



The HuT

Ongoing monitoring activities in the Demonstrators

Deliverable D4.3

DEVELOPED WITHIN

WP4 Science and Technology, T4.2 Innovative Nexus Modelling

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1. Technical references

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- * PU = Public
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 RE = Restricted to a group specified by the consortium (including the Commission Services)
 CO = Confidential, only for members of the consortium (including the Commission Services)



1.1. Document history

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3. Purpose

The objective of the Deliverable is to provide an update on activities related to the theme of "monitoring," as proposed in Task 4.2 of the Project. For simplicity, the text of the Task is included:

The Task has the goal of developing, within the demonstrators, cutting-edge approaches for monitoring precursors and indicators of extreme climate events.

[Subtask 1] IoT monitoring: exploiting new low cost and robust technologies (e.g., Internet of Things sensors) to improve the observation of weather forcing (e.g., increased spatio-temporal resolution) or impacts at or in the ground (e.g., soil moisture).

[Subtask 2] Human Sentinels: involving people working/living in risky areas for a proper maintenance of sensors or for documenting the impacts of extreme climate events (e.g., photos and reports by community members uploaded in local data platforms).

The activities underlying the Task are essentially two: monitoring through remote sensing (DEM1) or sensor-based methods (DEM9, DEM 10), often supporting the development of predictive models for early warning purposes (DEM2, DEM3, DEM6, DEM7), and the development of citizen science initiatives (DEM2, DEM5), such as collecting information on vulnerable or potentially impacted areas through reports from expert citizens acting as territorial sentinels (DEM3).

This Deliverable (and its "twin" within Task 4.3 on modeling activities) is structured according to the scheme of the 10 Demonstrators, providing a summary of what has been conducted over the first two and a half years of the project for each one. The primary sources of information for this work have been the summaries presented during the Annual Meetings and the Logbook, a periodic reporting tool where the various Demonstrators provide updates on their activities. This information has been further verified by the DEM leaders to ensure that no important elements were overlooked. Obviously, not all DEMs have worked on or have specific activities related to the Task; at the same time, within the Nexus framework, some activities carried out as part of other Tasks can also be leveraged as part of instrumental or "human" monitoring activities.

Following the activities carried out within the individual Demonstrators, the Deliverable also provides details on an additional initiative undertaken during the period: the creation of a working group (coordinated by the NGI partner) aimed at promoting knowledge sharing among partners on a topic that has generated significant interest—the estimation and measurement of volumetric water content and its use as a proxy for predicting geo-hydrological instability events. As will be evident in the next sections, instruments for measuring volumetric water content have been installed in several DEMs. In many cases, to ensure the widest possible territorial coverage, low-cost instruments have been preferred. These provide an indirect estimate of volumetric water content based, for example, on variations in the electrical conductivity of the "soil-water-air" medium. This estimate, obtained through literature-based equations, is often intended to provide insights into the evolution of volumetric water content rather than its exact point value (which would require time- and resource-intensive ad hoc calibration). The working group aims to understand how this data can be used, how it can be complemented through various initiatives that estimate volumetric water content from atmospheric reanalysis or remote sensing data—offering broader spatial coverage but often with lower resolution and less immediate indirect estimation methods.

The main challenge anticipated for the final phase, in synergy with WP5, is to ensure the amplification of activities conducted at the scale of individual Demonstrators so that these activities can be replicated or transferred, for instance, to similar contexts or issues, or officially integrated into operational systems for Disaster Risk Reduction (DRR). In the following sections, for each of the DEMs involved, four main items are presented:



- *The tools:* A brief overview of the tools adopted, their location, and key details regarding the technology used.
- *Motivation for the Adoption:* The objectives of the initiative, the reasons behind its implementation, and the target outcomes across different time horizons.
- *Main Preliminary Results:* The initial results achieved, particularly in terms of integrating the NEXUS The HuT.
- *Citizen Science Initiative:* An analysis of the citizen science activities conducted within the various demonstrators, also leveraging the Nexus.



4. Activities in the Demonstrators' Arena

4.1. DEM1 - Valencia city, Spain

The tools:

In DEM1, a surface temperature map of the city was produced using Landsat 8 satellite imagery (data source: NASA/USGS). The images are post-processed by using Google Earth Engine. The map features a spatial resolution of 30 meters and an acquisition frequency of less than one month, making it particularly suitable for monitoring the evolution of urban heat islands [Figure 1]. The main features are related to the urban morphology (analysis of the distribution of urban fabric and building density), green Spaces (identification of vegetated areas that act as “cold spots”), critical Urban Elements (evaluation of factors such as large buildings, industrial zones, shopping centers, and sports facilities with artificial turf, all of which contribute to the formation of “hot spots”).

