# Hydro PC

Final Report

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PR3908
November 2020

# About this project

<table>
<tr><td>Project Title</td><td colspan="2">HydroPC: Hydrological Forecasting using Publicly available data and free Cloud-based technologies (Mozambique)</td></tr>
<tr><td>Contract</td><td colspan="2">7195130</td></tr>
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<tr><td>Project objective</td><td colspan="2">The project HydroPC focused on co-development and application of innovative data technologies and comprehensive training of beneficiaries to support water and disaster risk management in Mozambique. A particular objective was to strengthen the technical autonomy of the Unit for Flood and Drought Control (UFDC), hosted within the National Directorate for Water resource Management in Mozambique. A synergetic treatment of official and non-official hydrological data was incorporated in the co-development of a free and open-access online platform that operates in the Google Earth Engine environment. The platform focuses on Mozambique, but has functionalities included that provide data service on a wider regional scale, some even world-wide.</td></tr>
<tr><td>Data types and technologies</td><td colspan="2">Data: Open global data sets, local hydrologic time series. See full list in Appendix E "Data Sources".<br>Technology: Google Earth Engine</td></tr>
<tr><td>Sustainable Development Goals</td><td colspan="2">This project connects to several of Sustainable Development Goals SDGs, either directly through addressing associated indicators, or indirectly by addressing overarching goals. Among these, the connections with SDG6, SDG11 and SDG13 are the most prominent. Appendix G reflects on outputs from the project that address these three most prominent SDGs.<br>
</td></tr>
</table>

**Acknowledgements**

This project, *HydroPC: Hydrological Forecasting using Publicly available data and free Cloud-based technologies (Mozambique)*, submitted in response to the 2018 call for proposals by the World Bank's Development Economics Data Group (DECDG) and the Global Partnership for Sustainable Development Data (GPSDD), is supported by the World Bank's Trust Fund for Statistical Capacity Building III (TFSCB) with financing from the United Kingdom's Foreign, Commonwealth & Development Office, the Department of Foreign Affairs and Trade of Ireland, and the Governments of Canada and Korea.

This research project was co-supervised by the World Bank's Disaster Risk Management unit of the Social, Urban, Rural, and Resilience Global Practice (GPSURR) and DECDG, and will inform GPSURR's (and related Global Facility for Disaster Reduction and Recovery (GFDRR)) projects in Mozambique.

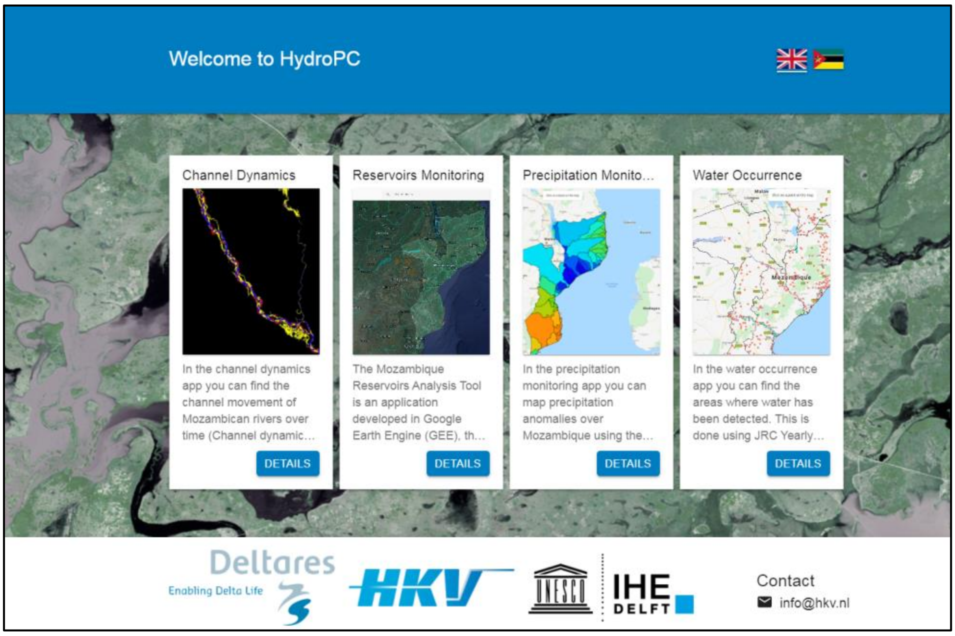
# List of Abbreviations

| | |
|---|---|
| AI | Artificial Intelligence |
| ARA | Agência Regional de Agua (Regional Water Agency) |
| DECDG | Development Economics Data Group |
| DEM | Digital Elevation Model |
| DNGRH | Direcção Nacional de Gestão de Recursos Hídricos (National Directorate for Water Resource Management) |
| FEWS | Flood Early Warning System |
| GEE | Google Earth Engine |
| GFDRR | Global Facility for Disaster Reduction and Recovery |
| CHIRPS | Climate Hazards InfraRed Precipitation with Station data |
| GPM | Global Precipitation Measurement |
| GPW | Gridded Population of the World |
| GPSDD | Global Partnership for Sustainable Development Data |
| GPSURR | Global Practice on Social, Urban, Rural, and Resilience |
| HAND | Height Above the Nearest Drainage |
| INAM | Instituto Nacional de Meteorologia (National Meteorological Institute) |
| INGC | Instituto Nacional de Gestão de Calamidades (National Institute for Disaster Management) |
| JRC | Joint Research Centre |
| NDVI | Normalized Difference Vegetation Index |
| NDWI | Normalized Difference Water Index |
| MNDWI | Modified Normalized Difference Water Index |
| PNP | Percent Normal Precipitation |
| SAR | Synthetic Aperture Radar |
| SDG | Sustainable Development Goal |
| SPI | Standardized Precipitation Index |
| SRTM | Shuttle Radar Topography Mission |
| TFSCB | Trust Fund for Statistical Capacity Building |
| UFDC | Unit for Flood and Drought Control |
| UNITAR | United Nations Institute for Training and Research |
| UNOSAT | United Nations Operational Satellite applications program |
| WB | The World Bank |

# Executive summary

This is the Final Report of project '*HydroPC: Hydrological Forecasting using Publicly available data and free Cloud-based technologies (Mozambique)*'. The project focused on making use of Google Earth Engine (GEE) for various types of hydrological analyses. GEE is an online environment to access, process, and analyse satellite data. Specific attention was given to analyses that support flood and drought forecasting.

This report gives an overview of activities, outcomes and products of the project. Key objectives of the project were (i) to provide new hydrological data access and analysis techniques to authorities in Mozambique and (ii) to strengthen and enhance the technical autonomy of the Unit for Flood and Drought Control (UFDC) and of its partnering government organizations in Mozambique. For this purpose, training and co-development sessions were held that led to an interactive data platform using GEE[1]. The image below shows the entry page of the HydroPC platform[2].




The HydroPC platform links to four interactive applications that are implemented in Google Earth Engine. The applications were co-developed with beneficiaries in Mozambique, who also helped selecting and prioritizing functionalities of the applications to make sure that the platform has practical use. Below a brief summary is given of the main features of the four interactive applications[3].

[1] 'Training Period 1' and 'Training Period 2', each consisting of seven or eight technical sessions spread out over a period of two weeks.
[2] Visit the HydroPC platform at: https://dmmangrove.hkvservices.nl/hydropc/
[3] See further details in Appendix B 'User Instructions Web-apps'.

### *1. Water occurrence app*

*The water occurrence app shows the areas where surface water has been detected in the JRC satellite images since 1989. In the visualisation a distinction is made between permanently and seasonally wet zones. For selected extreme events the detected flood extents derived from other satellite images have been included to show areas that have in recent years been flooded. Also, a map showing the terrain's 'Height-Above-Nearest-Drainage' (HAND) is included, indicating areas where waters could accumulate in the event of a flood.*

### *2. Channel dynamics app*

*In the channel dynamics app you can observe the channel movements of Mozambican rivers from 1986 until today. Several additional data layers have been included in the app (elevation, land cover, locations of dikes), to allow interpretation of channel movements.*

### *3. Precipitation monitoring app*

*The precipitation monitoring app gives precipitation anomalies over Mozambique using the Percent Normal Precipitation (PNP) Index. These anomalies can be viewed on different temporal and spatial scales, giving insight into flood or drought conditions. A download function facilitates data preparation for hydrological models.*

### *4. Reservoir monitoring app*

*The reservoir monitoring app gives information on the water availability in reservoirs in Mozambique and beyond. Based on surface area detections from recent years, a proxy time series of water storage can be viewed. For a selection of key reservoirs the proxy time series has been translated to time series of water volumes or of water surface levels.*

In co-developing these applications with beneficiaries and potential users in Mozambique, the level of autonomy in the field of spatial hydrological data analysis has been given a boost at Mozambican government agencies. The participants in the sessions learned new data analysis techniques for hydrological forecasting, and how to implement, operate, maintain and further develop these into an online interactive platform. Also, to assure continued and possibly increasing utilisation of the HydroPC platform we provided comprehensive training and reference material in English as well as in Portuguese[4]. The platform, its four applications and the accompanying material can be accessed by anyone, at no costs and without need for user registration.

The HydroPC platform is easy to operate, easy to maintain and easy to expand. An important feature of the HydroPC platform is that it automatically remains up-to-date by making use of the most recent satellite data is available in GEE[5]. Also, it is replicable and scalable to other geographical areas. Some of the functionalities in the platform already cover areas that go beyond the national

[4] See Appendix A 'Training material' and Appendix C 'Developer Instructions Web-apps'.
[5] GEE continuously updates it database of satellite images, and these will then automatically be available to the HydroPC platform. Manually uploaded data to the HydroPC platform, such as dike positions or pre-processed historical flood events, still require manual updating.

boundaries of Mozambique, such as the reservoir monitor which is implemented world-wide. The HydroPC platform can also be expanded to include additional types of data-analysis functions, involving for example in-situ water levels observations, locations of infra-structures, demographic data or even links to hydrological or meteorological forecasting models.

This project demonstrated some of the useful possibilities that GEE has to offer in the field of hydrological data provision and analysis and, in particular, its value to improve capabilities and autonomy in flood and drought forecasting for countries like Mozambique. Through close collaboration with beneficiaries we addressed specific information needs, and also identified possible synergies with on-going projects and water-management-related activities. While directly improving local autonomy in hydrological data analysis, the products of HydroPC can support and improve water management practice in Mozambique for many years to come.

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# 1 Introduction

## 1.1 The challenge

The African country of Mozambique faces extreme and complex hydrological hazards. The country has been repeatedly exposed in recent years to disastrous events, with significant consequences for vulnerable populations. For example, in recent decades floods have impacted populations, infra-structures and economies in the Limpopo, Pungwe, and Zambezi river basins. Less than two years ago, in March 2019, cyclone Idai led to heavy flooding and devastating losses in the Zambezi, Búzi, and Pungwe river basins. Idai was followed by cyclone Kenneth which made landfall in the less populated North of Mozambique. Also, extreme precipitation events frequently lead to excessive urban flooding. In cities as Maputo and Beira, urban flooding now occurs on a yearly basis. In contrast, during the past seven years, severe droughts have also impacted the southern region of the country. It seems that difficult hydrological conditions as these are a new reality for Mozambique, and it may even still become worse if climate change leads to increasing recurrence and intensity of these devastating events. It is a reality that Mozambique has to learn to cope with.

Despite various past and on-going efforts to improve this situation, the country remains vulnerable to extreme hydrological events. Specifically, better anticipation on extreme hydrological events is needed and better use is required of resources of the various institutions dealing with floods and drought at regional and national scales. Key water-related organizations in Mozambique are the National Directorate for Water Resources Management (DNGRH), the National Meteorology Institute (INAM), and the National Institute for Disaster Management (INGC). DNGRH is responsible for the provision of hydrological data in cooperation with regional water authorities (ARAs) and INAM. INGC has the responsibility to assure adequate disaster preparation and response strategies. To boost flood and drought information services, DNGRH created the Unit for Flood and Drought Control (UFDC) in 2017.

UFDC is tasked to reduce flood and drought vulnerability by coordinating and distributing hydrological information among partner organizations and stakeholders, and by improving the anticipation of extreme hydrological events. However, access to hydrological data is seldom an easy and cheap process in many low- and middle-income countries, such as Mozambique. Often, only sparse observation networks are operated, which are difficult to maintain and to keep operating at a required standard. It is also uncommon for official data providers (such as DNGRH) in Mozambique to integrate their observed data with for example remotely sensed data to fill the gaps.

## 1.2 HydroPC

The project '*HydroPC: Hydrological Forecasting using Publicly available data and free Cloud-based technologies (Mozambique)*' (or in short: 'project HydroPC') is set up to address the challenges in water and disaster risk management that are described in the previous paragraph. This is realized by developing innovative hydrological data assessment tools and, indirectly, by strengthening and enhancing the technical autonomy of the Unit for Flood and Drought Control (UFDC) and of partnering government organizations.

Key objectives of HydroPC are:

- Involve beneficiaries in developing an online interactive information platform that gives access to and combines (processed) data from global datasets (flood hazard zones, reservoir levels) with local data.
- Increase autonomy of the UFDC and partnering organizations by training staff in use of Google Earth Engine, increase their capabilities in (online) data-processing and at making more use of earth-observation data

A specific synergy to be achieved in this project is the joining of official and non-official hydrological data. As deliverable, online web-applications are developed that support hydrological analyses, in particular in relation to flood and drought events. These applications are accessible to everyone and can support decision-making in various fields of water and disaster management. The project HydroPC specifically also aims at helping to make a transition to license-free tools.

This report constitutes the Final Report of the project, presenting activities that were carried out, highlighting the results that have been achieved and discussing possible ways forward.

## 1.3 Prioritized topics and activities

During the Inception Phase of this project, priorities were identified for development of hydrological analyses tools. These priorities formed the basis for two technical training periods and associated co-development activities that are described in the Inception Report of the project[6]. An overview of selected topics and activities is given in Table 1.

*Table 1*
*Topics and activities treated in HydroPC (prioritized topics are labelled with 'P')*

| Overview of topics: | Description of product: |
| --- | --- |
| Google Earth Engine (P) | General training on functioning of GEE, including writing of code for selection and combining of data and online processing. |
| Channel dynamics (P) | Tool to understand system behaviour: indicate erosion and sedimentation |

[6] See: 'HydroPC – Inception Report, June 2020'

| | |
|---|---|
| | zones along rivers, showing channel movements over the past ~3 decades. |
| Reservoir monitoring (P) | Development of tools for mapping of reservoir surface water extents and translation to water volumes. |
| Flood mapping (P) | Tool for mapping of flood extents, and processing multiple flood extents into multi-year flood probability maps. |
| Population mapping (residential areas and infrastructure) | Tool for extraction of residential and built environments from satellite imagery for flood impact estimates. |
| Precipitation | Development of indicators for rainfall quantities that are useful for flood and drought monitoring. |
| Evapotranspiration and soil moisture | Development of indicators for evapotranspiration and soil moisture that are useful for flood and drought monitoring. |
| Platform for combining of data | Introductions to the Delft-FEWS system with pre-configured imports and processing modules for an agreed selection of the above datasets. |
| Synthesis and development of web-viewer (P) | Development of a web-viewer (GEE application) that includes products from activities mentioned above. |

Topics treated in Training Period 1 and Training Period 2 are given in Table 2. A common aspect in all training sessions was learning how to work with Google Earth Engine (GEE). All GEE-exercises were designed in such a way that the results provided a step forward in the development of GEE-tools that provided functionalities as desired by the beneficiaries.

The two training periods contained modules that addressed specific topic to a certain level of depth (Level 1 or Level 2). Modules of Level 1 focussed on application of technologies, which include an introduction to the main concepts, learning how to apply existing tools and interpretation of the results. Modules of level 2 went a step further and focussed on improving technologies and creating autonomy in their use. This included processing raw data towards useful information and modification of technologies to allow application to other areas or using other data.

*Table 2*
*Topics addressed during training periods*

| Topic | Training Period 1 | Training Period 2 |
|---|---|---|
| Google Earth Engine | Level 1 | Level 2 |
| Flood mapping | Level 1 | Level 2 |
| Channel movements | Level 1 | Level 2 |
| Reservoir monitoring | Level 1 | Level 2 |
| Combining official and non-official data | Level 1 | Level 2 |

| | | |
|---|---|---|
| Precipitation monitoring | | Level 1 |
| Soil moisture and evapotranspiration | | Level 1 |
| Population mapping (residential areas and infrastructure) | | Level 1 |
| Web applications | Level 1 | Level 2 |

Due to Covid-19 travel restrictions, the training sessions were conducted online. The sessions were in English with real-time translation into Portuguese. Each of the sessions included the following materials (see Appendix A for an online link to all materials):

- Powerpoint presentations to introduce the different topics and guide discussions around possible functionalities.
- Technical manuals (in English and Portuguese) with step-by-step guides of the exercises.
- Basic scripts developed within this project for the implementation in Google Earth Engine, including access to background libraries.
- Instructional videos (in English) with step-by-step demonstrations of exercises.
- Exchange of questions and ad-hoc support via a Whatsapp group.

