The B-SaFFeR project – sensor network implementation

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Abstract— **In this paper the B-SaFFeR project is presented, with its goals, ambitions and results.**

The Rwenzori Mountains in Uganda are increasingly affected by flash floods, resulting in severe human and socio-economic losses. The B-SaFFeR project, funded by VLIRUOS, seeks to strengthen local capacities for disaster risk reduction through a combination of low-cost technology, hydrological modelling, and community engagement.

A sensor network integrating rainfall gauges, radar river level measurements, and CCTV-based computer vision has been deployed to collect real-time meteorological and hydrological data. Data are transferred via low-power 4G connections to the APTERRA cloud platform, enabling open access for researchers and supporting the development of a spatially explicit hydrological model.

Preliminary results demonstrate successful installation and validation of monitoring stations, alongside capacity building with local partners to ensure knowledge transfer and system sustainability. Future work will integrate AI-based flood prediction, citizen-driven data collection, and watershed modelling to design a proof-of-concept flood early warning system. By coupling technological innovation with socio-economic resilience mechanisms and stakeholder co-steering, B-SaFFeR aims to deliver long-term academic, community, and policy impacts in the Rwenzori region.

Keywords—Flash Floods; Internet of Things; East-Africa; VLIRUOS

I. Project Concept

Flash floods frequently occur in the Rwenzori Mountains - Uganda, causing fatalities and socio-economic damage. Despite existing local knowledge to reduce risk, capacities are lacking to monitor floods, enhance community response mechanisms and design and implement sustainable risk reduction. In cooperation with district authorities and Join for Water, B-SaFFeR will enhance interdisciplinary academic capacities to build socio-ecological resilience for all within Rwenzori communities against flash floods.

A low-cost low-power sensor network will monitor rainfall in two river catchments in the Rwenzori mountains and three other points surrounding the catchments. On both river catchments another system will produce 5 seconds of streaming video, every hour and will use computer vision and AI to predict flash floods. Both systems will be coupled with a spatial hydrological model to calibrate a proof of concept of a flood warning system. AP will deliver the data of both systems to a cloud-based data repository, which provides a PhD student with the data to develop the proof of concept of a flood warning system.

Next to the technical aspects, risk sharing socio-economic solidarity mechanisms (SESM) existing at grassroot level will be documented and their impact on household resilience demonstrated. Co-steering of the project with key stakeholders, training and direct support of DRR (disaster risk reduction) actions of pilot villages and environmental radio program will ensure sustainable impact of B-SaFFeR on local communities' resilience. This is outside the scope of this paper, but it is a reminder that technology and innovation can help solve human problems.

The project lasts for 5 years and is a cooperation between Mountains of the Moon University (UG), Ugandan Martyrs University (UG), VUB (BE), AP University of Applied Sciences and Arts (BE), TU Delft (NE).

AP will do the technical implementation of the sensor network.

Other stakeholders are the Ugandan Red Cross, Join for Water, Albert Water Management Authorities, Uganda Wildlife Authority, Ministry of Water and Environment. THRIVE Development Facility and Join for Water, a Belgian NGO

The project is funded by VLIRUOS. This is the Flemish organisation for academic development cooperation.

II. PRELIMINARY RESULTS

A first monitoring network is installed on the Nyamwamba river. A junior expert team of students from AP University of Applied Sciences and Arts has deployed the first connected low-cost weather stations, Weather Integration Module - WIM (measuring humidity, air pressure, temperature, rain) and CCTV cameras for monitoring river flow and discharge, River Observation Base station – ROB, at different strategic locations of each river. In addition, a radar system to measure river levels is installed.

Real-time data transfer to an online cloud is set up through a 4G-connection (low-cost connection). The APTERRA platform collects all the data in appropriate databases (sensor data, video footage) and provides a dashboard and open access to the data for all researchers involved. AP Terra is designed to be a general platform for IoT-data for all research and student projects from AP.

The development of the hard- and software was done by a team of AP students and researchers with input from MMU and VUB partners for the scientific and technological requirements. A proof of concept was first tested in the field in Belgium before deployment in the Rwenzori.

Local deployment was done in close cooperation with the technical team at Mountains of the Moon University (MMU) to ensure knowledge transfer and ownership by the local team.

