**Belize Water Resources**

*A Google Earth Engine Dashboard for Assessing Coastal Water Quality in Belize’s Coral Reefs to Identify Sustainable Development Goals for Achieving Sustainable Use of Natural Resources*

**Project Team**

***Project Team:***

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**Project Overview**

***Project Synopsis:*** In conjunction with the Wildlife Conservation Society (WCS) and Coastal Zone Management Authority and Institute (CZMAI), the NASA DEVELOP Belize Water Resources Team created a Google Earth Engine (GEE) dashboard to extract and evaluate water quality parameters near the Belize Barrier Reef System. This tool allows for a time series analysis of water quality metrics, such as chlorophyll-a and turbidity, which is essential for informing coastal conservation efforts and water management strategies. The spatiotemporal insights generated from this tool will support our partners’ efforts in preserving the coral reef system and its crucial ecosystem services.

***Abstract:***

The Belize Barrier Reef is a biodiverse marine ecosystem and the largest coral reef system in the western hemisphere. The reef also provides ecosystem services in the form of fisheries and tourism and is estimated to be responsible for 12 to 15% of the nation’s gross domestic product. Retaining these ecosystem functions requires sustainable coastal management and preservation of water quality, especially in the face of global changes in climate and local anthropogenic impacts. The Belize Water Resources Team at NASA Jet Propulsion Laboratory and NASA Ames Research Center partnered with the Coastal Zone Management Authority and Institute, a Belizean governmental agency, and the Wildlife Conservation Society to evaluate water quality conditions and inform coastal management decisions. Using Google Earth Engine, we developed a tool that outputs a time series of sea surface temperature, turbidity, and chlorophyll-a concentration derived from Landsat 8 Operational Land Imager (OLI) and Sentinel-2 Multispectral Instrument (MSI), Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) and Terra MODIS satellite imagery. With optical data available from 2013 onward, our partners can efficiently identify reef areas threatened by depreciating water quality, designate Marine Protected Areas and no-take zones, and conduct temporal analyses of water quality changes following environmental disturbance events, such as hurricanes. Additionally, this tool will assist in identifying indicators that may be used to measure Belize’s progress towards Sustainable Development Goals regarding marine environments. Using the tool, partners can better monitor changing water quality and make decisions accordingly in regards to sustainable resource use, coral reef conservation practices, and environmental capital.

***Keywords:***

water quality, chlorophyll-a, turbidity, Landsat 8 OLI, Sentinel-2 MSI, MODIS, remote sensing, Google Earth Engine

***National Application Area Addressed:*** Water Resources

***Study Location:*** Coastal Belize and the Belize Barrier Reef Reserve System

***Study Period:*** January 2013 to May 2019

***Community Concerns:***

* As one of the longest coral reef systems in the world, the Belize Barrier Reef supplies numerous ecosystem services, such as shoreline protection, tourism, habitat for marine species, and fisheries.
* This reef system contributes to approximately 12 to 15 percent of the Belize GDP; degradation of the reef or its aquatic environment negatively impacts the aforementioned services and reduces their economic benefits.
* Natural disturbances and human activities can have detrimental effects on coastal water quality, putting these ecosystems at risk.
* Improving water management practices is necessary to protect these ecosystems from further degradation. Such strategies require a robust monitoring system that is spatially and temporally comprehensive.

***Project Objectives:***

* Create maps that identify locations along the coast where poor water quality persists, thus informing coastal managers where conservation efforts are needed
* Produce a dashboard hosted on Google Earth Engine that performs atmospheric corrections and extracts water quality parameters from Landsat 8 Operational Land Imager (OLI), Sentinel-2 Multispectral Instrument (MSI), and Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) datasets
* Analyze water quality time series to understand the impacts of natural hazards and human activities on coastal water conditions

**Partner Overview**

***Partner Organizations:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **Wildlife Conservation Society** | Alexander Tewfik, Marine Conservation Scientist; Myles Phillips, Technical Coordinator | End User | Yes |
| **Coastal Zone Management Authority and Institute (Belize)** | Chantalle Clarke-Samuels, Chief Executive Officer; Andria Rosado, Data Analyst | End User | No |

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

As a Belizean governmental agency, the Coastal Zone Management Authority and Institute (CZMAI) holds federal jurisdiction over defined coastal planning regions. The CZM Institute leads the country’s marine scientific research, while the CZM Authority implements and monitors policies that govern coastal zone use and development. The CZMAI developed an Integrated Coastal Zone Management Plan (ICZMP). Updated every five years, it provides guidance on permitting and coastal zone activities to other government agencies. It is also the basis for determining potential land or coastal repercussions of a proposed project. The CZMAI reviews these proposals and accepts or rejects them according to its assessment. The Government of Belize has established Marine Protected Areas (MPAs) for more than 21% of territorial seas. The Wildlife Conservation Society (WCS) partnered with the Belizean Government to increase the area of no-take, or replenishment, zones from 3% of Belize’s territorial sea to 10% by the end of 2018. Belize was the first country to use the WCS Spatial Monitoring and Reporting Tool (SMART) in a marine environment. SMART is a ground data collection and GIS tool used primarily for enforcement of MPAs by Belizean officers.

