Lund-Hansen, L. C., M. Petersson, and W. Nurjaya (1999). Vertical sediment fluxes and wave-induced sediment resuspension in a shallow-water Coastal Lagoon, *Estuaries*, 22(1), 39-46.
Miller, M. C., I. N. McCave, and P. D. Komar (1977). Threshold of sediment motion under unidirectional currents, *Sedimentology*, 24, 507-527.
Murthy, C. R. (1972). Complex diffusion processes in coastal currents of a lake, *Journal of Physical Oceanography*, 2, 80-90.
Nelson, C. S. (1983). Bottom sediments of Lake Rotoma, *New Zealand Journal of Marine and Freshwater Research*, 17, 185-204.
Peeters, F., A. Wuest, G. Piepke, and D. M. Imboden (1996). Horizontal mixing in lakes, *Journal of Geophysical Research*, 101(C8), 18,361-18,375.
Petticrew, E. L., and J. Kalff (1991). Predictions of surficial sediment composition in the littoral zone of lakes, *Limnology and Oceanography*, 36(2), 384-392.

Pickett, R. L. (1980). Observed and predicted Great Lakes winter circulations, *Journal of Physical Oceanography*, 10(7), 1140-1145.
Piñones, A., A. Valle-Levinson, D. A. Narváez, C. A. Vargas, S. A. Navarrete, G. Yuras, and J. C. Castilla (2005). Wind-induced diurnal variability in river plume motion, Estuarine, *Coastal and Shelf Science*, 65(3), 513-525.
Ryan, D. A., A. D. Heap, L. Radke, and D. T. Heggie (2003). *Conceptual Models of Australia's Estuaries and Coastal Waterways Applications for Coastal Resource Management*, Geoscience Australia Record 2003/09, 135 pp.
Saylor, J. H., and G. S. Miller (1987). Studies of large scale currents in Lake Erie, 1979-80, *Journal of Great Lakes Research*, 13(4), 487-514.
Schnurrenberger, D., J. Russell, and K. Kelts (2003). Classification of lacustrine sediments based on sedimentary components, *Journal of Paleoliminology*, 29, 141-154.
Schoettle, M., and G. M. Friedman (1973). Organic carbon in sediments of Lake George, New York: Relation to morphology of lake bottom, grain size of sediments, and man's activities, *Bulletin of the Geological Society of America*, 84, 191-198.
Schröder, R. (1984). An attempt to estimate the fish stock and the sustainable yield of Lake Ziway and Lake Abaya, Ethiopian Rift Valley, *Arch. Hydrobiol./Suppl.*, 69(3), 411-441.
Schütt, B., and S. Thiemann (2004). Modern water lever and sediment accumulation changes of Lake Abaya, southern Ethiopia - A case study from the Bilate River delta, northern lake area, *Sustainable management of headwater resources: Research from Africa and India*, 137-154.
Schütt, B., S. Thiemann, and B. Weneclawiak (2005). Deposition of modern fluvio-lacustrine sediments in Lake Abaya, south Ethiopia - A case study from the delta areas of Bilate River and Gidabo River, northern basin, Z. *Geomorph*, N. F., 138, 131-151.
Sheng, Y. P., and W. Lick (1979). The transport and resuspension of sediments in a shallow lake, *Journal of Geophysical Research*, 84(C4), 1809-1826.
Shotbolt, L. A., A. D. Thomas, and S. M. Hutchinson (2005). The use of reservoir sediments as environmental archives of catchment inputs and atmospheric pollution, *Progress in Physical Geography*, 29(3), 337-361.
Smith, N. D. (1978). Sedimentation processes and patterns in a glacier-fed lake

with low sediment input, *Canadian Journal of Earth Sciences*, 15, 741-756.
Stocker, R., and J. Imberger (2003). Horizontal transport and dispersion in the surface layer of a medium-sized lake, *Limnology and Oceanography*, 48(3), 971-982.
Sundborg, Å. (1992). Lake and reservoir sedimentation and prediction and interpretation, *Geografiska Annaler. Series A, Physical Geography*, 74 (2-3), 93-100.
Thomas, R. L. (1969). A note on the relationship of grain size, clay content, quartz and organic carbon in some Lake Erie and Lake Ontario sediments, *Journal of Sediment Petrology*, 39, 803-809.
Thomas, R. L., A. L. W. Kemp, and C. F. M. Lewis (1972). Distribution, composition and characteristics of the surficial sediments of Lake Ontario, *Journal of Sedimentary Research*, 42(1), 66-84.
Van Maren, D. S., and P. Hoekstra (2005). Dispersal of suspended sediments in the turbid and highly stratified Red River plume, *Continental Shelf Research*, 25(4), 503-519.
Warrick, J. A., L. A. K. Mertes, L. Washburn, and D. A. Siegel (2004). A conceptual model for river water and sediment dispersal in the Santa Barbara Channel, California, *Continental Shelf Research*, 24(17), 2029-2043.
Warrick, J. A., L. A. K. Mertes, L. Washburn, and D. A. Siegel (2004). Dispersal forcing of southern California river plumes, based on field and remote sensing observations, *Geo-Marine Letters*, 24(1), 46-52.
Winant, C. D. (1980). Coastal circulation and wind-induced currents, *Annual Review of Fluid Mechanics*, 12, 271-301.
Wright, L. D., and C. A. Nittrouer (1995). Dispersal of river sediments in coastal seas: Six contrasting cases, *Estuaries*, 18(3), 494-508.
Wright, L. D. (1977). Sediment transport and deposition at river mouths: A synthesis, *Geological Society of America Bulletin*, 88 (6), 857-868.
Yuretich, R. F. (1979). Modern sediments and sedimentary processes in Lake Rudolf (Lake Turkana) eastern Rift Valley, Kenya, *Sedimentology*, 26(3), 313-331.
Yuretich, R. F. (1986). Controls on the composition of modern sediments, Lake Trukana, Kenya. In: Frostick, L. E. et al. (eds). *Sedimentation in the African Rifts, Geological Society Special Publication*, 25, 141-152.

13 Analysis of dyke breaks during the 2002 flood in Saxony/Germany

T. Heyer, H.-B. Horlacher, D. Carstensen, U. Bielagk,[1] *E. Bielitz and U. Müller*[2]

13.1 Abstract

In August 2002 exceptional precipitation caused extreme floods in Saxonian Rivers. As a consequence along the rivers Mulde and Elbe alone about 100 dyke breaks were reported. Intensive research was conducted in order to determine the main causes auf failure, the failure mechanisms and to possibly describe the dam break chronology along both rivers. The paper reports about some of the results mainly focusing on the wide description of the dyke breaks in many respects, e.g. main causes of failure, circumstances of damage, direction of collapse.

13.2 Introduction

In August 2002 exceptional precipitation caused the occurrence of extreme flash and river floods in many Saxonian Rivers. In most cases record water levels were observed. As a consequence flood protection devices became damaged resulting in heavy losses in economic terms and even human life. Regarding the dykes only along the rivers Mulde and Elbe about 100 dyke breaks were reported on Saxonian territory.

Unfortunately only one week after the first flood another serious flood warning urged the authorities to immediately close all breaches with any materials available. Due to this time pressure a professional survey of the breaches could not be

[1]Institute for Hydraulic Engineering and Applied Hydromechanics, Technische Universität Dresden, Germany
[2]Dam Authority of the Free State of Saxony, Pirna, Germany

Figure 13.1: General map of the study area

accomplished.
However, in 2004 the Dam Authority of the Free State of Saxony contracted the Institute for Hydraulic Engineering and Applied Hydromechanics of the Technische Universität Dresden (IWD) to conduct subsequent analysis regarding the dyke breaks in order to outline the main failure causes and modes.
The area under investigation stretched across the catchment areas of the rivers Vereinigte Mulde (including the tributaries Freiberger and Zwickauer Mulde) and Elbe on Saxonian territory (Fig. 1 & Table 1).

First of all intensive inquiries had to be made due to the time offset of the analysis to the flood event. Beside the inquiries at the local authorities (Dam Authority of the Free State of Saxony, communities, municipalities) also fire brigades, emer-

River	Length (in km)
Elbe	≈ 175
Vereinigte Mulde	≈ 92
Freiberger Mulde	≈ 54
Zwickauer Mulde	≈ 11

Table 13.1: River reach lengths

gency forces and other potential eye witnesses were interviewed over a period of one year in order to get the best overall picture for each dyke break. All of the relevant locations had been investigated on site. As a result various data was gathered. All information was administrated in a database also for the purpose of a statistic analysis of the collected data.

13.3 Hydrology

13.3.1 Flood causes

In the first two weeks of August 2002 exceptional rainfall occurred in the Elbe catchment. Thunderstorms with excessive precipitation were followed by less intense but long lasting rainfall. According to the classification of van Bebber, who categorised typical paths of low pressure areas, this weather situation was of type Vb (Fig. 2). This meteorological situation already caused several flash and river floods in central Europe in the past. Nevertheless, the 2002 event was extraordinary, since precipitation rates reached the alltime records at many locations. The rain gauge Zinnwald-Georgenfeld in the Ore Mountains measured 312mm of precipitation in just 24 hours time. This is the highest value ever measured in Germany.
Beginning on the 12^{th} of August the areawide precipitation generated flood situations in many Saxonian rivers. Especially the smaller mountain rivers showed their enormous destructive potential through the occurrence of flash floods.

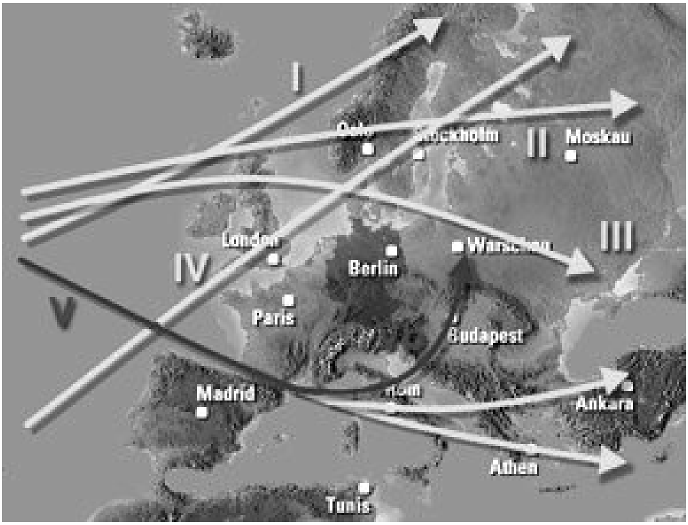


Figure 13.2: Path classification of low pressure areas after van Bebber (source: www.zdf.de)

13.3.2 Elbe River

Mainly because of the precipitation in the Moldau and Eger catchments on the 6^{th} and 7^{th} of August the water levels in the river Elbe have risen rapidly. The Dresden gauge showed a water level rise of 400cm in only 3 days. On the 17^{th} of August the peak water level was reached with 940cm above datum so the maximum ever recorded value was exceeded by 63cm (Tab. 2).

According to the statistical analysis the related discharge of 4680m^3/s is approximately equivalent to a 125-year flood. One should bear in mind that the design flood for protection measures in Germany is usually set to a flood event with a statistic occurrence probability of 0.01 (1 in 100 years).

Gauge	HHW	Year (past)	W_{peak}	Date	□
		cm	cm		cm
Usti (CZ)	1119	1845	1185	16/08/02	+66
Schoena	868	1941	1204	17/08/02	+336
Dresden	877	1845	940	17/08/02	+63
Torgau	863	1940	949	17/08/02	+86

Table 13.2: Comparison of peak water levels at selected gauge stations along the Elbe River.

13.3.3 Mulde river

On the 11^{th} of August the discharge of the Mulde River was still on average. Caused by the excessive precipitation on the 12^{th} and 13^{th} of August the storage capacity of the upriver area was quickly reached. Hence, the biggest share of rain was transferred directly as overland flow. The Mulde River is in the upper part divided into two rivers, the Freiberger Mulde and the Zwickauer Mulde (see Figure 1). Coincidentally the discharge peaks of both tributaries simultaneously reached the confluence on the 13^{th} of August, thus creating a tremendous flood wave. Consequently the water levels in the river exceeded the historical records by up to 3 metres. The statistical analysis of the peak discharges along the river Mulde yielded to recurrence intervals between 100 - 300 years. Therefore, flood protection measures along the river were significantly overloaded.

13.3.4 Database

With the objective of clearly storing and arranging the collected data a relational thematically structured database was established. Having in mind the parameters that could influence the dyke’s failure mechanisms, a large number of attributes were defined within a record: geographic location, geometry, distance of toe to the main river bed (direct dykes, with floodplain), dyke structure (homogeneous, heterogeneous), subsoil structure, vegetation, pre-existing damage caused by animals, breach geometry and approximate time of failure to name but a few.
Before data could be entered in the database it was necessary to verify the reported dyke failures. Since there is no fixed definition when a dyke actually has t’t’failed“ the following criteria were defined to determine the set of dyke failures:

- sudden or gradual development of a breach due to a critical combination of parameters

- not manually initiated

- free surface flow through the breach with the water level below original dyke crest in the long run

The verification procedure identified 84 record sets that fulfilled these criteria (Fig. 3).

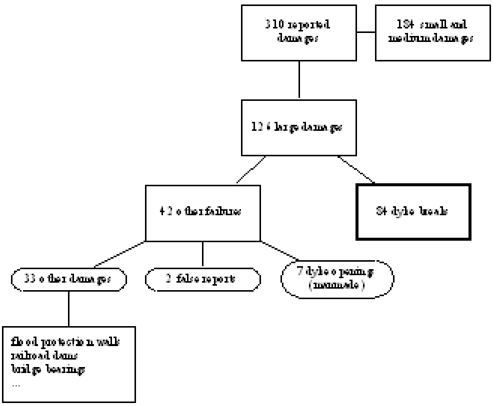


Figure 13.3: Verification outcome of reported damages

From the mathematical point of view a large number of statistical evaluations are possible, since beside single parameter evaluations multiple parameter analysis can be conducted for the whole record. Restrictions derive from the varying information content in the records and from physically reasonable combinations of parameters. In the following only selected evaluations will be presented.

13.4 Analysis

13.4.1 Chronology of failures

The determination of the dyke failure chronology turned out to be very difficult, since most dyke breaks occurred in rural areas. Only in very few cases could the exact moment of failure be appointed through the reports of eye witnesses. However, by analysing aerial photographs it was possible to determine dates of failure for all dyke breaks. It became evident that the frequency of occurrence correlates directly with the transition of the flood waves in the rivers Mulde and Elbe (Fig. 4).

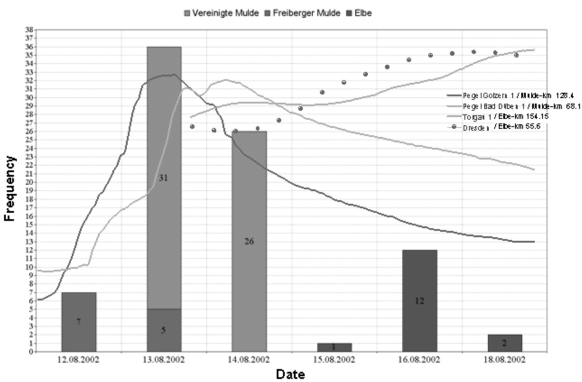


Figure 13.4: Frequency of dyke breaks related to stage hydrographs of the 2002 flood

Comparing the stage hydrographs in the Mulde River the influence of the dyke breaks should be noticed.
It appears that most dyke breaks occurred after the design water levels were exceeded so that most dykes achieved their design goals. Because of the limited knowledge about the moment of failure and the scarcely available stage hydrographs along both rivers more detailed conclusions were not possible.

13.4.2 Degree of damage

The development of different breach shapes depends on the failure mechanism, the duration, direction and intensity of flow through the breach and on the conditions of the dyke body and subsoil. Regarding their cross sections (perpendicular to the dyke's axis) the breaches were classified into three groups - partial damage (a), total damage (b), total damage with large scours (c) (Fig. 5).

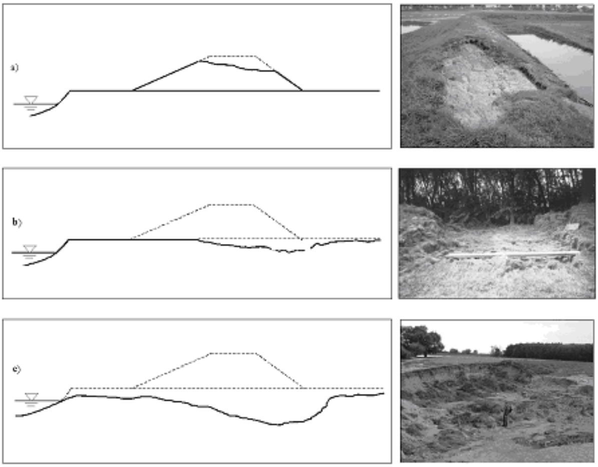


Figure 13.5: Breach classification regarding cross section profiles

As a result almost $2/3$ of the dyke breaks were assigned to the set "total damages with scour" (Fig. 6 & Tab. 3). Especially along the river Mulde, where the water levels far surpassed the design values, this breach type was determinant.

13.4.3 Dyke overtopping

As mentioned before large-scale dyke overtopping occurred during the 2002 flood. Overtopped dyke sections could be located by analysing air photographs taken during the flood event. The analysis showed that in 74 cases (88%) dykes broke in overtopped sections. It should be noted that although the dykes were

Degree of Damage	Sum	Elbe	Mulde	Freiberger Mulde
partial	14	9	3	2
total	18	1	14	3
total with scour	52	5	40	7
Sum	84	15	57	12

Table 13.3: Frequency of dyke breaks classified after degree of damage

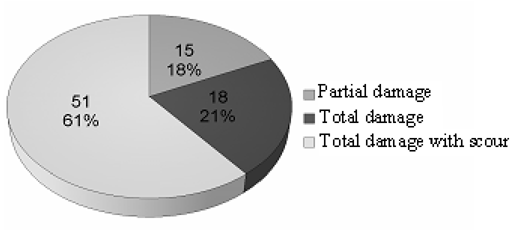


Figure 13.6: Breach classification, criteria: degree of damage

overtopped over long stretches the breach itself developed more or less only punctually (Fig. 7). Hence, the existence of certain additional conditions is responsible for the breach development on a specific location. Regarding dyke failure mechanisms the overtopping of the dyke may trigger several types of failure, e.g. outer erosion of inner slope, infiltration and others (Kortenhaus & Oumeraci 2002, Lecointe 1998, Wahl 1998). Further detection of the main failure mechanism initiated by overtopping can only be done on the basis of measured or observed data. In most cases such information was not available.

13.4.4 Direction of failure

Overloaded river embankments usually fail from river to land since this is in most cases the direction of the pressure gradients in the dyke body and the subsoil. The analysis of dyke failures along the river Mulde lead to the somewhat surprising result, that 15 (26%) out of 57 dyke breaks failed in the opposite direction.
This phenomenon can be explained as follows: landside failures are caused by "normal" waterside failures in upstream river sections. The area behind the dyke

then becomes flooded. If the spreading of the water is limited through the topography of the flooded area (“polder region“) the water level in that area can rise very quickly. The water head in the polder region can be higher than the actual water level in the river profile.

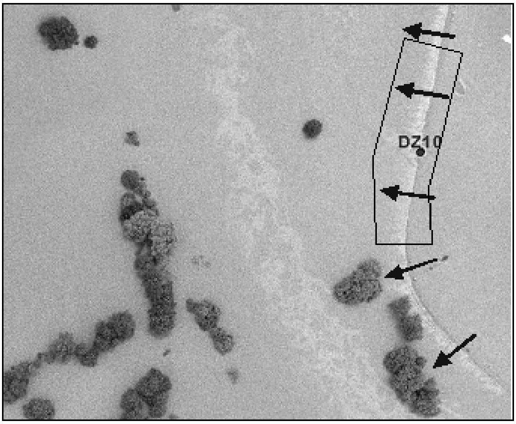


Figure 13.7: Overtopping and final breach extend (Mulde River)

During the 2002 flood landside dyke overtopping with overflow depths of about 1m had been observed whereas the water level in the river bed was still some decimetres below the dyke crest. Landside overtopping of dykes mainly occurred in corners of the polder area, which where for instance formed by the dyke connection to land of higher elevation or connections of dykes with bridge bearings. On the Elbe River all embankments failed from the waterside to landside since the dyke protected territory is extremely flat. As a consequence one single dyke failure usually caused the irrigation of large areas. Near the town of Torgau one breach with a width of about 340m flooded an area of over 20km^2.