## 1.4 Training period 1: introduction to Google Earth Engine

Training Period 1 took place between 20 and 31 July 2020 and covered general aspects of working with Google Earth Engine, including hands-on exercises on prioritized fields of application 'channel dynamics', 'reservoir monitoring' and 'flood mapping'. A schedule of Training Period 1 is given in Table 3. An impression of Training Session 1 is given in Figure 1. Chapter 2 covers the main outcomes of Training Period 1.

*Table 3 Schedule of Training Period 1*

| Training component | Lead by | Date and time | | participants |
|---|---|---|---|---|
| **1st Week** | | | | |
| Day 1- Google Earth Engine | HKV | Mo 20 July | 9:00-12:00 | DNGRH, INAM, INGC and ARAs |
| Day 2- Channel dynamics | HKV | Tue 21 July | 9:00-12:00 | DNGRH and ARAs |
| Day 3- Flood extent | IHE | Thu 23 July | 9:00-12:00 | DNGRH, INGC and ARAs |
| Day 4- Questions/local data validation | Deltares and HKV | Fr 24 July | 9:00-12:00 | DNGRH, INAM, INGC and ARAs |
| **2nd Week** | | | | |
| Day 5- Google Earth Engine | HKV | Mo 27 July | 9:00-12:00 | DNGRH, INAM, INGC and ARAs |
| Day 6- Reservoir monitoring | Deltares | Tue 28 July | 9:00-12:00 | DNGRH and ARAs |

| | | | | |
|---|---|---|---|---|
| Day 7- Flood extent | IHE | Thu 30 July | 9:00-12:00 | DNGRH, INGC and ARAs |
| Day 8- Questions/local data validation + Introduction Delft-FEWS | Deltares and HKV | Fr 24 July | 9:00-12:00 | DNGRH, INAM, INGC and ARAs |

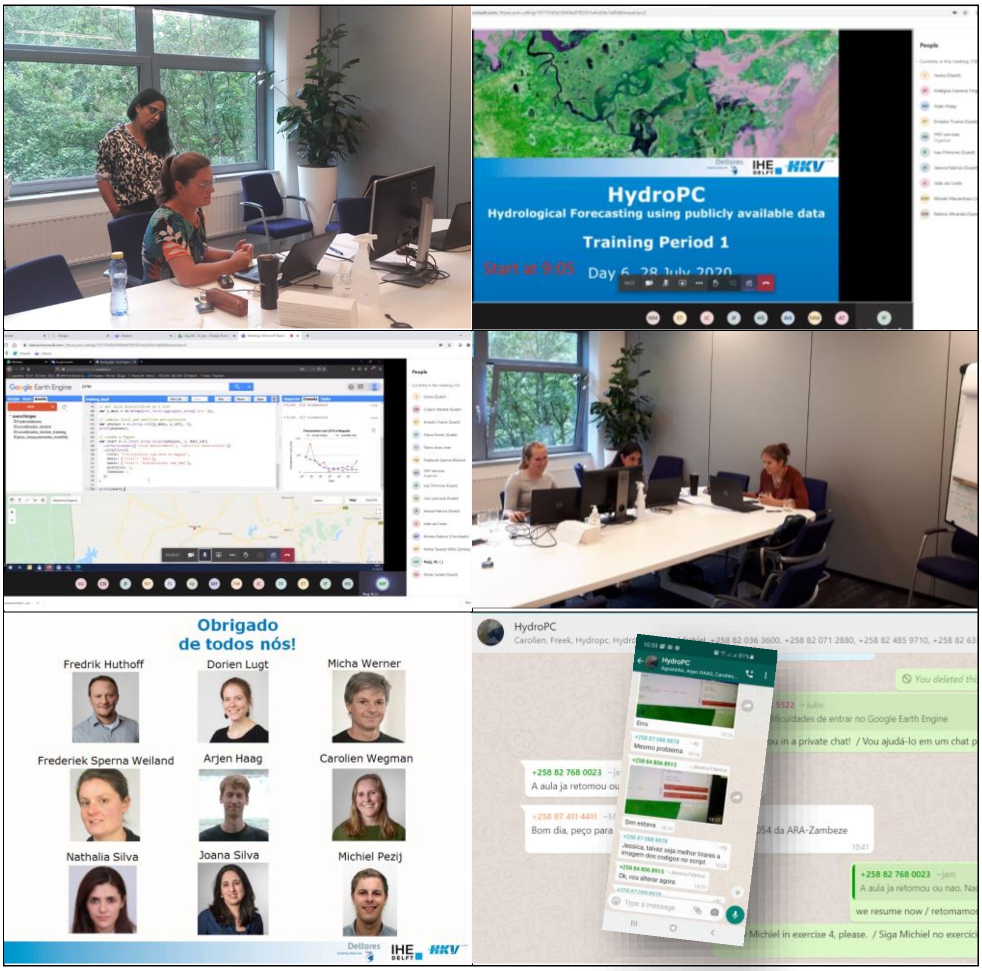



*Figure 1*
*Impression of online sessions during Training Period 1*

The developed GEE-tools from Training Period 1 formed the basis for implementation of an interactive web-platform, which was the primary objective of Training Period 2.

## 1.5 Training Period 2: co-development of online applications

Training Period 2 took place between September 21 and October 8 (2020) and elaborated on the development of GEE tools that were covered during Training Period 1. Specific focus was to develop applications that integrated local and global data sets, and to embed such functionalities in interactive web-applications. A schedule of Training Period 2 is given in Table 4. More details on the activities during Training Period 2 are explained in Chapter 2.

*Table 4*
*Schedule of Training Period 2*

| Training component | Lead by | Date and time | | participants |
|---|---|---|---|---|
| **1st Week** | | | | |
| Day 1- Google Earth Engine (combine data) | HKV/Deltares | Mo 21 Sept | 9:00-12:00 | DNGRH, INGC and ARAs |
| Day 2- Reservoir monitoring | Deltares | Tue 22 Sept | 9:00-12:00 | DNGRH, INGC and ARAs |
| Day 3- Channel dynamics/Flood extent | HKV | Thu 24 Sept | 9:00-12:00 | DNGRH and ARAs |
| **2nd Week** | | | | |
| Day 4- Google Earth Engine (web-apps) | HKV/IHE/ Deltares | Mo 28 Sep | 9:00-12:00 | DNGRH, INGC and ARAs |
| Day 5- Remaining topics | IHE | Tue 29 Sept | 9:00-12:00 | DNGRH and ARAs |
| Day 6- Remaining topics | HKV/IHE/ Deltares | Thu 1 Oct | 9:00-12:00 | DNGRH and ARAs |
| **3rd Week** | | | | |
| Day 7- Round up (online app functionalities) | HKV/IHE/ Deltares | Thu 8 Oct | 9:00-12:00 | DNGRH, INGC and ARAs |

## 1.6 Launch event: HydroPC platform

On 4 November 2020 the launch event of the online HydroPC platform took place. During this event the developed platform was revealed and functionalities were demonstrated to stakeholders in Mozambique, which included the national water directorate DNGRH, the regional water boards (ARA's), the Disaster Management Agency INGC, the meteorological institute INAM and associated interested participants. Figure 2 shows a screen-print of the online Launch Event of the HydroPC platform. The Powerpoint presentation that guided the event is included in Appendix D.

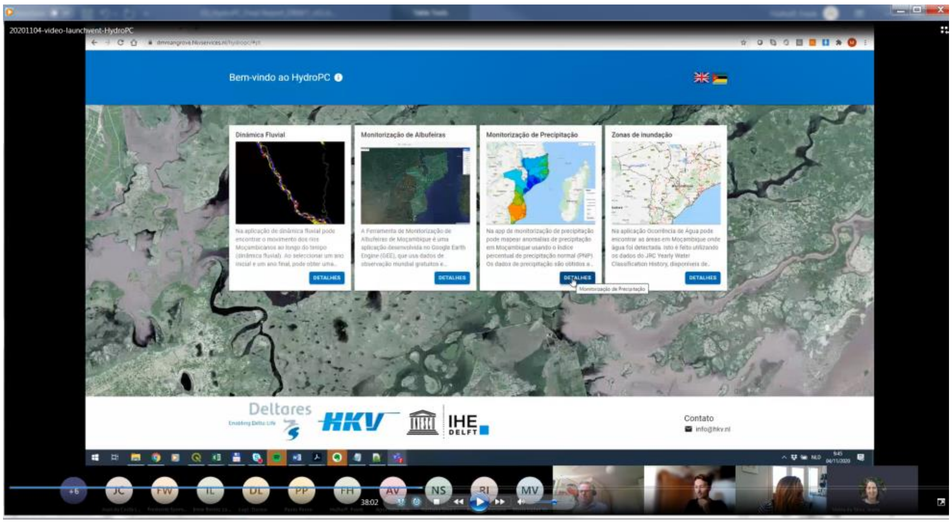



*Figure 2*
*Launch event of the HydroPC platform*

# 2 Results

This chapter elaborates on the activities and results of Training Period 1 (section 2.1) and Training Period 2 (section 2.2) that led to the development of the online HydroPC platform (section 2.3). All training material is archived and freely available on a Google Drive, see appendix A.

## 2.1 Training Period 1

### 2.1.1 Introduction to Google Earth Engine

**Aim**

Getting acquainted with concepts of satellite remote sensing and cloud computing, getting to know the capabilities of Google Earth Engine and using existing applications.

**Training activities**

The training focussed on functioning of GEE and how to run codes in it:

- Description GEE and JavaScript
- Show existing data products in GEE
- Show how these products can support activities of the UFDC
- Exercises:
    - Getting familiar with the GEE interface
    - Exploring and visualizing SRTM, Sentinel 2, Landsat 8 and GPM data
    - Exploring the data catalog and uploading / importing datasets and shapefiles
    - Performing spatial calculations
    - Plotting graphs
    - Map layout and legend
    - Exporting data sets and figures

**Results**

On the first training day the participants were introduced to the GEE interface and JavaScript. Participants created a script in which they visualized SRTM data (elevation data) for Mozambique (Figure 3). They selected Sentinel-2 images for a river basin in Mozambique and exported the image to jpeg (Figure 4).

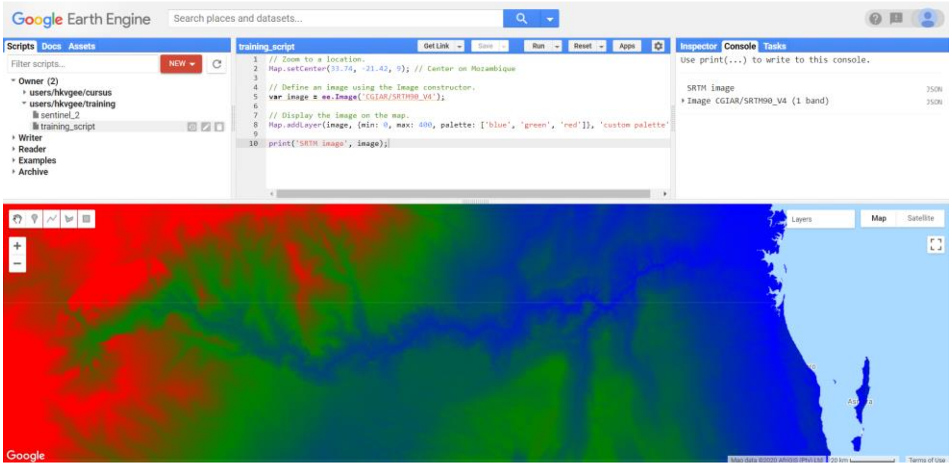



*Figure 3*
*Visualization of SRTM data for Mozambique.*

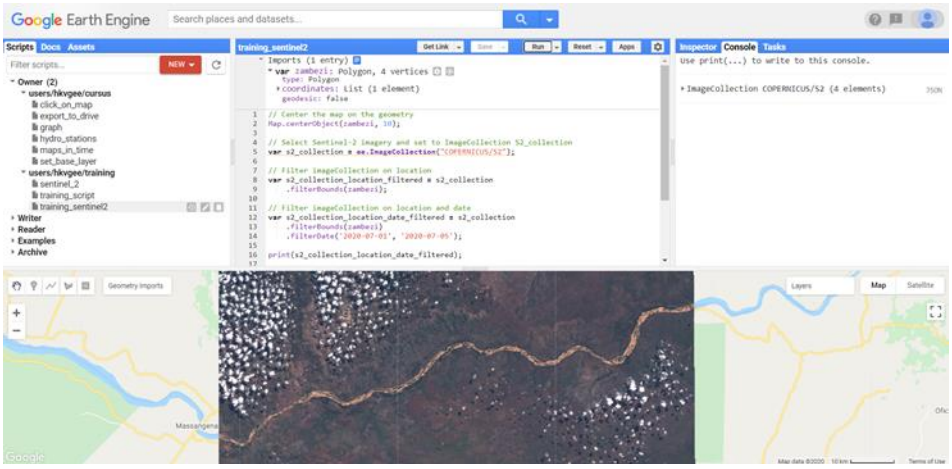



*Figure 4*
*Sentinel-2 image for a river in Mozambique.*

The second session on general GEE skills took place in the second training week, after participants had been introduced to channel dynamics and flood extent analyses. In this session participants did a precipitation analysis, using Global Precipitation Measurements (GPM) data. They studied the spatial distribution of precipitation in Mozambique for the period between March 3$^{rd}$ and March 17$^{th}$ 2019, when cyclone Idai hit the country (Figure 5).

For a precipitation measurement station on the ground in Magube, they uploaded monthly precipitation sums for the year 2018 and compared the measurements with satellite observations on the same location. The participants created a graph and a bar plot of the monthly precipitation for both the ground station and the satellite observations and exported the figures to their PC (Figure 6).

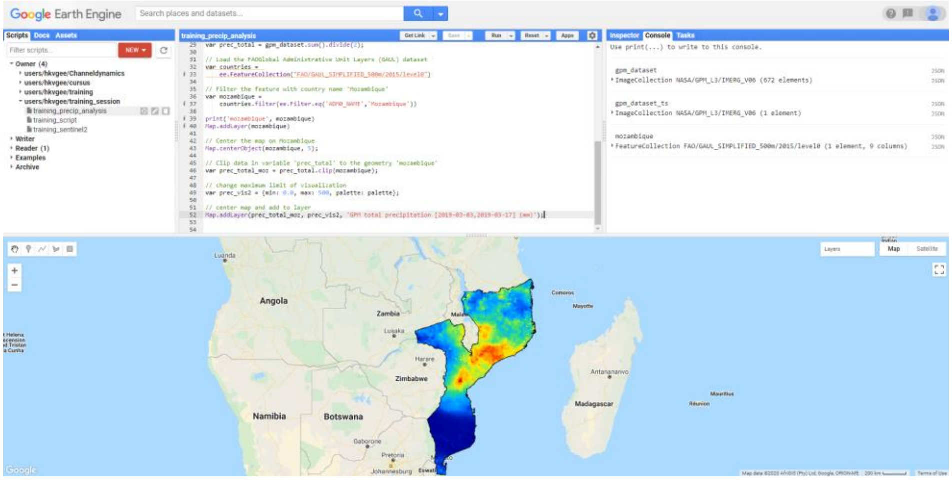



*Figure 5*
*Visualization of precipitation (GPM) in Mozambique between March 3-17, 2019.*

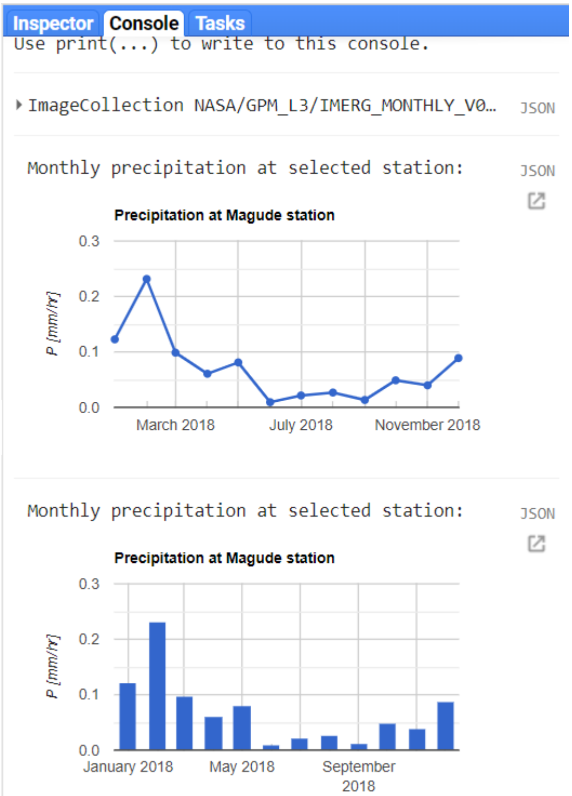



*Figure 6*
*Graph and bar plot of monthly precipitation (GPM)*

## 2.1.2 Channel dynamics

### Aim

Get a basic understanding of the channel movement algorithms and be able to run the existing algorithm.