The project has so far accomplished the following:

- Design, development, testing and validation of a standalone, robust, connected microclimate measurement unit, called Weather station Integration Module, short WIM.
- Design, development, testing and validation of a standalone, robust, connected CCTV computer-vision unit, called River Observation Base station, short ROB.
- Design, development, testing and validation of a turnkey solution for sensor data collection and representation back-end and front-end, called AP Terra.
- Installation of an off the shelf radar level gauge from Obscape, measuring the river water level,
- Integration of WIM, ROB and POL into AP Terra, as use-cases.

III. WIM SYSTEM

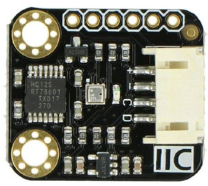
The functions of WIM are rainfall detection and meteorological parameters measurements, being outside temperature and humidity, and inside temperature, humidity and air pressure

WIM is constructed with a ESP32 microcontroller and a 4G expansion board

Its sensors are

- a Davis 6466M Tipping Bucket, which measures rainfall through pulses, with 0.2mm rain per tip / pulse,

- DFRobot BME280, for temperature inside, humidity inside and pressure,

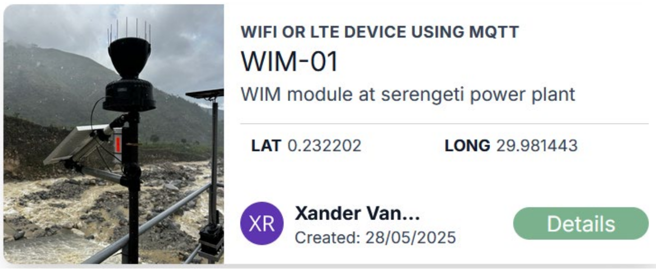


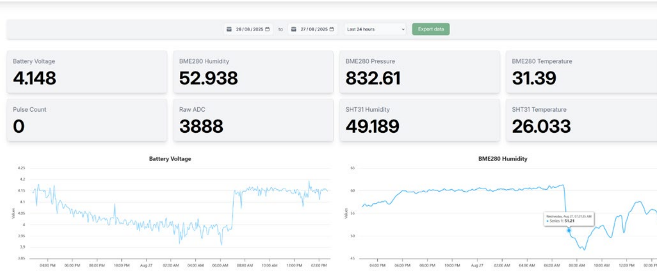
- DFRobot SHT31, for temperature outside and humidity outside and pressure.

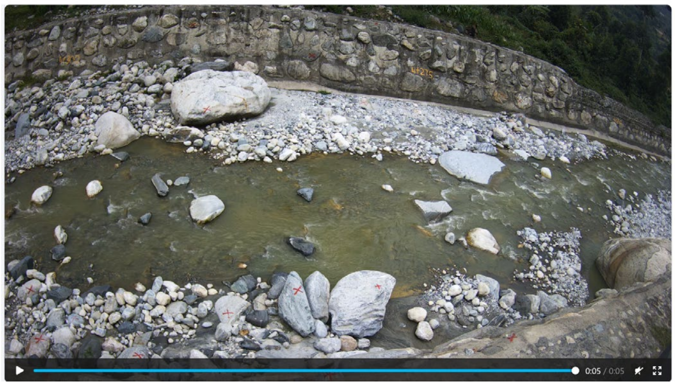
Autonomy is assured through a 20 W solar panel, a MPPT charging board and battery

The system has been validated before implementation through a long test period on the roof of the AP University of Applied Sciences and Arts. There it performed well in comparison with the weather station in Stabroek of the Royal Meteorological Institute of Belgium.

In situ the 5 WIMs deployed are still performing well and are all still operational, since end of May 2025.

