**Tonlé Sap Food Security & Agriculture III**

*Evaluating Changes in Ecosystem Vitality and Freshwater Health in the Tonlé Sap Basin using Remotely Sensed Data*

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**Project Overview**

***Project Synopsis:***

Tonlé Sap is the largest freshwater lake in Southeast Asia and supports over 1 million people. Overfishing, agriculture, climate change, and natural disasters put Tonlé Sap lake’s water quality at risk. In collaboration with Conservation International (CI), this project seeks to fill the data gaps of water quality and ecosystem vitality parameters within the Freshwater Health Index (FHI), calibrate the current Soil & Water Assessment Tool (SWAT), and synthesize the results of previous terms’ work into a cohesive package to monitor water parameters.

***Abstract:***

Tonlé Sap Lake, located in Cambodia, Southeast Asia, is one of the most productive inland fisheries in the world. With the unique reverse flow hydrology of the Tonlé Sap River, this freshwater system contains rich biodiversity and provides critical freshwater resources for the local community. Overfishing, stronger seasonality, drought, dam construction, forest fires, and untreated industrial domestic sewage threaten the ecosystem vitality and economic success of Tonlé Sap. In collaboration with Conservation International and the Cambodian Ministry of Water Resources and Meteorology’s Tonlé Sap Authority, we calibrated and finalized remotely-sensed proxies for sub-indicators of the Freshwater Health Index (FHI). We used NASA Earth observation data from Moderate Resolution Imaging Spectroradiometer (MODIS), and the Gravity Recovery and Climate Experiment (GRACE). These datasets were used in RS proxies and a Soil and Water Assessment Tool (SWAT) model that previous teams developed for sub-indicators of FHI. They included landcover, bank modification, and water quality metrics. It was determined that the ground water storage in Tonlé Sap Lake exhibited a slight declining trend over from April 1st, 2002 to February 3rd, 2017. To calculate chlorophyll-a concentration in the Tonlé Sap Lake, we used Copernicus Global Land Service mission data which provided a Trophic State Index of the lake. Between January 1st, 2000 and December 31st, 2020, the lake and surrounding region within the study area boundary displayed a slight decrease in vegetation density and consistently high chlorophyll-a concentrations. The SWAT model calculated nitrogen and phosphorus content measured in outlet points of the lake. We demonstrated that remotely sensed data is valuable for providing additional information for the FHI, but is not fully capable of replacing its *in situ* counterpart. We also concluded the water quantity is on a slowly declining trend within the basin.

***Key Terms:***

SWAT, Tonlé Sap Basin, Freshwater Health Index, GRACE, NDVI, watershed health

***National Application Areas Addressed:*** Food Security & Agriculture, Water Resources

***Study Location:*** Tonlé Sap Lake and River Basin, Cambodia

***Study Period:*** October 2000 – December 2020

***Community Concerns:***

* Tonlé Sap Lake supplies critical ecosystem services and economic drivers such as fishing, freshwater supply, crop irrigation, and recreation, all of which are impacted by the lake’s water supply and quality.
* Deforestation, changes in precipitation patterns, increased drought frequency, agricultural activity, and hydropower developments threaten the natural seasonal fluctuations in water quantity and quality that support the livelihood of 4.5 million dependent people.
* Recent increases in rice and overall crop production have directly stressed the water supply by increasing pumping for irrigation practices, potentially causing ecological imbalances.

***Project Objectives:***

* Synthesize and summarize work done in previous terms
* Obtain the first three inputs for the FHI: 1) water quality, 2) water quantity, and 3) drainage basin condition
* Map regional water quality changes to provide partners with a better understanding of the implications of those changes

***Previous Terms:***

2021 Spring (LaRC) – Tonlé Sap Food Security & Agriculture I

2021 Summer (LaRC) – Tonlé Sap Food Security & Agriculture II

**Partner Overview**

***Partner Organizations:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **Ministry of Water Resources and Meteorology, Tonlé Sap Authority (Cambodia)** | H.E. Sin Viseth, Secretary General; H.E. Khov Meas, Deputy of Secretary General; Mr. Heng Sovannara, Director of Department of Exploitation Control and Conservation; Mr. Srun Siline, Officer; Mr. Kvan Pheaktra, Officer | End User | No |
| **Conservation International** | Derek Vollmer, Freshwater Science Program Senior Director; Nicholas Souter, Freshwater Research Manager | End User | Yes |

***Decision-Making Practices & Policies:***

The Ministry of Water Resources and Meteorology (MoWRaM) and the Tonlé Sap Authority (TSA) are currently striving to balance the overfishing, hydrological development, agriculture, and pollution of a growing population and the health of the Tonlé Sap Lake ecosystem. Policy makers use *in situ* data to help make management decisions, but with the COVID-19 pandemic, gathering *in situ*data has been more difficult and time consuming.

Since 2008, Conservation International has been working with MoWRaM to provide technological expertise to help with decision-making.  Conservation International wishes to expand inputs to the Freshwater Health Index (FHI) by assessing the feasibility of using remote sensing for sub-indicator processing. This would supplement the *in situ* data collected by MoWRaM and the Mekong River Commission, which includes water quality indicators (phosphorous, nitrogen, chlorophyll-a, ammonium, nitrate, silica) and water quantity (lake depth).

