**Maldives Climate II**

*Evaluating the Potential Impacts of Sea Level Rise on Human Development and Coastal Infrastructure*

**Project Team**

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**Project Overview**

***Project Synopsis:***

The Maldives is the lowest-lying nation in the world, and the risk of sea level rise threatens coastal communities and development across the archipelago. The Maldives Climate II team partnered with the Maldives Ministry of Environment, Climate Change, and Technology to track land use changes across the islands and predict how the nation will be affected by future sea level changes using NASA Earth observation data. Understanding the potential impacts of sea level rise on each island is essential to the low-lying nation’s coastal infrastructure adaptation planning and future development.

***Abstract:***

The Republic of the Maldives is a low-lying island nation in the Indian Ocean which has experienced rapid urbanization, landcover changes, and sea level rise over recent years. The growth of tourism, coastal erosion, and urbanization all have driven land reclamation efforts across many islands. As in-situ landcover change monitoring has proven difficult across the vast archipelago, the NASA DEVELOP team collaborated with the Maldives Ministry of Environment, Climate Change, and Technology; USAID; and the U.S. Department of State to utilize Earth Observations to predict sea level rise impacts on coastal infrastructure. The team used a supervised classification algorithm within Google Earth Engine to create land use maps and time series analyses of nine islands and atolls using imagery from Landsat 7 Enhanced Thematic Mapper Plus, Landsat 8 Operational Land Imager, Sentinel-2 Multispectral Instrument, and PlanetScope, covering a combined period of 2000 through 2023. Additionally, the team projected coastal inundation with a modified deterministic Bathtub model utilizing elevation data from CoastalDEM and 2050-2100 Shared Socioeconomic Pathway scenarios identified in the NASA Sea Level Rise Projection Tool. The team found that islands undergoing urban growth experienced a 23% decrease in vegetation between 2014 and 2022. Furthermore, the model predicted that 57–63% of the study area’s built environment has a chance of inundation by 2100 under the low and high sea level scenarios. These analyses demonstrate how remote sensing can be used to both track land use changes over time and project how coastlines will be affected by sea level rise.

***Key Terms:***

remote sensing, LCLU, sea level rise, land reclamation, coastal inundation, time series analysis

***National Application Area Addressed:*** Climate

***Study Location:*** The Republic of Maldives

***Study Period:*** January 2000 to March 2023, Forecasting to 2100

***Community Concerns:***

* With limited land, rapid urbanization, and coastal erosion, the Republic of the Maldives will be significantly impacted by sea level rise, which will encroach on land available for human habitation and development, devastate water and food sources, and disrupt ecosystems vulnerable to seawater inundation.
* Land loss and erosion pose a threat to existing urban infrastructure and restrict the possibility of further construction without the use of land reclamation. Maintaining shorelines with each nourishment and other coastline protection measures are arduous and expensive processes.
* Flooding can contaminate groundwater and other freshwater sources, rendering it undrinkable without proper treatment. It can also pose a challenge to waste management and other essential services, and have a deleterious impact on the tourism industry, a significant contributor to the economy.

***Project Objectives:***

* Produce land cover/land use (LCLU) maps for 2000-2023
* Conduct time series analyses of LCLU changes
* Generate coastal flood risk maps for 2050 and 2100 using a range of IPCC scenarios
* Create a Google Earth Engine Tutorial that performs land use change analyses and produces timeseries graphs and charts, and generates maps of coastal inundation risk

***Previous Term(s):***

2022 Fall (ARC) – Maldives Climate I

**Partner Overview**

***Partner Organizations:***

|  |  |  |
| --- | --- | --- |
| **Organization** | **Contact (Name, Position/Title)** | **Partner Type** |
| Maldives Ministry of Environment, Climate Change, and Technology | Khadeeja Naseem, Minister of State; Dr. Abdulla Naseer, Minister of State; Thibyan Ibrahim, Assistant Director; Aishath Reesha Suhail, Programme Officer; Ahmed Raidh, Senior Coastal Analyst; Mohamed Azan Abdulla, Environmental Analyst | End User |
| U.S. Department of State, Bureau of South and Central Asian Affairs, Office of Bangladesh, Nepal, Sri Lanka, Maldives, and Bhutan | Alan Brinker, U.S Mission Maldives A/DCM; Ellen Connorton, Senior Science Advisor; Charlotte Volpe, Economic Officer; Abigail Bard, Foreign Affairs Officer; Aishath Rifga, U.S Mission Maldives Economic Specialist; Alex Andrew, Political and Economic Officer, U.S. Mission Maldives; Lance Erickson, Public Affairs Officer | End User |
| USAID, Maldives Office | Hillery Midkiff, Program Coordinator; Nihani Riza, Environmental Program Specialist | End User |