### Training activities

This training session focussed on monitoring of river channel dynamics using remote sensing datasets and cloud-based processing tools. Monitoring of river channel dynamics is valuable in preventing and mitigating flood and drought events and to provide input for spatial planning. Also, we focussed on a system-based understanding of why rivers are dynamic and why in some places they are more dynamic than in others. We addressed these issues by analysing channel movements in relation to land cover and height information. Also, remote sensing imagery was used to identify historical (paleo-) channels, which may become active during flood situations.

The tools presented in this session can be used to identify hazard areas for bank erosion and flooding, indicating also the suitability of locations for infrastructure development.

The training focussed on existing algorithms of detecting channel movements and the river system as a whole:

- Introduction to the Aqua Monitor as an example.
- Describe remote sensing datasets suitable for river channel detection, such as Landsat 8 satellite imagery.
- Use the Google Earth Engine to collect and process remote sensing data to create river channel maps. Show already existing information products which are included in Google Earth Engine (such as height information (DEM) and land cover maps).

### Results

In the first training period on channel dynamics the focus was on enhancing GEE-skills whilst at the same time improving river system understanding. By first identifying the river dynamics over time using the Normalized Difference Water Index (NDWI) in a step-by-step manner, the participants could see clearly that some parts of the river are more dynamic than others. Even though the movement of a river over the past 30 years is an indication of the area of river dynamics, participants found that historical channels (oxbow lakes) cover regularly a much larger area. This indicates that the river envelope of the river is much wider than the movement we see over the past 30 years.

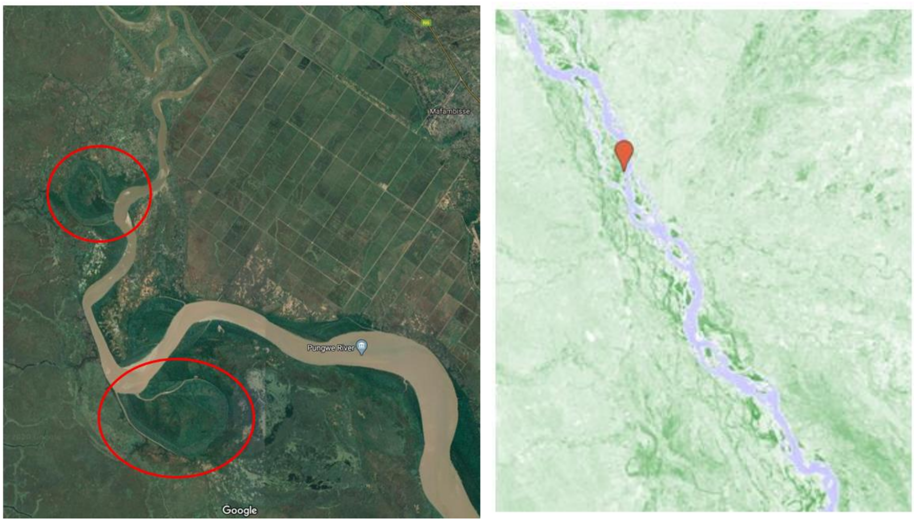
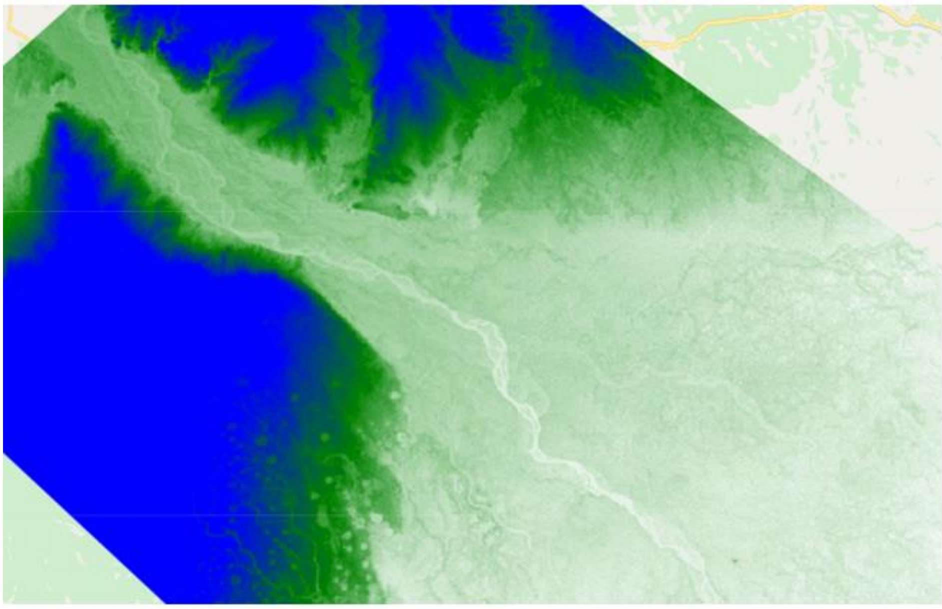



*Figure 7*
*Left: oxbow lakes in Mozambique;*
*Right: NDWI-map derived by participants during the training.*

In the second part of this first training the focus was on understanding the dynamics of the river. By including height information (DEM) available in GEE via the SRTM-database it could be determined if the river is flowing through a plain or through mountains which influences it ability to move. Furthermore, the importance of land cover was addressed: if the land around the river is densely vegetated it may be less susceptible to erosion.

*Figure 8*
*Digital Elevation Map derived by participants during the training.*



## 2.1.3 Flood extent

**Aim**

Be able to describe the principles of flood extent mapping algorithms using satellite images, and be able to run existing algorithms for selected areas and interpret the resulting maps.

**Training activities**

The training focussed on existing algorithms using the satellite data to detect and analyse flood extent:

- Show examples for selected flood events in Mozambique, including the floods due to Cyclone Idai in 2019 and flooding in the lower Shire River (2015). For these events images from different satellites were used.
- Describe remote sensing datasets suitable for flood extent detection, such as Sentinel-1, Sentinel-2 and Landsat-7 satellite imagery and the difference between these. This includes the differences between the use of optical images and images developed using Synthetic Aperture Radar (SAR).
- Use Google Earth Engine to collect and process remote sensing data to create flood extent maps, including the filtering techniques that need to be applied to derive the flood extent.
- Discuss how images can be combined to filter gaps in flood extent maps resulting from cloud cover.

- Address the advantages and limitations of remote sensing of flood extent, and how this compares to in situ methods.
- Introduce methods to refine and validate flood extent maps using methods such as Height Above Nearest Drainage maps.

### Results

The applicability of remote sensing to detect flooded areas using radar and optical images was introduced. Based on the generic knowledge on GEE obtained from the previous trainings and the step by step guide (provided as a document supported by short instruction videos), participants were able to reproduce four exercises about flood extent maps of events occurred in Mozambique.

The first exercise was developed using radar images from Sentinel 1 to map the flood event that occurred due to Tropical Cyclone Idai near the city of Beira in 2019 (see Figure 9). The second exercise used optical images from Landsat 7 to map the flood extent due to the heavy rainfall events in 2015 along the Shire Valley (see Figure 10).

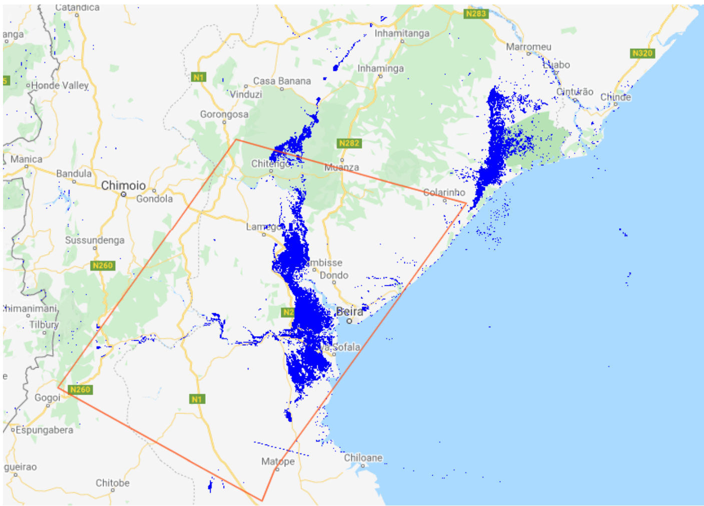



*Figure 9*
*Flood extent map for the 2019 floods near Beira.*

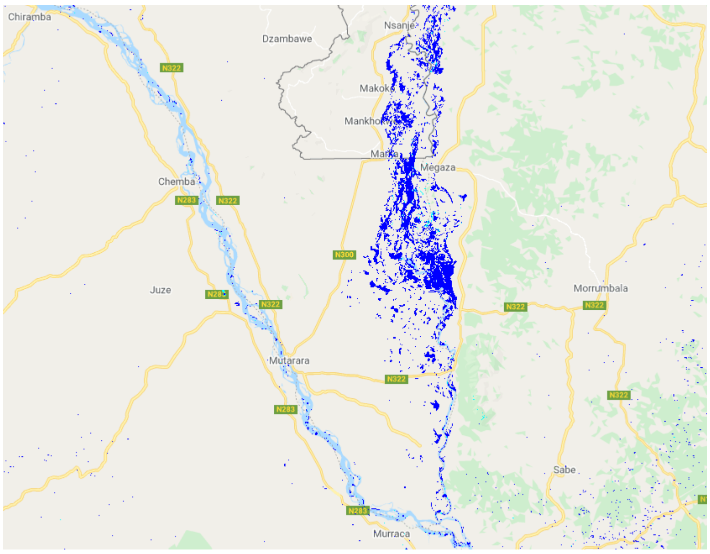



*Figure 10*
*Flood extent map for the 2015 flood in lower Shire and Zambezi Rivers*

In the second exercise, the participants analysed different techniques to derive flood extent maps. Participants developed flood maps using different Satellite-derived indexes used for water detection such as NDWI, NDVI and MNDWI. The advantages and disadvantages of the use of radar and optical images were discussed, as well as the relative complexity of each procedure.

The aim of the second part of the first training period was to show how to calibrate the flood extent maps that were developed during the first session. Also, the Height Above the Nearest Drainage (HAND) dataset was introduced as a quality control method. HAND is a method that identifies which locations in a terrain act as sinks for water and where during flood events likely inundation could occur[7]. Figure 11 gives an example of a HAND-map. Participants were able to apply HAND and filter the flood extent map derived from Landsat 7 imagery, extracting the areas that are not likely to flood and deriving a more accurate flood extent map (see Figure 11). The participants were asked to change the threshold that determines the areas that are not likely to flood, to analyse the sensitivity of this parameter and how this affects the final result.

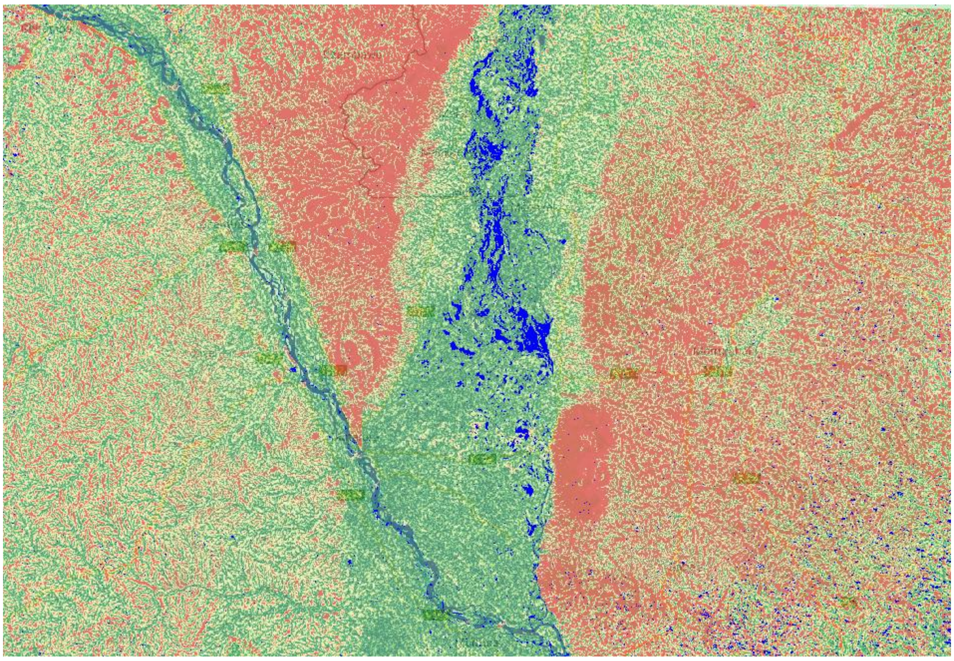


*Figure 11*
*Flood extent map from Figure 10 shown in combination with HAND-map (green = relatively higher flood hazard).*

Finally, an approach to derive flood frequency flood maps using the JRC Monthly Water History data set, that is available in GEE, was introduced. Participants were able to reproduce the flood frequency map and the legend on the area near to the lower Limpopo River based on data from 1984 to 2019 (see Figure 12).

[7] See the article by Nobre et al. (2011) "Height Above the Nearest Drainage – a hydrologically relevant new terrain model" https://www.sciencedirect.com/science/article/abs/pii/S0022169411002599

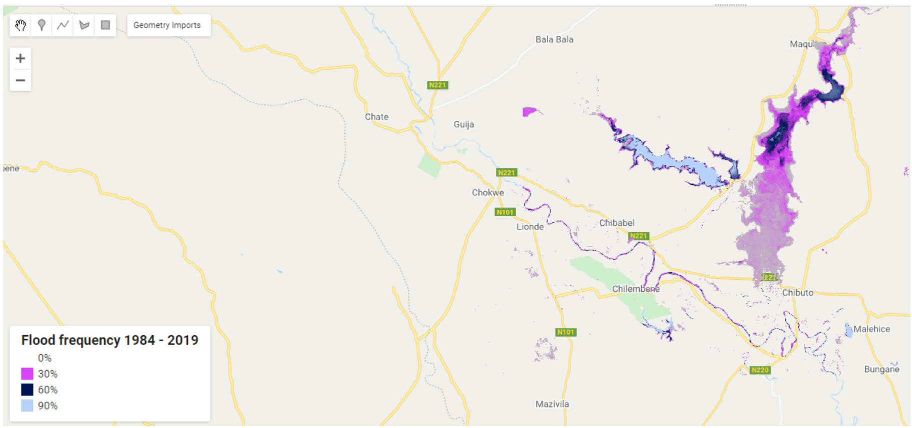



*Figure 12*
*Flood frequency map for lower Limpopo River.*

At the end of the training, a discussion was held with participants on how they can apply the tools they had gained experience with during the training and what they would like to address in the next training periods. Among the answers, participants highlighted the quantification of risk in areas at risk, as well as the use of the methods learned to improve communication. Among the participants two perspectives on the use of flood extent mapping based on satellites were highlighted. A first use was to support a forensic analysis of historical flood events, as this provides insight into key processes. The second important use that was highlighted, was the use of real time data to support the management of flood incidents.

### 2.1.4 Reservoir monitoring

**Aim**
Obtain a basic understanding of the theory behind the reservoir algorithms and be able to run the existing algorithm.

**Training activities**
The training focussed on existing algorithms and their application to one or two reservoirs in Mozambique:

- Theory on the derivation of reservoir extents from satellite data.
- Introduction to remote sensing datasets suitable for reservoir monitoring, such as Landsat and Sentinel-2 optical imagery as well as Sentinel-1 Synthetic Aperture Radar (SAR) imagery.
- Introduction to the GEE scripts for the retrieval of reservoir extents.
- Address the advantages and disadvantages of remote sensing versus in situ methods.
- Train the participants to enable them to derive example time-series of surface extents for Massingir dam.
- Provide scripts for retrieval of historical time-series of an additional reservoir.
- Collect a list of reservoirs of interest to the participants to be used in the follow-up training.

## Results

Participants used their generic knowledge and skills on remote sensing and GEE obtained in the previous sessions and were introduced to a few new concepts, such as the influence of clouds (and how to overcome these), long time-series of satellite data (spanning multiple decades) and water detection in reservoirs.

The training was set up such that participants learned, step-by-step, how to derive the reservoir extent for a single reservoir (Massingir reservoir on the Limpopo river in Mozambique). This started from water detection on a single, cloud-free satellite image (see Figure 13) and ended with participants using the full Landsat archive in GEE. The result is shown in Figure 14, where the shown fluctuations in water surface area can be interpreted as a time-series of water availability in the reservoir.