Motivation for the Adoption:

The primary objective of this analysis is to examine the impact of urban heat islands in relation to the city's morphology, demonstrating how surface temperature distributions vary across different urban areas. Special attention has been given to vulnerable areas, known as Sensitive Urban Spaces, to assess the thermal risks faced by exposed populations and to support targeted mitigation interventions. The back analysis of internal variations in the urban fabric helps to understand how a large-scale temperature value (and thus, for example, an anomaly extending over multiple days) can manifest at finer scales. This allows, on the one hand, an understanding of the role of adaptation measures (NBS) [WP3] and, on the other, an estimation of future developments using climate projections as input [Task 4.3]. Finally, the set of information, integrated into the broader initiative of the developing Portal, serves as a decision-support tool for local administrators and civil protection agencies [WP1; <https://doi.org/10.5194/egusphere-egu24-19945>].

Main Preliminary Results:

- Significant differences in average surface temperature were observed across various census sections, revealing distinct spatial patterns. Areas with abundant green spaces exhibit lower temperatures, while high-density zones with prominent urban structures register higher temperatures.
- Sensitive Urban Spaces experience an average surface temperature that is 0.70°C higher than that of other neighborhoods, with this difference increasing to 0.9°C in areas of extreme vulnerability—those combining adverse housing, demographic, and socio-economic conditions.
- A positive and statistically significant correlation was found between urban density and surface temperature, indicating that higher density leads to increased thermal exposure for vulnerable populations.

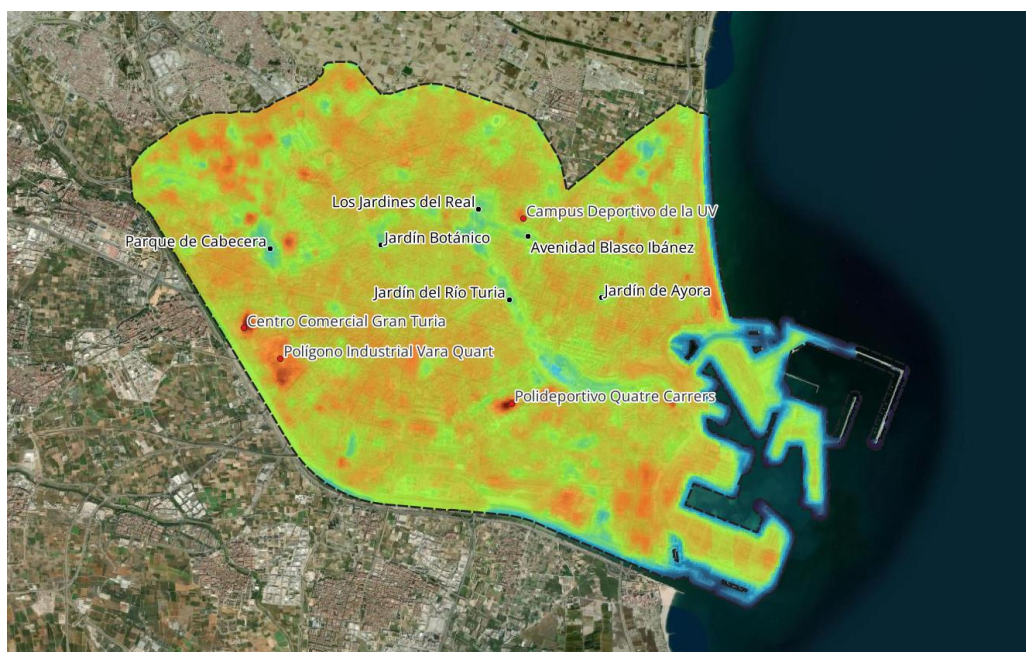


Figure 1: Surface temperature map for Heatwave affecting the municipality of Valencia (30/7/2022-14/8/2022); anomaly was about 3.5°C, Tmax about equal to 37 °C

4.2. DEM2 - Val d'Aran region, Spain

The tools:

In DEM2, the activities carried out under Task 4.2 have led to the installation of six new measurement stations (see Figure 2). Specifically, new sensors (temperature, humidity, and soil moisture) have been installed in the lower areas near the river in the Aran Valley. Additional sensors, including rain gauges, have been installed in the higher remote areas of the Pilot that currently lack coverage. Since these zones do not have mobile coverage, we are utilizing the LoRa network established by Arantec to transmit the data. The stations are powered by solar panels.