13.4.5 Failure Modes

The failure of river embankments is in most cases the consequence of a time-depending combination of several causes and effects. Event trees are one theo-

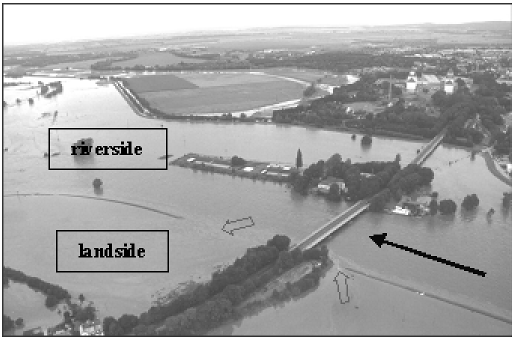


Figure 13.8: Landside and waterside failure near Wurzen (Mulde River)

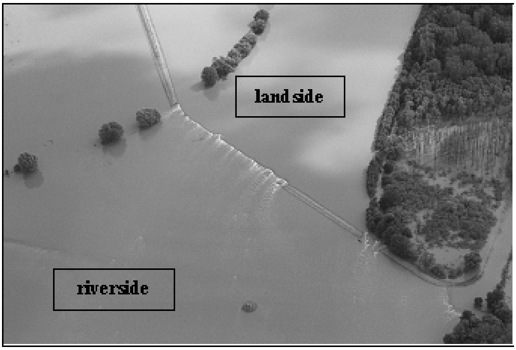


Figure 13.9: Landside failure near Grubnitz (Mulde River)

retic model to map the natural processes based on a theoretical background as for instance specified by Foster & Fell (2000) for the case of failure due to internal erosion.

Concerning the dyke breaks under investigation the problem posed was the subsequent determination of the main failure modes or even the single events which lead to failure. In order to achieve reliable results the presence of direct observa-

tions is required, which was rarely the case. Therefore in most cases a combined parametric-subjective analysis was conducted.
Given the limited project frame a detailed analysis was not feasible. The assignment of the main failure causes, which are presented in the following give only a rough estimate about the prevailing types of failure.
Alone the number of possible types of failure depends on the structure and the location of the dyke and is therefore variable. Kortenhaus & Oumeraci (2002) give an overview about the possible types of failure and name about 20 mechanisms. Although mainly focussed on sea dykes most outlined failure types are also relevant for river embankments. With regard to the large number of breaches and the uncertainty in reasoning due to the limited amount of information, only four general classes of the main failure types were defined (Fig. 10).

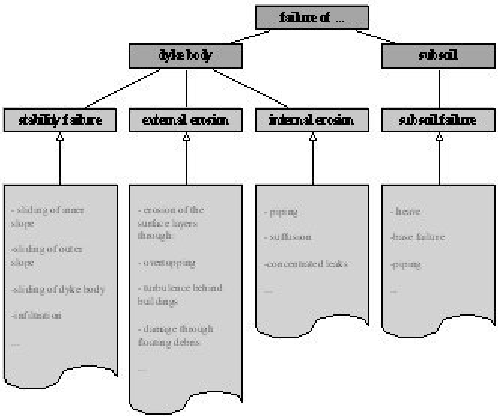


Figure 13.10: Classification of main failure modes

13.5 Conclusions

The 2002 flood relentlessly revealed the weak points of the existing flood protection systems along many rivers in Saxony. Regarding the river embankments over

100 failures were reported, many of them were investigated within this project. Developing a dyke break database is one major achievement of this project. The detailed compilation of over 80 failures during one flood event is considered extremely valuable for practical and even more for scientific purposes. Further research activities might build upon this information since the records might be used for calibration, validation and verification purposes, e.g. in breaching models or risk assessments.

13.6 References

Bielagk, U. 2004. Diploma thesis: *Analyse der Deichbrüche an Mulde und Elbe während des Hochwassers 2002 im Bereich Sachsen*. Institut für Wasserbau und Technische Hydromechanik (IWD), Technische Universität Dresden, Germany

Carstensen, D. & Horlacher, H.-B. et al 2004. B*ewirtschaftungsmaSSnahmen zum Erhalt der Schutzfunktion der Deichanlagen in Sachsen*. Institut für Wasserbau und Technische Hydromechanik (IWD), Technische Universität Dresden, Germany

Foster, M. & Fell, R. 2000. *Use of event trees to estimate the probability of failure of embankment dams by internal erosion and piping*. In Proceedings of the 20^{th} International Congress on Large Dams (ICOLD), Beijing, Vol. 1, pp. 237-260.

Kortenhaus, A. & Oumeraci, H. 2002. *Probabilistische Bemessungsmethoden für Seedeiche (ProDeich)*, Leichtweiss-Institut für Wasserbau, Technische Universität Braunschweig, Germany

Lecointe, G. D. 1998. *Breaching Mechanisms of Embankments. MSc project. School of Civil Engineering*, The University of Birmingham, United Kingdom

Singh, V. P. 1996. *Dam Breach Modeling Technology*. Kluwer Academic Publishers, Dordrecht, The Netherlands Wahl, T. 1998. Prediction of Embankment Dam Breach Parameters: A Needs Assessment, IAHR Congress San Francisco, USA, 10.-15. August 1997

LfUG. 2002. V*orläufiger Kurzbericht über die meteorologisch-hydrologische Situation beim Hochwasser im August 2002*. Landesamt für Umwelt und Geologie, Dresden, Germany

14 IWRM and Water Governance

Striving for 'Incentive Compatibility' in the Water Sector

Walter Huppert[1]

14.1 Abstract

Integrated Water Resources Management (IWRM) and Water Governance: there are hardly any other topics that have drawn so much attention of water professionals in recent years. The reasons are obvious. Water is becoming a scarce resource in many countries and awareness is rising that this has serious consequences in many respects. The challenge of Water Governance is to reconcile the often conflicting water related demands made by different sectors and provide "the means by which order is accomplished in the relations between the various stakeholders in order to avoid potential conflicts and realize mutual gains" (Williamson). This calls for the ability to quickly analyse a multi-sectoral water system with respect to its "incentive compatibility". In other words, water managers need to gain a quick overview whether or not the governance of a water system applies rewards or sanctions ("the incentives") in a way that is compatible with the intended overall goals and objectives. An approach that allows a rapid appraisal of this "incentive compatibility" is presented in this paper. Its application is demonstrated with a practical IWRM case example.

14.2 Introduction

IWRM. Practically everyone working in the field of water management is familiar with this acronym. Indeed, since the end of the nineties, IWRM - Integrated

[1]IWRM and Water Governance, Paper presented at the second "Lake Abaya Research Symposium", May 7-11, 2007, Arba Minch, Ethiopia.

Water Resources Management - has become synonymous with the progressive, future-oriented, environmentally sound management of water resources. IWRM, and the goal of managing existing water resources in an “integrated“ way, are today an accepted creed among international water experts.
How could the call to practise integrated management of water resources become such a unanimous and all-embracing leitmotif for the water management of the future? The reasons are obvious: the dramatically worsening water shortages in many parts of the world pose new problems for various aspects of water management. The need to ensure optimum “production“, allocation and utilisation of the scarce water resources is confronted with a large number of divergent demands and interests. Supplies of drinking and service water at rural and urban level, agriculture, fisheries, power generation, waste management, shipping, forestry, tourism and the conservation of water-related ecosystems - all are stakeholders who can rapidly become competitors for the scarce water resources that are of existential importance to all. This situation is further aggravated by the problem of water quality. In many places, rivers and streams are being transformed into receiving watercourses for waste water, creating major health problems, causing ecological problems and further restricting the availability of usable water.
The options of overcoming water shortages by increasing water availability, for instance by expanding existing storage capacities and transmission systems, by tapping new water resources and in particular by making greater use of groundwater reserves, are already exhausted in many places, and soon will be in others. Climate change seems set to worsen the problem. In situations like this, which affect developing countries in particular, the challenge is to find ways of making “optimum“ use of the scarce, life-giving water resource, and of ensuring optimum distribution. Hence, the actual and future demand on water engineers is to widen their perspective and take into account these underlying conflicts of interest. This leads to the goal of “holistic“ management of water resources, i.e. to integration and to balancing various claims and interests. The propagation of IWRM is the expression of this objective at the international level.

14.3 Understanding IWRM

The most frequently cited definition of IWRM is the one put forward by the "Global Water Partnership" (GWP). It reads as follows:
"Integrated Water Resources Management is a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems."
A list of aspects that ought to be considered in an integrated or coordinated manner within the framework of IWRM is presented, for instance, by Svendsen (2002). This list calls for the integration / coordination of the following topics, fields and sectors:

- Various sectors of water use (drinking water and waste water/sewage, agriculture, industry, transport, others)
- Administrative responsibilities
- Ground and surface water
- Human and ecological water use
- Demand and supply management
- Water quantity and water quality
- Land and water use
- Transboundary claims on water use.

A closer look at this list allows to identify three distinct fields of integration / coordination:

1. Inter-sectoral integration: the coordinated consideration and handling of different resource sectors and water uses with a view to achieving a common, supra-sectoral management (e.g. coordination between water uses for agriculture, domestic uses and ecology).

2. Intra-sectoral integration: the coordination of different aspects of management within a particular water sector (e.g. conjunctive use of groundwater and surface water in irrigation).

3. The coordination of roles and responsibilities of multiple actors at different levels of decision-making and administration (e.g. water managers at local, district and national levels).

Taken together, these integration needs result in the requirement to coordinate the interactions, i.e. the services and supporting *services*[2] performed by multiple actors with respect to water in various sectors. Such services may consist in directly allocating, storing, distributing or providing water and/or protecting the water sources and maintaining water quality or they may be supporting services that enable such interventions (e.g. planning, book-keeping, management of personnel etc.).

14.4 From Water Management to Water Governance

Considering IWRM, it is important to be aware of the meaning of the term "management". This term has both process-related and institution-related connotations. The former points to management functions like planning, controlling, organizing and leading. The latter makes reference to a group of individuals or a particular organisational arrangement ("the management") that has decision making authority and can issue orders and directives to subordinate organisational members. Here, serious misunderstandings may arise with regard to the management term used in IWRM. The claim of IWRM for an "integrated management" is often exclusively interpreted in a way that calls for one overarching umbrella organisation - e.g. a river basin agency - that assumes overall decision making power over the various sector related organisations. However, this must be perceived as only one option in the context of IWRM. Often also, sector organisations will retain their original role, mandate and sector related responsibilities while being called upon by IWRM to interact and coordinate closely with relevant other sector organisations. What is important in either case is the need to

[2] With the term "services" we refer to all activities, provisions and functions that are the subject of interactions or exchange relations between two partners (principal and agent; provider and client; customer and supplier; superior and subordinate staff etc.)

set up mechanisms that help to organize the relations between the different actors within and between the sectors in a way that allows for easy mutual adjustment of activities and appropriate balancing of conflicting interests. A wide variety of social steering mechanisms are possible to be used here. Depending on the situation at hand, such mechanisms may involve laws, regulations, market mechanisms, formal and informal agreements or also - as in the case of centralised agencies - hierarchical administrative mechanisms. Approaches and mechanisms like these, that balance out the interests of a wide variety of actors and align them with a common goal, are best being described using the term *"governance"*[3]. "Water Governance", in adaptation of the governance definition put forward by *Williamson*[4] , may be defined as follows:
"Water Governance is the means by which order is accomplished in the relation between the different stakeholders in the water sector in order to avoid potential conflicts and realize mutual gains in the context of IWRM".

14.5 "Incentive Compatibility" - Getting the Incentives Right

Following such an understanding of Water Governance, where order must be accomplished in multiple relations between many stakeholders, it becomes evident that effective Water Governance hinges upon two preconditions:

1. The governance mechanisms intended to "accomplish order" in the relations of certain stakeholders with other stakeholders (e.g. in the relation between the Department of Water with the Department of Agriculture; between the regional water engineer with the local water engineers etc.) so as to optimize IWRM, must be designed in such a way that they *provide incentives* to these stakeholders to engage positively in such a relationship;

2. The incentives created by the governance mechanisms applied in multiple stakeholder relationships must be compatible with the overall goals or ob-

[3] To avoid an additional discussion about the term "governance" it will be taken for the purposes of this article to mean the collection of rules, pertinent implementing mechanisms and interactive processes which gear the activities of a large number of (relatively) independent actors to a common goal, and which coordinate these activities.

[4] Williamson states that "Governance is the means by which order is accomplished in a relation in which potential conflict threatens to upset opportunities to realize mutual gains" (Willimson, 1996).

jectives set by the IWRM concept in question ("Incentive Compatibility"); e.g. incentives provided by water fee arrangements in irrigation must be designed such that they contribute to actual water savings in agriculture as a partial goal of IWRM (in contrary, water fee arrangements linked to area irrigated often provide incentives to use excessive volumes of water).

An *incentive* for a certain actor is understood here as any reward or sanction, which has as its effect a modification of the actor's behaviour. *Incentive Compatibility* is achieved if the applied incentives induce a change in behaviour that is in line with previously set goals or objectives.
Incentive Compatibility is a basic but widely neglected concept in water management and IWRM. Its importance is self-evident: if relations between multiple stakeholders are governed in ways that provide no (or even negative) incentives to the actors to behave in ways appropriate to achieve IWRM objectives, water governance will have dysfunctional effects. Therefore a simple analysis of Incentive Compatibility will provide a meaningful check of the potential chances of success or failure of given IWRM and water governance arrangements. Such an Incentive Compatibility Analysis (ICA) should include five essential steps (see also *Fischer et al.*, 2004):

1. Specifying the IWRM goals and objectives

2. Determining the essential services and service relations within the network of multiple stakeholders

3. Identifying the applied governance mechanisms

4. Assessing the effectiveness of the applied governance mechanisms for incentive creation as well as the compatibility of the incentive provision with the specified goals and objectives.

Such an analysis can be established independently of the overall organisational context of the applied IWRM concept, whether it may be based on a centralised governance mode (such as a river basin organisation) or on a mode of decentralised but well coordinated sector organisations.

14.6 Case Example - the “Neste System“ in Southern France

14.6.1 The General Set-up

Considering the following case example, attention should *not* be given to the organisational set-up as such - which in this case centres around a regional semi-public water management company - but to the mechanisms that govern the service relationships, the incentives created by these governance mechanisms and the compatibility of the incentive provision with the established IWRM goals and objectives.
The “Neste System“ is a system of storage reservoirs, canals, small rivers and irrigation schemes that is located in the region of Midi-Pyrénées, in southern France. The hilly landscape in that region stretches from the south to the north and is interspersed with a total of 17 small rivers and streams, which, owing to the morphological structure, only have extremely small water-catchment areas. As a result, water flow would, under normal conditions, not be possible all year round. To improve the availability of water, both for agricultural purposes and for drinking water supplies to the cities and local communities in this area, a link canal (“canal de la Neste“) was built some time ago. This canal is fed by storage dams in the Pyrenees and carries water both to the river Neste and to the head of the other 17 small rivers and thus makes it possible to provide minimum flows of water even during the time of the year when these rivers would normally run dry.
The “Compagnie d’Aménagement des Coteaux de Gascogne“ (CACG) is a semi-public company (“societé d’économie mixte“) that is mandated by the state to promote the development of the region of Midi-Pyrénées primarily through measures in the field of IWRM. CACG regards itself explicitly as a service provider to irrigation farmers, water supply companies and to the State (with respect to environmental services and the maintenance of state owned infrastructure). It claims to be one of the few large-scale, regional water management organisations that achieve full cost recovery in operating and maintaining its various sub-systems.
The overall goal consists in an effective and efficient IWRM in the region Midi-Pyrénées. Major objectives contributing to that goal are the following:

1. Supplying water all year round to streams and rivers for different water uses (irrigation, water supply, industry)

2. Maintaining minimum flow rates in the water courses for reasons of environmental protection

3. Ensuring effective and efficient management of parts of the region-wide irrigation systems on the basis of a concession by the state

4. Maintaining the entire (state owned) infrastructure of the Neste canal system in full working order (“sauvegarde du patrimoine national“). Looking at the water governance practices in the Neste Systems reveals particularly high incentive compatibilities. Given the limitations of space, we will highlight such achievements with only two examples that relate to objectives (b) and (c).

14.6.2 Maintaining minimum flows in the water courses

Objective

IWRM-objective (b) in the Neste System consists in maintaining minimum flows in the water courses during dry seasons for reasons of environmental protection.

Service Contents

The service “to maintain minimum flows in the water courses“ can be regarded as a service provided for the state water agency (Agence de l’eau). This service includes appropriate management of the storage reservoirs in the Pyrénées and a well balanced water allocation to the various water courses. In addition to an absolute minimum flow of 4 m^3/s, the cumulative total of a further 5m^3/s (in autumn and winter, this figure is set at 6.5m^3/s) has to be maintained in the 14 re-supplied streams and rivers at the point of entry into the receiving Garonne in order to sufficiently dilute the sewage that has been released. Minimum flows of this kind are enforced by the state for reasons of hygiene. Furthermore, account is thus taken of ecological aspects, such as the conservation of natural flora, as well as the concerns of the fishing industry.

Governance Mechanisms and Incentive Provision

In return for maintaining minimum flow rates, the water agency grants the CACG a subsidy known as “aide à la gestion des étiages“ (subsidy for managing minimum water levels). This subsidy is financed from a water duty, i.e. a sort of tax paid to the water agency. This economic governance mechanism has positive incentive implications for CACG, for the state and for the general public and water users: CACG, not wanting to lose this subsidy, will strive to live up to the given objective; the general public and the water users who all are interested to have environmentally healthy water courses, are ready to pay that tax contribution; and the state has the incentive to get the service provided to the public without a substantial burden for the treasury.
There is an additional governance mechanism in place to provide incentives for objective achievement: The CACG has a considerable incentive to maintain the agreed minimum flows in the water courses, since the level of subsidy provided to the CACG by the water agency is linked up with certain ideal hydrographic standards of water provision in the canal system, which are monitored directly by the state Department of Environment (DIREN). If the CACG fails to keep to the defined levels, it will face a cut in subsidy payments from the water agency. Consequently, the CACG has the incentive and makes every effort to adhere to the regulations governing water supplies.
The example shows that there is a high compatibility between the IWRM objective to maintain minimum flows in the water courses and the incentives provided by the chosen governance mechanisms to the various stakeholders.

14.6.3 Operating and Maintaining the Irrigation Perimeters

Objective

As mentioned above, CACG is commissioned by the state to achieve the objective of effective and efficient operation and maintenance of a certain part of the irrigation perimeters in the region. In fact, CACG has been granted a 10-year franchise for the water management of a total of about 70 000 ha of irrigated area. This franchise is extended automatically each year, unless the water users wish for some other arrangement.

Service Contents

The service of CACG consists in providing water at previously agreed flow and pressure rates to the field hydrants of individual water users. Thus, the CACG is responsible for operating all system components right through to the individual point of withdrawal and also for any maintenance and repair work. The special feature of this type of service provision is that the CACG has a direct service relationship with the *individual* water users and not with a user association. Nevertheless, the CACG still supports the respective associations in their administrative and bookkeeping activities, as an additional service provision.