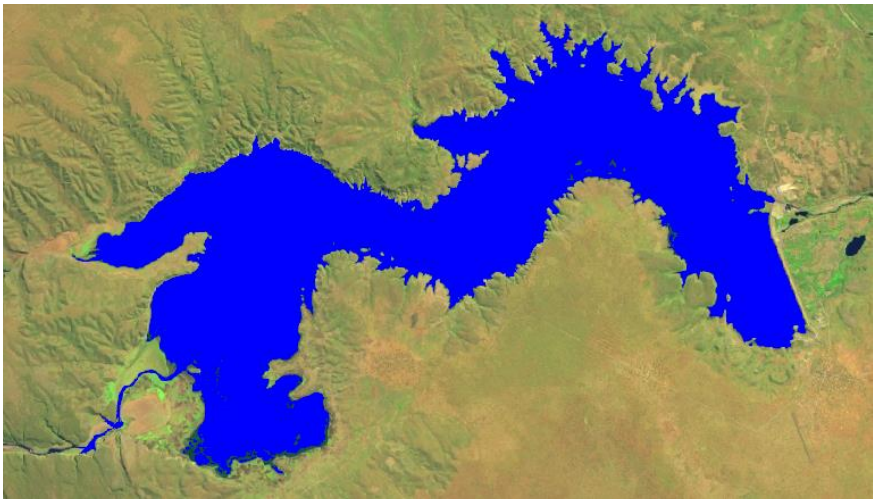


*Figure 13 Massingir Reservoir extent derived by participants from a Landsat 8 image on July 11, 2019.*

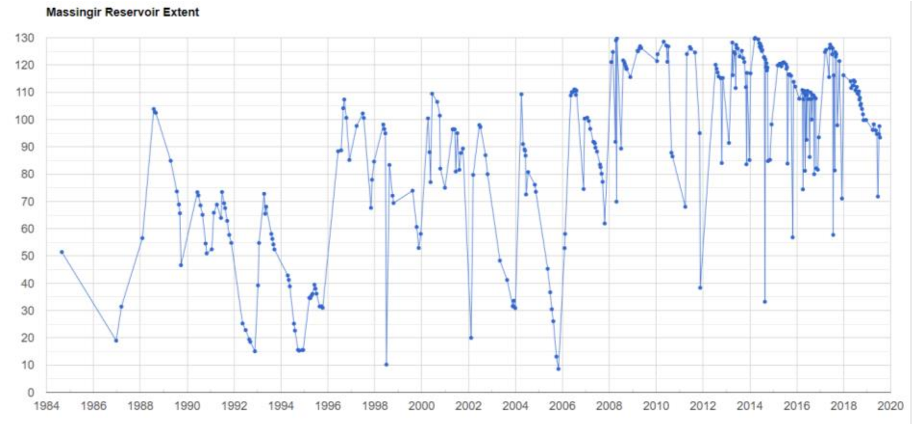



*Figure 14 Massingir Reservoir extents derived by participants during the training, using Landsat satellites with optical sensors (1984-present). The vertical axis gives square km's of surface water extent.*

At the end of the training, participants were asked what they would like to see included in the Training Period 2, both from a technical point of view as well as reservoir locations. This highlighted the issues of clouds and sparse remote sensing measurements.

## 2.2 Training Period 2

A key objective of Training Period 2 was to further elaborate technical skills to modify the applications that were applied and co-developed as part of the Training Period 1. Also, the applications were further developed into interactive online tools. The same topics as in Training Period 1 were addressed ('channel dynamics', 'reservoir monitoring' and 'flood mapping'), supplemented with additional topics ('precipitation monitoring', 'soil moisture and evapotranspiration' and 'population/infrastructure mapping').

### 2.2.1 Google Earth Engine

**Aim**
Be able to change scripts for data-processing in GEE and to publish results online and create interactive functionalities.

**Training activities**
The second training period addressed changing of codes and the development of Web-applications:

- Review of lessons learned form Period 1.
- Modifying scripts for processing of data in GEE.
- Publishing processed data from GEE in a web-applications with interactive functionalities.

**Results**
At first some of the skills learned form Period 1 were reviewed. In the second part of the training the participants learned how to create a GEE app and how to publish it. In an exercise an app was created (using GPM data) that provided precipitation graphs from the last 7 days at a given location (if the user would click on the map).

### 2.2.2 Channel dynamics

**Aim**
Be able to produce online applications of channel movements over time, including channel occupancy maps and combination with local data (position of dikes).

**Training activities**
Activities focussed on how to combine existing algorithms with local data to achieve more insight on possible impacts of channel movements and publishing in online applications:

- Use satellite data to create river occupancy density maps.
- Combine maps with local data (example in Figure 15).
- Extract information from GEE in different data formats such as *.csv or *.tiff.

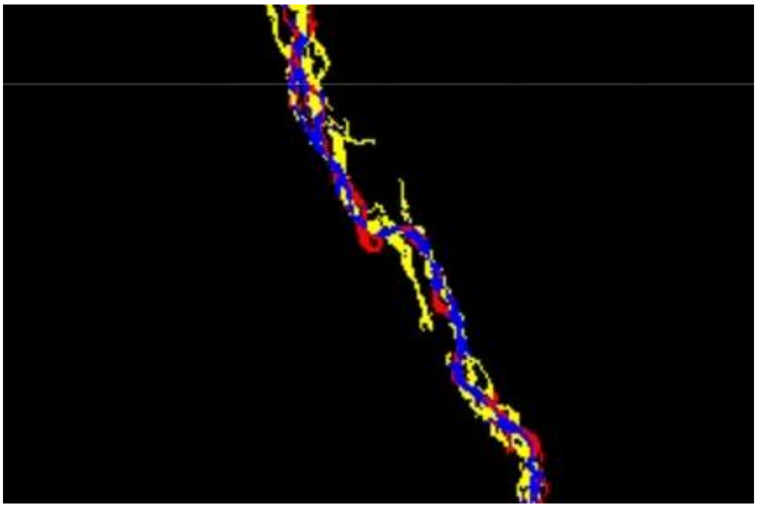
- Use satellite data to map the historical pathways of rivers as an indication of flooding patterns during extreme events.
- Compare two satellite images with each other to get insight in the channel dynamics over time. The dynamics are displayed by showing the areas that are water in both images as well as the areas that either changed from water to land or the other way around (example in Figure 16).
- Develop an online interactive application.

### Results

During this training session the participants learned how to make in GEE a water detection map, which showed which areas were dry and which were occupied by water. Also, the visualisation of the multi-year river envelope was treated. The participants also learned how to combine these with a Digital Elevation Model (DEM) and local data (i.e. the location of dykes), and how to derive meaningful interpretation from these combinations of data sources. The last exercise was focused on the channel movements for a particular region along the Zambezi river. Finally, a web-app was co-developed, which included the treated functionalities relating to channel movements (see paragraph 2.3.1).

*Figure 15*
*Channel dynamics for a section of Limpopo river. Red areas depict satellite detected wet areas. The Black lines show the locations of dikes.*


*Figure 16*
*Channel dynamics detection showing permanent water in blue, water turned to land in red, land turned to water in yellow.*



### 2.2.3 Flood extent and flood risk assessment

**Aim**
Be able to independently produce applications of flood mapping, such as flood frequency maps and combinations with local data (roads, education and health facilities). Apply the techniques to areas and historical flood events other than those discussed in the examples provided.

**Training activities**
Activities focussed on how the techniques learned in the first period can be used to develop maps that identify vulnerable areas with high density population and important facilities. Also, it was treated how to apply these algorithms to other areas and events than those discussed in the examples provided. Activities were:

- Assess potential impacts of extreme wet hydrological events by identifying high density population areas, urban and crops areas based on Copernicus Global Land Cover Layers and GPW Population Density datasets.
- Identify areas with more than 2% of flood probability.
- Identify flood prone areas with high density population.
- Assess threatened urban infrastructure (roads, schools and hospital) based on a flood map extent derived from algorithms discussed on training period 1.
- Publish results in a web-application.

**Results**
During this training session the participants learned how to make in GEE a water occupancy map, which showed how often areas were dry or wet during a selected period of time. The method of detecting waters was similar as was used in Section 2.2.2, and is based on water detections from satellite imagery in the visual spectrum (Landsat). For particular flood events more different data sources were used, including also radar observations, to get a more complete image of historic flood extents. The inundation detections were combined with local data such as population centres and infrastructures, allowing a qualitative interpretation of flood impacts. Finally, a web-app was co-developed, which included the treated functionalities relating to water occurrence and flood extents (see paragraph 2.3.4).

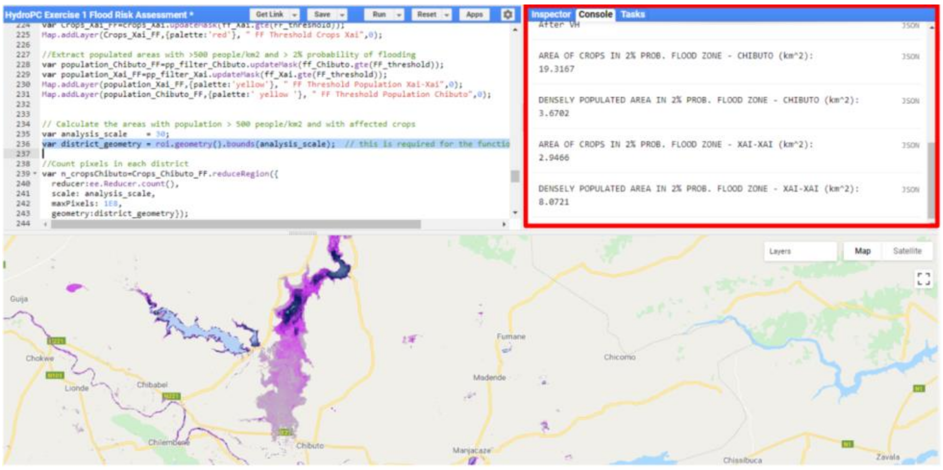


*Figure 17*
*Calculation of areas with more than 2% of flooding probability*

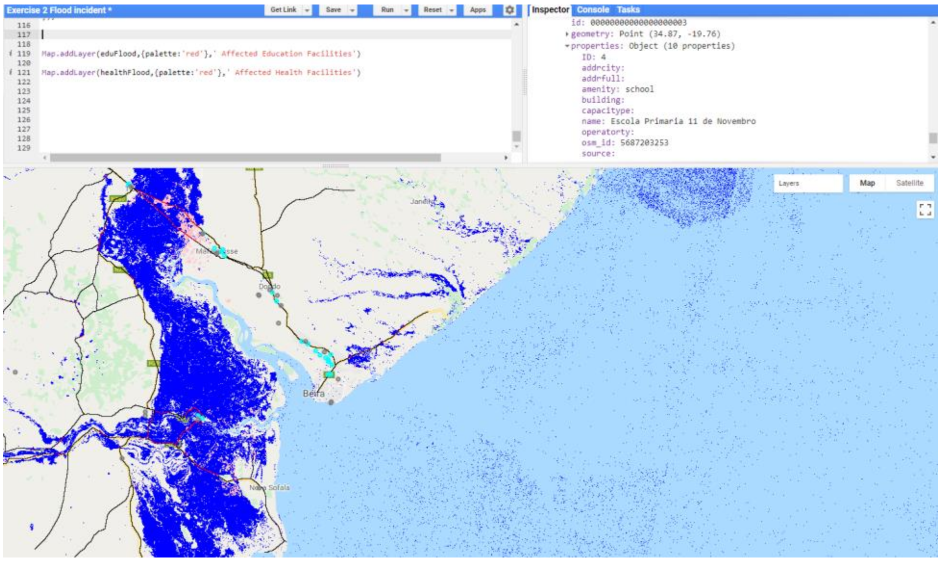


*Figure 18*
*Roads, education and health facilities affected by Idai cyclone in 2019*

## 2.2.4 Reservoir monitoring

### Aim

Be able to retrieve reservoir observations using the GEE scripts for a selection of reservoirs. Combine with local data and create an online application.

### Training activities

We focussed on how to modify the existing application to monitor the additional reservoirs proposed by the participants:

- Summary of the first training session.
- Train the participants to:
  - use Sentinel-1 Synthetic Aperture Radar (SAR) data (to overcome issues with clouds in optical imagery).
  - use the developed GEE scripts to collect and process this data to retrieve information for an arbitrary reservoir.

- create time series of reservoir observations for the reservoirs that were proposed by the participants in the first training.

- Show how the information from remotely-sensed estimates of reservoir extent and provided in-situ water level observations can be combined to construct reservoir area-level curves.
- Discuss the satellite based reservoir monitor in the context of existing hydrological bulletins of DNGRH.
- Publish results in a dedicated web-application.

**Results**

During this training session the participants learned how to detect in GEE the surface area of reservoirs and to create a time-series for such detections. Next, local in-situ data was included in GEE to be able to link water surface area to % reservoir filling rate, or to reservoir water level (see Figure 19). Correlations between these quantities were used to obtain water level and volume time-series of selected reservoirs. A web-app was co-developed, which included the treated functionalities relating to reservoir monitoring (see paragraph 2.3.2).

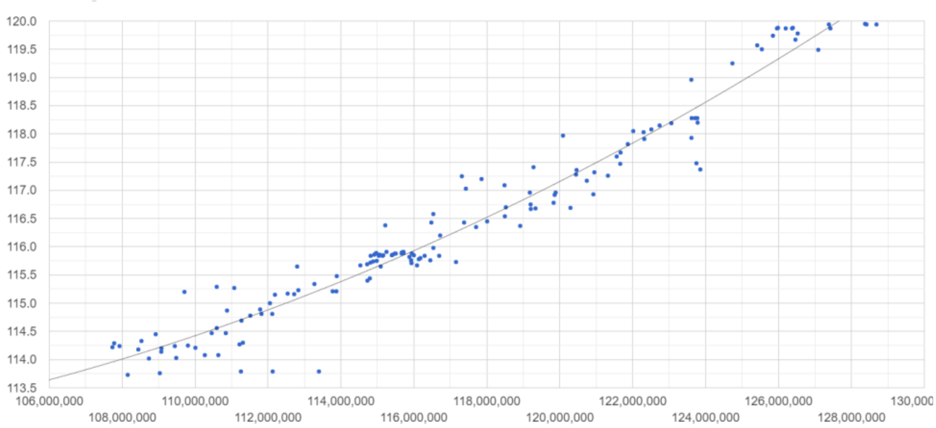



*Figure 19 Scatterplot with fitted line for Massingir Reservoir, extents derived from Sentinel-1 SAR imagery (x-axis, m2) vs. local in situ water level measurements (y-axis, m+REF).*

## 2.2.5 Precipitation monitoring

**Aim**

Learn about precipitation indicators, understand how they can be calculated in GEE and how they can be interpreted in relation to floods and droughts. Combine with local data and create an online application.

**Training activities**

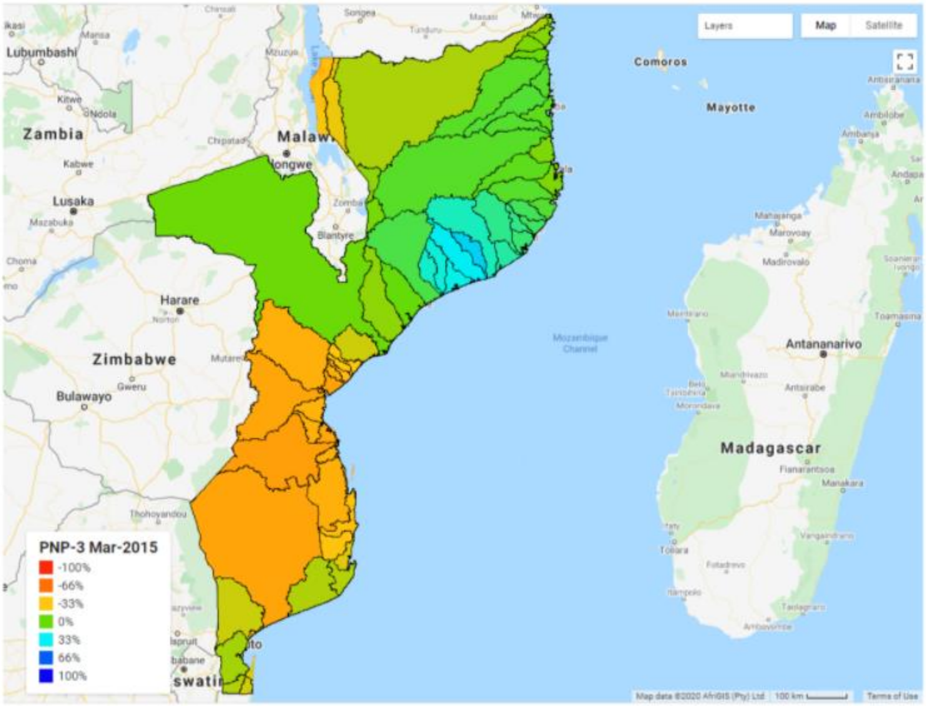
Activities included:

- Summary of the first training session.
- Introduction precipitation indicators:
  - Indicator Percent Normal Precipitation (PNP)
  - Indicator Standardised Precipitation Index (SPI)
  - Calculating precipitation indicators
  - Interpreting precipitation indicators

- Using CHIRPS satellite data to calculate indicators in GEE
- Discuss indicators in the context of flood and drought events
- Publish results in a dedicated web-application.