Motivation for the Adoption:

The new stations serve various purposes: the rain gauges are primarily installed in areas not adequately covered by the official regional network; the temperature and relative humidity sensors complement surface balance estimates by providing indications of potential losses associated with atmospheric demand. Measurements of volumetric water content at the locations of atmospheric forcing measurements help calibrate the modeling tools under development [Task 4.3] and partly allow for an estimation of predisposing conditions. In fact, they are included in the portal under development for the DEM [WP 1].

Main Preliminary Results:

Monitoring data (principally precipitation, but also soil moisture) has been used to cross-check the outputs of the modelling activities and the findings confirm the robustness of the hydrological modelling suite under development.

Citizen science activities:

The ongoing activity involves high school students, with whom training has already begun over the past years (for example, during the scientific week in Veilha). The current activity includes training

for the construction of a simple device for measuring and transmitting precipitation data ("Build my first gauge"). These unconventional measurements can enhance awareness of quantitative precipitation estimates while also providing an opportunity to improve the spatial coverage of precipitation through opportunistic sensors.

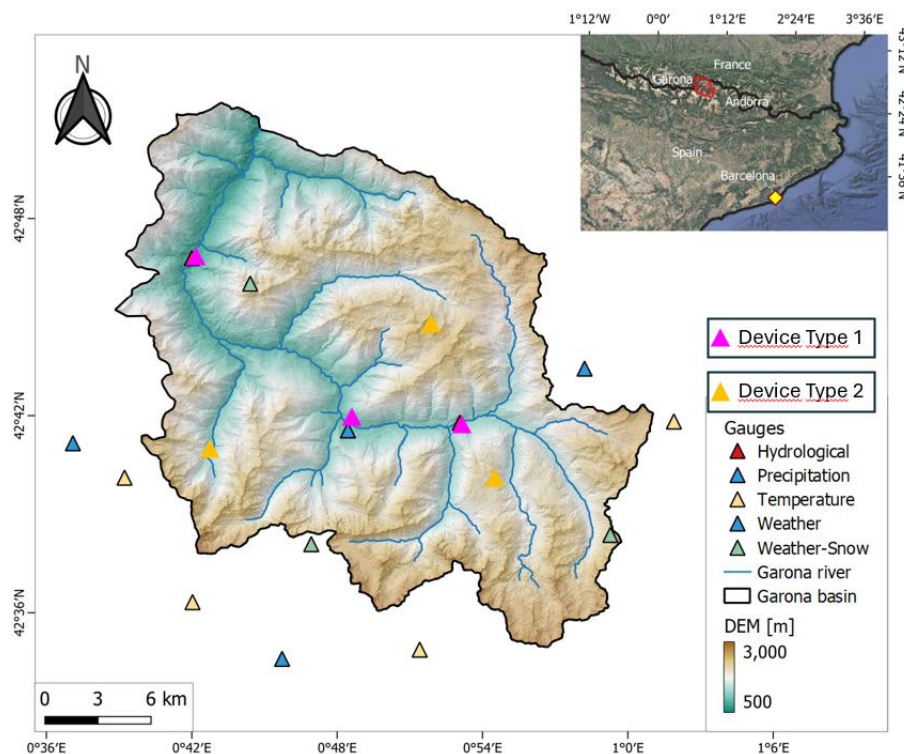


Figure 2: Location of monitoring stations from the regional official networks and installed within the framework of The HuT Project (big triangles); pink: volumetric water content, temperature and relative humidity, yellow: rainfall, volumetric water content.



Figure 3: Installation of new monitoring stations within the DEM2; (from left to right: excavation for sensor installation, installed weather station, researchers engaged in sensor installation, volumetric water content sensors installed horizontally on the excavation face.

4.3. DEM3 - Lattari mountains, Italy

The tools:

In DEM3 (Monti Lattari), new measurement points have been installed in two municipalities: Sorrento and Amalfi. In Sorrento, two measurement points have been identified: the first involves rain gauge and volumetric water content measurements using IoT sensors on a slope overlooking the historic center, while the second focuses on measuring the flow rate of a small seasonal stream that is later channeled underground (right at the entrance to the historic center in the area known as Vallone dei Mulini) before flowing into the sea. Specifically, a radar is used to measure the distance between the installation point and the surface of the water stream.

In Amalfi, there are essentially two measurement points: in the first, located in the upper part of the basin where Amalfi is situated, a rain gauge has been installed. In the second, just upstream of the town center, sensors have been placed at different vertical levels to measure volumetric water content, along with a flow meter for a small seasonal stream that, as in the case of Sorrento, runs beneath the town before reaching the sea. [Figure 4]. The transmission is ensured by using the mobile network while all the equipment is solar-powered.