***Project Benefit to End User:***

The end products of this project will expand the partners’ use of GIS by introducing remotely sensed data from NASA and European Space Agency satellites into their monitoring practices. The employment of satellite observations will be an invaluable asset for managing water quality, offering a new level of efficiency over field sampling. Having previously relied on ground observation and field sampling for monitoring coastal water quality, the evaluation of potential ecological and economic repercussions under the ICZMP will be more efficient and robust. The GEE tool will give partners access to map turbidity and chlorophyll-a data in a time series format. This will be of great value in comparing water quality before and after large disturbance events, such as hurricanes or algal blooms. Furthermore, the tool will allow for a visual inspection of spatial patterns in water quality to identify areas requiring specific environmental management efforts, such as the establishment of an MPA or no-take zone.

**Earth Observations & End Products Overview**

***Earth Observations:***

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| --- | --- | --- |
| **Platform & Sensor** | **Parameters** | **Use** |
| **Landsat 8 OLI** | turbidity | Reflectance bands were used to extract turbidity metrics at a 30 m resolution from 2013 to 2019. |
| **Sentinel-2 MSI** | chlorophyll-a, turbidity | Reflectance bands were used to extract turbidity and chlorophyll-a metrics at a 10 and 20 m resolution from 2015 to 2019. |
| **Aqua MODIS** | chlorophyll-a, sea surface temperature (SST) | MODIS was used because of the sensor’s high temporal resolution of 1 to 2 days. The chlorophyll-a and SST bands provided data at a 1 km resolution from 2013 to 2019. |
| **Terra MODIS** | chlorophyll-a, SST | MODIS was used because of the sensor’s high temporal resolution of 1 to 2 days. The chlorophyll-a and SST bands provided data at a 1 km resolution from 2013 to 2019. |

***Ancillary Datasets:***

* United Nations Environment World Conservation Monitoring Centre, Protected Areas Shapefile – Provided selectable regions of interest in the GEE dashboard
* Wildlife Conservation Society, Hurricane List – Allowed for analyses of the impacts of storms on water quality
* NOAA PERSIANN – Provided daily precipitation data that are incorporated into the time series figures within our GEE dashboard

***Software & Scripting:***

* Google Earth Engine API – Development of user-facing dashboard that extracts water quality parameters (turbidity, chlorophyll-a, SST) from Landsat 8 OLI, Sentinel-2 MSI, Terra MODIS, and Aqua MODIS imagery; random sampling of data for validation
* ACOLITE Python 20190326.0 – Atmospheric correction and extraction of water quality parameters from optical imagery
* ESRI ArcMap 10.6 – Raster manipulation, attribute management, analysis, and visualization
* R 3.5.0 – Data processing, statistical comparison, and figure generation

***End Products:***

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| --- | --- | --- | --- |
| **End Products** | **Earth Observations Used**  | **Partner Benefit & Use** | **Software Release Category** |
| **Turbidity and Chlorophyll-a Maps** | Landsat 8 OLISentinel-2 MSITerra MODISAqua MODIS | These products will help inform our end users on where to focus water management practices to ensure the conservation of the reef system. | I |
| **Optical Reef and Coastal Area Assessment (ORCAA) GEE Tool** | Landsat 8 OLISentinel-2 MSITerra MODISAqua MODIS | This cloud-based tool streamlines the water quality analysis needed by our partners as cloud computing reduces hardware and software constraints. Our partners can use this tool to analyze long term trends across a wide range of locations and times. | IV |
| **ORCAA Tool Tutorial** | N/A | This tutorial will inform our partners on how to use and customize the ORCAA Tool. | N/A |

**Project Handoff Package**

***Transition Plan:*** A formal handoff took place at the end of the project term in the form of a video conference via WebEx. WCS and CZMAI will receive access to the GEE tool, including access to datasets and code, after Software Release is approved. All other end products and deliverables were sent to partners via NASA Large File Transfer. All project deliverables were also made available in both English & Spanish.

***Software Release Plan:*** The partners were informed of the Software Release Process and the subsequent delayed delivery of the GEE user interface. Upon completion of Software Release, the POC listed below will notify our partners and direct them to the GEE repository that hosts the tool.

***Project Continuation Plan:*** A second term will continue refining the water quality monitoring tool. The working GEE script and assets will be handed off to future project participants who may calibrate the tool to be applied to other coastal regions in Central America. Additional water quality parameters or algorithms may be added to expand the tool’s functionality. Upon completion of the second term, a second Software Release Process is expected to begin that will focus on changes and improvements made to the script produced by the first term team.

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***Software Release POC:*** Charlie Devine, cjdevine@email.arizona.edu

***Partner POC:*** Myles Phillips, mphillips@wcs.org

***Handoff Package:***

* Turbidity and Chlorophyll-a Maps
* ORCAA Tool Tutorial (in both English and Spanish)
* Technical Paper (in both English and Spanish)
* Presentation (in both English and Spanish)
* Poster (in both English and Spanish)

**References**

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