Governance Mechanisms and Incentive Provision

The above services are funded by contractually agreed fees the irrigation farmers pay to the CACG. These fees cover the entire service package and are made up of a basic rate and a certain cubic-metre price. A key governance mechanism is to be seen in the actual concession that the state grants the CACG. A franchise agreement regulates the individual rights and duties of the CACG whilst a "Conseil Administratif", which includes representatives of important stakeholders, ensures its correct interpretation and implementation.
Water provision itself is agreed with each individual farmer separately within the framework of a contract governing the supply of irrigation water (contrat de fourniture d'eau d'irrigation). This contract covers the operation of all system components right through to individual field hydrants and corresponding maintenance and repair work by the CACG.
The incentive for the CACG to provide a good and reliable service centres on the possibility of the franchise being extended. In case the water users perceive CACG services to be unsatisfactory, the 10-year franchise may not be renewed and the commission may be awarded to another provider.
As for the water users themselves, they have high incentives to belong to such franchise perimeters as an attractive alternative to an irrigation system run by the farmers themselves. Here, they are not dependent on the operational capacity of a membership-based organisation and not at its mercy should it lack such capacity. They can rely on the agreed quantities of water being supplied to the edge of their respective fields. Although no specific organisational structure is in place to

govern any supra-ordinate issues within the “périmètres en concession“, they all, without exception, have a formal or informal association that discusses general issues concerning the perimeter with the CACG, and, on the other hand, is also represented in the Neste Commission. With this important discussion forum - an additional governance mechanism - they feel involved in the overall decision making process.
There is another important governance mechanism: The franchise perimeters differ decisively from other forms of operation in that the function of “police d’eau“ has been transferred by the state to the CACG. CACG implements this service to the state via state certified experts (“agents assermentés“). This results in the fact that water users that do not pay their contractual fees can be shut off from the water supply. Without any doubt this acts as a particularly strong incentive to pay the fees.
Here again, a look at the stated objective, the actors involved, the services provided and the governance mechanisms that are in place reveals a high incentive compatibility. No wonder then, that CACG has gained high reputation for its effectiveness.

14.7 Conclusion

While IWRM and water governance have attracted high attention by water research and management in recent years, an important precondition for their functioning is widely neglected: appropriate *incentive creation* and *incentive compatibility* are essential requirements to be met. Approaches for a rapid “Incentive Compatibility Analysis“, as the one presented here, can help to identify and remedy critical governance deficits both in IWRM and in mono-sectoral water management.

14.8 References

Fischer, A., L. Petersen and W. Huppert (2004). Natural Resources and Governance: Incentives for Sustainable Resource Use. A Manual. GTZ, Eschborn
Svendsen, Mark (2001). Integrated Management of Water in River Basins. Brief 13, in: Overcoming Scarcity and Quality Constraints, IFPRI, 2020-Vision Paper,

Focus 9. *Williamson, Oliver E. (1996).* The Mechanisms of Governance. Oxford University Press.

15 Impact of Land Use / Cover Change on Streamflow: the Case of Hare River Watershed, Ethiopia

Kassa Tadele[1] *and Gerd Förch*[2]

Extended Abstract

15.1 Introduction

This study investigates land use/cover dynamics and its consequent impacts on the streamflow at Hare River watershed, Southern Rift Valley Lakes Basin, Ethiopia. It further addresses the seasonal streamflow variability due to land use/cover dynamics and understand the upstream-downstream linkages with respect to irrigation water use. Hare River watershed is situated between 37^o 27' and 37^{o}37' Eastern longitude and 6^o 03' and 6^o 18' northern latitude and drains a land area of 167.3 km^2 into Lake Abaya. It is mainly covered by steep mountains characterized through abrupt faults and rises from 1,180m a.s.l. to 3,480m a.s.l. The climate of the area ranges from tropical to alpine due to its great difference in altitude and topographical elevation. The average annual temperature are 23^{o}C & 14^{o}C, and mean annual rainfall are 890mm & 1430mm at the lowland and highland respectively. Though Hare River is small, it is extensively used by downstream farmers to irrigate a command area of 2224 hectares. Smallholder agriculture is the dominant form of resources use in upper watershed where the population density is high (323 persons per km^2).

The knowledge how land use/cover change influence watershed hydrology will

[1]Arba Minch Water Technology Institute, Arba Minch University, P.O. Box 21, Arba Minch, Ethiopia, kassa.tadele@uni-siegen.de

[2]Research Institute Water and Environment, University of Siegen, Paul-Bonatz-Str. 9-11, 57076 Siegen, Germany, gerd.foerch@uni-siegen.de

enable local governments and policy makers to formulate and implement effective and appropriate response strategies to minimize the undesirable effects of future land use/cover change or modifications. Given that impacts of land use/cover change on water resources are the result of complex interactions between diverse site-specific factors and offsite conditions, standardized types of responses will rarely be adequate. General statements about land-water interactions need to be continuously questioned to determine whether they represent the best available information and whose interests they support in decision-making processes (FAO, 2002).

Hydrologic response is an integrated indicator of watershed condition, and changes in land use/cover may affect the overall health and function of a watershed. Such changes vary spatially and occur at different rates through time. Direct and powerful linkages exist among spatially distributed watershed properties and watershed processes (Miller et al, 2002). To envisage the future effects of land use change on river flow, it is important to have an understanding of the effects that historic land use/cover changes have had on watershed hydrological system. Moreover, detecting and simulating the effects of land use/cover change and management on hydrological processes requires a new and improved procedure to instrument watersheds, based on the hydrological sensitivity due to land use/cover changes at sub-watershed levels.

The method to evaluate the hydrological impacts due to land use/cover changes and land use modifications can be achieved through integrating Remote Sensing, Geographical Information System (GIS) and Soil and Water Assessment Tool (SWAT) model. SWAT model (Arnold et al., 1998) is developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in watersheds with varying soils, land use and management conditions over long periods of time. It is a semi-distributed physically based model that operates on a daily time step. SWAT is capable of simulating a high level of spatial detail by allowing the division of a watershed into a large number of sub-watersheds. It has been used to predict streamflows which were compared favourably with measured data for a variety of watershed scales. Recently, some researchers applied SWAT to a meso-scale watershed to assess the impact of land use changes on the annual water balance and temporal runoff dynamics (Santhi et al., 2001, Van Liew, M.W., and J. Garbrecht. 2003).

15.2 Methodology

This study was carried out in four steps. First, a database was established and land use/cover maps for the years 1967, 1975 and 2004 were produced to analyse the land use/cover dynamics. Second, SWAT simulation run was carried out using a set of input variables and sensitivity analysis was performed to identify parameters that most influenced predicted streamflow. Third, the efficiency of the model was assessed by comparing simulated and observed annual and monthly streamflow. Fourth, in order to test the assumption that land use/cover change has affected the watershed streamflow, further simulations were performed using both maps for the same period.
The basic data sets that are required to develop an input database for the model are: topography, soil, land use and climatic data. A digital contour was processed and interpolated to derive a Digital Elevation Model (DEM) of the study area. The DEM was used to delineate the topographic characterisation of the watershed and determine the hydrological parameters of the watershed such as slope, flow accumulation, flow direction, and stream network. AVSWAT, an ArcView interface, was used to delineate the watershed. To capture heterogeneity in physical properties, the watershed was divided into fifteen sub-watersheds and each one of the sub-watersheds was partitioned into Hydrologic Response Units (HRUs) that consist of homogeneous land use, management, and soil characteristics. A total of ninety-two HRUs were created at which the model computes the effect of management practices.
Simultaneously, spatial databases were developed using black and white aerial photographs of 1967 and 1975, and a satellite image of 2004 was obtained from Ethiopian Mapping Agency (EMA) and was verified by intensive on-field land use mapping in 2005. Three land use/cover maps of 1967, 1975 and 2004 were produced through visual interpretation of the aerial photographs and supervised classification based on maximum likelihood of the satellite image. The generic approach of land use/cover change analysis is based on post-classification comparison method, which is commonly employed in land cover change detection studies (Liu and Zhou 2004). Spatial analyses were carried out at watershed and

sub-watershed levels to describe land use/cover changes over time, measure the rate of change, and relate overall land use/cover changes to streamflow variability and physical features of the landscape. For this study only the 1975 and 2004 land use/cover maps were utilized due to the limited availability of streamflow data.

Climatic input data were obtained from Ethiopian National Meteorological Service Agency (NMSA) for the nearby weather stations. Daily precipitation, maximum and minimum temperature, wind speed, humidity and sunshine hour data of Arba Minch, Chencha and Mirab Abaya stations were utilized for this study as per the availability. To account for the orographic effect of precipitation, a polynomial regression equation was fitted to the rainfall-elevation relation, and elevation bands were used to generate rainfall inputs for the sub-watersheds. On the other hand, a soil database was established through an intensive data collection from forty-two representative sites throughout the watershed. The physical characteristics including soil texture, bulk density, and hydraulic conductivity were identified from the samples collected at different layers. Similarly, the management operations required for the HRUs were determined through a socioeconomic assessment conducted during the field research work and secondary information obtained from the district agricultural office.

The time series of discharge at the outlet of a watershed is the most important data to calibrate and validate the hydrological model. A daily streamflow data of 1980-2005 was obtained from Ethiopian Ministry of Water Resources (MoWR) that has been gauged at the outlet of the watershed. The data was divided in to two sets of the periods 1980-1991 and 1992-2005 corresponding to the 1975 and 2004 land use/cover maps respectively. Both periods were again divided into two for calibration and validation processes. The streamflow data was also used to evaluate streamflow components with an automated digital base flow separation technique and compare the result provided by the SWAT2005 model.

In order to asses the variability of streamflow due to the land use/cover dynamics from 1975 to 2004, the SWAT model was run using the two land use/covers maps while setting all the other set of input variables similar for both simulations. Prior to the calibration and validation process, a sensitivity analysis, based on the integration of Latin Hypercube and One-Factor at a Time sampling techniques, was performed to reduce uncertainty and provide parameter estimation guidance.

Both manual calibration and autocalibration tool of SWAT2005 based on Shuffled Complex Evolution (SCE_UA) algorithm, which is a global search algorithm for minimization of a single function, were utilized in the calibration process. Moreover, Parameter Solutions (ParaSol), which is an optimization and statistical uncertainty analysis method, and Sources of Uncertainty Global Assessment using Split SamplES (SUNGLASSES) are being used to estimate the uncertainty originating from parameter uncertainty and evaluate the correctness of the model prediction to be used for decision making. In this study, the model performance was assessed using Coefficient of Determination, Root Mean Square Error, and the Nash-Sutcliffe model efficiency. After calibrating and validating the model using the two land use/cover maps for their respective periods, the model was also run using both the 1975 and 2004 land use/cover maps for the period of 1992-2005 to quantify the impacts introduced on the streamflow due to the land use/cover change.

15.3 Results

The results of the land use/cover change analysis indicated that farmland and settlement class has expanded which is mostly associated with the decrease in forest class. As indicated in fig1., the farmland and settlement land use class grows from 28.3% cover in 1975 to 52.0% cover in 2004 with a rate of change of +136.9 ha/year. On the other hand forest cover reduced from 28.4% in 1975 to 16.2% in 2004 with a rate of change of -70 ha/year. The upper watershed and the border zone in between the uplands and lowland were the most affected parts of the watershed.

The sensitivity analysis pointed out that eight parameters were found to be most crucial parameters for the studied watershed, namely: Curve Number (CN), Soil Available Water Capacity (SOL_AWC), Soil Depth (SOL_Z), Soil Evaporation Compensation Factor (ESCO), Saturated Hydraulic Conductivity (SOL_K), Slope (SLOPE), Groundwater “revap“ Coefficient (GW_REVAP) and Groundwater Recession Factor (ALPHA_BF. These parameters generally govern the surface and subsurface hydrological processes and stream routing.

The measured and predicted streamflow was calibrated and validated on monthly and annual time steps. The results of these tests illustrated that the monthly Co-

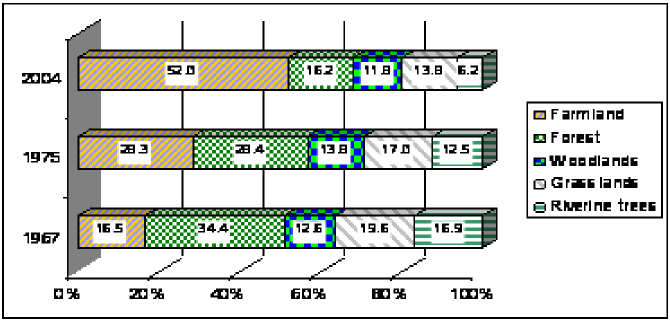


Figure 15.1: Land use/cover dynamics (1967-2004)

efficient of Determination values range from 0.72 to 0.92, with the highest value (0.92) during the calibration of the model for the 2004 land use/cover condition. Likewise, the Nash- Sutcliffe coefficient varies from 0.41-0.92 for annual and 0.43-0.82 for monthly calibrations and validations that verified the model had predicted quite satisfactory annual and monthly flows.

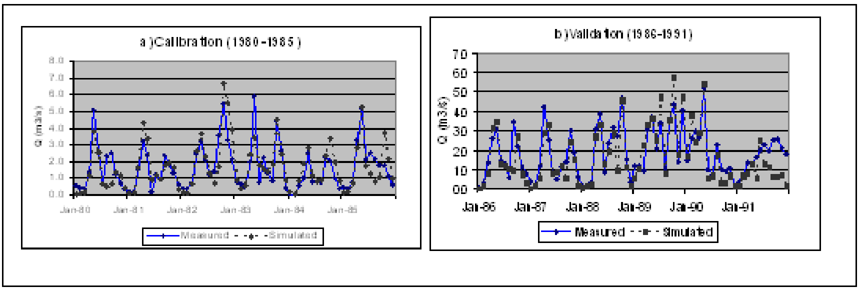


Figure 15.2: Monthly calibration and validation for the period of 1980-1991

Moreover, it was identified that mean monthly discharge for wet months has increased by 12.5% while in the dry season it has decreased by up to 30.5% during the 1992-2004 period due to the land use/cover change. As a result, at present

Hare River only satisfies 15.75% of downstream irrigation demand even with 100% diversion during the dry season.
Use of GIS and remote sensing were found to be helpful tools to detect and analyse spatio-temporal land use/cover dynamics. SWAT2005 was useful in analyzing the impacts of land use/cover changes on streamflow and it provides an acceptable hydrological performance. Accordingly, this study reveals the successful application of the SWAT model in areas with limited readily available data and hence can be utilized in similar watershed elsewhere.
From the results of this study, it can be concluded that Hare Watershed has experienced a significant change in land use/cover over the past four decades. It can be presumed that deforestation and increase in farmland that was manifested by the rapid increase in human population has altered the whole Hare Watershed in general and some sub-watershed in particular. Modifications of land uses (rain-fed to small scale irrigations) are expected in the near future, since farmers in the upper watershed have already started using ground water and surface water to cultivate market oriented cash crops like apple. This study also highlighted that detail understanding of historical land use/cover changes and consequent impacts on streamflow will enhance our capability to predict future land use modifications. Therefore, further scenario simulations and optimization strategies that take into account upstream-downstream water users can provide valuable information to devise more effective watershed management strategies to sustain the livelihoods of the local community.

15.4 References

Arnold, J. G., R. Srinivasan, R. S. Muttiah, and J. R. Williams, 1998. Large area Hydrologic modelling and assessment; part I: model development. J. of Amer. Water Res. Assoc. 34(1):73-89.
FAO, 2002. Land-Water Linkages in Rural Watersheds Case Study Series. Food and Agriculture Organization of the United Nations, Rome, Italy.
Liu, H. and Zhou, Q., 2004. Accuracy analysis of remote sensing change detection by rule-based rationality evaluation with post-classification comparison, *International Journal of Remote Sensing*, 25(5), 1037-1050.
Miller,S.N., W.G. Kepper, M.H. Mehaffey, M. Hemandez, R.C. Miller, D.C.

Goodrich, K.K. Dovonald, D.T. Heggem, and W.P. Miller, 2002. Integrating landscape assessment and hydrological modelling for land cover change analysis. J. of Amer. Water Res. Assoc. 38(4):915-929.
Santhi, C., J.G. Arnold, J.R. Williams, W.A. Dugas, R. Srinivasan, and L.M. Hauck, 2001. Validation of the SWAT model on a large river basin with point and non-point sources. J. of Amer. Water Res. Assoc. 37(5):1169-1188.
Van Liew, M.W., and J. Garbrecht, 2003. Hydrologic simulation of the Little Washita River Experimental Watershed using SWAT. Journal of the American Water Resources Association 39(2):413-426.

16 Evaluation of the Suitability of Pangani Falls Redevelopment (Hydro Power) Project in Pangani River Basin, Tanzania: An IWRM Approach

R.J. Kimwaga[1] *and S. Nkandi* [2]

16.1 Abstract

The Pangani Fall Redevelopment (Hydropower) Project which is in Pangani River Basin (PRB) in Tanzania has experienced years of declining discharges of the Pangani River, which has caused lower production (electricity) figures. Many streams and valleys that have contained water before are now dry and contain water only during the rainy season. As a result, the Pangani Falls Hydro-power Station has over the last five years seen a declining production capacity. The Nyumba ya Mungu Reservoir and Power Station experienced during the 2005 the lowest water level ever. Human activities have been responsible for the degradation of many watersheds within PRB. Others will state poor management of resources, climate change and low rainfall as the reasons for declining discharges of Pangani River. The competing demands for water for small and large scale irrigation schemes, industrial and domestic consumption and for power generation have and may in the future create unnecessary turmoil's. This study therefore saw the need to examine the problem of entire PRB in an integrated approach. This study was therefore carried out to meet the following objectives;

- To assess the institutional arrangement of Pangani River Basin, that is Pangani Basin Water Office (PBWO), by looking at its strengths and weak-

[1]University of Dar es Salaam, Department of Water Resources Engineering, P. O. Box 35131, Dar es Salaam, Tanzania. Fax +255222410029, email: rkimwaga1970@yahoo.co.uk

[2]University of Dar es Salaam, Department of Water Resources Engineering, P. O. Box 35131, Dar es Salaam, Tanzania. Fax +255222410029

nesses

- To compare the water use of hydropower production and irrigation by examining the water use for different crops, economic returns from irrigated crops and hydropower generation as well as the impact of irrigation and hydropower production on water resources
- To analyze people's perception of the use and management of water for irrigation and environmental needs
- To propose the future scenarios for water availability in the PRB

The study has shown that PBWO has been able to bring fragmented water uses and users together, it has also internalized upstream/downstream and other conflicts and thereby made them easier to deal with. The study has also shown that the management of the basin's water resources will require improved funding which currently it is inadequate. People have now positively perceived the best management practices for watersheds which aim at correcting land use mistakes by conserving and protecting their biological value and to integrate watershed practices with other resource development efforts such as forestry, agriculture, energy and water resources. Likewise the study has shown that agriculture is the biggest user of water which has also more economic return per m^3 of water than hydropower.
Keywords: *hydropower, irrigation, integrated watershed practices, integrated water resources management.*

16.2 Introduction

The increasing scarcity of water resources in the Pangani River Basin in Tanzania calls for strategic water resources management that will ensure the sustainability of water supply and the goods and services supplied by aquatic environments, as well as the efficient and equitable use of these resources. Sustaining water supplies for the numerous users in the basin will depend on reducing losses due to catchments degradation and wastage due to inefficient practices. One of the water users in the basin is the Pangani Fall Redevelopment Project (Hydropower).
The Project has experienced years of declining discharges of the Pangani River,

which has caused lower production (electricity) figures. Many streams and valleys that contained water before are now dry and contain water only during the rainy season. As a result, the Pangani Falls Hydro-power Station has over the last five years seen a declining production capacity. The Nyumba ya Mungu Reservoir and Power Station experienced during the 2005 the lowest water level ever. Inflows to Nyumba ya Mungu reservoir from the rivers Ruvu and Kikuletwa are declining and very little or no water is actually provided to Pangani River by the Mkomazi Tributary. What are the reasons? Human activities have been responsible for the degradation of many watersheds within Pangani River Basin. Vegetation degradation and soil erosion problems on both flat as well as steep terrains in watershed areas are associated with unsustainable land use practices, such as poor cultivation techniques, increased population pressure, de-forestation and overgrazing. These are of course depending on several factors of which one - degradation of watersheds in combination with too large amount of uncontrolled and controlled water abstractions from surface and ground water sources - is probably the main factor. Others will state poor management of resources, climate change and low rainfall as the reasons for declining discharges of Pangani River. The competing water demands for small and large scale irrigation schemes, industrial and domestic consumption and for power generation have and may in the future create unnecessary turmoil's.
The study was therefore carried out to assess the hydropower project after its completion by meeting the following objectives;

- To assess the institutional set-up in Pangani River Basin, that is Pangani Basin Water Office (PBWO), by looking at its strengths and weaknesses

- To compare the water use between hydropower production and irrigation by examining the water use for different crops, economic returns from irrigated crops and hydropower generation and the impact of irrigation and hydropower production on water resources

- To analyze people's perception of the use and management of water for irrigation and environmental needs

- To propose possible future scenarios for hydropower water availability

16.3 Methodology

The study was carried out in the Pangani Basin which covers an area of about 58,800 km^2 administratively and includes the main Pangani River Basin and the smaller river basins of Umba, Msangazi, Sigi, and Coastal Rivers, including Mukulumuzi (Fig1.). The Pangani River itself has two main tributaries, both of which rise in the basin's northernmost portions. The first of these, the Kikuletwa, rises on the slopes of Mount Meru and the southern slopes of Mount Kilimanjaro, while the second, the Ruvu, rises on the eastern slopes of Mt. Kilimanjaro and Lake Jipe. These rivers join at Nyumba ya Mungu, a reservoir of some 140 km^2 (Røhr and Killingtveit, 2002). The Pangani River drains the reservoir, flowing for 432 km before emptying into the Indian Ocean.