Motivation for the Adoption:

The new measurement points serve two main functions: the rain gauge aims to complement the measurements from the official regional network in an area that is not adequately covered. The volumetric water content measurements are intended to assess their role as proxies for geo-hydrological instability events. Similarly, the flow rate measurements from seasonal streams aim to provide comprehensive indicators of the basin's hydrological state, offering insights into both hydrological and geo-hydrological risks. These measurements are integrated into the portal under development as part of WP1 and support the assessment of the usability of widespread data, such as those derived from atmospheric reanalyses or other initiatives within the Copernicus ecosystem (e.g., EFAS/GLOFAS). A preliminary identification of the investigated catchments and the related boundaries has been already carried out.

Main Preliminary Results:

So far, almost a year of measurements has been collected from the various sites. The data is not complete due to issues with sensor power supply during the winter season when limited solar energy availability required the installation of larger solar panels, as well as some transmission problems (via the mobile network). Nonetheless, the collected measurements have made it possible to hydrologically characterize certain precipitation events and have supported the calibration and validation of data-driven tools for assessing predisposing conditions.

Citizen science activities:

In DEM3, a web app has been developed and is currently in the testing phase. Its goal is to collect input and reports (especially photographic) on areas requiring maintenance and vulnerable areas affected by hydrological disturbances (e.g., wildfires). The target users include members of the active and expert citizen community, such as hikers, trekkers, and local civil protection volunteers.

The architecture was developed using Kobo Toolbox, which has proven to be an easy-to-use and highly flexible tool for the Demonstrator's needs. Following the coding phase on the desktop version of the portal, an application can be released that is linked to the mobile version available on major app stores, enabling immediate use. All reports are then collected on the web portal and can be utilized, thanks to georeferencing options, within the portal under development [WP1] [Figure 5].





Figure 4: Location of sensors in Sorrento and Amalfi in situ monitoring stations; (first row) left: the location of radar for measurements of water discharge in Sorrento; right: pluviometer and investigated soil profiles in terms of volumetric water content. (second row) left: location of additional rain gauge identified as “Pluvio Arantec”; right: S1,S2, S4 identify soil volumetric water content investigated profiles while S3 identifies the location for radar measuring water discharge; center.

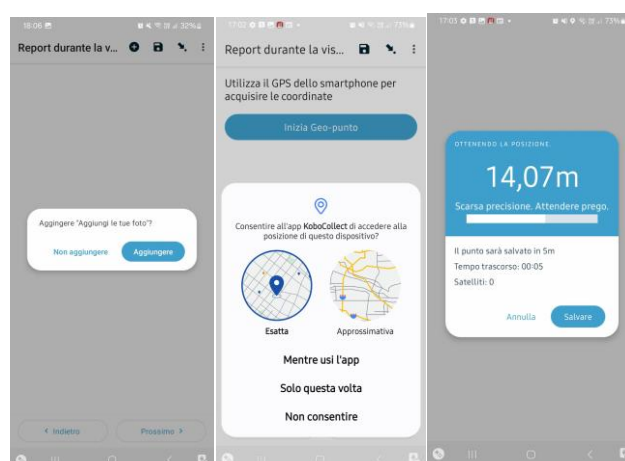


Figure 5: Screenshot from the mobile app, developed in Kobo Toolbox environment, to collect reporting from human sentinels in DEM3

4.4. DEM4 - Vilnius city, Lithuania

The tools:

In DEM4 (Vilnius), the monitoring activity, unlike the previously presented DEMs, is not based on the use of in-situ instrumentation or remote sensing. Instead, it focuses on reconstructing a catalog of events through documentary research. Specifically, the events of interest are pluvial flooding dynamics that have repeatedly affected the urban fabric in recent years. These phenomena are not related to fluvial dynamics but rather to the presence of highly impervious urban basins. Since 2013, about 50 such cases have been identified, when media reported about flooded streets, intercrossings, yards in Vilnius. The most prominent cases are consistent with extreme precipitation events (50-80 mm per less than 12 hours). However, there are also flooding cases when less intensive rainfall was recorded (possibly due to the fact, that meteo-station is located outside the city recorded less rainfall than really occurred). In many cases, flash floods are no longer recorded on specific streets where enlarged pipes stormwater systems have been installed in 2020.

