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ACTIVITY REPORT

LIFE LATESTadapt Project Tasks
T2.4 “Identifying and testing novel sensing techniques to monitor NBS performance”

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Table of Contents

Introduction

The deliverable was developed within the framework of the Project “LIFE LATESTadapt – Developing and demonstrating portfolio of nature based and smart solutions for improving urban climate resilience in Latvia and Estonia”, ref. No. LIFE21-CCA-EE-LIFE LATESTadapt/101074438. The Project aims at improving the climate resilience within territories of Estonian and Latvian municipalities , to solve practical urban climate-coping challenges as well as to transform the regions to be more resilient in extreme weather events in the future.

During the implementation period from 2022 till 2027 the Latvian and Estonian partner organizations will work in close cross-border co-operation, focusing on four Project-specific objectives:

- **Nature-based solutions**. New nature-based solutions will be developed and demonstrated to protect, manage, and restore natural or modified ecosystems in Estonian and Latvian municipalities.
- **Digital change**. Municipalities will be equipped with digital tools for planning adaptation measures to pro-actively respond to floods and other negative effects in case of extreme weather events.
- **Quality of urban planning**. Municipalities capacity will be increased in terms of local urban municipal planning of green infrastructure and nature-based solutions.
- **Engaged communities and skilled enablers**. Local communities, specialists and other stakeholders’ knowledge-skills and awareness will be raised in terms of climate change effects as well as sustainable and nature-based solutions for solving those problems.

More specifically, the project will develop and test a set of measures that will help to prevent and respond in case of pluvial flooding, i.e., flooding generated locally by an overload of the urban drainage system by extreme rainfall as well as urban heat island effect. The new high-potential plant communities will be composed, pluvial flood simulation model and integrated decision support system for mitigation measures will be developed and nature-based solutions (NBS) will be designed. These tools and solutions will be tested in 8 urban demonstration sites of Latvian and Estonian municipalities, 5 of them are located in Estonia- Viimsi, Narva, Rakvere, Haapsalu, Võru and 3 in Latvia – Cēsis, Rīga. Valmiera Green infrastructure (GI) and NBS will be operationalised in local urban municipal planning by co-creation of policy and management options, adoption of NBS maintenance rules and urban greening plans. In addition, capacity of local governments (planners, project managers and politicians) will be strengthened on developing and managing NBS and urban planning of GI. Also, awareness will be raised on adaptation to climate change effects and thriving co-creation of NBS with the local communities. The purpose of Task T2.4 “Identifying and testing novel sensing techniques to monitor NBS performance” is to gather existing best practices available for monitoring the effectiveness of NBS and propose novel solutions for improving the current standardized monitoring protocols and existing best practices.

The deliverable of Task T2.4 includes a written report describing existing, novel monitoring technologies and approaches, as well as highlighting prevalent knowledge gaps and further research needs.

Performance Monitoring of Nature Based Solutions (NBS)

Importance of NBS Performance Monitoring

In the realm of urban development, the integration of nature-based solutions (NBS) for effective drainage management has gained remarkable traction. These solutions, ranging from green roofs and permeable pavements to natural wetlands, present promising avenues for sustainable urban water management. However, their real-world performance hinges on intricate interactions between natural processes and engineered interventions. This is where the significance of performance monitoring becomes evident as "you can't manage what you can't measure."

By systematically assessing the efficiency, resilience, and ecological impact of NBS in managing urban drainage, stakeholders can refine design strategies, calibrate expectations, and make informed decisions. Such monitoring not only ensures NBS' efficacy but also fosters a holistic understanding of their role in creating water-sensitive and livable urban environments. Ultimately, the ability to quantify their contributions empowers urban planners and policymakers to enact evidence-based practices that harmonize urban growth with environmental well-being.

Data Requirements for Objective Performance Monitoring

The significance of data-driven monitoring of nature-based solutions performance within urban drainage systems is underscored by its pivotal role in ensuring the functionality, adaptability, and efficacy of these interventions. NBS implementation presents a paradigm shift in drainage management, emphasizing the harmonization of natural processes and engineered components. This shift necessitates a robust framework for objective monitoring, which involves the continuous observation of a plethora of critical parameters across distinct stages of NBS life cycles.