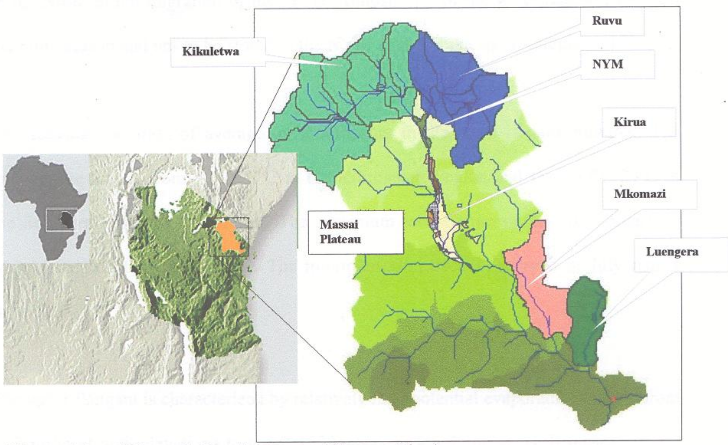


Figure 16.1: Schematic Location Map of Pangani Basin (Moges, 2003)

The methods that were used in carrying out this study were field trips and meeting with all stakeholders within the Pangani Basin. However, the key collaborator for this study was PBWO which provided much of information needed for this study. The information was later on synthesized to reach at the conclusions.

16.4 Results and Discussion Institutional Set Up of Pangani Basin Water Office

The Pangani Basin Water Office was established in 1991 under the Directorate of Water Resources in Tanzania and is responsible for allocating, managing, monitoring and controlling the water use in Pangani Basin. It is also tasked with creating awareness on effective and efficient water use and launching water conservation programmes (PBWO, 2005). The institutional set-up of PBWO is as shown in Fig.2.

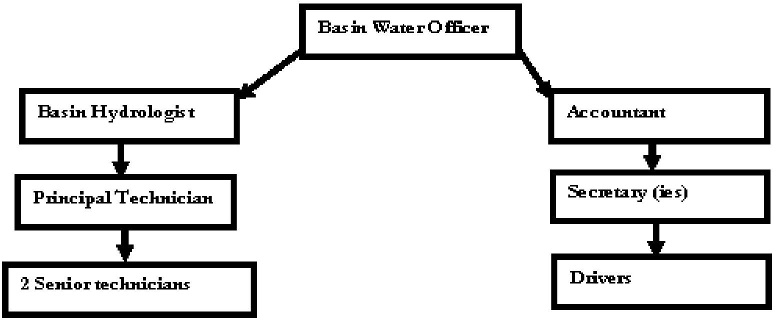


Figure 16.2: PBWO Organization Structure (PBWO, 2005)

The Basin Water Officer is in charge of the PBWO dealing with day to day activities in the office. He is also the secretary to the PBWB. The basin hydrologist is responsible for analyzing and documenting hydrological data of the basin. He is assisted by principal technicians and two senior technicians (PBWO, 2005). The functions and main activities of the PBWO is controlling and monitoring the water utilization in the basin. Specifically it performs the following tasks (PBWO, 2005): water use and water right inspection, water right applications, conflict resolutions, awareness campaign and updating the data base.

16.4.1 Strengths of PBWO

PBWO has been able to bring fragmented water uses and users together and created a framework that deals with the entire Pangani River Basin. All interests and stakeholders in the water affairs of the basin have suitable protection and adequate representation, including the natural environment and less powerful water users. The PBWO has also internalized upstream/downstream and other conflicts and thereby made them easier to deal with. Because coordination involves voluntary agreement among participating jurisdictions, it provides a strong political base for action.

16.4.2 Weaknesses of PBWO

1. **Institutional Weakness**
   Tanzania has turned increasingly to Community-Based Natural Resources Management (CBNRM). Such a 'sectoral' approach to management is present on both sides of the border (Tanzania and Kenya), and refers to situations where departments are involved with the management of forests, water, irrigation, wildlife and other resources. The PBWO has the difficult and debilitative task of ensuring that the various departments communicate with one another by sending representatives to the Pangani Basin Water Board (PBWB). The PBWO also lacks enough human resources to carry out all its functions including inspection and allocation of water rights.

2. **Funding Weakness** As it is, the Pangani Basin Water Office can not meet their obligations adequately with their existing funding. This stems from (a) inadequate provision from central government (via the Ministry of Water) and (b) inadequate recovery of water user fees. As a result, the PBWO has inadequate resources for planning, enforcement and monitoring, let alone for setting in place a system for the optimal allocation of water resources.

16.5 Comparison Of Water Usage For Different Water Users

Table 1 below summarizes water usage and their economic values.

Type of Use	Estimated Water Consumption	Estimated average value (Tsh per m³)
Domestic use	18 – 70 m³/head	1,200 – 1,500
Coffee estates	1,000m³/ha	723 – 6205
Sugar estates	12 – 17,000m³/ha	32 – 101
Flower terms	18, 250 m³/ha	3500 – 5300
Small scale irrigation		
traditional furrow	3,000m³/ha	211
Upper basin traditional furrow	3,000m³/ha	475-574
Upper basin improved schemes	850-1,195m³/ha	574-1,400
Lowland traditional furrow	3,000m³/ha	109
Livestock		
(dairy cattle)	36m³/head	2263
Upper basin (dairy & beef cattle)	27m³/head	860
Lowlands (beef cattle, goats)	18m³/head, 2.5m³/head	479-926
Hydro-electric power production	2.4 – 19 m³/kWh	73-300

Table 16.1: Average value of water per m3 for different uses. (These are rough estimates only) (Turpie, et. al., 2005)

16.6 Analysis Of The Perception Of Traditional Irrigation Organizations On Water Management

16.6.1 Perception of Water Rights

The issue of water rights has been perceived differently by water users groups in Soni and Luengera sub-catchments. Some people understand the importance of water rights but others don't. This is attributed to historical and cultural backgrounds. However awareness campaigns are being conducted and this has born fruits as the majority of people now understand the need of having water rights. So the water right issue is positively perceived after 10 years of water users' sensitization. However, this is shown by a number of water right applications that have been received by the PBWO. People now have realized that water is finite entity and need to be conserved.

16.7 Possible Future Scenarios Of Water Availabibity For Hydropower

Whether the Pangani Basin moves toward a more sustainable future concerning its water resources is largely a question of management. How can this shared resource be best used for the benefit of human populations on each side of the river and the region's uniquely diverse ecosystems? Potentially, there can be enough water, of acceptable quality, to support the domestic water needs of 3.7 million people in the area. To make this possible, agricultural use of water will have to be reduced significantly. Market mechanisms and mutually beneficial arrangements between cities and irrigation districts can bring about more efficient water use as well as make the rural-urban reallocation one of cooperation rather that conflict.

16.8 Conclusions And Recommendations

It is recommended to create incentives for catchment managers to maintain catchment forest areas, preferably through a system of 'payments for ecosystem services' which involves payment by those that benefit from the service, via PBWO, to catchment managers. The required price increases for water services will also function as a demand management tool that encourages more efficient use of the water that is allocated to various uses. Before water is allocated among different user sectors, it will be necessary to allocate sufficient water to aquatic ecosystems to maintain ecosystem functioning and the values derived from them. This can be achieved with the help of an 'instream flow assessment' which takes both ecological and socio-economic factors into account.

16.9 Ackowledgments

The authors would like to acknowledge the financial support from SIDA/SAREC through which this study was carried out.

16.10 References

Moges, S. A. (2003). *Development and Application of Hydrological Decision Support Tools for Pangani River Basin in Tanzania*. Ph.D. Thesis, Department of Water Resources Engineering, University of Dar es Salaam, Tanzania.
Pangani Basin Water Office Quarterly Report, (2005).
Røhr and Killingtveit, (2002). Study of two catchments on the hillside of Mt. Kilimanjaro. In Ngana, J. O. (ed.) *Water resources management: the case of*

Pangani River Basin. Issues and Approaches. Dar es Salaam, Dar es Salaam University Press: 211 - 231.
Turpie, J., Ngaga, Y. and Karanja, F. (2005). *Maximizing the Economic Value of Water Resources in Pangani Basin Tanzania*. IUCN - The World Conservation Union, Eastern African Regional.

17 Flood Forecasting and Early Warning System (FFEWS)

An Alternative Technology for Flood Management System and Damage Reduction in Ethiopia: A Concept Note

Dr. Semu Ayalew Moges[1]

17.1 Abstract

This concept note was developed as a response to the recent flooding in Ethiopia which ravaged almost the entire country. From emerging reports of various climate centers, the rainfall pattern is likely to show increasing trends in the eastern part of Africa, while it may exhibit decreasing trends in the western and southern part of Africa. The evidence of recent flooding provided by the climate prediction centers makes Ethiopia more vulnerable that ever. Therefore, it is high time for Ethiopia to work towards the development of adaptation and flood management mechanisms to cope with the future flood situations. This concept note deals with one form of flood management system which is based on flood forecasting and warning system. The proposal places emphasis on the need for a Flood Forecasting and Early Warning System (FFEWS) in Ethiopia and suggests a possible institutional framework and real time communication strategy with involved institutions. It also highlights the need for research and development support in the process of developing the FFEWS. Finally the training needs and capacity building aspect have been considered as an element for a successful Flood FFEWS Centre.

[1]Arba Minch University, School of Graduate Studies, P.o.box, 21, Arbaminch, Ethiopia; Email: semu_moges_2000@yahoo.com, smoges@nilebasin.org

17.2 Introduction

Of all the natural hazards capable of producing a disaster, floods are the most common phenomenon that causes human suffering, inconvenience and widespread damage to buildings, crops and infrastructure. Floods have been observed to disrupt personal, economic & social activities and set back a nations security & development by destroying roads, buildings and other assets.
According to UNEP - Division of Early Warning & Assessment technical (2002), flood disasters account for about a third of all natural disasters throughout the world and are responsible for more than half of the fatalities (Berz, 2000). Economically, floods are a leading to a course of losses from natural events. The money spent world wide on flood control through building dykes, reservoirs, barrage, etc. has been found to be far greater than that spent on protection from other impacts from nature.
A more frightening fact is that the trend of major flood disasters and the losses generated by them have increased drastically in recent years. In countries like Bangladesh, China and Cuba, floods are frequent enough to be considered as annual event (UNED Division of EW, 2002). According to (Glickman et al., 1992) between 1945 and 1986, the average annual numbers of floods causing 25 or more deaths have more than tripled, a trend that is confirmed by the OFDA series from 1964 to 1996. The burden of flood is most heavily borne by the impoverished countries of Asia. While less than half of all flood disasters occurred in Asia (41%), over 80% of people killed, affected or made hopeless are located in this continent. There is also a mounting evidence of flood disasters that have created huge impact in African livelihood and economy. The major recorded flood disasters that still linger in our mind is the Mozambique flood (2000) and the current flood in Ethiopia (2006).
The occurrence of the current flood in Ethiopia can be characterized as national catastrophe. The flooding occurred in almost all parts of the country. In the north, localities in Tigray and in the northeast, the Amhara region have been affected by emerging floods. In the south and east, the major flood damage was registered with loss of a huge number of human and animal lives as well as loss of property. In the south, the Baro River was swelling to create a flood situation.
From reports of various climate prediction centers, (unpublished IPCC report), it

has been indicated that there is a tendency of increased rainfall in the eastern part of Africa while rainfall may decrease in the western and southern Africa. The evidence of recent flooding coupled with the IPCC prediction leads one to consider Ethiopia to be more vulnerable that ever. Therefore, flood hazard in Ethiopia may continue as a result of increasing population that intensifies the flood damage due to increasing land and forest degradation as well as the encroachment of settlements into the close proximity of flood prone areas. Ethiopia should look forward to an efficient, cost effective adaptation mechanism to cope with the anticipated flood risks.
The purpose of this concept note is to underline the importance of establishing an institutionalized Flood Management System in the country and indicate the range of alternative flood mitigation options that may be implemented through institutionalized arrangements. Furthermore, it is intended to indicate the direction of immediate research and development areas with respect to technical, technological and institutional issues that are essential to an institutionalized flood management system. Ethiopia is one of few countries in the world who has been ravaged by the two extreme hydrological phenomena, i.e. extreme flood and drought. The overall conceptual approach of Flood Management in Ethiopia may be framed around two concepts:

- Minimizing the Damage of Flood Water through Maximizing the Benefits of Flood for Food Security and Poverty Reduction

- Efficient, Cost Effective and Sustainable Flood Management System that is institutionally manageable and technologically advanced and flexible.

The first framework will form part of a continuous study, research and development to convert the harmful effects of floods through deriving the benefits from flood water. In most cases, this involves building structural measures such as reservoirs and diversion structures as well as directing the flood water to dry areas for the purpose of beneficial use. The second concept focuses on institutionalized flood detection, prediction and issuing early warning to potential flooding area. The focus of this concept note lies on the second alternative of flood damage reduction which entirely depends more on software aspects than physical control structure. Therefore, the technical, technological, and institutional facets of establishing a sustainable National Flood Management System has been discussed.

17.3 Technical and Technological Measures of Reducing Flood Hazards in Ethiopia

Plenty of options are available for flood management and mitigation measures. These measures can be classified broadly into structural and non-structural measures. Many considerations have to be sought to select a suitable flood mitigation scheme. Some of the factors such as the type and characteristics of the flood (magnitude, return period, peak, damage, etc), cost implications and opportunity to maximize the benefit from the flood water must be considered by selecting feasible solutions. The structural measures (engineering or technical solutions) are designed and constructed to *modify the characteristics of floods* before arriving to the potential flood damage areas through various physical constructions such as reservoirs, diversions, levees, dykes, or channel modifications and river retaining works. Structural measures such as diversion or flood storage dam may be suitable to prevent the ravages of flash floods but the enormity of the financial, economical and ethical requirements undermines the importance of these flood prevention measures. Alternatively, instead of damming the flash flood rivers, it may be a more cost effective possibility to identify the major flood generating sub-watersheds and implement series of check dams and detention dams. This solution needs more research to be conducted for an ultimate assessment. These methods above are usually capital intensive and in some instances drain the national economy.

Non structural measures are designed to *modify the damage potential* of the flood without interfering to the characteristics of the flood (magnitude, peak, duration, etc). Such methods focus on software and hardware technological aspects, such as flood proofing, flood warning systems, land use control, etc. For instance through flood forecasting and early flood warning mechanisms, the potential of flood damage to properties and human lives can be reduced. Early warning systems can be implemented to evacuate the population and property at risk before the flood wave reaches to the flood prone area. However, flood warning systems require an efficient communication network to relay information and messages from observation stations to the forecasting centre and from forecasting to response agencies (like DPPA) and ultimately to potential flood affected areas. For instance, the flood of Omo River, Baro and other big rivers are affected by slowly rising floods and gives comparatively more chance of saving property and life than the rapid flash floods than the one occurred in Dire Dawa. As far as flood damage is concerned, a simplified flood warning and communication system suffices the purpose. Therefore, through national flood mapping and zoning, one or a combination of methods can be implemented to reduce the damages of flood in the country. Before implementing measures, detail study and analysis on alternative options is of paramount importance. However, the focus of this concept note is to introduce two alternative measures namely application flood forecasting and early warning system technology as an alternative flood managements system in Ethiopia.

17.4 Proposed Flood Forecasting and Early Warning System in Ethiopia

Generally utilizing the flood water requires some sort of controlling or diverting its course to an area where water inflow is required (structural measures). This essentially requires the construction of structures along all flood prone areas to effectively utilize the water as well as reduce the flooding. This may be the best solution that may occur immediately to anyone as there is already discussion towards construction of dams and diversion structures to reduce food insecurity in the country but it may be less feasible solution to the country as it has huge cost implications. The best solution is to establish a National Flood Management Centre that recommends a feasible combination of measures applicable to different flooding areas in the country.

With regard to Flood Forecasting and Early Warning System, the best system for Ethiopia must be adapted on the basis of various factors such as hydro-meteorological data availability (suitable to forecasting), the human skills, costs, communication infrastructure, etc. Therefore, it requires further thorough investigation and understanding. The overall system should be i) very simple but reliable ii) can be run with a minimum set of available hydro-meteorological data iii) focused to highly flood prone areas of the country but generic in its form to assume forecasting to other areas iv) can either utilize existing communication networks or a minimum communication system can be immediately established using mobile or wireless technologies v) have 24 hour (standby) committed combination of highly skilled professionals, technicians and data readers.

Key points in Ethiopian flood management system

- Identification and classification of floods in Ethiopia
- On the basis of types of flood, establish forecasting and warning system
- Forecasting for Flash floods
  - State level Flood Management System
  - Event based Lumped Rainfall-runoff models
  - Automatic rainfall gauging stations equipped with continuous recorder
  - Turbulent river flow measuring devices
- Flood forecasting for large river systems and reservoir/lakes
  - National level Flood management system
  - Stream Flow Models or Watershed Models

  1. including Rainfall runoff Prediction models (black box, conceptual or distributed, etc)
  2. Channel routing models
  3. Lake/Reservoir water balance and routing models, etc
  4. Real time reservoir operational models
- Acquire available flood forecasting tools (e.g. Mike 11, Flood 11, etc)

17.5 Proposed Institutional Arrangements for Reducing Flood Damage

Effective flood Management has been seen as a multi-stage and multi-institutional involvement with effective communication and networking devices. At early stage of system development, national and state level institutions can be envisaged. The State Flood Management Institutions will mostly deal with floods requiring very short forecasting time and small areal coverage such as flash floods. The National level Institution focuses on riverine and backwater floods as well as flash floods that are considered to be national catastrophic level (such as Dire Dawa flooding case).

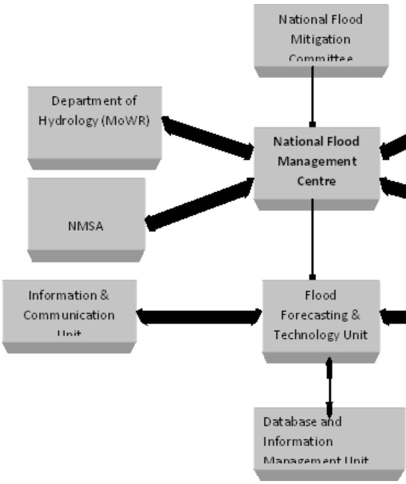


Figure 17.1: Institutional Framework for Establishing National Flood Management Centre (NMFC)

The state institutional arrangements have to be worked out including functions and roles and its linkages with the national institutions. The proposed national institutional arrangement is shown in figure 1 above.

Other areas that are essential for the sustainability of the flood forecasting and warning system includes research and human capacity development.

17.6 Conclusion and Recommendation

There are ample available technical, technological and institutional solutions for the immediate to long term interventions to alleviate flood ravages in Ethiopia. Countries have managed to drastically reduce flood damages through integrated flood detection, forecasting, warning and response actions through institutionally framed processes. Ethiopia shall adapt similar alternative measures of flood reduction methods that are adapted to the needs and requirements of the country situation.