Motivation for the Adoption:

The database is expected to be used to:

- to estimate "hotspots" of pluvial floods in Vilnius city and to assess the change over time;
- to estimate the amount of precipitation related to particular flood events;
- to assess whether the extreme and/ or catastrophic rainfall criteria were exceeded those newly MoE approved indicators for extreme, catastrophic meteorological and hydrological phenomena;
- to monitor the effectiveness of rainwater collection infrastructure and support and strengthen new urban land management and planning tools and strategies, associated both to the technical and nature based solutions (the eco-network, green and blue infrastructure, other sustainable and resilient urbanisation measures)
- to raise awareness on urban pluvial flooding problems in Vilnius for public and governmental institutions as well as for Vilnius municipality

Main Preliminary Results:

The different outputs are also instrumental for The HuT purposes: indeed, in the framework of "climate proofing design", the Project is exploring innovative ways to support dynamic design moving from the physical or regulatory thresholds and going back up to climate projections to understand the probability of exceeding such thresholds given the expected changes in weather forcing due to climate change. Furthermore, the database can also support the identification of rainfall patterns and seasonality related to events potentially triggering pluvial flooding events in the DEM [Task 3.1]

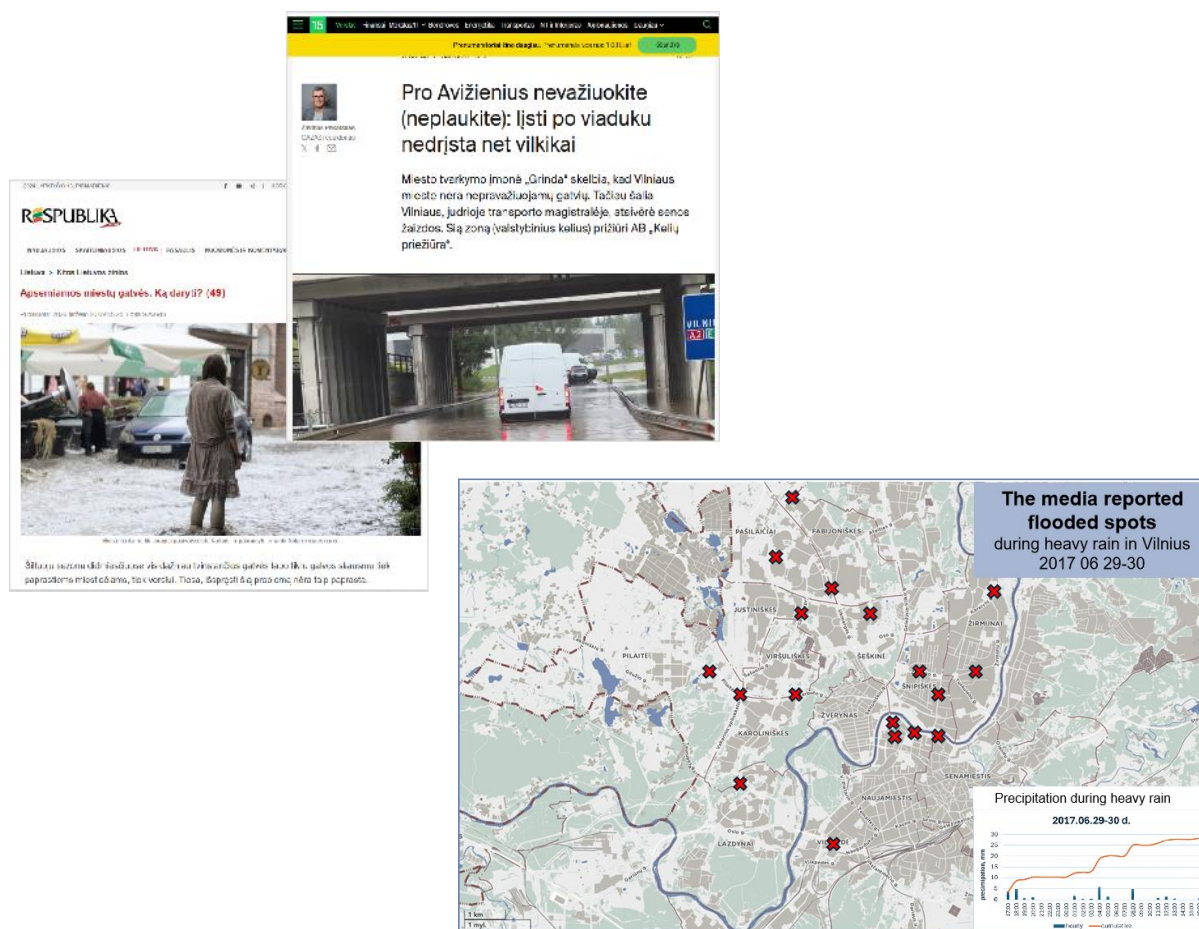


Figure 6: (left) screenshots from website used for documenting pluvial floodings in Vilnius; (right) location of the areas recognized as affected by pluvial flooding in June 2017