Central to this monitoring endeavour is the acquisition of concrete knowledge regarding what is being measured, as well as the precise locations and rationale behind these measurements. Such knowledge serves as the cornerstone for informed decision-making and evidence-based adaptations. Monitoring of NBS encompasses the continuous observation of various parameters, including but not limited to:

- ***Total precipitation and rainfall dynamics*** (e.g., intensity, patterns, spatial and temporal distribution etc.), which provide insights into the capacity of NBS to effectively manage stormwater volumes.
- ***Terrain and hydrological characteristics of the catchment area***, enabling a nuanced understanding of how different NBS might perform in diverse geographical contexts.
- ***Hydraulic performance of various NBS components***, to ascertain their resilience under varying flow conditions and evaluate proportions of urban water balance components (e.g., runoff versus infiltration versus evapotranspiration).
- ***Water quality parameters*** such as pollutant loads and concentrations, nutrient levels, and microbial content, both upstream and downstream of these systems. This evaluation helps to assess their potential contributions to enhancing urban environments.

These comprehensive monitoring measures facilitate a holistic evaluation of NBS effectiveness, providing critical data for optimizing their design, operation, and maintenance. They offer valuable insights into the real-world performance of NBS, aiding urban planners, engineers, and policymakers in creating sustainable and resilient urban drainage systems.

To facilitate this data collection, a diverse array of sensing technologies, remote sensing platforms, and telemetry systems can be deployed. These technologies provide real-time or near-real-time data, enabling rapid response to dynamic changes and enhancing the overall adaptability of NBS.

Subsequent sections delve into the specifics of these monitoring technologies and their intricate relationships with the aforementioned factors. It is essential to note that while the technological and ecological aspects of data-driven monitoring are explored herein, socio-economic considerations lie beyond the immediate scope of this text.

Existing Observation Methods

The arrangement of diverse monitoring approaches and their integration within the context of NBS performance analysis is delineated in Figure 1 below. It's worth noting that a particular method, such as camera observations, isn't confined to a sole parameter. Instead, it can be associated with and leveraged to assess multiple aspects, as demonstrated in Figure 1 where it's applied to evaluate both hydraulics and water quality. Research indicates that CCTV can also be employed to derive real-time rainfall intensity ('CCTV-Based Rainfall Measurements', 2020).

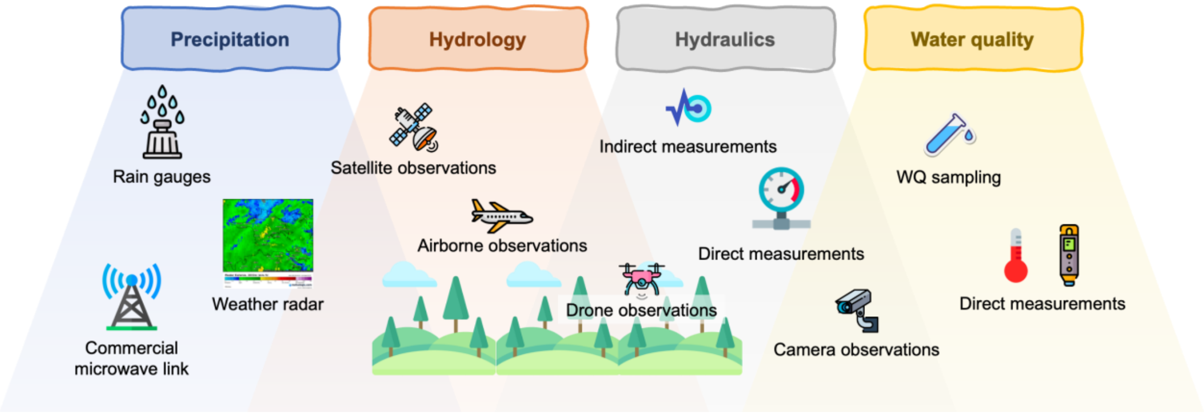

Figure 1 NBS performance analysis parameters and various monitoring methods.

The interplay between various monitoring methods and the corresponding observational scales is elucidated through the visual representation in Figure 2. Notably, this depiction underscores the strategic alignment of these methods with optimal utilization scenarios, ensuring the attainment of the most objective and accurate results.

It is imperative to recognize that while each monitoring method possesses the potential for application across diverse scales (for example, satellite observations can be used to gather data about soil moisture on a sub-catchment scale), a nuanced consideration of their effectiveness is warranted. Venturing beyond the confines of a method's recommended operational range introduces diminishing returns owing to a gradual reduction in precision. This diminishing precision is particularly prominent as one deviates further from the method's established range, leading to a progressive decline in the reliability and robustness of the acquired data.

Hence, the holistic understanding of the connection between monitoring methods and observational scales entails a critical assessment of not only their inherent capabilities but also the contexts in which they deliver optimal results. By acknowledging the intricate balance between methodological precision and scale, practitioners can make informed choices that resonate with the quest for comprehending Nature-Based Solutions' performance in urban drainage contexts.