The PNP indicator was implemented in the web-application, see Figure 20. In this application the user can choose to have indicators over predefined spatial boundaries. The time period over which PNP is calculated ranges from 1 month to 12 month periods and can be selected by the user. In Figure 20 the result is shown on the river-basin spatial scale for a 3 month period is shown (PNP-3).

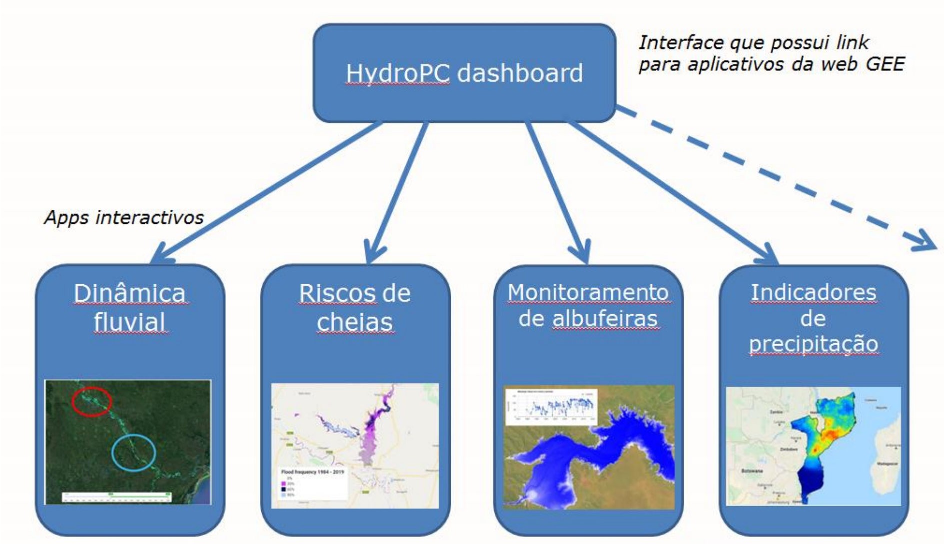
*Figure 20*
*Map showing values for the PNP indicator on a river basin scale*




## 2.3 The online HydroPC platform

On the final day of Training Period 2 the final set-up of the online platform was discussed and functionalities were decided upon with the participants. Preliminary functionalities were already shared with the beneficiaries during Training Period 1, see the conceptual design in Figure 21.

*Figure 21*
*Conceptual design of user interface that links to different GEE web-applications*




On 4 November 2020 the platform was launched, which contained four interactive web-applications. The web-site as shown in Figure 22 can be viewed in English or in Portuguese and presents the entry point to four web applications that were developed during the training periods, which are:

1. Channel dynamics app
2. Reservoir monitor app
3. Precipitation monitor app
4. Water occurrence app

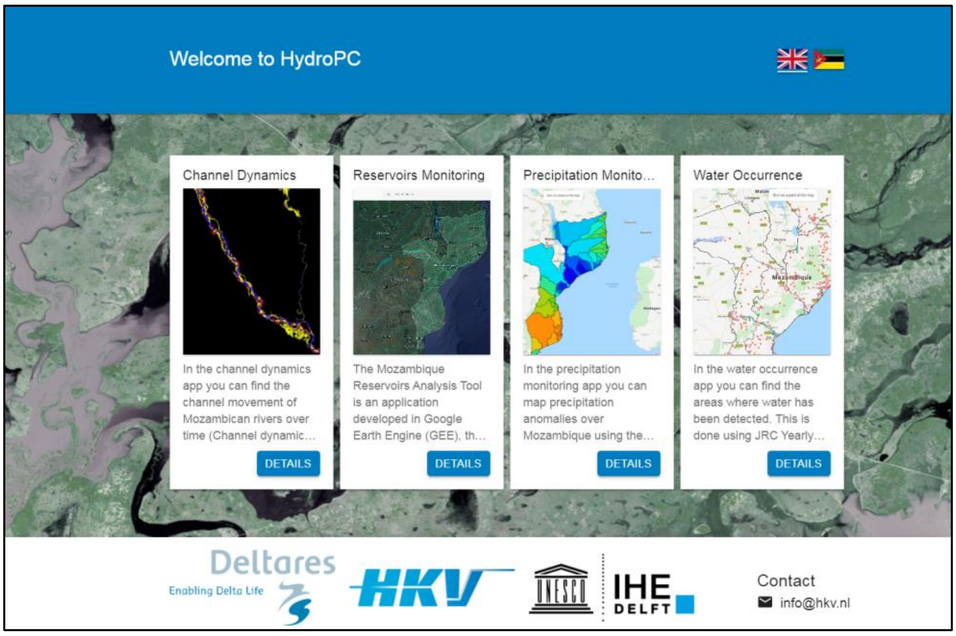
The online HydroPC platform can be found at:
*https://dmmangrove.hkvservices.nl/hydropc/* .

In the following paragraphs the functionalities of these four apps are discussed in further detail. Appendix B explains how to use these web-apps. It is important to note that only the entry-page that is shown in Figure 22 runs on a local server, but that the four web-apps all operate in the cloud. These can also be accessed directly (i.e. going directly to the app using its specific URL[8]). The underlying code can be accessed in the Google Earth Engine environment. The server and apps are entirely license free and without operational costs.

Also, during the two training periods ample time was spent on co-developing the scripts that are behind the four apps. Therefore, participants from those sessions should be able to understand the functioning of the apps and, if needed, perform minor adjustments or corrections to the apps. We discussed with the participants what could be useful aspects to elaborate upon in the four apps, and for these aspects we included in Appendix C a separate step-by-step guide to assist such actions. This guide is also available in Portuguese.

[8] See explanation per application in the following paragraphs.

*Figure 22*
*HydroPC platform linking to four web-apps in Google Earth Engine*

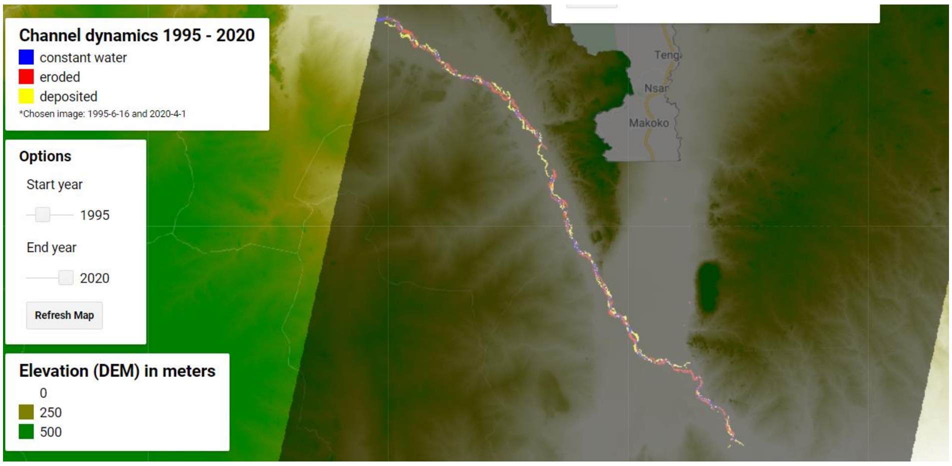



*https://dmmangrove.hkvservices.nl/hydropc/*

## 2.3.1 Web-app 1: channel dynamics

The purpose of this app is to provide insight into the temporal and spatial changes in river morphology. Being aware of these dynamics can help in anticipation of potential erosion locations, and may direct spatial planning.

*Figure 23*
*One of the layers in the channel dynamics app showing the river behaviour over a selected time period.*




*https://hkvgee.users.earthengine.app/view/channeldynamics*

**Description:**

This app is created in Google Earth Engine using several freely available satellite images and datasets. In the channel dynamics app you can find the channel movement of Mozambican rivers from 1986 to (currently) 2020 (Channel dynamics layer)[9]. For the channel dynamics layer both Landsat 5 and Landsat 8 satellite images are used. An example is shown in Figure 23. The red colour indicates areas that were land in the start year and are water

[9] The channel dynamics app will update automatically in years to come as long as the Landsat 8 satellite provides its images to Google Earth Engine.

in the end year, the yellow areas were water in the start year and are land in the end year. The start and end year can be chosen by the user. Also, the area of interest on channel dynamics can be selected by clicking on that area in the app. The other layers in this app give more information to understand the river dynamics better, such as differences in height (Elevation), landcover (Landcover) and dikes (Dikes).

**Support in forecasting:**
The channel dynamics app shows the movement and presence of the river in the past. However, this can give insight in future channel dynamics as well. The same river will be more dynamic in some places than in others. This can be dependent on many factors such as height differences, land cover and human interference (dikes). These factors can be viewed in the app as well. This builds understanding of the users on the reasons for (possible) channel movement and the width over which the river is likely to move in the future. This range in width over which the channel moves can be viewed by the river occupancy (the percentage of time there was water present in a certain cell over the last 30 years) combined with old channel relics such as oxbow lakes which show much older channel positions. Combining all this knowledge on channel movement influencers and past width of the river gives a first understanding on future behaviour of the river and therefore on possible suitable locations for infrastructure such as bridges for example.

### 2.3.2 Web-app 2: Reservoir monitoring

The purpose of this app is to allow satellite-based monitoring of reservoirs within Mozambique and those upstream in neighbouring countries.

**Description:**
The Mozambique Reservoirs Analysis Tool is an application developed in Google Earth Engine (GEE), that leverages the freely available earth observation data in GEE and combines it with in-situ data. The application pulls in satellite-derived reservoir extents for selected reservoirs within Mozambique (all major reservoirs) and relevant upstream reservoirs from within the transboundary river basins of Mozambique (full selection is from participants that attended the training sessions). In addition to the satellite-derived extents, it also shows water levels, volume and filling percentages. Water levels are derived from the extents by use of a regression analysis done on historical satellite-derived extents and in-situ measurements (see Figure 19). Volumes and filling percentages are derived from level-storage curves and maximum reservoir capacities, respectively, all provided by the relevant agencies of Mozambique. Results are updated with the latest available imagery on a weekly basis.

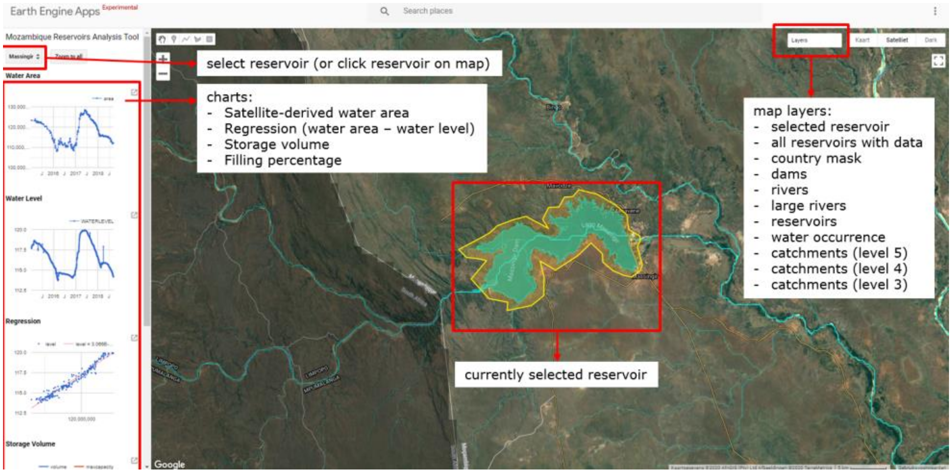



*Figure 24*
*Reservoir monitoring app*

*https://hkvgee.users.earthengine.app/view/mozambique-reservoirs*

**Support in forecasting:**
The current status of reservoirs can help management actions in anticipation of flood or drought events. Knowing the water level, and thus the remaining storage capacity of upstream reservoirs, can help assessing the likelihood of flood wave occurrences downstream of these reservoirs within Mozambique.

This can also be used, in combination with longer historical records, to anticipate on possible actions relevant for water resources allocation in times of droughts. In the final version of the app this has been further enhanced by the inclusion of upstream reservoirs that lie within the transboundary river basins of Mozambique, to help assess the influence of those reservoirs on the expected inflow into the country.

### 2.3.3 Web-app 3: Precipitation monitor

The purpose of this app is to monitor precipitation over Mozambique at a monthly time scale. Precipitation monitoring is provided through the Percent Normal Precipitation (PNP) indicator. This is a simple indicator that is calculated at a monthly time step. It shows for the month that has been selected the anomaly of the precipitation, calculated as a percentage with respect to the normal precipitation for that month. If the month is a very wet month, then the PNP values will be positive. If for example at a selected location the normal precipitation is 58mm for a particular month, but in the selected month the precipitation is observed to be 78mm, then the PNP index is calculated as 34%. This means that precipitation is 34% higher than normal for that month. This information is useful to the user, as it provides an indication of exceptionally wet periods, which may also be periods when flash floods may occur due to wet antecedent conditions.

The PNP index can also be used as a drought index. Negative values indicate a lower precipitation than normal. If in the month above only 22mm was observed in the selected month, then the PNP value would be calculated as -62%. This is again useful to support the monitoring of drought.

The PNP app can be used to monitor the most recent months (depending on the availability of data). The user can also select an accumulation period of 1 to 12 months. This allows the exploring of the precipitation anomaly for one or multiple months, and can help answer questions such as what is the precipitation anomaly for a period of 3 months. Or for a whole wet season, or even for a whole year. Additionally, the user can select historical data (between 1982 and the current year) to explore historical precipitation anomalies. The PNP indicator can be mapped as a gridded product across Mozambique, as well as an average for a shapefile (currently showing the basins in Mozambique).

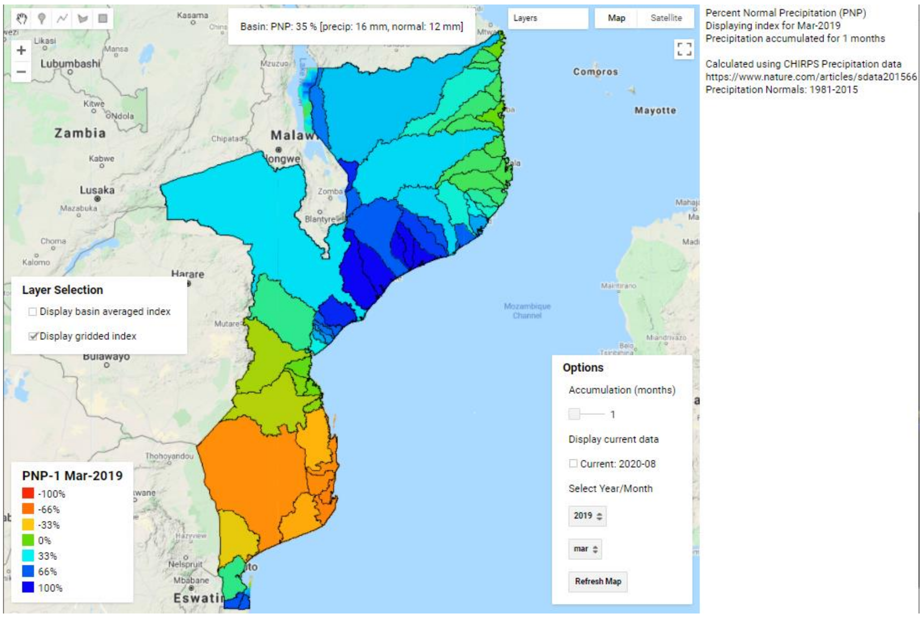
The data used in the app to map precipitation is derived from the CHIRPS precipitation dataset. These are based on satellite observations, corrected using observations from ground stations[10]. Note that this data is available until about 2-3 months prior to the current date. Therefore, only historical analyses until three months ago can be made. The app also displays accumulated data (as actual precipitation) from the Global Precipitation Mission (GPM[11]). These data are calibrated based on historical biases, and may be corrected later. The app does not show these in the form of rainfall anomalies, but rather as accumulated rainfall for each of the months preceding the current date. This provides the user insight into more recent rainfall patterns. An export function is also provided to export the GPM rainfall totals as a daily time series averaged over the basins in Mozambique, to support modelling activities.

Note that the PNP indicator is calculated based on an analysis of normal precipitation (these are reference precipitation values derived from long term averages). This statistical analysis is developed using a script in Google Earth Engine, and the same CHIRPS data, with precipitation normals calculated over the 1981-2015 period. This period can be updated by running the maintenance script. This will update the "normal values" (i.e. the averaged reference values) by also including more recent precipitation data.

Currently precipitation data in the app is averaged over the river basins in Mozambique. These are presented as a shape file. The shape file can be easily adapted to also provide averages over other, if desired (for example to be used for input of sub-basins in a hydrological model).

