REMOTE SENSING ENHANCED WATER BUDGET CALCULATIONS FOR THE SUDD AND BAHR EL GHAZAL BASINS

By

Nahla Alaa Abbas Helmy

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
in
Irrigation and Hydraulics Engineering

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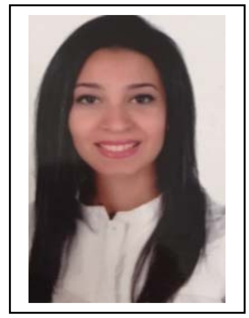

Registration Date: 1/10/2013
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Remote Sensing Enhanced Water Budget Calculations for the Sudd and Bahr El Ghazal Basins

Key Words:

Satellite Images; Satellite Radar Altimetry; Water Budget; Sudd Wetlands; Bahr el Ghazal

Summary:

This study aims at developing a methodology for continuous monitoring of the Sudd and Bahr el Ghazal wetland extent, evaporation losses and storage variations. Wetland extent map time series are produced based on a thorough calibration process of MODIS satellite images at small time increment. Four different satellite radar altimetry datasets are used to derive matching characteristic water levels. Both area and level time series are employed to obtain an Area-Level-Volume relationship that allows for continuous monitoring of storage variations. A set of Python codes have been developed and validated for automating the image processing, and water level extraction, as well as synchronization of both time series. Results indicated that the former studies over-estimated the extent of the Sudd wetlands areas and the corresponding evaporation losses, but Bahr el Ghazal area results agree with literature. Storage variations estimates confirm that both wetlands don't act as a reservoir but more as a sink. Since flow records in the basin cease to exist, the developed workflow provides a reliable tool for wetlands hydrologic monitoring and enhanced water budget calculations.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it is has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

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Acknowledgments

At the beginning, I would to thank God Almighty.

I am deeply grateful for my supervisors Prof.Dr. Ahmad Wagdy, Prof.Dr. Mohamed Hamdy Nour, and Dr. Mohamed Aly Elkordy for their patient guidance, cooperation and effort in this thesis.

I would like to thank my colleagues and professors in the Irrigation and Hydraulics department, CUFE, for their generosity in sharing their diverse knowledge.

I would like to thank Prof. Dr. Hussam Fahmy, Professor Emeritus, NWRC for his valuable advice and helpful suggestions.

Special thanks to Mrs. Naglaa Yehia, Dr. Rameen Abdel Hadi, and Ms. Sabah Saied who did not save any effort in order to make this a presentable thesis.

Finally, I owe sincere gratitude and appreciation to my parents, my mother Maha Safwat, my father Alaa Abbas and my dear husband Yasser El Gabri for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

Nahla Alaa Abbas, 2019

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Nomenclature

BRAT	Basic Radar Altimetry Toolbox
CNES	Centre National d'Etudes spatiales
ENVISAT	Environmental Satellite
ESA	European Space Agency
Eta	Actual Evapotranspiration
ETM	Enhanced Thematic Mapper
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
GDR	Geophysical Data Records
GERD	Grand Ethiopian Renaissance Dam
GIS	Geographic Information System
IGDR	Interim Geophysical Data Record
LaSRC	Landsat 8 Surface Reflectance Code
MMU	Minimum Mapping Unit
mNDWI	Modified Normalized Difference Water Index
MODIS	Moderate Resolution Imaging Spectroradiometer
MRT	MODIS Re-projection Tool
MSI	Multispectral Satellite imagery
NASA	National Aeronautics and Space Administration
NBI	Nile Basin Initiative
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NIR	Near Infra-Red
NOAA	National Oceanic and Atmospheric Administration
NTEAP	Nile Transboundary Environmental Action Project
OLI	Operational Land Imager
OSDR	Operational Sensor Data Record
PISTACH	Prototype Innovant de Système deTraitement pour les Applications Côtières et l'Hydrologie
RMSE	Root Mean Square Error
SEBAL	Surface Energy Balance Algorithm for Land Module
SGDR	Sensor Geophysical Data Records

SRA	Satellite Radar Altimetry
SWIR	Short Wave Infra-Red
TIRS	Thermal Infrared Sensor
T/P	TOPEX/ POSEIDON
USA	United States of America
UTM	Universal Transverse Mercator

Abstract

Wetlands are complex dynamic ecological systems that preform a significant function in keeping environmental quality standards, subsidizing livelihoods and enriching biodiversity. Most of Nile Basin wetlands are recognized as wetlands of international importance, including the Sudd and Bahr el Ghazal wetlands. Therefore, their environmental assessment and continuous monitoring is a necessity. Situated in the central western part of the Nile Basin, Bahr el Jebel and Bahr el Ghazal basins encompass large wetland areas fed by Bahr el Jebel river and tributaries of Bahr el Ghazal river, respectively. Together they contribute nearly half of the White Nile inflow.

Hydrological and ecological processes that take place in this area are of the most complicated and least understood in the Nile Basin; therefore, the root cause of the encountered losses remains unknown. Literature show large variation in the estimation of areas of these wetlands from thousands to tens of thousands square kilometers, which in turn leads to variation in the calculated evaporation losses and miscalculation of prospective savings through channelization projects. Moreover, ground truth measurements in Nile Basin wetland areas do not exist due to their inaccessibility in addition to political sensitivities.

The overall goal of this research is to improve the Sudd and Bahr el Ghazal basins water budget calculations, using readily accessible satellite datasets. The primary objective of this study is to suggest and assess a new technique that enables the year around monitoring of wetlands at short intervals. On the technological development side, the aim is to design and implement an automated workflow that combines datasets for Multispectral Satellite Imagery (MSI) and Satellite Radar Altimetry (SRA). Such automated workflow should enable continuous monitoring of wetlands with minimal dependence on ground measurements and be generic in order to be replicated in any river basin.

In pursuing the primary objective of this research, a combined technique is introduced and implemented, to monitor changes in the extent of wetlands, net evaporation losses and storage variations using satellite measurements. The proposed technique conjugates datasets of MSI and SRA through an automated workflow. Six Python scripts constitute the automated workflow; where five are developed and one existing script is modified. These codes are developed to assemble, process, crop the boundaries of the study area, apply masks of quality, fill gaps, and synchronize a large number of MSI tiles and tracks of SRA. Wetland extent map time series are produced based on a thorough calibration process of MODIS satellite images at an 8-day time increment. Subsequently, the corresponding evaporation losses time series is generated using historical evaporation rates and the generated wetland area time series. Four different satellite radar altimetry datasets are used to extract water level variations in a continuously varying extent of wetlands and derive characteristic water levels. The datasets include standard Sensor Geophysical Data Records (SGDR) from Jason1, Jason2, and ENVISAT missions; in addition to experimental PISTACH products. With the wetland area estimates, characteristic levels are used to formulate an Area-Level-Volume relationship that allows for continuous monitoring of storage variations.

The time series of wetland area is produced for the period from 2002 to 2016 for both study areas. The Sudd average permanent wetlands area amounts to 1200 km^2 in addition to seasonal swamps area of about 5000 km^2. The average annual evaporation