4.5. DEM5 - Schleswig-Holstein state and harbor cities, Germany

Citizen science activities: DEM5 is not directly involved in WP4; however, within the activities carried out in the Glückstadt area and leveraging the Nexus approach, the "Buddy System" initiative is also considered part of the citizen science efforts. Indeed, Glückstadt is a relatively small town of 14,000 people, and everyone knows each other through well-connected neighborhoods. Citizens volunteer to keep their neighbors informed through a buddy system, especially those who don't have access to digital early warning channels. The initiative is primarily aimed at the most vulnerable segments of the population, including immigrants, the elderly, and people with disabilities. These groups may struggle to access messages shared via social media or other technologies, risking a lack of timely information when weather-induced hazards impact the area. The system is expected to ensure that well-informed and/or physically capable citizens take on the responsibility of properly alerting vulnerable individuals and making sure they have the necessary resources to cope with the emergency.

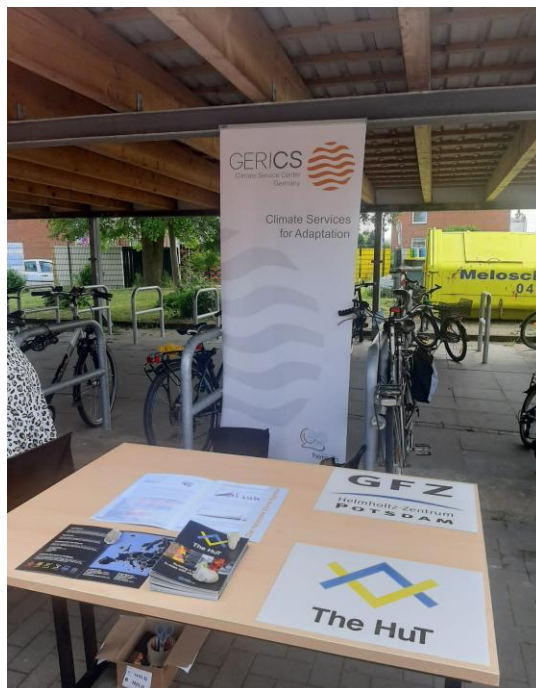


Figure 7: Presentation desk for the The HuT project during a dissemination event organized in the Glückstadt municipality

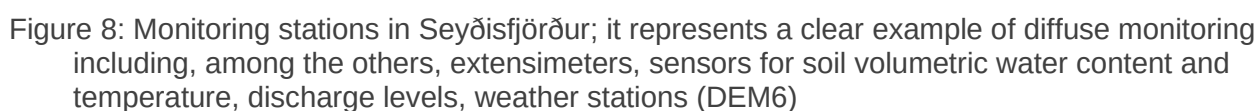
4.6. DEM6 - East fjords, Iceland

The tools:

A network of monitoring instruments is in place in Seyðisfjörður. Automatic weather stations, weather radar, automatic snow sensors in mountains, water level in boreholes, soil moisture, inclinometers (shape arrays) in boreholes, automatic total station and network of prisms, automatic GNSS stations, ground based INSAR radar. Extensimeters have been added recently.

Motivation for the adoption:

The data from the instruments are monitored manually twice a day on normal days and more frequently if needed. Some ideas of thresholds for the different types of data have been formed and landslide and avalanche specialists on duty have experience and training in evaluating the data and recognizing possible danger signs. IMO uses the data along with weather forecasts and observations by snow observers on site to issue early warnings, and make decisions on preventive measures such as evacuations during periods of high danger. The aim in The HuT project is to create a automatic tool for landslide and, perhaps, avalanche forecasters to support the Early Warning System (EWS) based on data from those instruments, especially the water level sensors. The activity is carried out with the support of Norwegian Geotechnical Institute [NGI] (efforts shared with Task 4.3).



The tools:

Motivation for the adoption:

In this regard, the measurement database is currently being cross-referenced with a catalog of flood events to assess whether soil moisture levels can act as predisposing factors for such phenomena. This information could be highly relevant in certain contexts, as it would enable more authoritative early warning alerts or promoting more consolidated prevention actions.