Minimizing the damage of flood water through maximizing the benefits of flood water for food security and poverty reduction is another area of intervention to be studied.

Coordinated and focused research at national level through collaborative framework of various stakeholders (MoWR, NMA, DPPA, ect), academic and research institutions shall be initiated and engaged in various level of flood management research indicated in proposed research intervention areas.

Effective means of communication to collect real time data (meteorological and hydrological observation) and dissemination of the threat of flooding down to the community level has to be covered.

For an effective communication and data management system, the National Meteorological Service Agency (NMSA) and Department of Hydrology may be merged in the long run and form the National Hydro-Meteorological Service Agency (NHMSA). This institutional arrangement can be evolved a National Water Resources Research Centre incorporating several national water related research institutes under it.

17.7 Reference

UNEP-Division of Early Warning & Assessment System (2002) *Early Warning, Forecasting and Operational Flood Risk*, Monitoring in Asia (Bangladesh, China & India), A Technical Report of Project (GT/1010-00-04), Kenya, Nairobi.

Berz G. (2000) *Flood disaster: lesseons from the past worries for the future*, Proc. Instn Civ. Engrs. Water & Mar. Engn, Vol. 142 Mar. 3-8, p.3-8 (cited in UNEP-Division of Early Warning & Assessment System, 2002).

18 A Framework for Integrated Management of Transboundary Basins: The case of Sio subcatchment in East Africa

Joy A. Obando[1], *Albinus Makalle*[2] *and Yazidhi Bamutaze*[3]

18.1 Abstract

The Sio subcatchment is transboundary, originating in Kenya and flowing into the Berkeley Bay of the Lake Victoria basin. It forms an important subcatchment of the Nile basin and a significant basis for the livelihood of small scale farmers engaged in mixed farming, depending on agriculture and livestock keeping. A large share of the population depends on fishing, as well. Indeed, high population densities exceeding 300 persons per square kilometre and cattle densities of 38 animals per square kilometre have been noted within the basin, and continue to increase. Thereby, they are pressing heavy demand on the watershed resources - water, soil, vegetation. Thus, the basin continues to be deforested as demand for human settlements, agriculture and grazing land increases. This leads to land degradation that is characterised by fertility losses, erosion by water and increases in sediment load as it drains into Lake Victoria. The living of the population has been adversely affected and this has, in turn, led to unsustainable utilization of natural resources.
Integrated watershed management provides an appropriate analytical and management unit for the sustainable utilization of resources. This is particularly important as a means of coping with the ever increasing population. Furthermore,

[1] Kenyatta University, obandojoy@yahoo.com
[2] University of Dar es Salaam, makalle@udsm.ac.tz
[3] Makerere University, bamutaze@arts.mak.ac.ug

it can contribute to the achievement of the Millennium Development Goals, particularly the reduction of poverty and the facilitation of sustainable environmental management. A framework for an integrated management of the Sio basin will enable the protection of the resources within the basin, whilst allowing the sustainable use of the same resources for the increasing population. This paper provides a framework for the management of the Sio transboundary basin within an integrated approach, drawing on both local and scientific knowledge for sustainable resource management.
Keywords: *Integrated watershed management, transboundary, watershed resources, Sio subcatchment, Lake Victoria, Kenya, Uganda*

18.2 Introduction

Integrated watershed management provides an appropriate analytical and management unit for the sustainable utilization of resources. This is particularly important as a means of coping with the ever increasing population and can contribute to the Millennium Development Goals, particularly to the reduction of poverty and a sustainable environmental management (Förch et al 2005). This is especially relevant to the Lake Victoria Basin (LVB), which supports more than 30 million people and is facing an increase of population and challenges of sustainable management of resources. Indeed, the LVB forms a large part of the Nile basin and therefore, changes in resource use within the LVB affect people in more than 14 African countries. The LVB has been deforested since the demand for human settlements, agriculture and grazing land increases, thus leading to land degradation. This degradation is characterised by fertility losses, soil erosion by water, wind as well as increases in sediment load of the drains into Lake Victoria (Ogutu *et al.*, 2005; Balirwa *et al.*, 2003; Isabirye *et al.*, 2001; Yanda *et al.*, 2001; and Shepherd *et al.*, 2000).
The Sio basin is transboundary, belonging to Kenya and Uganda, and the land use changes are likely not only to have impact on the livelihoods but also on the environment. Indeed, population densities in the subcatchment exceed 300 persons per square kilometre and cattle densities amount to 38 animals per square kilometre(MAAIF 1993). Thus, a framework is necessary for the simultaneous management of resources in the Sio basin. The overall objective of the ongo-

ing research project is to understand the interactions within the Sio basins, and integrate local and scientific knowledge in order to achieve a sustainable management. A framework for an integrated management of the Sio sub-catchment will enable protection of the resources in the basin, whilst allowing a sustainable use of the same resources for the increasing population.

18.3 Methods

The research design is a case study that is conducted by using a multitude of procedures. Primary data are being collected through participatory research methods which include key informants, in-depth and household interviews. Tools of geological information of Remote Sensing, GIS and GPS are being used in data capture and analysis of changes in resource use. In addition to that, data on soil properties and tree biomass are being analysed. The study will use the Integrated System for Knowledge Management (IKSM) as a conceptual framework (Allen *et al.*, 1995; Bosch *et al.*, 1995) so as to integrate local and scientific knowledge for sustainable land management practices. ISKM is an approach that is designed in order to support an ongoing process of constructive community dialogue and to provide practical support for resource management decisions of land managers and policy makers (figure 1).

18.4 Study Area

The Sio subcatchment is transboundary, originating in Kenya and flowing into the Berkeley Bay of the Lake Victoria basin (figure 2). It originates in Kaujai and Luucho Hills in the Bungoma District, Kenya, at an altitude of 1800m and flows into the Berkeley Bay in Lake Victoria Basin in Uganda. The upper 65% of this sub-catchment is in Kenya, while the remaining part is located in Uganda. The subcatchment forms a significant base for the livelihood of small scale farmers which are engaged in mixed farming, are depending on agriculture and livestock keeping, as well as on fishing.

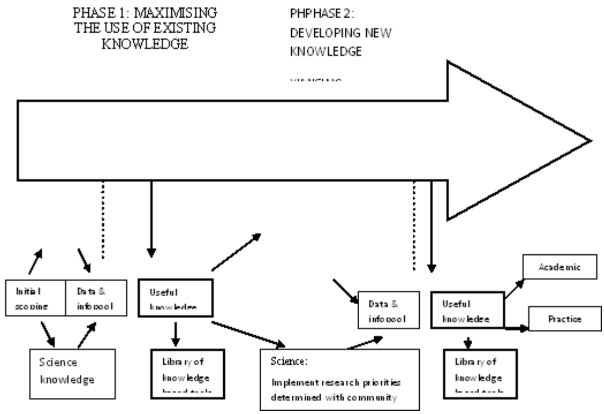


Figure 18.1: ISKM a Participatory Research Framework

18.4.1 Selection of study sites

The selection of study sites in the Sio sub-catchment in Uganda and Kenya were guided by field visits, interpretation of existing topographic maps and literature. The selected sites in Uganda are downstream of Sio River entering Lake Victoria, situated at the mouth. In Kenya, the sites are located in villages representing the midstream section of the sub-catchment (Figure 2). These study sites were selected on the basis of the observed changes: through onsite observations and preliminary interviews with key informants, through literature review.

18.4.2 Data Collection

Primary data on livelihoods has been collected through local community involvement using participatory research methods, which include key informants, in depth and household interviews, to capture the development-environment interaction in the river basins. A total of 400 in-depth questionnaires have been administered in the selected study sites within the sub-catchment to find out about the livelihood activities as well as perceptions on resource management. The land use change is being interpreted from satellite images and topographic maps over a 40 year period between 1965 and 2005. Soil samples have been collected along selected transects, and these will be used to provide information on the physical properties. Data has also been collected on tree biomass along selected transects to provide further information of tree resources.

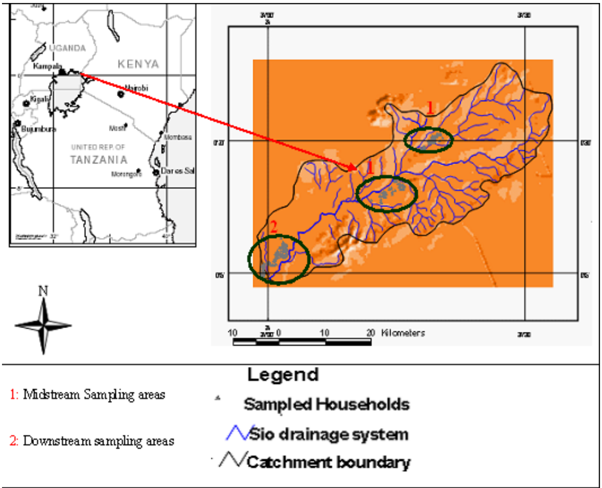


Figure 18.2: Location of Sio sub-catchment and sampled sites

18.5 Data Analysis

18.5.1 Sources of livelihoods

Analysis of questionnaires was done using the SPSS package as a means of finding out the impact of land use changes on community livelihoods. This included sources of livelihoods and perceptions of local communities on various issues, such as resource management and involvement of communities in management of these resources. Image classification is still ongoing and will be verified with field observations that will result in digitized land use maps, comprising the same categories. Laboratory analysis of the soil samples is also ongoing. Further, participatory mapping of the natural resources will provide an insight of the local communities' views on the development-environment interactions and the livelihood options and strategies, providing a linkage between the local and scientific knowledge. This information will be useful in providing an integrated framework for sustainable management of transboundary river basins.

18.5.2 Land use change and biophysical properties

The land use change analysis is being done by satellite images and topographic maps over three major periods between 1965 and 2005. The current topographic sheets for the study area were compiled using photographs of the 1960's and form the baseline. The other periods selected are 1973, 1984/86, 1995 and 2004/05. Laboratory analysis is being done for selected physical properties of soil, collected along transects in the sites, and include particle size fraction analysis and organic matter content. These will be correlated with attributes from the sub-catchment. Data has also been collected on tree biomass along selected transects to provide further information of tree resources.

18.6 Results and Discussions

Results indicate that Sio sub-catchment has experienced land use and land cover changes which have exerted negative ecological impacts affecting the livelihoods of communities (Obando *et al* 2007). The issues identified in this transboundary sub-catchment include: encroachment on the river bank resources, reclamation and conversion of wetlands for cultivation purposes, conversion from perennial to annual crops.

The intensity of these land use changes is currently being investigated with regard to the effects on both the livelihoods and the environment. Change in land use has been observed in various forms: from natural vegetation to agricultural uses, subsistence cropping to large scale cash crop farms, agricultural to grazing, and from agricultural to secondary natural vegetation. These changes have been influenced by the changing resource base in the sub-catchment, as well as the ways it is utilized by a community which is increasingly becoming vulnerable, and this in turn has led to the circle of unsustainable use of natural resources. It is clear that there are differences within the sub-catchment in both Uganda and Kenya in terms of sources of livelihood. The community perceptions and participation in the river basin management and the institutional capacity are varied in downstream and upstream sections of the sub-catchment. Given the dependence of the community on the natural resource base, there is need to manage the sub-catchment in an integrated manner since there are linkages and effects as upstream encroachments affect midstream and downstream areas. The emphasis on community participation in decision making is having a positive effect on the management of resources, and creating awareness on the interdependence of the resources within catchments, and the need for sustainable management.

18.7 Conclusions

For sustainable management of transboundary river basin resources, there is need for regional coordination in planning and management, as well as integrated planning at the district level with participation of local communities. In Sio Kenya, different institutions have been charged with management of the various resources, including, the Water Resources Management Authority, and the Ministry of Lands, Agriculture and Environment and Natural Resources. There is need to harmonise these various acting bodies in Kenya, and synchronize them with the Ugandan institutions responsible for catchment management within an integrated framework for East Africa. In any case, the participation of communities should be of paramount importance. Such a framework needs to inculcate the core values of the East Africa Community vision and strategy framework for management and development of Lake Victoria Basin (LVDP 2004). The research is still on-going, and analysis of the biophysical and satellite images will enable further conclusions to be drawn with a view of proposing an integrated framework for the management of transboundary river basins.

18.8 Acknowledgements

We acknowledge the Lake Victoria Research Initiative (VICRES) for funding the study. We are also grateful to the local communities and local governments in

Uganda, Kenya and Tanzania for the support extended to us.

18.9 References

Allen, W.J.; Bosch O.J.H.; Gibson R.G.; and Jopp, A.J. 1995. Co-learning Our Way to Sustainability: Integrating Local and Scientific Knowledge Through an Evolutionary Research Approach to Support land Management Decision-making. Proceedings 1st International Conference of MODSS for Agriculture and Environment, Honolulu, July 23-29.

Balirwa, J.S., Chapman, C.A., Chapman, L.J., Cowx, I.A., Geheb, K., Kaufman, L., Lowe-McConnelly, R.H., Seehausen, O., Wanink, J.H., Welcomme, R.L., and Witte, F. 2003. Biodiversity and fishery sustainability in the Lake Victoria basin: An unexpected marriage? Bioscience 53, 703 - 716.

Bosch, O.J.H.; Williams J.M.; Allen W.J.; and Ensor A., 1995. Integrating Community-based Monitoring into the Adaptive Management Process - the New Zealand Experience. Proceedings of the 5^{th} International Rangelands Congress, Salt lake City, July 23-28.

Förch, G., Winnegge, R. and Thiemann, S. 2005 (Eds.). FWU Water Resources Publications, http://fwu.fb10.uni-siegen.de/bkd/FWU_WRP.htm, Vol. 3, 2005 Topics of Integrated Water Resources Management.

Isabirye, M., Magunda, M., Ssali, C.K., 2001. People and agroecosystems: Issues and strategies for sustainable land management in Mayuge district. Land use management technical report No.7. Lake Victoria Environment Management Project, NARO-Kawanda, Uganda.

LVDP (2004) Lake Victoria Development Programme, The Vision and Strategy Framework for Management and Development of Lake Victoria Basin, East Africa Community Secretariat.

MAAIF, 1993. Report on Uganda National Census of Agriculture and Livestock 1990-91. Vol. 1 to 5. Ministry of Agriculture, Animal Industry and Fisheries, Entebbe, Uganda.

Obando, J. A., Bamutaze, Y. and Makalle, A. 2007 (In prep). The Impact of Land Use Changes on Community Livelihoods of Sio sub-catchment in the Lake Victoria Basin.

Ogutu, Z.A.; Misana, S.; and Mwaka, V. 2005. Land Use Research in the Lake

Victoria Basin: Analysis and Synthesis. IUCEA, SIDA.
Shepherd, K., Walsh, M., Mugo, F., Ong, C., Hansen, T. S., Swallow, B., Awiti, A. Hai, M., Nyantika, D., Ombalo, D., Grunder, M., Mbote, F. and Mungai, D. (2000). Improved land management in the Lake Victoria basin: Linking land and lake, research and extension, catchment and basin, Final Technical Report, Startup Phase July 199 to June 2000, Natural Resource Problems, Priorities and Policies Programmes, Working Paper Series 2000-2, International Centre for Research in Agroforestry and Kenya Ministry of Agriculture and Rural Development, Soil and Water conservation branch, National Soil and Water Conservation Programme.
Yanda, P.Z.; E.K. Shishira, F.N. Madulu; and A.S. Kauzeni, 2001. Survey and Mapping of Land Use/Cover and Erosion Hazard in Lake Victoria Basin. Institute of Resource Assessment (IRA) in Collaboration with lake Victoria Environmental Management Project (LVEMP) Final Report.

19 Development of Intensity-Duration-Frequency Relationships for gauged and ungauged location of Southern Nations, Nationalities Peoples Region (SNNPR)

Feleke Gerb and Semu Aylew Moges[1]

19.1 Abstract

The Intensity-Duration-Frequency (IDF) relationship of rainfall amounts is one of the most commonly used tools in water resources engineering for the planning, designing, and operation of water resources projects. The objective of this research is therefore to develop operational IDF relationships for the SNNPR State based on nineteen first class stations. Three different forms of IDF curves have been developed considering the application to both, gauged and ungauged, areas and have been presented in the form of general mathematical equation - curves relating Intensity-Duration-Frequency of rainfall and the IDF regionalized maps. The IDF curve and the general mathematical forms are intended to estimate the magnitude of the rainfall intensity of a given return period within 25km radius of the principal station. For areas farther than 25km from the principal station (ungauged area), regional IDF parameters have been developed and can be used to estimate the magnitude of intensity values.
Therefore, planners and designers in the country, as well as the regional state, can effectively utilize one or all of the procedures to derive the IDF value in any part of the region for planning and designing purpose of water and road infrastructures. We also recommend the projects that are operating in the state may revise

[1]Arba Minch University, School of Graduate Studies, P.O. Box 21, Arbaminch, Ethiopia telephone: +251-46-8810775; Corresponding author: email: semu_moges_2000@yahoo.com

their planning and design guidelines on the basis of the new findings.
Keywords: *IDF curve, Regional IDF curves, distributions, parameters, Standard Error of Estimates (SEE)*

19.2 Introduction

Rainfall Intensity-Duration-Frequency curves (IDF curves) are a graphical representations of the amount of water that falls within a given period of time. The Intensity of Rainfall (I) is the rate at which the rain is falling, Duration (D) is the time for which it is falling with a given intensity, and frequency (F) is the average recurrence time of that magnitude of rainfall (DuPont & Allen, 2000).
The development of intensity duration frequency IDF curves for precipitation remains a powerful tool for the risk analysis of natural hazards. Indeed, the IDF curves allow for the estimation of the return period of an observed rainfall event or conversely of the rainfall amount corresponding to a given return period for different aggregation times. The purpose of this study mainly is to produce IDF relationships for the precipitation of nineteen different first order recording climate stations in the South Nations Nationalities and Peoples Regional State.
This study can be considered as an essential work to fill the existing gap of design parameters as a result of limited data. The study was intended to develop at station and regional IDF curves for the Southern Nations Nationalities and Peoples Regional State (SNNPR) which are sited in the south western part of Ethiopia (figure 1).
According to the Central Statistics Authority (CSA, 2005), annual statistical report cited in (www.ethiopar.net, 2005) that the state has an estimated area of about 112.323 square km and accounts for about 10 percent of the total Ethiopian area. The regional state has an estimated population of about 14.9 million or 20 percent of the country's total population.
About 56 % of the state's area is located below 1.500 metres altitude, which is thus categorised largely as the hottest low land ("Kolla"). The remaining 44% are found in the temperate climatic zone. The state's mean annual rainfall ranges from 500 - 2.200mm. Its intensity, duration and amount increases from South to Northeast and Northwest. The mean annual temperature of the state in general ranges from 15oC to 30oC (www.ethiopar.net, 2005).

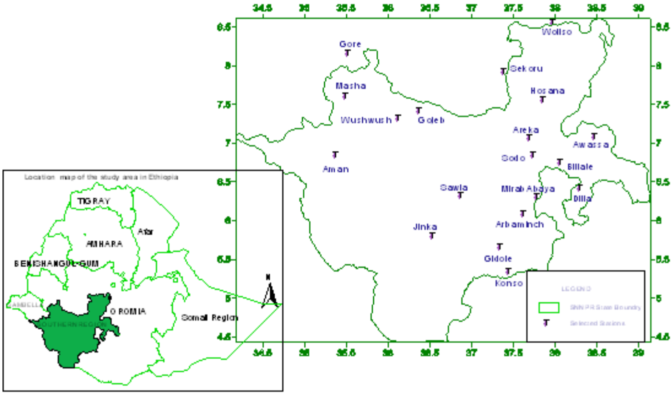


Figure 19.1: Location maps of the selected rainfall stations within the study area

19.3 Data

Rainfall recording stations with automatic recorders have been identified in and around the state to extract different rainfall duration intensities. Data from a total of 19 stations have been classified and collected by the NMSA. All the stations are located within the state, except for Gore, Woliso and Sekoru which were adjoined from the neighbouring region, Oromia, in order to develop more refined regional curves that will be applicable for practical use. Table 1 lists the basic information and length of observed data for the selected stations.