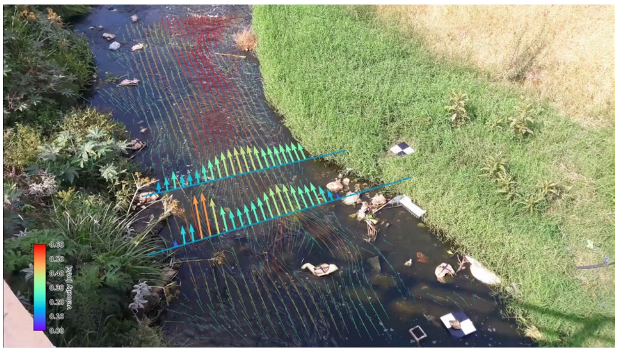






IV. ROB SYSTEM

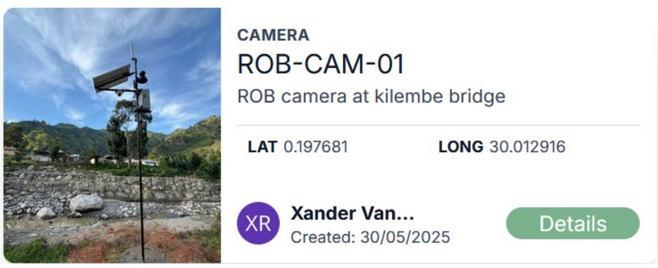
The primary function of ROB is to record 5 seconds of streaming video, every hour. These frames should be sufficient to determine water speed and level, through the pyOpenRiverCam, developed at the TU Delft by Hessel Winsemius.



ROB consists of an IP camera, Raspberry Pi, storage, solar panel, solar charge, 60 Ah $LiFePO_4$ battery, LTE Router with external antenna, Temperature and Humidity sensor, (DHT11) and a weatherproof enclosure.

The ROB-system has been validated before implementation through a long test period on the roof of the AP University of Applied Sciences and Arts. There it performed well and stable.

In situ the ROB's are installed at their specified river catchments, since the end of May 2025 and are still collection the data 2025.



V. APTERRA SYSTEM

AP Terra is designed to be a future-proof solution of the deployment of all our IoT-devices across the globe. It should make deployment easy, straightforward and stable for future projects in the field. At the same time, it is a go-to platform and portfolio for students', staff's and partners' fieldwork.

AP Terra is a turnkey solution for

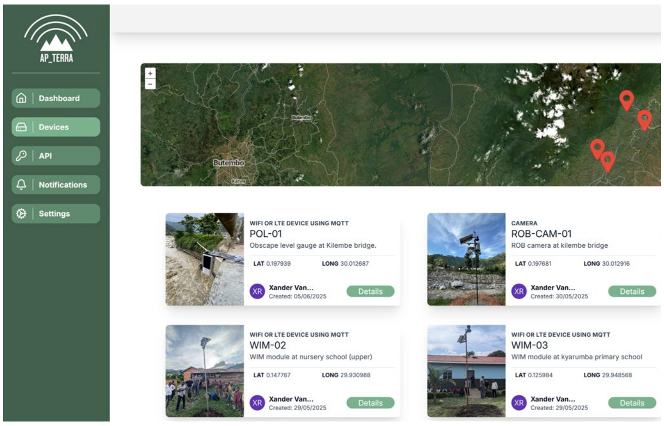
- Data collection
- Device management
- Project administration

Its key features are

- Global Project Management and Visualization: Central platform to manage and visualize projects worldwide.
- Seamless Device and Sensor Integration: Low/no-code tools to connect and monitor IoT devices via clear dashboards.
- User-Friendly Onboarding and Control: Step-by-step setup and easy management of notifications, users, and API keys

The front-end is designed with Angular, the backend is programmed in NestJS, and as a database we use PostgreSQL. Authentication is done by Keycloak, with Active Directory integration. For the project Turborepo was used for the management of the components, Jenkins as CI/CD system and Traefik as reverse proxyThe complete infrastructure is hosted in the cloud

As an essential part of the deployment of ROB, WIM and POL, the system is working very well. And delivers and displays stable sensor data, allows for easy data access for externals and easy export of data to other formats.



VI. NEXT STEPS

A model will be trained for automatic river discharge estimation from the IP cameras' videos. As a back-up and strategy for engagement of local community, local observers will be trained to record 30s video of the river flow with their smartphone and submit them through an app to the MMU server. Such citizen-based monitoring has proved efficient in past projects and will help secure data of flood events in case of data gaps from automatic stations.