[10] See https://www.nature.com/articles/sdata201566 for details.
[11] See https://doi.org/10.5067/GPM/IMERG/3B-HH/06

*Figure 25*
*Example of the PNP indicator mapped over the basins in Mozambique.*




*https://hkvgee.users.earthengine.app/view/pnpprecipitationmonitor*

**Description:**

In the precipitation monitoring app you can map precipitation anomalies over Mozambique using the Percent Normal Precipitation (PNP) Index. Precipitation data are obtained from the CHIRPS precipitation dataset. This index shows where precipitation is above or below the climatological normal precipitation for a selected month. The anomaly can be displayed for the month itself, or for a user selected accumulation period (between 1 and 12 months) The user can also select a year/month for which to display the data in the options panel, and selecting refresh to update the map. With this the user can explore precipitation anomalies over selected periods such as the whole year or over the wet season, as well as monitoring the most current situation. By default the index is displayed for the most recent data available to show current conditions.

**Support in forecasting:**

This app provides useful information on the catchment conditions, and if these are wetter or dryer than normal. In areas with higher than normal precipitation (PNP > 0) catchment conditions are expected to be wet. This means that the potential of floods is higher in those areas, depending on the amount of rainfall that is expected in the meteorological forecast. These maps can therefore be used as a pre-warning. The maps are also useful for monitoring droughts, and serve as a pre-warning to lower than normal soil moisture, lower river flows and lower groundwater levels.

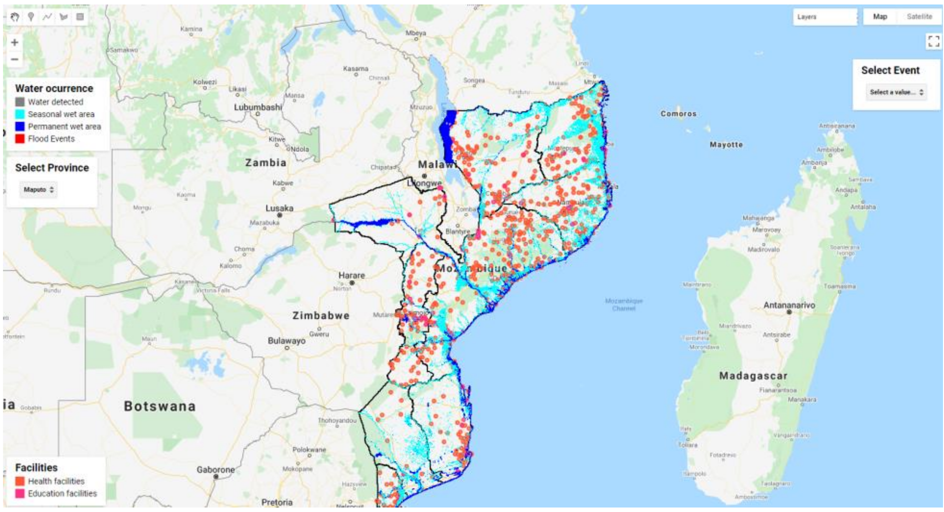
### 2.3.4 Web-app 4: Water occurrence

The purpose of this app is to provide insight into the behaviour of water bodies over the last 35 years in Mozambique using open source data. The app shows detected water in two categories: seasonal wet areas and permanent wet areas. Seasonal water refers to areas where water was observed at least one month every year and permanent water are pixels where water was detected in all 12 months per year, see Figure 26. The app also uses available data from https://data.humdata.org/ to locate key infrastructure such as hospitals and schools, in order to analyse the risk of flooding of these infrastructures.

Additionally, the app can display flood extent maps of selected flood events that have occurred during the last decade. This includes for example a flood extent map of the area near Beira, which was affected during Cyclone Idai in March 2019 (see Figure 27). This supports the forensic analysis of the patterns of flooding in these areas, providing useful information on potential inundation patterns of flood events, which is useful information to emergency management services.

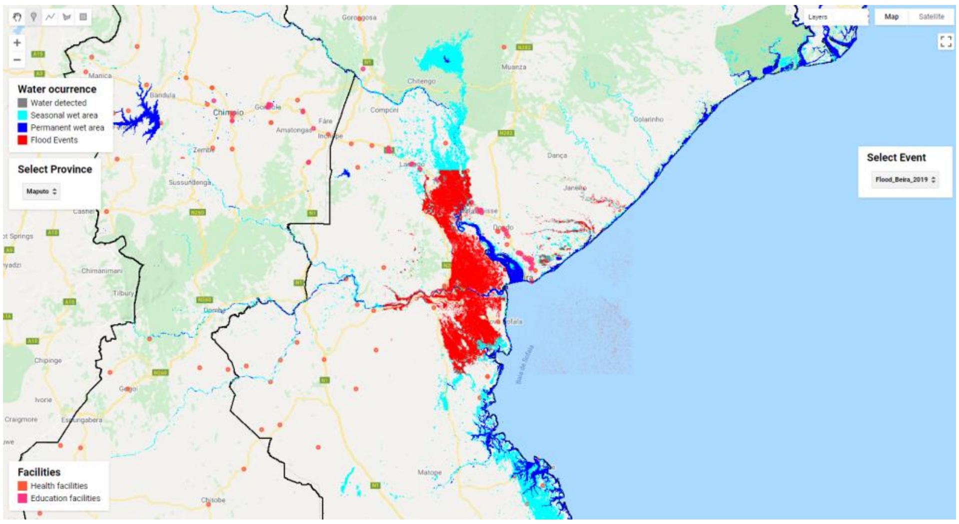
The historical flood extent maps from which the user can select are developed using remote sensing tools. A script is provided to help users analyse historical (or future flood events), and add this event to the list of events available to users of the app.

*Figure 26*
*Water occurrence app*




*https://hkvgee.users.earthengine.app/view/waterocurrencemoz*

*Figure 27*
*Flood extent due to cyclone Idai in 2019 near Beira*



**Description:**

In the water occurrence app you can find the areas where water has been detected. This is done using JRC Yearly Water Classification History data available from 1989 to 2019[12]. The areas are classified in seasonal wet areas and permanent wet areas. Also, education facilities and health facilities are shown on the app to assess the exposure of these assets to flooding. A drop-down list is provided to easily select between the different provinces in Mozambique and zoom into areas of interest. A second drop-down list is provided to display flood extent maps of important historical floods events (e.g. flooding near Beira due to Cyclone Idai in March 2019).

**Support in forecasting:**

This app provides information on yearly water occurrence and historical flood extents, which can help flood risk managers and emergency operations to support their preparations and response. It shows which assets and populated centres are in areas that have previously been affected by floods, and therefore are at a higher risk of flooding. These insights can help prioritize and target emergency response.

[12] Pekel et al., 2016, https://www.nature.com/articles/nature20584

# 3 Conclusions

## 3.1 Are the objectives achieved?

The key objectives of the HydroPC project were:

1. Involve beneficiaries in developing an online interactive information platform that gives access to and combines (processed) data from global datasets (flood hazard zones, reservoir levels) with local data.
2. Increase autonomy of the UFDC and partnering organizations by training staff in use of Google Earth Engine, increase their capabilities in (online) data-processing and at making more use of earth-observation data.

Regarding the first key objective, we co-developed with participants from Mozambican government agencies an online platform with four interactive web-apps. This platform uses global data sets from Google Earth Engine and local data, such as reservoir water levels and locations of dikes. The various functionalities can support the analysis and anticipation of floods and droughts. The functionalities were chosen to align with procedures in Mozambique, and can thereby assist in production of evaluation reports of hydrological events or for making anticipatory assessments of oncoming rainy season or dry season. It was also confirmed by the participants in the training and those that were present at the launch event of the HydroPC platform, that the developed technologies were very useful in existing water management practice and could trigger new ways forward. Another advantage this project offered was that the used data from the Google Earth Engine environment is still rapidly expanding. Future data additions are therefore now also more easily available to the participants of this project and to other future users of the HydroPC platform.

Regarding the second objective; during the training periods all technical developments were mutually decided upon, and through exercises the web-apps were developed step-by-step together. Comprehensive training material was developed (bi-lingual manuals, videos) and made available online, such that all steps could be repeated by anyone at any time. Furthermore, the developed HydroPC platform is set up in such a way that new satellite data will be automatically incorporated in the web-apps. Therefore, current app-functionalities will remain effective for coming years as well. Only the manually uploaded data in the platform (dike locations, water level series of reservoirs) have to be updated manually, if required. In addition, the UFDC now has the skills to use the included scripts in the platform to collect data for remote areas during emergencies. Finally, the web-apps all function on online servers, no license costs are involved and scripts and functionalities are fully accessible. As such, the conditions for autonomous use have been fully provided. Whether sufficient autonomy has been created within this project remains to be seen through the future utilization and possible expanded use of the platform.

In conclusion, this project demonstrated some of the useful possibilities that GEE has to offer in the field of hydrological data provision and analysis and, in particular, its value to improve capabilities and autonomy in flood and drought forecasting for countries like Mozambique. Through close collaboration with beneficiaries we addressed specific information needs, and also identified possible synergies with on-going projects and water-management-related activities. While directly improving local autonomy in hydrological data analysis, the products of HydroPC can support and improve water management practice in Mozambique for many years to come.

## 3.2 Replicability and scalability of products

The HydroPC platform is easy to operate, easy to maintain and easy to expand. An important feature of the HydroPC platform is that it automatically remains up-to-date by making use of whichever most recent satellite data is available in GEE. GEE continuously updates it database of satellite images, and these will then automatically be available to the HydroPC platform. Manually uploaded data to the HydroPC platform, such as dike positions, water level time series in reservoirs or pre-processed historical flood events, still require manual updating.

The HydroPC platform is easily replicable and scalable to other geographical areas. Some of the functionalities in the platform already cover areas that go beyond the national boundaries of Mozambique, such as the reservoir monitor which is implemented world-wide. Some other functionalities have been limited to Mozambican territory to reduce online computation need. These functionalities are however easily expanded to other areas by modifying the defined data and analysis boundaries.

The HydroPC platform can also be expanded to include additional types of data-analysis functions, involving for example in-situ water level observations in rivers, locations of infra-structures, demographic data or even links to hydrological or meteorological forecasting models. Such expansions would require permissions to link with local official data systems and tools. Also, some expansions would require more specialized user capabilities, but they are certainly within reach from a technological point of view.

## 3.3 Lessons learned

### 3.3.1 Working online

Due to the inability to travel to Mozambique because of COVID-19 travel restrictions, it was necessary to carry out team meetings and all collaborative sessions online. These activities proved successful from a technical point of view, but they also resulted in project delays. Some delays occurred because online sessions had to be limited to a maximum of several hours per day and had to be spread out over more days than initially planned. Participants in Mozambique could otherwise not take part in enough sessions. Also, for online sessions the attention span of participants is naturally shorter than during actual face-to-face meetings. During Training Period 1 we observed that four half-day sessions in one week were still too much for almost all participants to fit into their agenda. For Training Period 2 we therefore limited the sessions to three half-day sessions per week, followed by a half-day roundup session in the third week. The second phase of the project (Training Period 2) also coincided with the start of the rainy season in Mozambique. As a result of this, fewer staff members in Mozambique were available to take part in our online training and co-development sessions, because they were needed in critical procedures related to flood alerts.

Use of a WhatsApp group for HydroPC-participants was not foreseen initially, but was introduced during the first training session and proved to be very helpful in exchanging questions and ideas. This greatly improved interaction, because short messages could now also be exchanged outside of training session hours. This was clearly appreciated by the participants and improved the exchange of questions and comments (for example: sharing of screenshots showing progress or errors, and short confirmation messages that steps were successfully completed). Whatsapp was also used to make announcements regarding upcoming collaborative sessions or meetings.

A positive side of the online collaboration is that project participants are now used to working with each other at a distance. This makes it easier if in the future support is needed in making adjustments to the platform or if any other issues arise related to the project results. Also, an effective collaboration format is now available that can easily be reinstated for possible refresher courses or work sessions in Mozambique or beyond.

### 3.3.2 Co-development and training periods

During the online sessions we had open discussions with the participants about the practicality of certain functionalities, and how these would align with everyday procedures or challenges that Mozambican government agencies are facing. Together we thus decided which functions to include in the four interactive web applications. Being flexible and adapting to the questions that are most pressing within the country proved to be a crucial aspect of the sessions. For example, as a result of these discussions the reservoir monitor not only included reservoirs in remote areas, but upon specific request by one of the ARA’s also included cross-border reservoirs. Also, the requested functionality to allow downloading of precipitation data as input for hydrological model further increased the practical use of the platform.

Furthermore, to assure alignment of HydroPC products with existing activities and on-going projects, the following aspects were addressed during the Training Periods:

- The UFDC expressed in the inception seminar that early-warning capabilities and impact assessments should be improved. The activities addressed during the training sessions contribute to this need by providing additional insight into prevailing hydrological conditions and how to interpret these for near-term future impacts. These insights can help to improve the publications of the UFDC that are shared with stakeholders. In particular, the flood extent and channel movement tools help to improve the information that is included in the daily hydrological bulletins during the rainy season. In these bulletins, potential floods are mentioned and warnings are given on potentially affected areas. This information can be made more specific, possibly even by including hazard maps. The reservoir monitoring tool contributes to the information provided in the monthly reservoir bulletins that are published during the dry season. Reservoir water volumes can be homogenised over longer periods of time, giving better insight in the existing state of reservoirs. Also, the reservoir monitor provides an alternative independent information source on cross-boundary reservoirs that affect Mozambican basins.
- DNGRH evaluates the rainy season at the end of each hydrological year. The discussion during the Inception Seminar showed that UFDC wants to improve its methods to quantitatively evaluate the past rainy season. The tools introduced in the training sessions can improve this evaluation. The use of remote sensing data helps to quantify the spatiotemporal dynamics of the water system during the past rainy season by providing statistics of average and extreme hydrological conditions.

## 3.4 Recommendations and closing remarks

An online interactive platform has been co-developed and delivered as part of this project. To take full advantage of this product and of other lessons learned in this project the following recommendations are made:

- The functionality provided in the Water Occurrence App could be extended with additional shape files of critical infrastructures. Currently this contains health and educational facilities, but these could be extended using available data from relevant Mozambican national datasets. These could include datasets of population densities, power stations (including transformer stations), drinking water facilities, critical roads for evacuation, dikes, and other datasets. Combining these data with expected flood extents gives insight into potential flood impacts, which provides key input to emergency managers during flood incidents.
- The precipitation app currently provides observed precipitation, derived from the CHIRPS datasets (available up to about 2-3 months prior to the current date). GPM data is provided up to about 2-3 days before the

current date. The app could be extended to also provide forecast precipitation, which could then be exported to serve as inputs to hydrological forecast models. Forecast data are already available in Google Earth Engine, but incorporating these into the app required more advanced data processing techniques that went beyond the possibilities of this project. It is therefore recommended to define a dedicated project exclusively for this purpose. That way, the precipitation web-app would gain a more direct forecasting functionality.

- To keep momentum in the use of the platform, the participants of the training sessions and the launch event requested a "refresher course" of the HydroPC platform. In such a course all highlights and (adaptable) functionalities should be reviewed. By then, lessons will be learned from using the platform, which could also help in further optimizing some of its functions.
- Synergies to other data platforms should be made. For example, UNOSAT (United Nations Operational Satellite applications program) is currently working with INGC on an operational AI-based flood protection platform. This platform aims to support INGC and other national stakeholders with near real time satellite-derived analysis and statistics about potential flood events during the coming rainy season. While the details of this project were unknown to the HydroPC team at the time of writing this report, a synergy with activities in the UNOSAT project should be sought.
- The platform should be made use of and be aligned with planned and ongoing flood management projects of The World Bank in Mozambique and other developing countries that face regular and intense hydrological risks. Examples of such programs are the World Bank's National Water Resources Development Project[13], the Cities and Climate Change Project[14], and the more recent Disaster Risk Management and Resilience Program[15].

HydroPC offered new possibilities on hydrological data provision and analysis to potential users in Mozambique, and also created a higher degree of autonomy of Mozambican authorities in the fields of water and disaster management. The developed HydroPC platform is set up in a way that allows relatively easy expansion and scaling up. Also, the collaborative training sessions with beneficiaries from this project are rather easily expanded, replicated or adapted. Given the many countries with similar challenges in water and disaster management as in Mozambique, HydroPC could be one to return.

