Assessing the Impacts of Environmental Changes on the Water Resources of the Upper Mara, Lake Victoria Basin

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Abstract

Growing population and unregulated access to forest land have exerted high pressure on the land and water resources of the Upper Mara basin, leading to changes in land and water use patterns in the basin. This study considers the interactions among climate change and variability, land surface, hydrology, and human systems, including societal adaptations to changing environmental conditions.

The Upper Mara River catchment forms the recharge area for the Mara River basin, a key transboundary river, and one of the permanent rivers feeding into Lake Victoria. The area is drained by two main rivers: the Amala and the Nyangores which merge at the middle reaches (1°2'15.2"S, 35°14'31.7"E) to form the Mara River. The study aims to assess how changes in climate, land use and management practices have impacted on the water resources of the Upper Mara basin.

The objectives of the study are: to assess the trends in changes in the climatic, land cover/land use, water quality and vegetation variables; to build and evaluate a hydrological model capable of simulating the response of watershed processes to changing climatic, land use, and management conditions under past, present conditions; and predict potential impacts of the changes in climate, land use and management practices, and contribute in advising policy in the formulation and development of strategies aimed at the sustainable management of water resources in the Mara River Basin.

Historical data including data for rainfall, temperature and streamflow; field collected data; and satellite remote sensing data is used in the study. The Soil and Water Assessment Tool (SWAT) is used to evaluate the impacts of the changes in climatic, landcover and management inputs. Changes are made to both the model crop database and management files to make it adaptable to tropical conditions. The model is calibrated using streamflow data, and validated using both streamflow and distributed data. The performance of the model is statistically assessed to be "good" and "satisfactory" for the percent bias and Nash Sutcliffe respectively. The water balance fractions are within typical hydrological ranges and significantly similar to the observed fractions. Distributed validation using remote sensed leaf area index (RS_LAI),

shows that the timing of the start of the growing season match well with SWAT simulated LAI.

Trend analysis is performed using the Mann-Kendall and Sen Statistics for rainfall and temperature variables. Rainfall data (1962-2009) from six stations located within the basin while temperature data (1992-2009) from three meteorological stations surrounding the study area is used. There is a general decreasing trend of upto 18mm/yr in the annual rainfall. 50% of the stations analyzed experienced significant decline (at $\alpha = 0.1$) in annual Rainfall in the last 50 yrs. While the minimum temperatures have significantly increased by between 0.02 and 0.04 ^{0}C/yr; there has been an upward but insignificant change in the maximum temperatures. Changes in the vegetation indices are analyzed using the normalized difference vegetation index (NDVI) data (1998-2010) from the Satellite Pour l'Observation de la Terre- VEGETATION (SPOT_VGT) sensor. All indices including, the integral NDVI, the vegetation condition index (VCI), the standardized vegetation index (SVI) and the vegetation productivity index (VPI) have a better than average vegetation health for different vegetation types showing an increasing trend in vegetation biomass.

Land cover change analysis using post classification methods, show that between 1976 and 2006, agriculture coverage increased by 109%, while forest, shrubs, and grassland decreased by 31%, 34%, and 4% respectively. Land change evolution using the three date (1986,1995,2006) NDVI-RGB method show that the highest loss in vegetation biomass was experienced in the 1990s. The biggest loser was the encroachment and degradation of the Mau forest areas.

Future management scenarios simulating the application of fertilizer at a typical rate of 100kg/Ha lead to significant increase in crop yields for all but two of the soil classes. The two soil classes have no marked improvement in yields even with high fertilizer application. The re-afforestation scenario to pre-1976 forest coverage results in reduction of streamflow and increase in evapotranspiration. In the irrigation scenario crop yields increase two to three fold even without fertilizer application. The replacement of the lowland cereal crops with grain sorghum led to higher water yields in the stream. Sorghum yield were comparable to the maize yields and the water stress days were halved in the sorghum scenario.

Sensitivity analysis of the climatic variables with SWAT indicate that on one hand, higher watershed evapotranspiration (ET) will result from higher rainfall and temperatures, with higher CO_2 leading to decline in ET. On the other hand higher rainfall and higher CO_2 will also lead to high water yields, but higher temperature will lead to a drop in the water yield.

The Long Ashton Research Station Weather Generator (LARS-WG) is used in the weather perturbations, and the construction of the GCM climate change scenarios. The projection of climate change with ensemble mean for 16 GCMs in the 2020s and 2050s show increase precipitation amounts compared to 1990s baseline. The 2050s will have higher projected rainfall than 2020s, while higher rainfall is projected under B1 than A1B IPCC climate scenarios. As a consequence, higher streamflow is expected for all future time periods. The return level at the outlet of the basin for a presumed 30, 50 and 100 yr flood was determined to increase by 11% in the 2020s to 19% in the 2050s. Bias corrected GCM outputs however indicate marginal increases in the different return levels (3% for 100yr flood) but more severe extreme low flows.