A PhD researcher will develop a spatially explicit hydrological model of the catchments based on OpenLISEM open-source software (Integrated Spatial Earth Modeller developed at ITC), with the goal to relate the climatic data to the recorded river discharge. The LISEM approach presents an ideal tool with respect to flash flood modelling and the data scarcity context of the region. Satellite images and GIS will help characterize land cover and derive key hydrological parameters for watershed modelling. The PhD will reconstruct past flash flood events using remote sensing and aerial photographs. The goal is to determine the frequency-magnitude of past flash floods and estimate the return period of different flood magnitudes. The validated hydrological model will give a new understanding of flash flood processes and will be tested as a proof-of-concept for an operational warning system. Research will benefit from existing expertise in flood modelling of TU Delft, which will be transferred to MMU partners to enhance their capacities to lead the development of context specific flash flood warning systems.

In a next run, WIM V2 will have more integrated sensors, to be a fully connected and autonomous system, including solar radiation and wind, for spatial micro climate measurements for agriculture and in the Rwenzori National Park. Serengeti Energy will be a private partner for this.

AP Terra will have The Things Network (TTN) integration and two-way communication, to steer actuators in the field.

A new use case for AP Terra will be biogas measurement in Dar es Salaam, for Ardhi University.

VII. ENGAGEMENT AND SUSTAINABILITY

In terms of sustainability of B-SaFFeR outcome, the retention of the created academic capacity is guaranteed. Staff trained at PhD level is selected within the existing staff of the partner institutions, ensuring that they will continue their academic activities beyond the project end. Additionally, specific efforts are dedicated to update or develop new educational modules in GIS, remote sensing and environmental modelling, that will be integrated in MSc programs of the partner institutions, ensuring long term impact on academic and professional capacities of a new generation of scientists and policy makers.

The sustainability of the monitoring network installed by B-SaFFeR will be facilitated by its low cost and ease of implementation (limited transport and field visits required), and the training of local academic staff to maintain it.

Testing of a parallel system of video-recording by local observers will provide an alternative for operational continuity in case of technical failure.

Involvement of policy makers and key NGOs active in the region in the B-SaFFeR steering committee and interactions with communities will favour the uptake of produced scientific knowledge in the long-term activities of these stakeholders. We especially consider that the Kasese disaster management committee and the Watershed management committees of the two selected rivers, which are official bodies in charge of managing floods, will be key in guaranteeing the long-term impact of B-SaFFeR output on policies.

The partnership between Ugandan and Belgian partners is based on a long-term history of collaboration. B-SaFFeR offers opportunities to strengthen the impact of previous projects in positioning the B-SaFFeR partners as key sources of knowledge in advising governmental and non-governmental organizations active in the Rwenzori. In addition, all partners are dedicated to secure additional funding from national or international organizations to continue the research collaboration and implement project findings beyond the end of this project.

VIII. CONCLUSION

The B-SaFFeR project has started with a technological very challenging and, at the same time rewarding, development and implementation of the sensor network, consisting of autonomous rain buckets, radar for level sensing and a IP camera system for water speed and level detection through computer vision.

The B-SaFFeR project demonstrates the feasibility of deploying a robust, low-cost, and scalable sensor network for monitoring rainfall and river discharge in the Rwenzori Mountains, Uganda. Through the successful design, validation, and installation of the WIM, ROB, and radar-based river level systems, as well as the integration of all data streams into the APTerra platform, the project has laid a solid foundation for developing a proof-of-concept flood early warning system.

Beyond the technical achievements, the project ensures sustainability through strong collaboration with local academic institutions, knowledge transfer to on-site experts, and active engagement with communities and policymakers. This dual focus on technological innovation and socio-ecological resilience enhances both scientific progress and community preparedness.

Looking ahead, the integration of AI-based flood prediction, citizen-driven data collection, and hydrological modelling will further improve the accuracy and reliability of early warning systems. By coupling academic research with practical disaster risk reduction strategies, B-SaFFeR is well-positioned to contribute to long-term resilience in the Rwenzori region and to serve as a model for similar flood-prone areas worldwide.

Acknowledgements

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The student team won The Provincial Prize for Global Research 2025, in Antwerp, Belgium, handed out by the governor and the depute for development cooperation.

References

[1] Ref 1

[2] Ref2