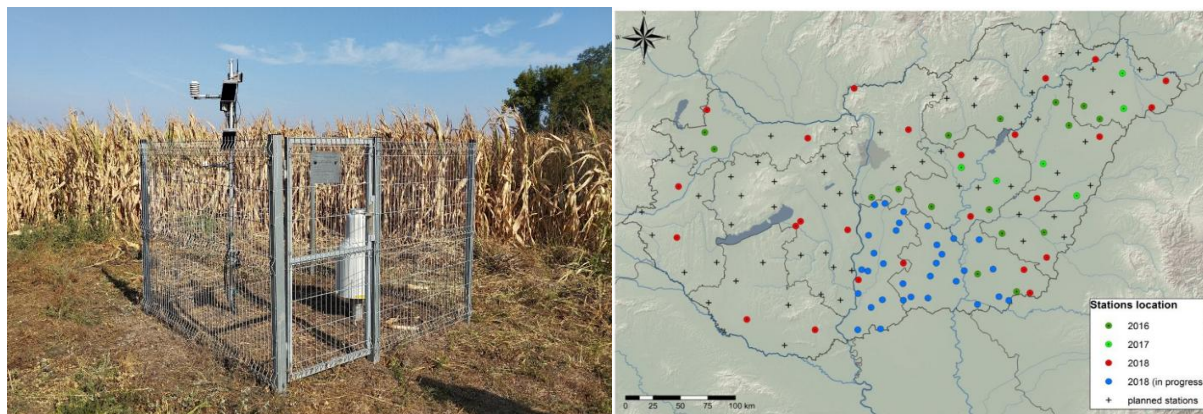


Figure 9: (left) monitoring station; (right) location of the monitoring points over Hungary (https://www.gwp.org/globalassets/global/gwp-cee_files/idmp-cee/idmp-drought-monitoring-hungary.pdf)

4.8. DEM8 - Ogliastro province, Italy

Not involved in the Task

4.9. DEM9 - Dorset county, UK

The tools:

A new weather station was installed in October 2024 to provide localised meteorological conditions on the cliffs at West Bay plan to link to stakeholder understanding of landslide conditioning. Access to outputs for MetOffice, Dorset Council, Bournemouth University and Golf Course. Furthermore, four new sensors installed to monitor landslide activity were installed beginning of July 2024. Unfortunately, the sensors stopped working sooner than anticipated due to battery problems.

Motivation for the adoption:

Weather stations and displacement measurement systems on slopes aim to inform predictive tools implemented in early warning systems. In this case, the dynamics are particularly complex because they involve rockslides, where even predisposing factors are strongly linked to local conditions. The innovative activity (also supported by Bournemouth University) involves the development and testing of innovative technologies that can ensure reliable measurements and continuity in transmission. The sensors adopt be Nb-IoT sensors (Narrowband Internet of things), i.e. communication via low-power wide-area network (LPWAN) radio technology. The relevance of these dynamics is also evidenced by the occurrence of two distinct rock fall events between January and March 2024.



Figure 10: Weather station located near the cliffs at West Bay (Dorset County, DEM9)

4.10. DEM10 - Bern canton, Switzerland

The tools:

In June 2023, a new precipitation monitoring station was installed at the Zuelg site within the area of interest for DEM 10. The station includes high temporal resolution measurements (2 minutes) and enhanced robustness thanks to the adoption of highly advanced instruments. Specifically, it features a Thies disdrometer (present weather sensor), an Ott Pluvio (reference pluviometer), and a Lufft weather station.

Motivation for the adoption:

In the area of interest for DEM10, the dynamics associated with very intense but short-duration rainfall events are of great significance. In this context, the geo-hydrological instability phenomena triggered by such events are primarily erosive in nature. To properly understand these phenomena, it is essential to have information on the kinetic energy associated with the events. This measurement can be inferred retrospectively from conventional precipitation data, but with significant uncertainty. In contrast, the use of disdrometers allows for the reconstruction of the precipitation field in terms of the number of hydrometeors and their average size. Similarly, additional properties associated with the event (such as momentum) can be reliably determined through the interpretation of data provided by the disdrometer. The readings are also included in the regional network and made available through the local data portal.