Whereas the historical trends depict a tendency towards a drier watershed, the uncorrected climate models predict a wetter future. This inconsistencies present a challenge in planning for future management of water resources at the Mara basin. Bias corrected climate projections indicate a trend which was more constistent with historical records. As an adaptation measure, the conservation of the flood water even at current flow levels can go a long way in alleviating water stress in the dry months. In the short term the adoption of better farm management practices including appropriate use of fertilizers and introduction of drought tolerant grain crops like sorghum should be encouraged.

List of abbreviations and acronyms

AAFC-WG	Agriculture and Agri-Food Canada weather generator
AGNPS	Agricultural Non-point Source
AnnAGNPS	Annualized Agricultural Non-point Source
ANSWERS	Area Non-point Source Watershed Environment Response Simulation
AR4	Fourth Assessment Report
ASAL	Arid and semi-arid lands
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
AVHRR	Advanced Very High Resolution Radiometer
BSAP	Biodiversity Strategy and Action Plan
CA	Cluster and average method
CAN	Calcium ammonium nitrate
CFR	Central Forest Reserves
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo (International Maize and Wheat Improvement Center)
CYCLOPES	Change in Land Observational Products from an Ensemble of Satellites
DAO	District Agricultural Officer
DAP	Di-ammonium phosphate
EAC	East African Community
EFA	Environment Flow Assessment
ENSO	El Niño/Southern Oscillations
EPIC	Erosion Productivity Impact Calculator
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agriculture Organisation
FD	Forest Department
GCM	General Circulation Models
GLUE	Generalized Likelihood Uncertainty Estimation method
GOK	Government of Kenya
GSSHA	Gridded Surface Hydrologic Analysis
HEC-HMS	Hydrologic Engineering Center's Hydrologic Modeling System
HRU	Hydrologic response unit
HSPF	Hydrological Simulation Program – FORTRAN
HydroSHEDS	Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales
HYMO	Hydrologic model
ICPAC	IGAD Climate Prediction and Applications Centre
IFA	International Fertilizer Industry Association

IFDC	International Fertilizer Development Center
IGAD	Intergovernmental Authority on Development
iNDVI	Integrated NDVI
IPCC	Intergovernmental Panel on Climate Change
ISODATA	Iterative Self-Organizing Data Analysis Technique
ITCZ	InterTropical Convergence Zone
IWRM	Integrated Water Resources Management
KENSOTER	Kenya Soil and Terrain
KINEROS2	KINematic Runoff and EROSion
KNBS	Kenya National Bureau of Statistics
LAI	Leaf area index
LARS-WG	Long Ashton Research Station-weather generator
LCCS	Land Cover Classification System
LH-OAT	Latin Hypercube – One At a Time
LVBC	Lake Victoria Basin Commission
LVBWO	Lake Victoria Basin Water Office
MAM	March-April-May
MCMC	Markov chain Monte Carlo
MLN	Maize leaf necrosis disease
MMD	Multi-model dataset
MODIS	Moderate Resolution Imaging Spectroradiometer
MoU	Memorandum of understanding
MRCC	Maritime Rescue Coordination Centre
MSS	Multi spectral scanner
(M)USLE	(Modified) Universal Soil Loss Equation
NDVI	Normalized Difference Vegetation Index
NRC	Non-Resident Cultivation
NSE	Nash-Sutcliffe efficiency
OLS	Ordinary Least Squares
OND	October-November-December
ParaSol	Parameter Solution
PBIAS	percent bias
PCMDI	Program for Climate Model Diagnosis and Intercomparison
PES	Payment for Ecosystem Service
PET	Potential evapotranspiration
PRMS	Precipitation-Runoff Modeling System
PSO	Particle Swarm Optimization

RREL	Relative range of the NDVI
RSR	Root Mean Square Error-observations standard deviation ratio
SEA	Strategic Environment Assessment
SHE	Systéme Hydrologique Européen
SPOT-VGT	Satellite Pour l'Observation de la Terre-VEGETATION
SRTM	Shuttle Radar Topography Mission
STHP	Sub Tropical High Pressure systems
SUFI2	Sequential Uncertainty Fitting-version 2
SVI	Standard Vegetation Index
SWAT	Soil and Water Assessment Tool
SWAT-CUP	SWAT - Calibration and Uncertainty Programs
TM	Thematic Mapper
TN	Total nitrogen
TP	Total phosphorus
TWRUF	Trans-boundary Water Resources Users Forum
UNEP	United Nations Environment programme
UNFCCC	United Nations Framework Convention on Climate Change
VCI	Vegetation Condition Index
VGT4Africa	Vegetation for Africa project
VITO	Vlaamse Instelling Voor Technologisch Onderzoek (Flemish Institute for Technological Research)
VPI	Vegetation productivity indicator
WEPP	Water Erosion Prediction Project
WGN	Weather generator
WHO	World Health Organization
WMO	World meteorological Organization
WRMA	Water Resources Management Authority
WRUA	Water Resources Users Association
WUA	Water Users Association
WWF-ESARPO	World Wildlife Fund-East and Southern Africa Programme Office
WXGEN	Weather generator

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