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

The Republic of Maldives is composed of over 1,190 islands and is home to an abundance of ecosystems, which the Ministry of Environment, Climate Change and Technology is tasked with monitoring and protecting. Currently, the Ministry uses satellite imagery in Google Earth Pro to manually create polygons for different land classes across the Maldives. The partners use that data to create publicly available land classification maps and land use plans. The Department of State, Bureau of South and Central Asian Affairs, Office of Bangladesh, Nepal, Sri Lanka, Maldives, and Bhutan currently supports the Maldives’ adaptation efforts by identifying areas of potential future development assistance that the United States could provide to Maldives, and complementing USAID programming focused on climate adaptation. The USAID, Maldives Office has several programs working on environmental issues in the Maldives which tackle climate change adaptation such as the Climate Change Adaptation Program and the REGENERATE coral reef management program.

**Earth Observations & End Products Overview**

***Earth Observations:***

|  |  |  |
| --- | --- | --- |
| **Platform & Sensor** | **Parameter(s)** | **Use** |
| PlanetScope SkySat, Dove Classic, Dove R, and SuperDove | True color (R, G, B), Normalized Difference Vegetation Index (NDVI) | The data was used between 2015 and 2023 to calculate land-use change, create maps, and develop time series analyses. |
| Landsat 7 ETM+ | Landcover, NDVI | The data was used between 2000 and 2013 to calculate land-use change, create maps, and develop time series analyses. |
| Landsat 8 OLI | Landcover, NDVI | The data was used between 2014 and 2023 to calculate land-use change, create maps, and develop time series analyses. |
| Sentinel-2 MSI | Landcover, NDVI | The data was used between 2016 and 2022 to calculate land-use change, create maps, and develop time series analyses. |

***Ancillary Datasets:***

* NASA IPCC AR6 Sea Level Projection Tool – Sea level projection data for 2050-2100 across various climate scenarios
* Maldives Land and Survey Authority Permanent Survey Marks (PSM) – Ground control points with orthometric height
* Dynamic World (GGE) – Landcover classification, timeseries, and change detection
* Climate Central CoastalDEM® – Elevation data

***Modeling:***

* Uncertainty Bathtub Model (uBTM) (POC: Lucas Terres de Lima, University of Aveiro) – Coastal inundation mapping

***Software & Scripting:***

* Esri ArcGIS Pro 3.1.0 – Raster manipulation, map creation, and mosaicking
* QGIS 3.28 – Raster manipulation, map creation, and mosaicking
* Google Earth Engine Code Editor – Land classification, coastal inundation mapping, and data processing

***End Product(s):***

|  |  |  |  |
| --- | --- | --- | --- |
| **End Product** | **Earth Observations Used**  | **Partner Benefit & Use** | **Software Release Category** |
| **Land Classification Maps** | Landsat 7 ETM+, Landsat 8 OLI, Sentinel-2 MSI, PlanetScope | Maps showing land use will help partners visualize the spatial distribution of different land classes in the region. The partners will use maps in conjunction with the time series analysis to observe where land use changes are occurring.  | N/A |
| **Coastal Inundation Map** | N/A | Maps visualizing coastal inundation projections will allow partners to further understand areas potentially affected by shoreline change and sea level rise within the study area.  | N/A |
| **LCLU Timeseries Analysis** | Landsat 7 ETM+, Landsat 8 OLI, Sentinel-2 MSI | Data within the time series analyses can be downloaded as CSV and provide detailed information about changes in land use types within the study area over the last 23 years. | N/A |
| **Google Earth Engine Product Tutorial** | Landsat 7 ETM+, Landsat 8 OLI, Sentinel-2 MSI, PlanetScope | The tutorial will provide partners with the ability to create a GEE-based tool that performs land use change analyses and produces timeseries graphs and charts. The tutorial will help the partners automate the process of classifying land use on each island in the Maldives. Partners may also integrate the bathtub model to plan for future coastal flooding risks. | N/A |

***Product Benefit to End User:***
The Maldives Ministry of the Environment, Climate Change, and Technology will create LCLU maps for any island or atoll of their choosing. Partners will also be able to make any modifications, such as changing the land classes for analysis. Furthermore, the partners will be able to create change detection maps and conduct time series analyses in the future to continue to monitor LCLU changes across the nation. The LCLU data and sea level rise projection data will be used for planning future infrastructure in the Maldives. The U.S. Department of State and USAID will use the end products to help the Maldives plan for sea level rise and mitigate the negative effects of climate change on the islands and their inhabitants.

**References**

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Terres de Lima, L., & Bernardes, C. A. (2019). Uncertainty Bathtub Model (uBTM) (1.0). Zenodo. <https://doi.org/10.5281/zenodo.3378019>

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