For most of the stations, charts of continuous data recorders are available and the rainfall intensity of different durations has been extracted. Table 2 shows sample intensity values for durations of 30-minutes, 1-hour, 2-hours, 3-hours, 5-hours, 6-hours, 12-hours and 24-hours that occurred in different months of the year 1974 at Arbaminch station.
For individual duration, the maximum rainfall depth is extracted as an annual maximum D-hour intensity (for e.g. the 1974 maximum intensity is shown at the bottom of table 2). This procedure has been implemented for all the years in

No.	Station Name	Sample size (years)	Location Long. (degree)	Lat. (degree)	Elevation (masl)	Period of record	Mean annual temp. ºC	Mean annual rainfall (mm)
1	Arbaminch	32	37.66	6.06	1219	1969-2005	20.83	833
2	Sekoru	17	37.4	7.92	2100	1987-2004		
3	Konso	17	37.58	5.25	1460	1986-2005	21.93	398
4	Sawla	11	36.88	6.32	1500	1987-2002		
5	Aman	10	35.38	6.85	1360	1988-2005		
6	Gore	22	35.53	8.15	2002	1968-1991	18.16	1897.8
7	Gidole	13	37.48	5.61	2550	1989-2001	16.66	1191
8	Masha	16	35.5	7.6	2310	1988-2005		2062.6
9	M/Abaya	13	37.83	6.33	1290	1990-2002	24.17	690
10	Jinka	28	36.63	5.83	1430	1972-2005	21.15	1345
11	Billate	31	37.96	6.65	1200	1971-2005	22.48	902
12	Sodo	28	37.71	6.83	2020	1972-2005	19.98	1333
13	Dilla	13	38.3	6.41	1670	1988-2005	20.12	1360
14	Areka	15	37.7	7.06	1750	1988-2003		1336
15	Awassa	30	38.5	7.06	1652	1975-2005	19.2	952.8
16	Hosaina	22*	37.83	7.58	2290	1979-2005	16.54	1194
17	Woliso	13	37.98	8.51	1960	1988-2005	17.99	1208
18	Wushwush	5	36.13	7.32	1950	1988-1993	18.33	1892
19	Gojeb	6	36.38	7.42	1250	1980-1985		

Table 19.1: Basic information of the rainfall stations

		Observed Rainfall (mm) for the indicated duration(hr)							
.Year	Date of record	0.5	1	2	3	5	6	12	24
1974	6-7/10/1974	3.7	4.5	4.5	5.9	6.5	6.5	6.5	6.5
1974	28-29/9/1974	1	0.4	5.2	7.4	7.4	7.4	7.4	7.4
1974	20-21/9/1974	13.5	15.9	17.8	18.5	18.9	18.9	18.9	18.9
1974	7-8/9/1974	0.9	10	27	29.1	30.1	30.1	30.1	30.1
1974	21-22/7/1974	4.3	4.5	5.5	8.4	10.5	10.6	10.6	10.6
1974	3-4/7/1974	6.4	11.5	13.2	13.2	13.2	13.2	13.2	13.2
1974	31/6-1/7/1974	8.7	10.2	11.5	15.8	21.6	21.6	21.6	21.6
1974	25-26/5/1974	1.7	6.3	10.1	12.3	20.5	21.9	25	25
1974	19-20/5/1974	6.7	7.5	9.6	10.2	10.4	10.4	10.4	10.4
1974	10-11/5/1974	31.8	45.5	46.9	50.4	52.4	52.4	53	53
1974	6-7/5/1974	8.3	10.3	13.3	14.8	19.5	19.5	19.5	19.5
1974	4-5/5/1974	14.8	14.8	14.8	14.8	14.9	14.9	14.9	14.9
1974	11-12/4/1974	19.5	20	20	20	20	20.1	20.1	20.1
1974	**Max**	**31.8**	**45.5**	**46.9**	**50.4**	**52.4**	**52.4**	**53**	**53**

Table 19.2: Samples of collected data from rainfall charts of 1974

which data were available and also for the 19 station.
In order to validate the quality and nature of data, various tests have been undertaken, such as outlier test (Maidment, 1993), independence and tests of sta-

tionarity. All in all, the outlier tests showed that there are no data out off the outlier test's threshold and that data series from all station have been noticed to be random.

19.4 Procedure And Development Of IDF Curves

19.4.1 Selection and evaluation of probability distributions for the rainfall data

The abstracted annual maximum series of different durations of rainfall depths have been treated by using a frequency analysis procedure so as to select the most applicable probability distribution and parameter estimates to each station (Rao and Hamed, 2000). 15 probability distribution methods have been tested, both graphically and numerically. Some of the graphical methods include Moment Ratio Diagrams (Cunnane, 1989), L-Moment Ratio Diagrams Hosking (1990) and probability plots. Finally, the standard error of estimate (SEE) has been used as a final distribution and parameter selection method. The most efficient method is the one that results in the smallest SEE (Rao and Hamed, 2000). Table 3 illustrates the type of distribution and estimation method for Arbaminch station.

Distributions	SEE for the indicated return periods in years					
	T=2	T=2	T=2	T=2	T=2	T=2
EV1/ML	2,13	3,16	3,94	4,97	5,76	6,54
EV1/PWM	2,14	3,4	4,39	5,71	6,71	7,71
LN/MOM	2,11	3,28	4,3	5,78	6,96	8,24
P3/MOM	2,36	3,47	4,57	6,36	7,88	9,57
P3/PWM	2,12	3,28	4,55	6,56	8,22	10,04
LP3/MOM	2,2	3,26	4,44	6,56	8,57	11,02
G2/MOM	2,17	3,46	4,52	5,89	6,9	7,92
G2/ML	2,17	3,48	4,51	5,83	6,79	7,76
G2/PWM	2,16	3,44	4,43	5,73	6,68	7,64
GEV/PWM	2,12	3,18	4,36	6,63	8,97	11,89

Table 19.3: SEE of the Candidate distributions for 1h rainfall at Arbaminch station

Based on the smallest standard error of estimate, the most adequate candidate distributions of different rainfall durations for all stations are shown in table 5.
Based on the distribution and parameter estimation methods shown in the above table, probable quantiles of the return period, starting from 2 to 100 years, have

Distributions	SEE for the indicated return periods in years					
	T=2	T=5	T=10	T=25	T=50	T=100
EV1/MOM	2.43	3.51	4.47	5.79	6.81	7.84
EV1/ML	2.43	3.39	4.27	5.49	6.44	7.4
EV1/PWM	2.43	3.52	4.49	5.82	6.85	7.9
LN/MOM	2.48	3.48	4.54	6.14	7.44	8.85
P3/MOM	2.54	3.59	4.71	6.47	7.92	9.49
P3/PWM	2.35	3.25	4.16	5.58	6.77	8.09
LP3/MOM	2.54	3.54	4.66	6.58	8.3	10.31
G2/MOM	2.49	3.59	4.53	5.78	6.69	7.62
G2/ML	2.49	3.6	4.53	5.75	6.64	7.55
G2/PWM	2.49	3.57	4.51	5.75	6.66	7.59
GEV/PWM	2.43	3.44	4.61	6.81	8.95	11.48
GEV/MOM	2.47	3.55	4.68	6.56	8.22	10.05
LLG/PWM	2.43	3.34	4.44	6.57	8.81	11.69
EXP/MOM	2.34	3.34	4.46	6.11	7.41	8.74

Table 19.4: SEE of the candidate distributions for 6-h rainfall at Arbaminch station

No	Station Name	0.5	1	2	3	5	6	12	24
1	Aman	P3/MOM	GEV/MOM	P3/MOM	P3/MOM	G2/ML	G2/PWM	P3/PWM	P3/MOM
2	Arbaminch	PII/PWM	EV1/ML	EV1/ML	EV1/ML	EV1/ML	EV1/ML	EV1/ML	EV1/ML
3	Areka	G2/ML	G2/ML	P3/MOM	P3/MOM	P3/MOM	G2/PWM	EV1/PWM	EV1/PWM
4	Awassa	EV1/ML	G2/ML	EV1/ML	EV1/ML	EV1/ML	EV1/ML	EV1/ML	P3/MOM
5	Billate	P3/MOM	G2/ML	EV1/MOM	LLG/PWM	P3/PWM	G2/MOM	G2/MOM	P3/PWM
6	Dilla	P3/PWM	P3/PWM	P3/PWM	P3/PWM	P3/PWM	P3/PWM	G2/PWM	G2/ML
7	Giddle	P3/PWM	P3/MOM	P3/MOM	P3/MOM	P3/MOM	G2/ML	P3/MOM	P3/MOM
8	Gore	G2/ML	G2/ML	G2/PWM	G2/PWM	G2/ML	G2/ML	EV1/ML	EV1/ML
9	Jinka	P3/MOM	G2/ML	G2/ML	G2/ML	EV1/ML	EV1/ML	EV1/ML	EV1/ML
10	Konso	P3/MOM	P3/MOM	P3/PWM	LN/MOM	G2/MOM	G2/MOM	WAKEBY-4	P3/MOM
11	M/Abaya	G2/ML	P3/MOM	P3/MOM	P3/MOM	P3/MOM	P3/PWM	P3/MOM	P3/MOM
12	Masha	GEV/MOM	G2/ML	EV1/ML	EV1/PWM	EV1/PWM	EV1/PWM	EV1/ML	EV1/ML
13	Sawla	P3/PWM	P3/PWM	P3/PWM	P3/MOM	P3/PWM	P3/PWM	P3/PWM	EV1/ML
14	Sekoru	P3/MOM	EV1/ML	G2/ML	G2/ML	G2/MOM	G2/ML	P3/PWM	G2/ML
15	Sodo	EV1/ML	EV1/ML	EV1/ML	EV1/MOM	P3/PWM	P3/PWM	P3/PWM	G2/MOM
16	Gojeb	GEV/MOM	G2/ML	G2/PWM	G2/PWM	EV1/MOM	GEV/PWM	GEV/MOM	GEV/MOM
17	Hosaina	P3/MOM	P3/MOM	P3/MOM	P3/MOM	P3/MOM	G2/PWM	P3/PWM	EV1/ML
18	Woliso	P3/PWM	P3/PWM	G2/MOM	P3/PWM	P3/PWM	LP3/MOM	GEV/MOM	P3/PWM
19	Wushwush	GEV/MOM	GEV/MOM	LP3/MOM	P3/PWM	GEV/PWM	G2/PWM	EV1/PWM	WAK-4

Table 19.5: Msot Adequte Distributions for the indicated durations

been derived for each station. These quantiles are used to derive the IDF curves. Table 6 shows typical quantiles for the Arbaminch station.Table 6: Estimated Quantiles for Arbaminch station

Return Period (years)	Estimated Quantiles for the indicated durations of rainfall, mm Arbaminch station							
	0.5hr	1hr	2hr	3hr	5hr	6hr	12hr	24hr
2	24,4	30,9	35,1	37,1	39,7	40,3	42,0	45,1
5	29,2	40,6	45,8	48,6	52,0	52,8	55,5	60,4
10	31,8	47,1	52,9	56,2	60,1	61,0	64,5	70,6
25	34,6	55,3	61,9	65,9	70,3	71,4	75,7	83,4
50	36,4	61,3	68,5	73,0	77,9	79,1	84,1	92,9
100	38,1	67,4	75,1	80,1	85,4	86,8	92,4	102,3

Table 19.6: Estimated Quantiles for Arbaminch station

19.4.2 Estimation of the IDF Parameters

The general mathematical form of the IDF equation (equation 1) has been used to align each estimate of return period quantiles of different durations. Parameter estimations of 'A', 'B' and 'C' have been achieved by using the minimum standard error of estimate (SEE) criteria. For instance, for the Arbaminch station each I_2, I_5, I_{10}, I_{25}, I_{50}, I_{100}, IDF equation can be received for each duration. This procedure has been applied to every of the 19 stations and thus, the derived IDF equation was given.

$$I = \frac{A}{(D+B)^C}$$

Where: I= rainfall intensity (mm/hr)
D= duration of rainfall (minutes)
A= coefficient with units of mm/hr
B= time constant in minutes
C= an exponent, usually less than one

The derived parameters of 'A', 'B', and 'C' for all the 19 stations and selected durations (2, 5, 10, 25, 50 and 100 hour) are given in table 7.
In general, the value of the "A" coefficient rises with an increase of the return period for most of the considered stations. However, there are some cases where this coefficient decreases with an increase of the return period. This decrease in the "A" coefficient is mainly obtained for larger return periods that span over 50 and 100 years. The "B" constant depends on the relative increase or decrease of the "A" coefficient. For most of the stations with different frequency these two parameters increase or decrease with an increase or decrease of the "A" coefficient. Similar to the cases of the "A" coefficient, there are some cases where these parameters decrease for an increase in the "A" coefficient.
After establishing the numerical value of the IDF parameters, the rainfall intensity for any duration and recurrence interval can be determined. Based on the estimated parameters of the IDF relationships, a general equation of the following form (equation 2) has been derived for all durations and each station.
$i = exp\left[(ln(A) - Cln(B+D))\right]$ (2)
The resulting six equations (3)to(8) for each station can be used for intensity calculations in the area which is represented by that station. The six equations for

the IDF relationships for the Arbaminch station are as follows: 2 Year return period, $i = exp[7.53 - 0.95^{*}ln(16.33 + D)]$ (3)
5 Year return period, $i = exp[7.9 - 0.96^{*}ln(22.96 + D)]$ (4)
10 Year return period, $i = exp[8.06 - 0.96^{*}ln25.8 + D)]$ (5)
25 Year return period, $i = exp[8.39 - 0.98^{*}ln(34.27 + D)]$ (6)
50 year return period, $i = exp[8.5 - 0.98^{*}ln(36.88 + D)]$ (7)
100 Year return period, $i = exp[8.68 - 0.997^{*}ln(42.13 + D)]$ (8)
Similar mathematical equations have been developed for each station that is located in the Regional State of SNNRP. Such equations can be used in order to plan and design water and related infrastructures such as bridges, culverts, dams, etc. for locations within a 25km radius from each station.

Station Name	T=2 Years			T=5 Years			T=10 Years			T=25 Years			T=50 Years			T=100 Years		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Aman	2470.83	20.55	0.95	3117.48	25.79	0.94	3259.40	27.80	0.92	3222.23	29.00	0.90	3092.32	29.03	0.88	3032.42	30.01	0.86
Arbaminch	1862.35	16.33	0.95	2703.13	22.96	0.96	3165.89	25.80	0.96	4388.28	34.27	0.98	4914.46	36.88	0.98	5903.33	42.13	1.00
Areka	1387.59	2.80	0.90	3117.48	4.62	0.90	1927.23	4.62	0.90	1992.46	3.97	0.89	1964.22	2.91	0.87	1988.51	2.58	0.86
Awassa	1238.34	0.10	0.87	3226.63	12.72	0.98	3653.69	13.48	0.98	4174.17	14.35	0.97	4582.97	15.09	0.97	5071.28	16.33	0.97
Billate	1393.18	4.09	0.91	1616.06	2.58	0.89	1856.77	3.20	0.89	2314.50	5.60	0.90	2702.43	7.47	0.92	3114.50	9.24	0.93
Dilla	1540.04	2.76	0.91	2167.66	6.00	0.92	2493.53	7.47	0.92	2807.34	8.70	0.92	2978.77	9.23	0.91	3175.53	10.09	0.91
Gidole	1753.47	9.23	0.92	2253.04	10.65	0.92	2667.47	12.70	0.92	3007.71	13.48	0.92	3361.77	15.03	0.93	3647.97	15.95	0.93
Gore	1722.91	5.37	0.94	2037.28	4.47	0.94	2170.17	3.97	0.93	2154.34	2.09	0.91	2091.12	0.53	0.90	2164.44	0.53	0.89
Jinka	1082.55	1.35	0.86	1175.23	0.99	0.83	1255.04	2.00	0.82	1271.90	2.10	0.80	1288.91	2.53	0.79	1286.48	2.58	0.77
Konso	1357.97	4.47	0.92	1719.28	4.63	0.93	2026.57	5.62	0.94	2500.73	7.47	0.96	2869.26	8.69	0.98	3306.14	10.10	0.99
M/Abaya	960.35	2.58	0.85	1631.72	8.76	0.89	2038.97	11.15	0.91	2527.86	13.42	0.92	2904.89	15.09	0.93	3255.91	16.33	0.93
Masha	1275.01	0.04	0.89	1528.14	2.09	0.86	1921.10	7.47	0.87	2617.62	16.33	0.88	3185.68	23.30	0.89	4045.19	32.27	0.91
Sawla	1987.81	14.47	0.97	2136.07	13.76	0.93	1940.82	11.12	0.89	1656.52	7.47	0.85	1445.53	4.47	0.81	1314.43	2.60	0.79
Sekoru	1615.40	10.09	0.93	2028.28	9.22	0.94	2297.00	8.76	0.94	2676.53	8.71	0.95	2948.03	8.60	0.96	3088.25	7.47	0.96
Sodo	1889.95	12.70	0.92	2428.47	10.95	0.92	2933.14	10.91	0.93	3540.04	10.09	0.94	4113.34	10.09	0.95	4711.54	10.09	0.96
Wushwush	1570.95	0.03	0.91	1969.86	0.53	0.93	2338.01	3.44	0.94	2015.58	0.53	0.91	2088.62	2.58	0.90	1742.19	0.04	0.87
Woliso	3109.40	42.42	1.02	3365.95	32.27	1.02	3605.08	29.00	1.02	3646.82	25.80	1.02	3700.04	23.27	1.02	3603.10	20.56	1.01
Hosana	546.34	0.53	0.77	828.81	0.53	0.82	987.28	0.16	0.83	1173.46	0.04	0.85	1301.85	0.04	0.86	1427.72	0.01	0.87
Gojeb	840.72	34.03	0.82	1768.13	55.42	0.92	2967.40	71.99	0.99	4978.40	88.05	1.06	7986.20	104.67	1.12	11664.43	117.38	1.17

Table 19.7: Summary of the estimated IDF parameters

19.4.3 Construction of the IDF curve

The IDF curves were plotted on a double logarithmic scale, the duration D as the abscissa and the intensity I as the ordinate, thus utilising the IDF curve fit tool. Figure 2 and 3 show the IDF curves that are plotted on a double logarithmic scale and, respectively, on a normal scale for the Arbaminch station.

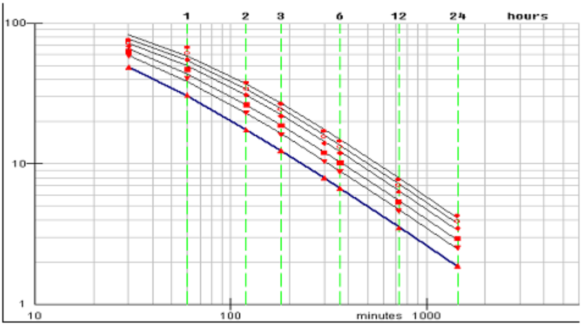


Figure 19.2: IDF curves plotted on double logarithmic scale for Arbaminch Station

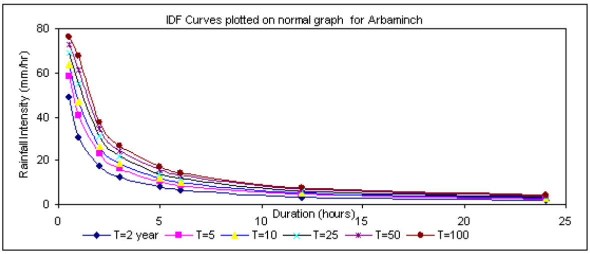


Figure 19.3: IDF curves plotted on a normal scale for Arbaminch station

19.5 Regional IDF Maps

Regionalisation refers to the identification of homogenous regions whose stations have similar climatic characteristics. This can be achieved by using information that is obtained from geographic proximity as well as physiographic and climatic characteristics. Statistically, a homogenous region is a region which consists of sites that have the same standardised frequency distributional form and parameters. Such a region must be geographically continuous to form a basic unit so as to carry out regional frequency analysis.
In the case of estimating rainfall quantiles, regional analysis is based on the con-

cept of regional homogeneity. This assumes that populations of annual maximum events at several sites in one region are similar regarding statistical characteristics and do not depend on the catchment size (Cunnane, 1989).
Regionalisation serves two purposes: For sites where data are not available, the analysis is based on regional data (Cunnane, 1989). For sites with available data, the joint use of data which were measured at a site, called at-site data, and regional data from a number of stations in a region provide sufficient information to enable a probability distribution to be used with greater reliability.