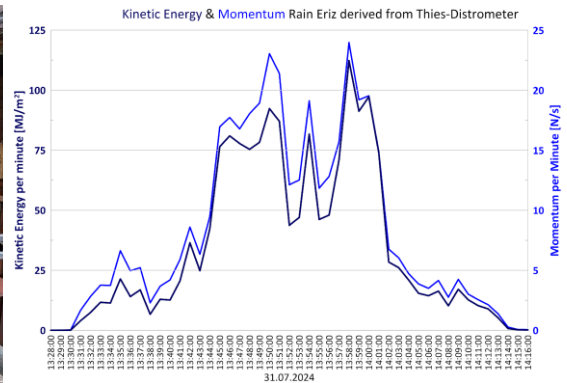


Figure 11: (left) a view of Thies disdrometer installed in Zug; (right) kinetic energy and momentum as returned by the disdrometer for a convective event occurred in the area on July, 31 2024

5. Working group on real-time monitoring and IoT-based warning

As evident from the previously reported information, many DEMs are carrying out activities fully aligned with the expected objectives of the Task. Nonetheless, the peculiarities of the different DEMs initially limited a truly effective exchange of knowledge between partners and DEMs. For example, the selection of sensors, the best technology for transmission and power supply are often tied to local conditions, making it difficult to imagine full replicability and transferability of what has been done in other contexts, even with greater local expertise.

To address this issue, it was decided to create an inter-DEM working group that could focus on topics beyond purely technical issues and challenges. This group is coordinated by NGI (Dr. Piciullo). Following a series of exploratory meetings, the topic that generated the greatest interest was real time monitoring and IoT based technologies to issue warnings. Some DEMs also showed great interest in using volumetric water content measurements to improve the estimation of predictive tools. This state variable plays a crucial role in triggering many geo-hydrological instability phenomena, acting as a predisposing factor and helping to determine whether the phenomenon may evolve with characteristics related to the simple transport of water or the transport of both water and soil.

Starting from these premises, the working group (WG) has focused on several aspects:

- **Sharing Information on IoT Procedures:** the WG facilitates the exchange of information on real-time monitoring and IoT procedures among The HuT partners and DEM. This collaboration aimed to align methodologies, share best practices, and ensure the effective deployment of real-time technologies in weather-induced affected areas. The discussions helped in identifying gaps and optimizing the use of existing IoT infrastructure.
- **Preparing a joint work on IoT-Based Warnings for Landslides:** a major effort has been directed towards the preparation of a publication that reviews IoT-based early warning systems for landslides. The document is under preparation and will provide an overview of current technologies, methodologies, and case studies, contributing to the broader knowledge base and guiding future research and implementation efforts.
- **Supporting the interaction on the evaluation of volumetric water content among DEM2, DEM3 DEM6, and DEM7.** WG is working closely with these DEMs to enhance the utilization of monitoring data for warning purposes. The activities aim at analyzing sensor data, refining data processing techniques, and integrating various datasets to improve the accuracy and reliability of forecasts for weather-induced criticalities. These collaborations are expected to lead to significant improvements in the interpretation and application of real-time monitoring information and forecasts. Indeed, certain conditions have recently enabled easier exploration of this variable: various remote sensing products provide an estimate of this variable, although only for the top few centimeters and with a spatial granularity on the order of a few kilometers; atmospheric reanalysis or similar products (e.g., the GLOFAS/EFAS initiatives) offer back-analysis estimates of this variable throughout the entire profile (often up to the presumed root depth); innovative technologies have significantly reduced the cost of in-situ equipment, allowing indirect correlation between some directly measured variables (e.g., electrical conductivity of the soil-air-water medium) and water content. At the same time, however, there are several weaknesses that need to be properly addressed: all measurement types are indirect and thus require calibration or physically based modeling, whose credibility and reliability still require local validation. The granularity of large-scale

measurements and the limited number of in-situ monitoring points create a mismatch that must be considered. In many cases, however, it is reasonable to assume that these estimates can provide indications not of "point-specific" values but of trends and possible deviations from the climatology of the area investigated.



6. Brief considerations

This Deliverable aims to provide insights into the ongoing activities related to monitoring, whether instrumental or through citizen science initiatives.

Regarding the first aspect, it is clear that almost all DEMs are engaged in initiatives aimed at directly improving (both in quality and quantity) the instrumentation currently used for forecasting weather-induced phenomena or leveraging already available information that has so far been used for other purposes. In this regard, the working group aims to capitalize on ongoing initiatives and support knowledge transfer among partners.

As for the citizen science initiatives, there are currently three case studies where activities are underway. In all three cases, the initiatives have a dual objective: on one hand, to increase local communities' awareness of the impacts and consequences of weather-induced events; on the other, to "harness" local knowledge (from hikers, trekkers, or neighborhood residents) or the knowledge generated as an outcome of the activity for better characterization and management of events.

In summary, no specific critical issues have been identified within the Task, and all planned activities are expected to be completed within the anticipated timeline of the Project.