**Earth Observations & End Products Overview**

***Earth Observations:***

|  |  |  |
| --- | --- | --- |
| **Platform & Sensor** | **Parameters** | **Use** |
| **European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis 5th Generation (ERA5)** | dew point, daily precipitation, U component of wind, V component of wind, daily maximum and minimum temperature, surface solar radiation downwards | ERA5 data were used as inputs for the SWAT model to calculate water quality and streamflow information. |
| **Gravity Recovery and Climate Experiment (GRACE)** | equivalent liquid water thickness | GRACE data were used for the computation of total groundwater storage, which is an input to the FHI. |
| **Shuttle Radar Topography Mission (SRTM)** | elevation | The NASA Digital Elevation Model was used as an input for the SWAT model. This allowed the model to produce stream information. |
| **Terra Moderate Resolution Imaging Spectroradiometer (MODIS)** | Normalized Difference Vegetation Index (NDVI) | MODIS-derived NDVI values were used to compute a bank modification parameter, an input for the FHI. |

***Ancillary Datasets:***

* Conservation International *in situ* streamflow and water quality dataset – These data were used for calibration and validation of the SWAT model
* United Nations Food and Agriculture Organization (FAO) Digital Soil Map of the World (DSMW)–The DSMW was used as a SWAT input to give the model data about the soil underneath the Tonlé Sap Basin
* European Space Agency (ESA) Climate Change Initiative (CCI) landcover maps – These were used as SWAT land use input maps
* European Commission Joint Research Centre (JRC) Copernicus Global Land Service (CGLS) Lake Water Quality – These data were used to calculate chlorophyll-a concentrations in the Tonlé Sap Lake
* Tonlé Sap Food & Agriculture II getSwatData python script – This was used to gather water quality data (precipitation, windspeed, solar radiation, temperature, and humidity) as inputs to the SWAT model
* King’s College London Global Georeferenced Database of Dams (GOODD) – This database was used as input for FHI ecosystem vitality indicators

***Modeling:***

* Soil & Water Assessment Tool (SWAT) (POC: Dr. Venkataraman Lakshmi, University of Virginia) – Used to derive the amounts of sediment and nutrients (nitrogen and phosphorus) that were mobilized from the land surface to the lake, which were then compared to *in situ* data
* Freshwater Health Index (FHI) (POC: Dr. Derek Vollmer, Conservation International) – Used to guide the creation of the framework for sub-indicator processing

***Software & Scripting:***

* QGIS (3.16.11) Soil and Water Assessment Tool (QSWAT 1.1.1) – For computing water quality and water quantity information
* Freshwater Health Index (FHI) Desktop Software – For compiling all our inputs into FHI statistics
* Google Earth Engine – For retrieving bank modification and processing and accessing GRACE data
* Google Earth Engine Python API – For retrieving and preprocessing SWAT data
* SWAT Calibration and Uncertainty Program (SWAT-CUP 2012) – For calibrating and refining the computer SWAT model
* ArcGIS Pro 2.9 – For analyzing chlorophyll-a concentration and creating supportive visual aids

***End Products:***

|  |  |  |  |
| --- | --- | --- | --- |
| **End Products** | **Earth Observations Used**  | **Partner Benefit & Use** | **Software Release Category** |
| **Bank Modification Map** | Terra MODIS | The NDVI time series map provides understanding of vegetation changes due to human and natural development around the lake. | III |
| **FHI-RDAC (Freshwater Health Index – Remotely Sensed Data Acquisition Companion)** | Terra MODISGRACEERA5SRTM | These tools collect bank modification and water quantity data inputs for the FHI. They also provide a package of inputs for running a SWAT model. | III |
| **SWAT Output for Tonlé Sap Basin** | ERA5SRTM | These outputs provide water quality measurements that will be used in the FHI to assess ecosystem vitality in the Tonlé Sap Basin. | N/A |
| **Freshwater Health Index (FHI) Score** | Terra MODISGRACEERA5SRTM | A final FHI score will serve as a baseline score for the region. MoWRaM and Conservation International can use indicator measurements to assess key ecosystem areas for improvement and resource allocation. | N/A |

***Product Benefit to End User:***

This project will provide the Cambodian community and key stakeholders in the region, including Conservation International, MoWRaM, and the Tonlé Sap Authority, with a valuable tool to measure ecosystem vitality and better implement the Freshwater Health Index. Our method aims to bridge the data gap caused by COVID-19 related travel restrictions which have made field data collection difficult. Using remote sensing and a calibrated SWAT model for sub-indicator processing, data gaps will be addressed by accounting for missing variables unable to be calculated from limited *in situ* data. This project will provide information to better guide policy decisions on topics such as recreation and conservation, to effectively allocate resources, to provide high-quality water for resilient communities, and to maintain healthy social-ecological systems for generations to come.

**References**

Ang, R., & Oeurng, C. (2018, February 19). Simulating streamflow in an ungauged catchment of Tonlesap Lake Basin in Cambodia using Soil and Water Assessment Tool (SWAT) model. *Water Science*, *32*(1), 89–101. https://doi.org/10.1016/j.wsj.2017.12.002

Fischer, G., Nachtergaele, F., Prieler, S., van Velthuizen, H.T., Verelst, L., & Wiberg, D. (2008). *Global Agro-ecological Zones Assessment for Agriculture (GAEZ 2008)* (1.2) [Data set]. IIASA, Laxenburg, Austria and FAO, Rome, Italy. https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/en/

Oeurng, C., Cochrane, T. A., Chung, S., Kondolf, M. G., Piman, T., & Arias, M. E. (2019). Assessing climate change impacts on river flows in the Tonlé Sap Lake basin, Cambodia. Water, 11(3), Article 618. https://doi.org/10.3390/w11030618

Sophally, S. (2014, February 17). *Groundwater Resources in Cambodia - data portal*. Mrcmekong.org. Retrieved November 10, 2021, from https://portal.mrcmekong.org/assets/v1/documents/Groundwate-Cambodia\_Sphally.pdf