19.5.1 Homogenous IDF Regions

Homogenous regions have been developed for the annual maximum rainfall depth of all durations on the basis of L-MRD. It is assumed that (LCs, LCk) values of one station vary linearly with (LCs, LCk) values of the neighbouring station and therefore, these parameters have been used to delineate homogeneous regions. Two boundaries are fixed, one from the LCs and the other from the LCk values. The final boundary between regions is installed between the midways of the two boundaries.
Two statistical tests have been utilised in order to test the homogeneity of each region (Hosking et. al., 1991; cited in Rao & Hamed, 2000). The first statistic is a discordance measure, intended to identify those sites that are grossly discordant with the group as a whole. The second statistic is a heterogeneity measure intended to estimate the degree of heterogeneity in a group of sites and to assess whether they might reasonably be treated as homogenous. Figure 4 shows the L-MRD and figure 5 depicts the eventually established homogenous regions.

19.5.2 Regional quantiles

The estimation of the quantiles for the classified regions is based on the most adequate distribution. The estimated quantiles are then pooled together so as to calculate the mean values of the stations within these regions for each return period and each duration. The pooled mean quantiles are employed for the estimation of the regional IDF parameters for the specified region. Typical pooled regional quantiles for region one and durations of 30 minutes and one hour are shown in table 8.

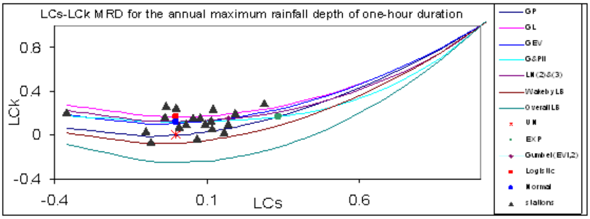


Figure 19.4: L-MRD used to identifying stations of similar nature

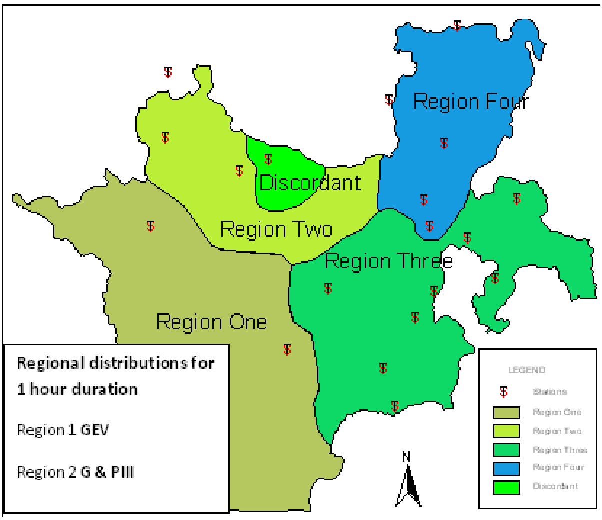


Figure 19.5: Established homogenous regions

The IDF parameters for each classified region have been obtained from pooled quantiles for each region and parameters derived on the basis of minimum SEE. The estimated regional IDF parameters are shown in table 9.

Return period in years(T)	Quantiles from regional distribution				Regional quantiles (mean of the stations)	
	Aman station		Jinka station			
	30 minutes	60 minutes	30 minutes	60 minutes	30 minutes	60 minutes
2	29.38	39.11	27.24	32.28	28.31	35.70
5	36.84	47.08	33.63	40.37	35.24	43.73
10	40.85	50.70	37.06	45.00	38.96	47.85
25	45.04	53.98	40.66	50.12	42.85	52.05
50	47.64	55.73	42.88	53.46	45.26	54.60
100	49.84	57.04	44.77	56.43	47.31	56.74

Table 19.8: Stationary and regional quantiles for 30 and 60 minutes of region one

Region	Parameters	Estimated parameters for the indicated frequency					
		T=2	T=5	T=10	T=25	T=50	T=100
Region one	A	1885.08	2029.85	1877.43	1628.18	1394.11	1781.66
	B	14.25	12.81	10.10	6.62	3.20	7.47
	C	0.92	0.89	0.86	0.82	0.78	0.81
	SEE	0.61	0.75	0.85	1.06	1.25	1.07
Region two	A	1483.25	1777.78	2211.10	2811.00	3464.46	4262.60
	B	0.01	0.99	5.35	11.15	16.94	23.27
	C	0.91	0.90	0.91	0.93	0.95	0.96
	SEE	2.24	1.61	1.10	0.59	0.52	0.72
Region three	A	1551.18	2182.20	2537.83	2992.38	3315.94	3576.87
	B	7.47	10.10	11.15	12.67	13.76	14.45
	C	0.92	0.93	0.93	0.94	0.94	0.94
	SEE	0.22	0.37	0.51	0.75	0.97	1.20
Region four	A	1403.61	1852.58	2098.90	2471.82	2741.05	2791.64
	B	10.80	10.09	9.24	9.21	9.23	7.47
	C	0.90	0.91	0.92	0.93	0.93	0.93
	SEE	0.55	0.71	0.91	1.25	1.58	1.95
Station Gojeb	A	840.72	1768.13	2967.40	4978.40	7986.20	11664.43
	B	34.03	55.42	71.99	88.05	104.67	117.38
	C	0.82	0.92	0.99	1.06	1.12	1.17
	SE	5.35	5.02	4.65	4.23	4.01	3.91

Table 19.9: Estimated regional IDF parameters with the SEE

19.5.3 Validation of the regional IDF parameters

To verify whether the estimated parameters are adequately representing the classified regions, the intensity of rainfall obtained from the estimated parameters of the stations within the region is being compared with the intensity values obtained from the estimated regional parameters. From the R^2 value for all stations taken from graphs of the two intensity values, it can be concluded that the regional parameters significantly represent the station parameters. Figure 6 indicates the graph of regional and stationary intensity values for region one.

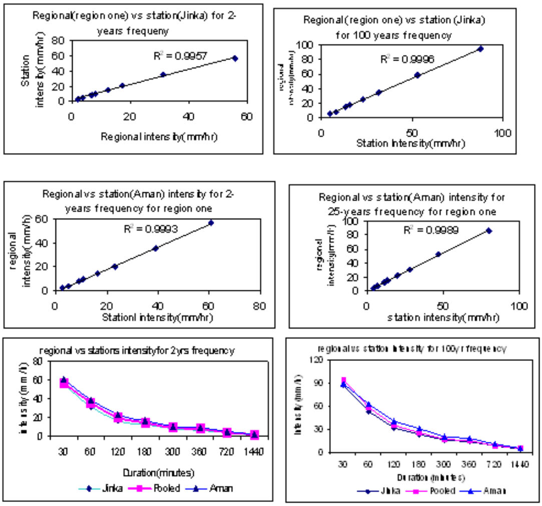


Figure 19.6: Evaluation of Estimated regional IDF parameters for region one

19.5.4 Regional IDF curves for UnGauged Catchments in SNNRP

IDF curves are constructed for the classified regions based on the regional intensity on a double logarithmic scale. Thereby, the IDF curve fit tool is used, as shown in figure 7. These curves can be applied for intensity determinations for ungauged areas within the regions, except for the limitations which were described in the previous sections.

19.6 Conclusion

Three different approaches have been implemented to derive rainfall Intensity-Duration-Frequency relationships in the SNNRP State. The first method is the

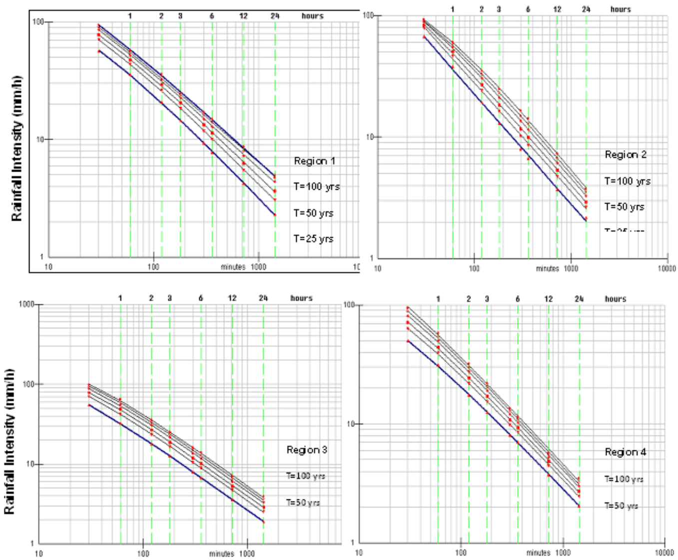


Figure 19.7: Derived Regional IDF curves for using in ungauged catchments

general IDF mathematical form that relates the intensity, duration and frequency of rainfall analytically. The second relationship is the IDF curve which is plotted on a double logarithmic scale with the intensity as abscissa and the duration as ordinate. The third method is the IDF map and regional curve that is applicable for ungauged areas of the regional state.
The mathematical form of the IDF is developed in the form of $I=A/(B+D)^C$ for each station in the region based on the optimum estimated IDF parameters. In general, the value of the “A“ coefficient increases with an increase in the return period for most of the considered stations. However, there are some cases where this coefficient decreases with an increase in the return period. The “B“ constant and the “C“ exponent depend on the relative increase or decrease of the “A“ coefficient. For most of the return periods these two parameters increases with an increase of the “A“ coefficient and vice versa.

The most adequate IDF curves have been developed based on the optimum parameters for each station by utilising the IDF curve fit tool in which all the curves show a similar shape. An exception for the shape of these curves displays the case of the Gojeb station in which an elliptic shape is obtained. The reason for this deviation can inferred from the short record length of the annual maximum rainfall that was used for this station.
IDF curves and mathematical expressions can be applied in order to estimate the rainfall intensity of a given return period and duration for areas within a radius of 25km from the principal stations (as per WMO Guidelines). To extract the intensity of rainfall of any duration and frequency at areas farther away from the principal stations, the Regional IDF curve or maps can be used so as to receive those rainfall intensity quantities. Therefore, planners and designers in the country as well as the Regional State can effectively utilise one or all of the procedures to derive the IDF value in any part of the region for planning and designing purposes. We also recommend that the projects which are operating in the state may revise their planning and design guidelines on the basis of the new findings.

19.7 References

Cunnane, C. (1989) Statistical Distributions for Flood Frequency Analysis.
Dupont, B.S & Allen, D.L. (2000) Revision of the Rainfall Intensity Curves for the Common Wealth of Kentucky. Research Report. Kentucky.
Maidment, D.R., (1993) Hand Book of Hydrology, McGRAW-Hill. Inc. USA
Rao, K.H, & Hamed, A.R. (2000) Flood Frequency Analysis. CRC press LLC, Florida
Sine, A. (2004) Regional Flood Frequency Analysis for Blue Nile River Basin, Ethiopia, Msc Thesis. Arbaminch University, Arbaminch, Ethiopia.
www. Alanasmith.Com. (1996) IDF Curve fit Software version 2.07. Alan A. Smith Inc. Software Development Company. Canada.
www.ethiopar.net.(2002) The Federal Democratic Republic of Ethiopia, Basic Information. Southern Nations and Nationalities.htm

20 The Use of Curve Number Method to Determine the Impact of Landuse and Land Cover Changes in the River Flow

A study of Kihansi River Catchment, Tanzania

S.M.M. Sabai[1], *B. Z. Birhanu*[2], *S. Mkhandi*[3], *F.W. Mtalo*[4] *and R.K. Kachroo*[5]

20.1 Abstract

For sustainable water resources management, awareness of land use and land cover impact on water resources is essential. Among the many methods to estimate the impact of landuse and land cover changes, this paper addresses a case study that uses Curve Number (CN) model to estimate and detect any changes in surface runoff from the Kihansi catchment.

The Kihansi catchment is popular for hydropower generation and the habitat for Kihansi Spray Toads (*Nectophrynoides Asperginis*), the unique amphibians living by natural mist found at the Kihansi gorge. The catchment is gradually encroached by agricultural activities affecting the natural streamflow pattern. This study intends to assess the impact of land use and land cover (derived from digital image processing of three satellite imageries) on surface runoff of the catchment. The analysis results showed that there is a decrease of forest (Fn) by 7.08%, grass land and scattered cropland (GSC) by 2.44 % and increase of bush land and scattered cropland (BSC) by 2.83% from the years 1979 to 1900. Regarding

[1]Lecturer, University College of Lands and Architectural Studies (UCLAS), P. O. Box 35176 Dar es Salaam. Tanzania, Email: mmsabai@yahoo.com

[2]PhD Candidate, Water Resources Engineering Department (WRED). Univ. of Dar es Salaam (UDSM).

[3]Senior Lecturer, WRED, UDSM.

[4]Professor, WRED, UDSM

[5]Professor, WRED, UDSM.

the change from 1990 to 1995: Fn, GSC and wooded grassland (WO) decreased by 23.81%, 11.25% and 87.88% respectively. The surface runoff increased by 2.07% from 1979 to 1995 while the stream flow reduced from 2.9 mm/day in 1979 to 2.1 mm/day (28%) in 1995.

20.2 Introduction

This paper describes a case study that uses Curve Number (CN) method as a tool to ascertain the amount of surface water runoff from rainfall in the Kihansi catchment. The basic assumption of the soil conservation service's (SCS) CN method is that, for a single storm, the ratio of actual soil retention after runoff begins to reach the potential maximum, retention is equal to the ratio of direct runoff to available rainfall for runoff (USDA-SCS, 1985). Although the method is designed for a single storm event, it can be scaled to find average annual runoff values (Chow, 1988).

The CN model can also account watershed wetness prior to the storm event of interest (Antecedent Moisture Condition, (AMC)) (USDA-SCS, 1985). Curve number values according to the Soil Conservation Service (1972) with respect to land cover classes in study area were used to compute the overall CN. In the Kihansi catchment, the hydrological soil is about 86% covered by clay loam which falls in the hydrological soil group C (Chow, 1988).

Two remotely sensed images (1979 and 1990) were used in this study and digital image processing techniques were employed using IDRISI 15 (The Andes Edition). IDRISI 15 is a GIS and image processing software covering the full spectrum of GIS and remote sensing needs from data base query and spatial modelling, up to image enhancement and classification (Eastman, 2006).

In Kihansi catchment, the cultivation activities are carried out mostly in the valley bottom especially during the dry season (*vinyungu*) (Norplan, 2003). Most of the valley bottom plots (*vinyungu*) extend closer to the riverbanks are facilitating soil erosion and sedimentation (Madulu and Dungumaro, 2002). SMEC International (2005) reported that 85% of the population is engaged in crop production.

20.3 Study Area Descriptions

The Kihansi River catchment is located upstream of the Kihansi reservoir (NC3 gauging station) within Kilolo and Mufindi administrative districts in Iringa region as shown in Figure 1. The catchment is situated in the Rufiji Basin between the longitudes of $35^o44'22$"E and $35^o53'45$"E, and the latitudes of $8^o13'08$"S and $8^o33'12$"S (SMEC International, 2005). The catchment has an approximate drainage area of 581 km^2 and lies between 1,200 m and 2200 m above sea level. The famous Udzungwa Forest Mountains cover a significant portion of the catchment, which constitutes approximately one-third of the entire water catchment of the Kihansi River (SMEC International, 2005). The area has long been known for its unique ecosystems and high biodiversity (LKEMP, 2004).

20.4 Materials and Methods

To detect the land use and land cover changes a 1979 Multi Spectral Scanner (MSS) image, two Thematic Mapper (TM) images of 1990 of the LANDSAT and a land use and land cover map purchased from IRA were used. Satellite imagery selection was based on availability, cloud cover percent and season.

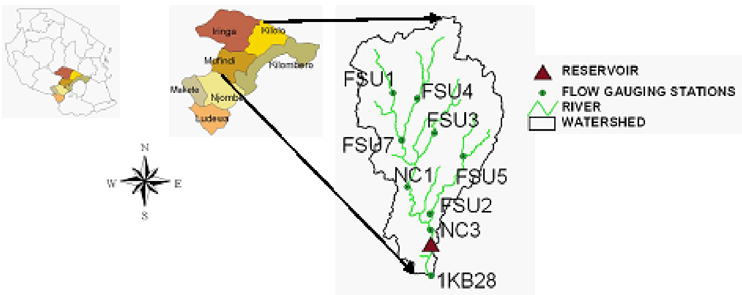


Figure 20.1: Kihansi catchment and its hydrometric networks.

The categories of land use/land cover include: Forest (Fn), Bush land with Scattered Cropland (BSC), Grassland with Scattered Cropland (GSC) and Wooded

Grassland (WO).
During the preparation of digital image processing, all images were rectified to a common Universal Transversal Mercator (UTM) coordinate system based on the 1:50,000 scale topographic maps. A supervised classification with the maximum likelihood algorithm was conducted to classify the Landsat images as presented by Eastman (2006) and Yeung et al. (2003), as well as digital image processing procedures used in various publications were adopted. The accuracy of the classified image was verified by existing land use and land cover maps of 1995 obtained from the Institute of Resources Assessment of the University of Dar es Salaam (IRA-UDSM).
The Curve Number model developed by Soil Conservation Services (1972) was used for computing runoff at Kihansi River catchment and to estimate the impact of land use and land covers on surface runoff which have direct impact on the stream flow. The soil hydrologic groups and land use and land cover categories are the variables for determination of the CN value (SCS, 1972). The steps followed were: computing the 5 day antecedent precipitation, identifying the dormant and growing seasons in the catchment, and computation of the average curve number for dry, normal and wet catchment conditions.
For dry conditions (AMC I) or wet conditions (AMC III), equivalent curve numbers can be computed by

$$CN(I) = \frac{4.2CN(II)}{10 - 0.058(CN(II))}(Source : Chow, 1988)$$

$$CN(III) = \frac{23CN(II)}{10 + 0.13CN(II)}(Source : Chow, 1988)$$

The potential maximum soil retention after runoff begins (S) was calculated and the initial abstractions, *Ia* (initial infiltration, evaporation, depression storage, and interception), could be defined as a percentage of S. And the surface runoff was calculated from the CN method developed by Soil Conservation Service (1972) and improved USDA-SCS (1985).

$$S = \frac{1000}{CN} - 10(in) \equiv 254^{*}(\frac{100}{CN} - 1)(mm)(Source : Chow : 1988)$$

$$Q = \frac{(P-0.2S)^2}{P+0.8S} For P > 0.2S, otherwise Q = 0 (Source: USDA-SCS, 1985) (4)$$

Where Q is Runoff (mm), P is Rainfall (mm), S is potential maximum retention after runoff begins (mm). The surface runoff changes were determined by dividing estimated runoff to annual rainfall according to equation 5.

$$\%Runoff = \frac{Runoff_{estimated}}{Rainfall_{annual}} x100\% (5)$$

After getting the percentage of runoff resulting from the respective rainfalls in 1979, 1990 and 1995, the runoff percentage change was determined by taking the differences between the years.

20.5 Results and Discussion

The analysis results of the satellite images of 1979, 1990 and the landuse/land cover map of 1995 together with the percentage changes from 1979 to 1990 and from 1990 to 1995 are shown in Table 1. Accordingly, a reduction of Fn, and GSC by 7.08% and 2.44% were observed from 1979 to 1990. Similarly a reduction of 23.81% and 11.25% was observed from 1990 to 1995 respectively for Fn and GSC. There is an increase of BSC by 2.83% from 1979 to 1990 and by 17.36% from 1990 to 1995. GW decreased from 1990 to 1995 by 88%.