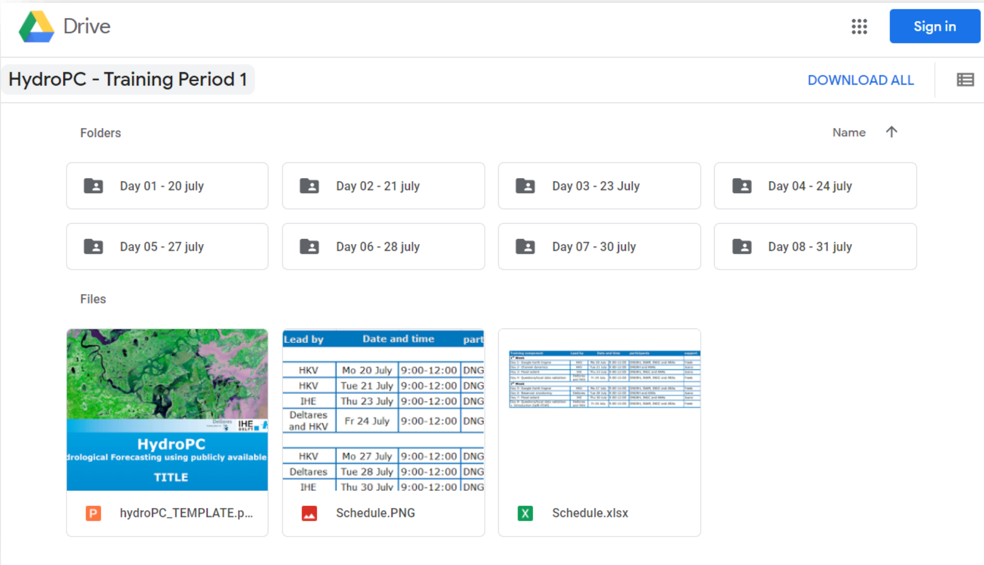
[13] Project nr. P107350, see: https://projects.worldbank.org/en/projects-operations/project-detail/P107350
[14] Project nr. P123201, see: https://projects.worldbank.org/en/projects-operations/project-detail/P123201
[15] Project nr P166437, see: https://projects.worldbank.org/en/projects-operations/project-detail/P166437

# Appendices

# A Training material

All Powerpoint presentations, instructional videos and manuals from the two Training Periods are available on Google Drive. The material is freely accessible to any user and set up in such a way that the entire training can be repeated solitarily.

Link to Google Drive of Training Periods 1 and 2:
https://drive.google.com/drive/folders/17uNH9thff-Ul7HgeN6Sb_yGbfK2NYxAC



# B User Instructions Web-apps

**See separate document:**
Appendix_B_user_instructions_web-apps.pdf (English)

# C Developer Instructions Web-apps

**See separate documents:**
Appendix_C_instructions_further_development_web-apps.pdf (English)
Anexo_C_instrucoes_programacao-web-apps.pdf (Portuguese)

# D Slides of HydroPC platform launch event

The HydroPC platform was launched on 4 November 2020. Below are the Powerpoint slides that guided the event.


## 1. Introdução ao projeto HydroPC

## Nossa equipe

Freek Huthoff

Frederiek Sperna Weiland

Micha Werner

Irene Benito Lazaro

Dorien Lugt

Arjen Haag

Nils van der Vliet

Carolien Wegman

Paolo Paron

Nathalia Silva

Joana Silva

Michiel Pezij

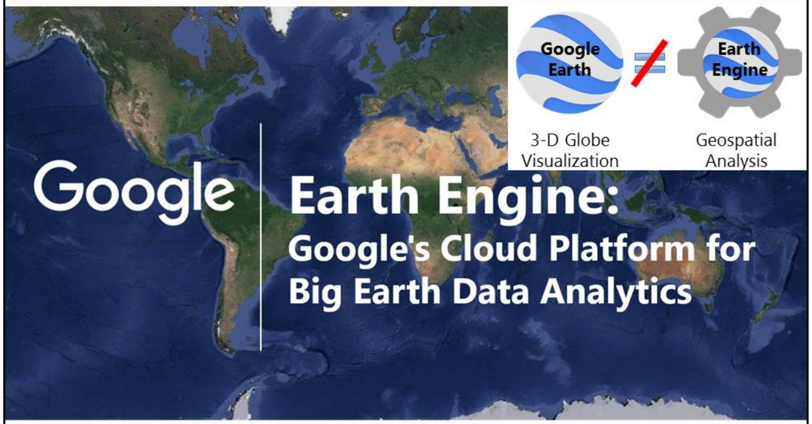
## Hydro PC

- Previsão hidrológica usando dados publicamente disponíveis e tecnologias online
- Introduzir técnicas inovadoras de análise de dados hidrológicos para apoiar a gestão de cheias em Moçambique
  - Use conjuntos de dados globais e sensoriamento remoto
  - Faça uso da computação online
  - Combine com dados locais para agregar valor
  - Foco nos serviços da UCCS e na cooperação com os principais parceiros (ARA, INAM e INGC)

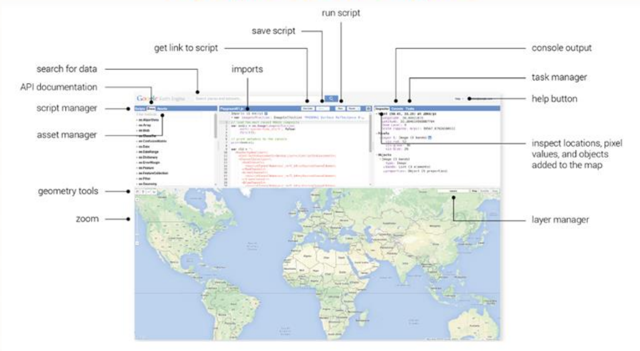
## Objetivos

- Identificar como fazer bom uso dos conjuntos de dados globais disponíveis para melhorar a gestão de cheias em Moçambique.
- Apoiar no trabalho com esses dados por meio de treinamento técnico e co-desenvolvimento de tecnologias.
- Desenvolver em conjunto uma plataforma com aplicativos GEE que sejam úteis para fins de gestão de recursos hidricos
- Desenvolver, treinar e criar autonomia no uso de aplicativos GEE

## Earth Observation / satellite data

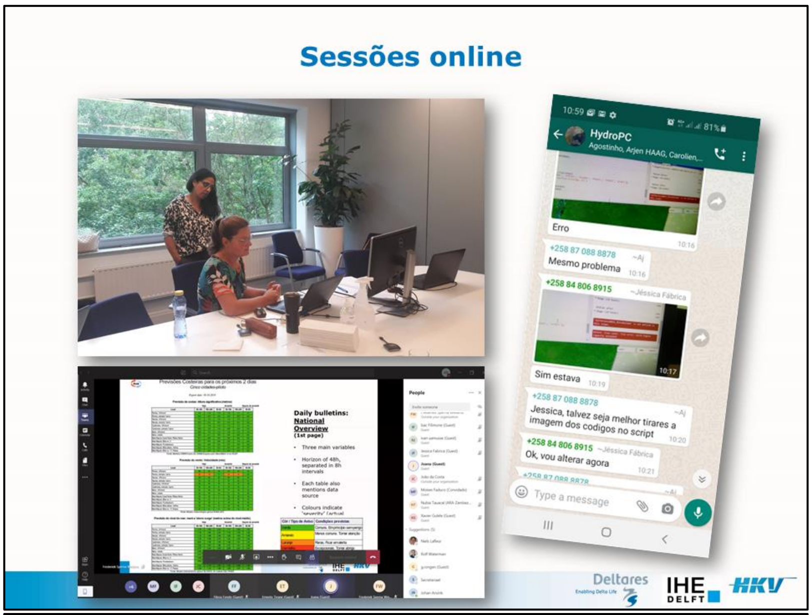


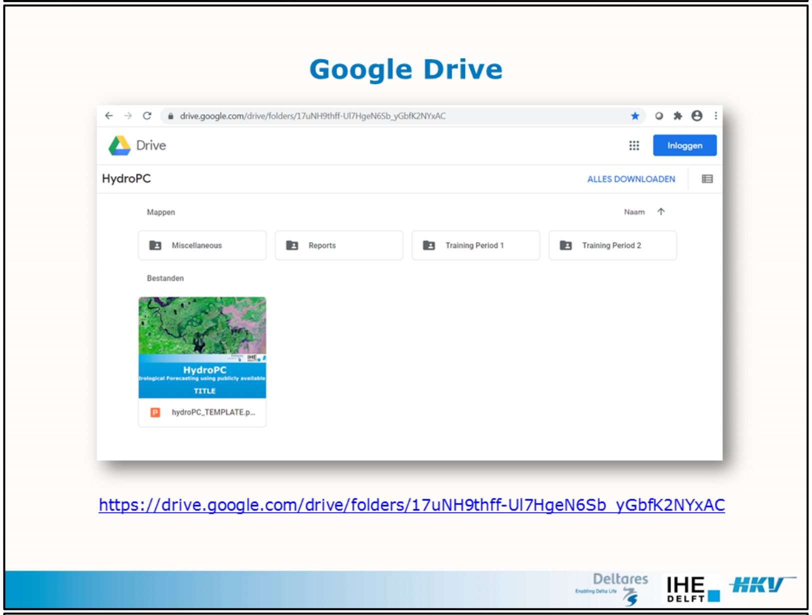

## Google Earth Engine




**Escrever código, editar código, executar e salvar**

https://earthengine.google.com/


Sessões online
HydroPC
Erro
Mesmo problema
Sim estava
Jessica, talvez seja melhor tirares a imagem dos codigos no script
Ok, vou alterar agora
Type a message
Daily bulletins: National Overview
Deltares
IHE DELFT


Google Drive
drive.google.com/drive/folders/17uNH9thff-Ul7HgeN6Sb_yGbfK2NYxAC
Drive
Inloggen
HydroPC
ALLES DOWNLOADEN
Mappen
Naam
Miscellaneous
Reports
Training Period 1
Training Period 2
Bestanden
hydroPC_TEMPLATE.p...
https://drive.google.com/drive/folders/17uNH9thff-Ul7HgeN6Sb_yGbfK2NYxAC
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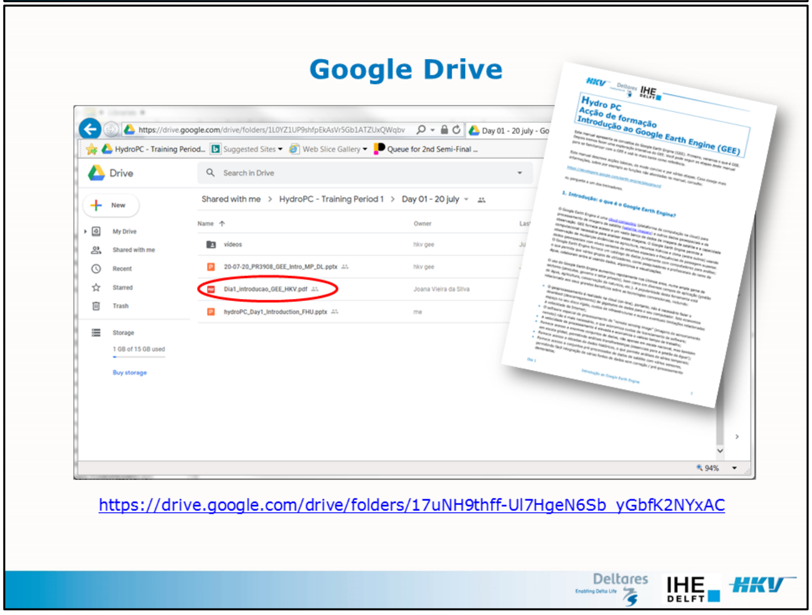
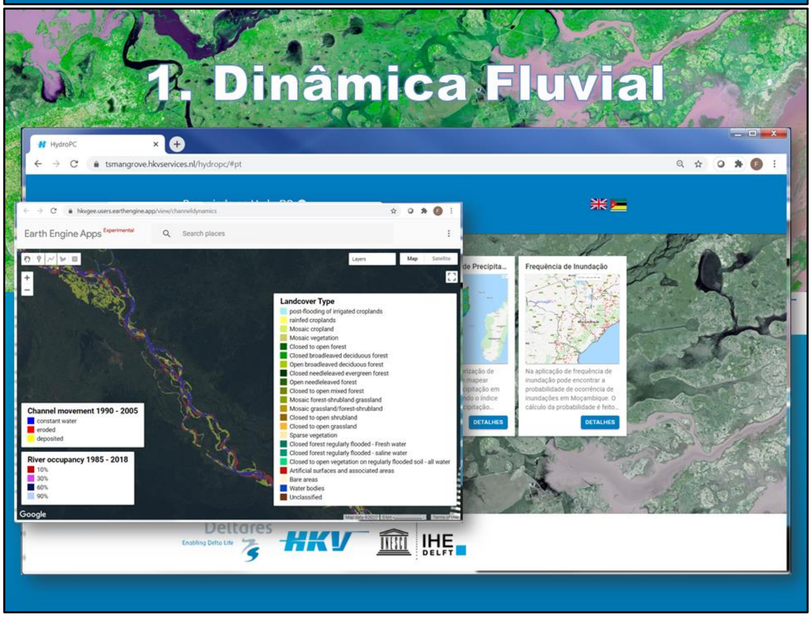
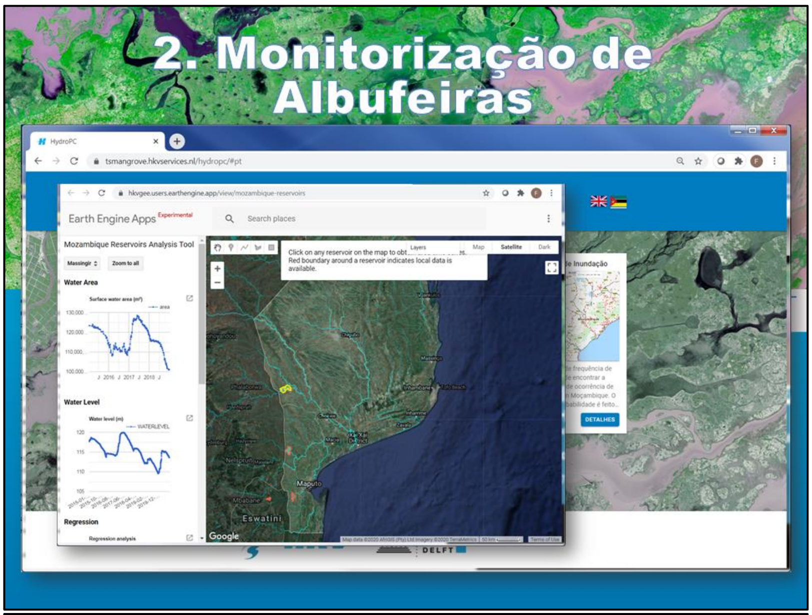
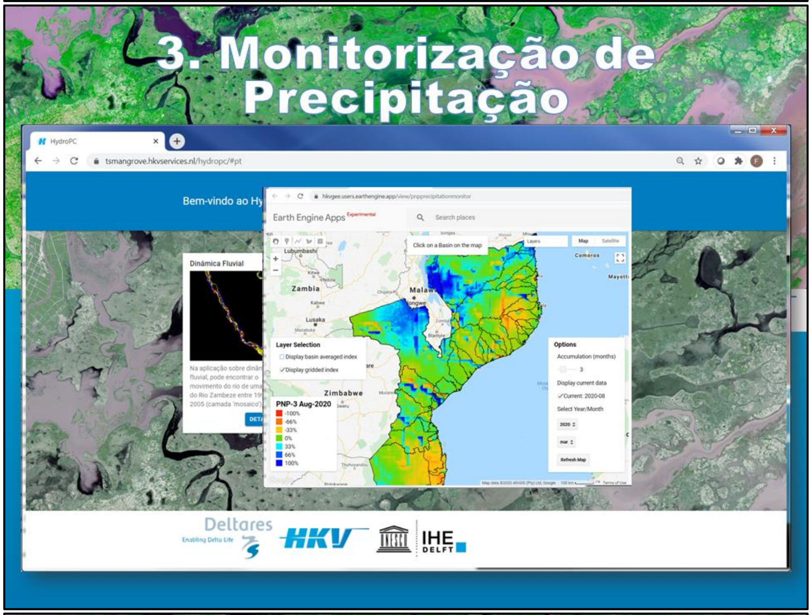

Google Drive
Drive
Search in Drive
Shared with me › HydroPC - Training Period 1 › Day 01 - 20 july
New
My Drive
Shared with me
Recent
Starred
Trash
Storage
videos
Dia1_introducao_GEE_HKV.pdf
Hydro PC
Acção de formação
Introdução ao Google Earth Engine (GEE)
https://drive.google.com/drive/folders/17uNH9thff-Ul7HgeN6Sb_yGbfK2NYxAC
Deltares
IHE DELFT


Demonstração da plataforma
de
HydroPC
Deltares
IHE DELFT
HKV


Quatro aplicativos interativos
Bem-vindo ao HydroPC
Dinâmica Fluvial
Monitorização de Albufeiras
Monitorização de Precipita...
Frequência de Inundação
DETALHES
Deltares
HKV
IHE DELFT


1. Dinâmica Fluvial
Earth Engine Apps
Landcover Type
Channel movement 1990 - 2005
constant water
eroded
deposited
River occupancy 1985 - 2018
Frequência de Inundação
DETALHES
Deltares
HKV
IHE DELFT

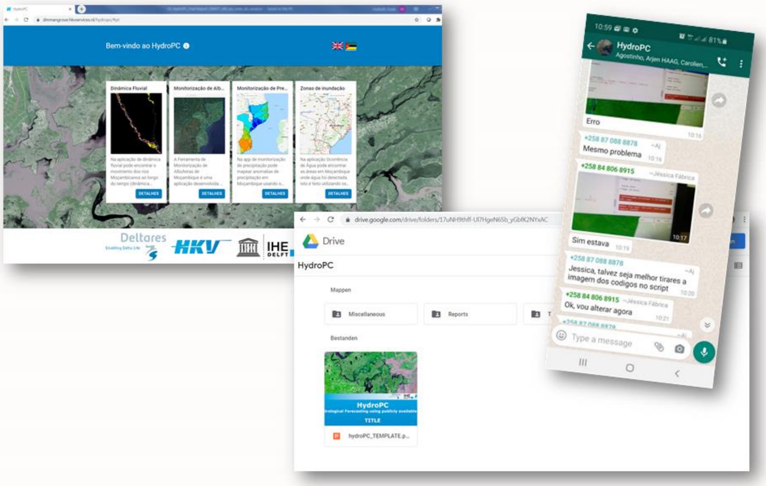

2. Monitorização de Albufeiras
HydroPC
tsmangrove.hkvservices.nl/hydropc/#pt
hkvgee.users.earthengine.app/view/mozambique-reservoirs
Earth Engine Apps Experimental
Search places
Mozambique Reservoirs Analysis Tool
Water Area
Water Level
Regression
Click on any reservoir on the map to obt...
Red boundary around a reservoir indicates local data is available.
Maputo
Eswatini
DETALHES


3. Monitorização de Precipitação
HydroPC
tsmangrove.hkvservices.nl/hydropc/#pt
Earth Engine Apps Experimental
Search places
Dinâmica Fluvial
Click on a Basin on the map
Zambia
Malawi
Zimbabwe
Lusaka
Layer Selection
Display basin averaged index
Display gridded index
PNP-3 Aug-2020
Options
Accumulation (months)
Display current data
Select Year/Month
Refresh Map
Deltares
Enabling Delta Life
IHE DELFT


4. Frequência de Inundações
HydroPC
tsmangrove.hkvservices.nl/hydropc/#pt
Bem-vindo ao HydroPC
Dinâmica Fluvial
Monitorização de Albufeiras
DETALHES
DETALHES
Floodfrequency 1984 - 2019
Deltares
Enabling Delta Life
IHE DELFT

## Comentários de usuários

https://dmmangrove.hkvservices.nl/hydropc/




https://drive.google.com/drive/folders/17uNH9thff-Ul7HgeN6Sb_yGbfK2NYxAC

## Trabalhando com a plataforma HydroPC

- O account do HydroPC no Google Earth Engine
  - Nenhum servidor local é necessário, sem custo de licença
  - Acesso à conta
- Scripts e funcionalidades são explicados no Google Drive
  - É possível repetir todas as sessões de treinamento
  - Manuais em Inglês e Português
- Atualize ou expanda os 4 aplicativos da web com dados locais
  - Aplicativo de dinâmica fluvial: localização de diques
  - Aplicativo de albufeiras: limites das bacias para melhor interpretação
  - Aplicativo de zonas de inundação: adicionar extensões de inundações
  - Aplicativo de Precipitação: delineamento das bacias para fazer download de dados
  - ***Essas ações serão explicadas passo a passo no relatório final do HydroPC***

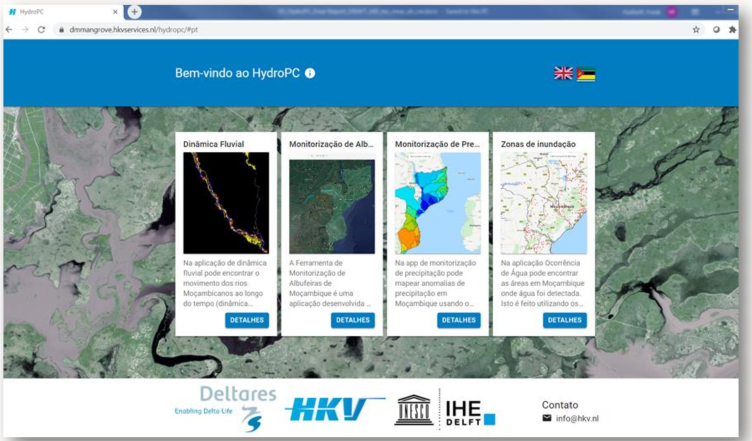
## HydroPC suporte de previsão

- Aplicativo de dinâmica fluvial:
  - Entenda movimentos dos rios para informar o planejamento terretorial
- Aplicativo de albufeiras:
  - Gestão do armazenamento de água em antecipação a eventos de cheias e secas
- Aplicativo de zonas de inundação:
  - planejamento de resposta de emergência
- Aplicativo de Precipitação:
  - As condições de umidade do solo podem servir como um pré-aviso para eventos de cheias e secas

## Possibilidades de expansão

- Alinhe-se com programas em andamento
  - Prepare dados para outros sistemas de informação
  - Preparar dados para estudos e relatórios (avaliação da epoca chuvosa, boletim hidrológico)
- Expanda as opções de dados
  - Adicionar dados locais adicionais
  - Estações fluviais
  - Estações de precipitação
  - Incluir dados de previsão (precipitação)

## Obrigado!




https://dmmangrove.hkvservices.nl/hydropc/

# E Data sources

Below are listed the data sources that are used in the HydroPC platform[16].

**1. Water occurrence app**

Used global data:

- SRTM Digital Elevation Data Version 4 – NASA/CGIAR
- Sentinel-2 MSI: MultiSpectral Instrument, Level-1C
- GPM: Global Precipitation Measurement (GPM) v6
- FAO GAUL 500m: Global Admin Unit Layers 2015, Country Boundaries
- Donchyts et al., Global 30m Height Above the Nearest Drainage ee.ImageCollection('users/gena/global-hand/hand-100')...

Used Local data:

- coordinates_station.csv in miscellaneous
- prec_measurements_monthly.csv in miscellaneous

**2. Channel dynamics app**

Used global data:

- Landsat 5 & 8 TM Collection 1 Tier 1 top-of-atmosphere reflectance.
- Landcover map (GlobCover 2009, Global Land Cover Map). Reference: ESA 2010 and UCLouvain.
- Digital Elevation Model (SRTM Version 4, Jarvis et al. 2008).

Used Local data:

- Dikes layer (Tracado_do_Dique_v2.shp)

**3. Precipitation monitoring app**

Used global data:

- Global Precipitation Mission (GPM[17])
- CHIRPS satellite data

Used Local data:

- (sub)basin layer

**4. Reservoir monitoring app**

Used global data:

- JRC global surface water ("JRC/GSW1_0/GlobalSurfaceWater")
- Global reservoirs ("users/gena/eo-reservoirs/reservoirs-all-and-points")
- Land mask ("users/gena/land_polygons_image")
- HydroBASINS (levels 3, 4, 5), stored at Google Cloud Storage
- Global rivers, Global dams, Country mask (Google Cloud Storage)

Used Local data:

- Reservoir water levels historical time series (shared with us by local representatives, now stored at Google Cloud Storage, for app only)
- Reservoir maximum capacity (taken from previously shared documents/powerpoints)

[16] All 'local data' that was used is added to the HydroPC Google Drive, folder 'miscellaneous/GIS data/': https://drive.google.com/drive/u/1/folders/1SBWPg1t6G-MlNpxVwzstJoF4IwiGr_sr

[17] See https://doi.org/10.5067/GPM/IMERG/3B-HH/06

# F Answers to output indicator questions

### Have you needed to address any risks? If yes, what were the risks and how were they managed or mitigated?

Due to travel restrictions we conducted our technical co-development sessions online (Training Period 2 completed). However, as the rainy season in Mozambique started, fewer technicians from beneficiary organizations were available for our sessions. Numbers of participants in Training Period 2 therefore went down as compared to Training Period 1. To mitigate this, we had more one-on-one communication with individual participants through email and whatsapp. Also, in both training periods all session materials were made available online (Google Drive, including accompanying manuals and instruction videos), such that each session could be repeated autonomously.

We held discussion sessions with beneficiaries to make sure that our final product addressed their needs (see Inception Report and Interim Report). Looking forward, a risk for under-utilization of our final product (the online HydroPC platform) is that only a limited number of beneficiaries were present at the launch event (scheduled for 4 November 2020). We will therefore welcome support in giving exposure to our products. We prepared a short teaser video of the HydroPC platform (in Portuguese) that can be used for this.

### Have you produced any measurable outputs? If so, please give a brief summary using measurable terms. (If you have recently submitted an interim or midterm report, please reference that as a source of additional detailed information.)

We submitted the Interim Report which covers outcomes of Training Period 1 (including co-development steps) and a planning for Training Period 2. Training Period 2 has been completed as well, and the results are described in the Final Report. All materials of these two training periods are available online on Google Drive: https://drive.google.com/drive/folders/17uNH9thff-Ul7HgeN6Sb_yGbfK2NYxAC (including scripts, manuals, Powerpoint presentations and instructional videos).

During the final session of Training Period 2 we demonstrated the test version the online HydroPC platform. The final version was launched during the Launch Event on 4 November. It can be accessed here:
https://dmmangrove.hkvservices.nl/hydropc/
Appendix E lists the data that is used in the platfrom, which are now easily accessible to beneficiaries.

Have there been any preliminary or final results or outcomes in which data or methods have allowed data to be produced: faster; more cheaply; at a higher resolution or granularity, or where there was no data before? If yes, please provide a brief description.

Through the co-developed HydroPC platform (see also previous question) satellite-derived hydrologic information is now more easily accessible to beneficiaries in Mozambique. Also, the data is presented in a format that is useful to them.
Examples are (full-country coverage):
- reservoir filling levels
- precipitation indicators (accumulated per month, or for selected nr of months)
- river movements
- flood probabilities

As a result of the training sessions the beneficiaries now also have the capability to access additional data sources in Google Earth Engine if needed.

Has the project contributed to the production and/or use of data disaggregated by a) sex b) disability c) age, d) geography (or other)? If yes, please give a brief summary of types of disaggregations and the context.

Geography: the co-developed apps have interactive functions to aggregate data per river basin or province.

Has the project contributed to the use and/or production of gender statistics? If yes, please provide a brief description. *

No, our HydroPC-platfrom deals with hydrological information only, which does not include a gender aspect. However, we have given attention to gender balance in our technical team and the participation of the technical session (see Interim report).

Has the project resulted in any compelling stories at the local level (including user testimonials) and/or received local or international media coverage? If yes, please describe briefly and include quotes and links to blog/social media/news articles, etc. *

No, we have not sought attention beyond the participation of technicians from beneficiary organisations in Mozambique. We intend to do this after the final deliveries of the project.

Throughout out project, feedback from beneficiaries was positive and we addressed specific requests from beneficiaries in the co-development stages of the project. For example, the requested functionality to be able to independently observe water reservoir levels in upstream neighbouring countries has been included in a web-application.

# G HydroPC and Sustainable Development Goals

## Linkage of HydroPC to SDGs

The services and products that we and our partners provide in this project connect to various of the Sustainable Development Goals (SDGs, see Figure 28[18]). Among these, the connections with SDG6 "Clean water and sanitation", SDG11 "Sustainable cities and communities" and SDG13 "Climate action" are the most prominent. Table 5 summarizes specific connections of HydroPC to these three SDGs.

*Figure 28 Overview of the 17 Sustainable Development Goals (SDGs)*


*Table 5 HydroPC results related to SDG targets*

| |
|---|
| 6 CLEAN WATER AND SANITATION<br>**SDG 6 "Clean water and sanitation"**<br>Pursuit of efficient water use and implementation of integrated water management at local, regional and international level. |
| <u>Target 6.5 "implement integrated water resource management":</u><br>HydroPC contributed to this target by providing diverse hydrological data and processing tools that support multi-sectorial water resource planning, including cross-boundary aspects.<br><br><u>Target 6.A "capacity building support to developing countries in water-related activities and programmes":</u><br>HydroPC included dedicated training and co-development sessions that increased technical capacity at government organizations. |

[18] See http://www.un.org/sustainabledevelopment/sustainable-development-goals/

Target 6.B "support and strengthen the participation in improving water management":
HydroPC delivered an interactive web platform that is accessible to everyone free of charge and can help in understating local hydrological conditions.

**SDG 11 "Sustainable cities and communities"**
Sustainable urbanization and risk reduction of water-related extreme events.

Target 11.3 "enhance inclusive and sustainable urbanization and sustainable settlements planning":
The HydroPC platform can help in identifying suitable settlement areas based on local flood risks and water availability.

Target 11.5 "reduce losses caused by water related disasters":
The HydroPC platform offers supporting information for disaster prevention or mitigation activities. First, by providing baseline information for risk-adverse spatial planning and, second, by providing early indications of oncoming floods or droughts.

Target 11.B "increase number of integrated plans towards mitigation and adaptation to climate change and resilience to disasters"
The HydroPC platform offers information for analysis of historical flood and drought events in recent decades, which allows study of climate change trends and learning from past disasters.

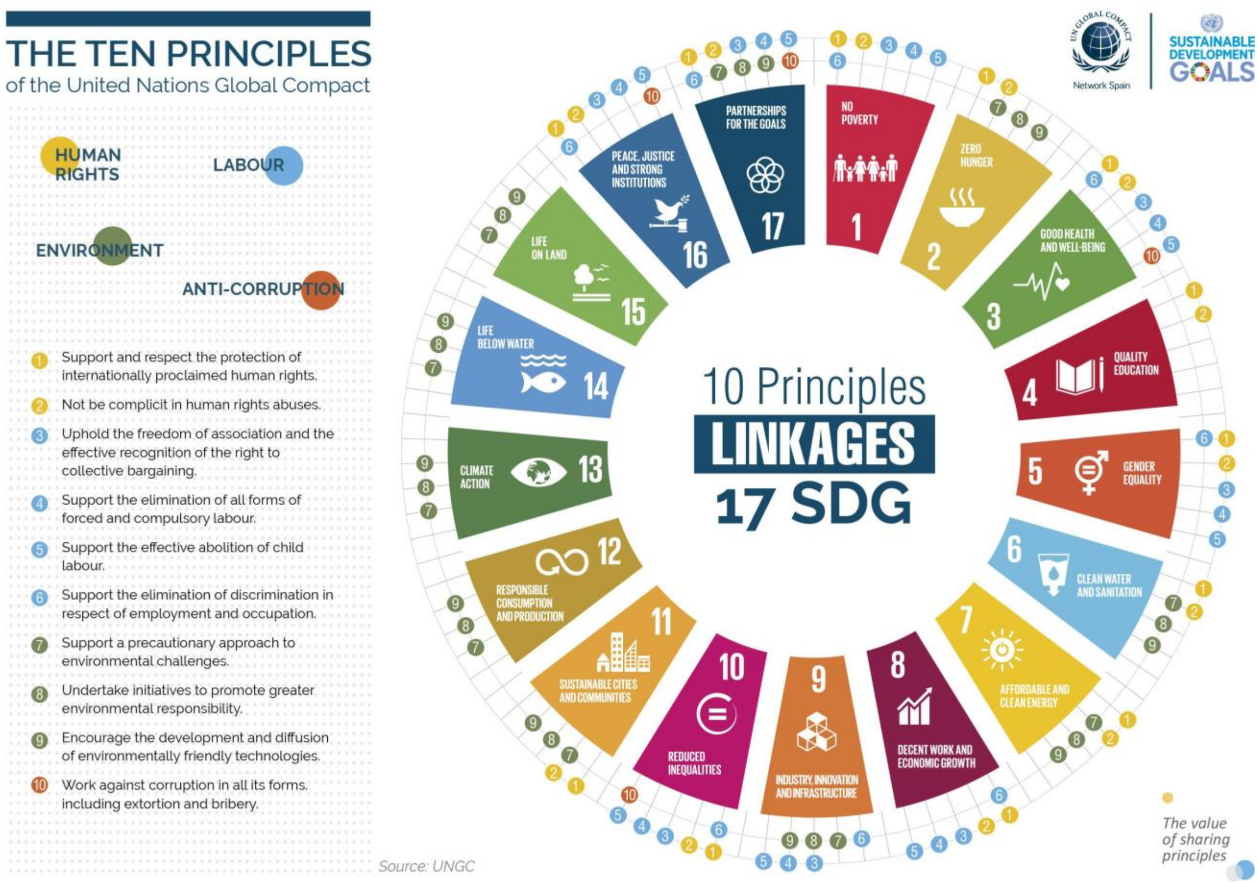
**SDG 13 "Climate action"**
Strengthen resilience and adaptability to natural disasters and climate-related risks.

Target 13.3 "Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning"
Target 13.B "promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries"

HydroPC provided dedicated and comprehensive training which created a higher level of autonomy of water and disaster management agencies in Mozambique. Also, an interactive platform was developed that is accessible to everyone and that allows hydrologic analysis over time scales up to several decades. The platform can help in identifying and in raising awareness of climate change impacts.

# HKV's Corporate Social Responsibility

HKV supports the ten principles of the United Nations Global Compact (www.unglobalcompact.org) that focus on human rights, fair labour, a better environment and anti-corruption. As a member of the Global Compact, we contribute to the implementation of these principles. The figure below shows how the UN Global Compact principles link to the 17 Sustainable Development Goals.




Source: UNGC