Land Cover	Land Cover Area (Sq. km)			Area change between the years (Sq. km)		Percent Area change (%)	
	1979	1990	1995	1979-1990	1990-1995	1979-1990	1990-1995
Fn	113	105	80	-8	-25	-7.08	-23.81
BSC	353	363	426	10	63	2.83	17.36
GSC	82	80	71	-2	-9	-2.44	-11.25
GW	33	33	4	0	-29	0.00	-87.88
Total Area	**581**	**581**	**581**				

Table 20.1: Land use/land Cover changes

Note: Fn =Natural Forest, BSC=Bush land with Scattered Cropland, GSC = Grassland with Scattered Cropland, GW=Wooded Grassland and -ve = decrease

A study made by Matilda (2004) in the Ihimbo catchment (Kilolo district), indicated that forest cover decreased by 39.4% from 1978 to 1991. This was mostly caused by people converting forest land into cultivation, settlement, lumbering, and charcoal making (Matilda, 2004). Our analysis also indicated the same by showing an increase in bush land and scattered cropland. From ground truthing it was indicated that currently the catchment is more of agricultural land, thus the increase in bush land and scattered cropland was due to the search of more land for cultivation.
To indicate the impact of the change in land use and land cover in the Kihansi catchment on stream flow; surface runoff was computed using CN method, the results of which is shown in Table 2. According to the analysis, the overall CN value in 1979, 1990, and 1995 were 80.66 73.37 and 80.95 73.48 and 82.72 respectively. According to Slack and Welch (1980), a low curve number is associated with low runoff from heavily vegetated lands while high curve number is associated with high runoff from cultivation land.

	Overall CN (II)	Runoff (mm/year)	Runoff (% of Rainfall) (%)	% change from 1979-1990 & 1990-1995 (%)	% change from 1979-1995 (%)
1979	80.66	212.60	16.67		
1990	80.95	216.10	16.95	0.28	
1995	82.72	239.10	18.74	1.79	2.07

Table 20.2: Estimated surface runoff

The results shown in Table 2 showed that surface runoff has increased by 2.07% from 1979 to 1995. According to Matiko (2007), the surface runoff has risen by 2.34% from 1990 to 2002. This revealed that the increase of surface runoff was attributed to the change in the land use and land covers. The increase of surface runoff (overland flow) from 212.60 mm/year (1979), 216.10 mm/year (1990) and 239.10 mm/year (1995) anticipated that the amount of water that infiltrates in to the soil (that acts as water storage) during the rain season which normally recharges the streams during the dry season, have decreased due to the change of land use and land covers in the river catchment.

20.6 Conclusion

The decrease of forest, grassland with scattered cropland, wooded grassland and an increase of bushland with scattered cropland contributed to the increase of the surface runoff by 2.07% from 1979 to 1995 but also contributed to the decrease by 28% in average flow and 35% during dry seasons respectively. This study indicated that CN method is a useful hydrological tool for assessment and protection of the water resources at the catchment level. In order to maintain a sustainable river flow in the catchment, it is recommended that people should plant trees and other vegetations surrounding their environment which will help to retain water during dry seasons and facilitate more time for infiltration. Sustainable agricultural practices that follow contouring, is also recommended in order to protect the soil erosion and provide more time for water to percolate into the ground.

20.7 References

Chow, V. T., Maidment, D. R., Mays, L. W. (1988). *Applied Hydrology, McGraw-Hill International Editions*, Singapole.

FORCONSULT (1995). *Forest Area Baseline for the Eastern Arc Mountains: Conservation and Management of the Eastern Arc Mountain Forests Project*, Ministry of Natural Resources and Tourism Forest and Beekeeping Division, Tanzania.

Eastman, J.R (2006) *IDRISI Andes Guide to GIS and Image Processing*. Clarke Labs Clarke University. Maual Version 15.00.

LKEMP, (2004). *Lower Kihansi Hydropower Project: Updated Environmental Management Plan, Division of Environment Vice President office*, Dar es Salaam. Tanzania.

Madulu, N. F. Dungumaro, E. W. (2002). *Public Participation in Integrated Water Resources Management: the Case of Tanzania*, a paper published during the WARFSA Symposium, Dar es Salaam, Tanzania 30-31 October 2002.

Matilda, S. (2004). *The impact of Land Use Change on Water Resources, A Case Study of Ihimbo Catchment of the Little Ruaha River, Un-published Report*, University of Dar es Salaam, Tanzania.

Matiko, Mwita (2007). *The Application of Curve Number Method to Estimate*

the Impact of the Landuse and Land Covers on Water Resources Paper presented during the Annual Water Experts Conference (AWEC) 2006, AICC Arusha, 15-19 January, 2007. Tanzania.
Norplan (2003). *Tanesco Lower Kihansi Hydropower Project Environmental Impact Assessment*. In Association with Norconsult IVO International.
SMEC international, (2005). *Landscape Widew Conservation Plan for the Upstream Kihansi Catchment.* Vice President Office. Dar es Salaam.
Slack, R. B. and R. Welch (1980). *Soil conservation service runoff curve number estimates from LANDSAT data*. Water Resource Bulletin 16(5):887-893.
Soil Conservation Service (1972). *National Engineering Handbook*, Section 4, Hydrology, Washington D. C.
USDA-SCS. (1985). *National Engineering Handbook*, Section 4 - Hydrology. Washington, D.C.: USDA-SCS.
Yeung, A. K W. and Lo, C. P. (2003). *Concepts and Techniques of Geographical Information Systems: Laboratory Manual*, Person ducation, Inc. U.S.A.

21 Climate Change Impact on Lake Ziway Watershed Water Availability, Ethiopia

Lijalem Zeray Abraham[1], *Jackson Roehrig*[2], *and Dilnesaw Alamirew Chekol*[3]

21.1 Background and Objective

According to the International Panel on Climate Change (IPCC) report, by 2100 global average temperature would rise between 1.4 and 5.8^{o}C and precipitation would vary up to $\pm 20\%$ from the 1990 level. Being one of the very sensitive sectors, climate change can cause significant impacts on water resources. Developing countries, such as Ethiopia, will be more vulnerable to climate change mainly because of the larger dependency of their economy on agriculture. Hence, assessing vulnerability of water resources to climate change at a watershed level is very crucial. This gives an opportunity to plan appropriate adaptation measures that must be taken ahead of time. Moreover, this will give enough room to consider possible future risks in all phases of water resource development projects. Hence, the objectives of this study were:

- To develop temporal climate change scenarios of precipitation and temperature for the Ziway Watershed from the year 2001 to 2099,
- To quantify the possible impacts of the climate change on the water resource availability of the Lake Ziway Watershed from the year 2001 to 2099, and
- To suggest possible adaptation measures against this impact.

[1]University of Applied Sciences Cologne, Institute of Technology in the Tropics, Contact address: Cologne University of Applied Sciences, Institute for Technology in the Tropics, Betzdorfer, Strasse 2, 50679 Cologne (Deutz), Germany. E-mail: lijalemz@yahoo.com
[2]University of Applied Sciences Cologne, Institute of Technology in the Tropics
[3]University of Bonn, Center of Development Research

21.2 Study Area

Lake Ziway is found in the Great East African Rift Valley Lakes of Ethiopia. It has an open water area of 434 km^2, average depth of 4 m, and an elevation of 1636 m.a.s.l. The Ziway Watershed falls in between 7^o15'N to 8^o30'N latitude and 38^oE to 39^o30'E longitude covering a total area of about 7300 km^2 (figure 1). It is composed of two main rivers, Meki and Katar, flowing into the lake and one river, Bulbula, flowing out of the lake. The climate is characterized by semi-arid to sub-humid with mean annual precipitation and temperature of 650 mm and 25^oC, respectively.

21.3 Methodology

Climate change scenarios were developed for maximum temperature, minimum temperature and precipitation based on the HadCM3 (Hadley Centre Coupled Model, version 3) GCM (global climate model or general circulation model) outputs that are established on the A2 and B2 SRES (Special Report on Emission Scenarios) emission scenarios. The outputs of HadCM3 were downscaled into a watershed scale using the Statistical DownScaling Model (SDSM). The scenario-years from 2001 to 2099 were divided into four periods of 25 years and their respective changes were determined as monthly temperature changes (in ^{o}C) and monthly precipitation changes (in %) from the base period (1981-2000) values. Flow was simulated using the ArcView 3.2 integrated SWAT (Soil and Water Analysis Tool) hydrologic model called AVSWAT. First, the model was calibrated and validated, and the total inflow volume into the lake was simulated for the base period under normal conditions. Then, the total inflow volumes of the future periods were simulated by applying the respective future changes of temperature and precipitation. Finally, the changes in total inflow volume from the base period volume were calculated to see the impact on the lake water-level and water-surface-area.

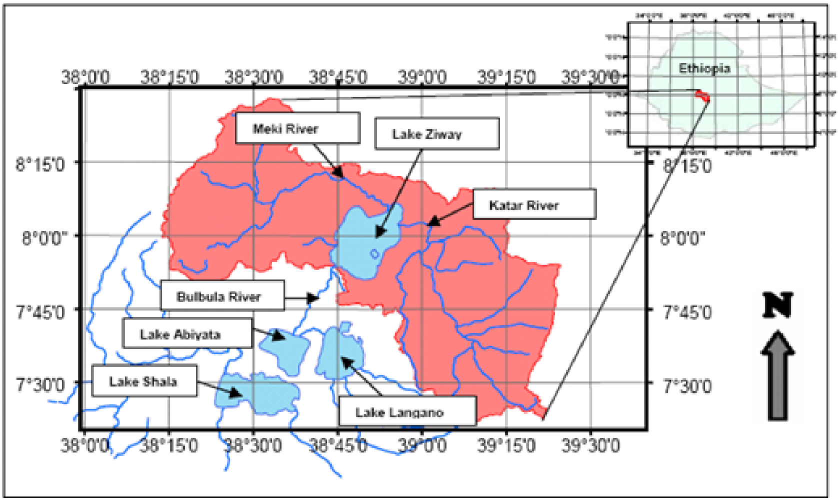


Figure 21.1: Location map of the study area

21.4 Results

21.4.1 Climate Change Scenarios Developed for the Future

The generated future scenarios for precipitation, maximum temperature, and minimum temperature generally showed an increasing trend from the base period values (figure 2 & 3).

The average monthly and annual precipitation in the watershed might increase up to 29% and 9.4%, respectively (figure 4).

Besides, as shown in figure 5 and 6, the average monthly maximum temperature might rise up to 3.6^{o}C and 1.95^{o}C; and the average minimum temperature up to 4.2^{o}C and 2^{o}C monthly and annually, respectively. Seasonally, the *Belg*[4] season is likely to exhibit a decrease of the total precipitation share along the periods. In contrary, the *Bega*[5] season might exhibit an increase in the total share. The

[4] Belg is a small rainfall season from March to May and contributes 20-30% of the total annual rainfall

[5] Bega is a dry season extending from October to February. It contributes 10-20% of the total annual rainfall

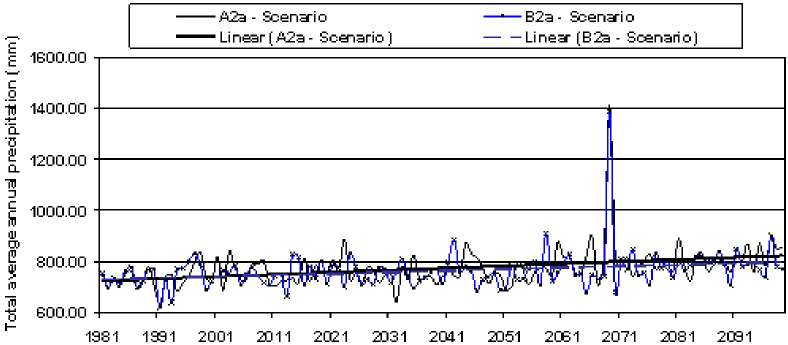


Figure 21.2: Future pattern of annual precipitation amounts

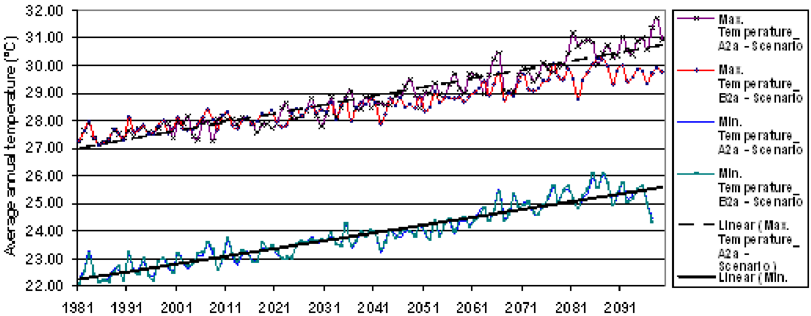


Figure 21.3: Future pattern of average annual maximum and minimum temperature

main rainfall season, *Kiremt*[6]; however, might keep on possessing more or less the same share along the periods.

Regarding maximum and minimum temperatures, the most remarkable increase of up to 2.6^{o}C might be observed during Kiremt. The Bega season might show a relatively minor increment.

[6]Kiremt is the main rainfall season from June to September and contributes 50-70% of the total annual rainfall

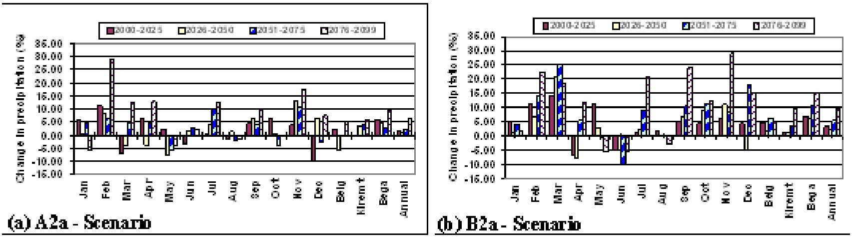


Figure 21.4: (a & b): Change in average monthly precipitation (2001- 2099)

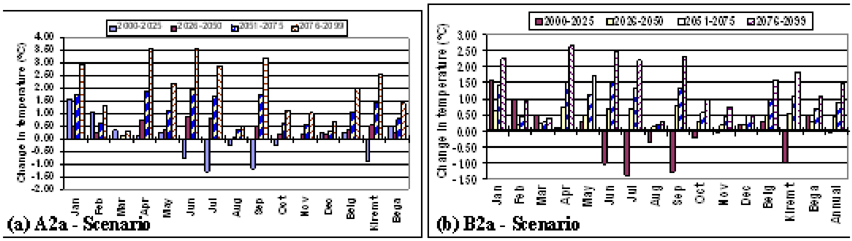


Figure 21.5: (a and b): Change in average monthly maximum temperature (2001- 2099)

21.5 Impact of the Changing Climate on Seasonal and Annual Inflow Volume

The total average annual inflow volume into Lake Ziway might decline significantly up to 19.47% for A2a- and 27.43% for B2a-scenarios. The decreasing trend of the average annual inflow volume is mainly associated with the decrease in the *Kiremt* inflow volume by between 11.8 & 28.4% for the A2a scenario and between 16.5 & 27.8% for the B2a scenario (figure 7).

21.6 Impact on Lake Ziway Water Level and Water Surface Area

Both scenarios show a significant decline of the Lake water level and shrinkage of the lake water surface area. The reduction might be especially eminent during the

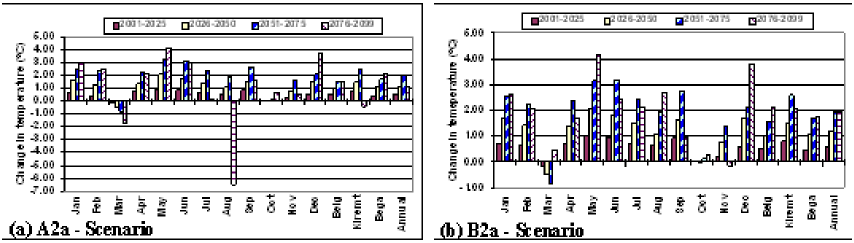


Figure 21.6: (a and b): Change in average monthly minimum temperature (2001- 2099)

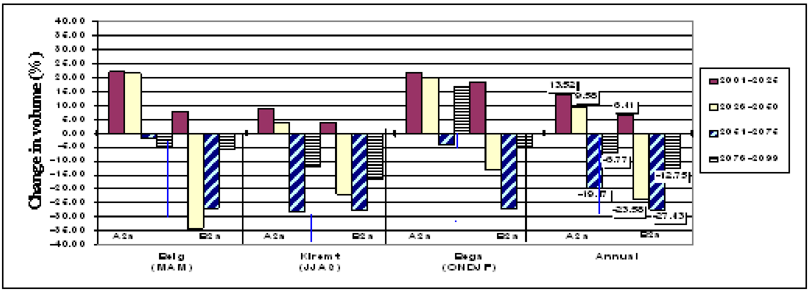


Figure 21.7: Percentage change of total seasonal and annual inflow volume into Lake Ziway

2051-2075 period, where the lake level decline might reach up to 62 cm (figure 8 (a)). Consequently, the water surface area might also shrink up to 25 km^2 (figure 8 (b)).

21.7 Adaptation Options

The main objective of the adaptation options is to reduce impacts of climate change. Hence, the adaptation options should focus on increasing water utilization efficiency and water availability, and on ensuring better management.

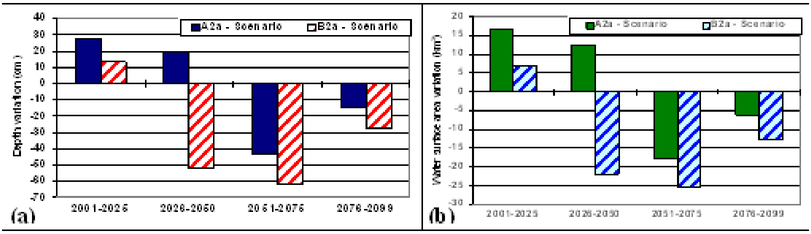


Figure 21.8: (a) Water level variation, and (b) Water surface area variation of Lake Ziway from the base period level

Among the adaptation options the most important ones are: implementation of appropriate irrigation water management practices; adoption of efficient irrigation systems and awareness creation on efficient water utilization; implementation of water pricing and water recycling; development of effective rainwater harvesting technologies; construction of small to medium sized storage reservoirs with a minimum impact on the environment; consideration of climate change and its impacts at all levels of water resource development projects; and establishment and implementation of policy measures that govern the amount of water to be abstracted. Besides, watershed based integrated water resources management should be the core part of the adaptation options.

21.8 Conclusion

The scenarios developed for the years 2001-2099 showed that both temperature and precipitation are likely to increase from the 1981-2000 level. These changes are likely to have significant impacts on the inflow volume into the lake. Despite the increasing trend of both climatic variables, the increase in precipitation seems to be obscured by increases in temperature. Hence, the total average annual inflow volume into Lake Ziway might decline significantly. This is likely to drop the lake level up to two third of a meter and shrink the water surface area up to 25 km^2, which is about 6% of the base period water surface area. This combined with the unbalanced supply-demand equation in the watershed is expected to have significant impact on the lake water balance. Therefore, in Lake Ziway Watershed, runoff is likely to decrease in the future and be insufficient to meet future demands for water of the ever increasing population.

21.9 Recommendations

This study involved a number of models and model outputs where each possessed a certain level of uncertainty. Hence, the results of this study should be taken with care and be considered as indicative of the likely future. This study should be extended by considering changes in landuse, soil and other climate variables. It is believed that the results of this study give a clue and increase awareness on the possible future risks of climate change. Hence, such studies should continue on different Ethiopian-watersheds. Continuing studies; however, should consider the wide range of uncertainties associated with models and try to reduce the uncertainties by the use of different GCM outputs, downscaling techniques, and emission scenarios. Different adaptation options need to be implemented so that future demand and supply can be balanced. For this reason, any kind of water abstraction in the watershed must be integrated and management should be based on a holistic approach.

Complete List of Volumes

Vol. 1

LARS 2007 Proceedings

Vol. 2

Alumni Summer School - Well Drilling and Rural Water Supply

Vol. 3

Summary of Master Theses from Arba Minch University

Vol. 4

Results from Expert Seminar - Topics of Integrated Water Ressources Management

Vol. 5

Adane Abebe - Hydrological Drought Analysis - Occurence, Severity, Risks: The Case of Wabi Shebele River Basin, Ethiopia

Vol. 6

Bogale Gebremariam

Vol. 7

Stefan Thiemann et al. Integrated Watershed Management - Financial Aspects of Watershed Management