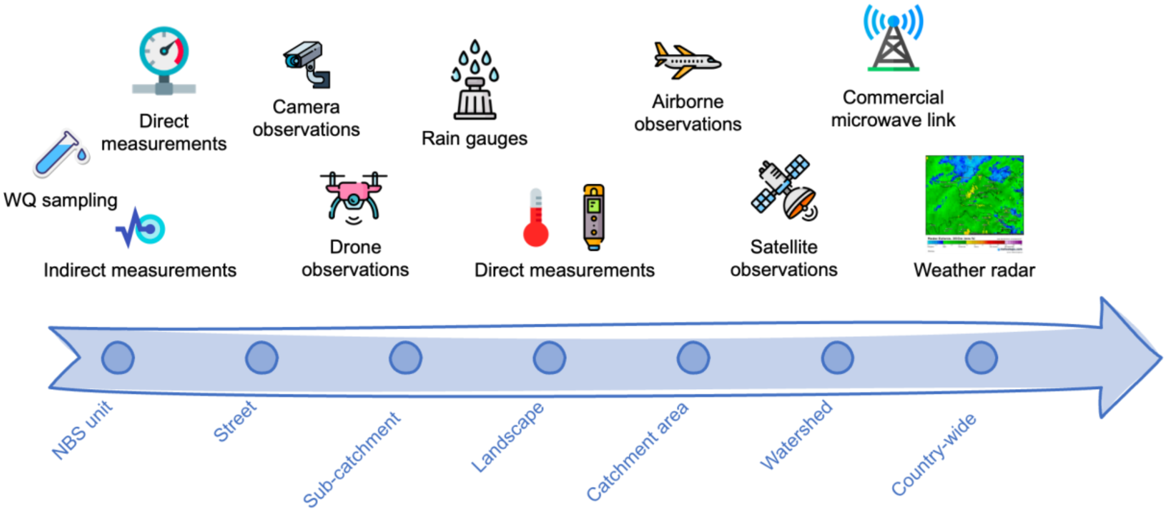

Figure 2 Remote monitoring methods sorted based on observation scale.

Existing, novel monitoring methods are summarized in Table 1 below.

Table 1

Type and methods	Scale and update frequency	Data usage and limitations	References
General review of NBS monitoring methods			(Berglund et al., 2020; Johnson et al., 2022)
Earth observations via satellites: - thermal infrared, - high-resolution visible infrared, - stereo imagery.	**Scale:** - landscape, - watershed, - catchment. **Update frequency:** 5-10 days	**Data usage:** - hydro-meteorological risk assessment outside urban areas, - catchment properties: ○ build-up density, ○ vegetation density, ○ water area proportional to catchment area, ○ land cover change, ○ energy/water/carbon fluxes*. **in the future, currently being researched* **Limitations:** - availability, combination, or comparison of different datasets, - connection of NBS impacts among different spatial scales, - quality (e.g., accuracy) of the available research means (100x100m), - replicability of these means for different NBS cases or aspects (e.g., social capacity), - resources required for their deployment.	(Acuña-Alonso et al., 2022; Chrysoulakis et al., 2021; EU METSAT, 2023; Kumar et al., 2021)
Airborne observations: - LiDAR surface 3D scanning, - orthophotography.	**Scale:** - catchment, - street. **Update frequency:** every 4 years**	**Data usage:** - hydro-meteorological risk assessment, - elevation data, - locating mobile and temporary elements in urban space. **Limitations:** - updated every 4 years* - limits mapping rapid changes,	(Eggimann et al., 2017; Kumar et al., 2021; Turconi et al., 2020)

Type and methods	Scale and update frequency	Data usage and limitations	References
		- requires pre-processing before use (remove obstacles). ***update frequency depends on the country*	
Drone observations: - infrared camera, - camera (3D), - LiDAR, - radar.	**Scale:** - small catchments, - street, - NBS unit. **Update frequency:** real time	**Data usage:** - temperature measurements (heat islands), - maintenance (agriculture -> spraying), - ground shifting, - crop water requirements. **Limitations:** - safety concerns - acceptance and integration by broader society, separation from people - noise generated by drone rotors, - maximum takeoff mass and flying height allowed (permissions required), - operator (limitations of qualified personnel)/autonomous flight, - weather conditions, - batteries not sufficient for long observations.	(Berglund et al., 2020; Kasprzyk et al., 2022; Savić, 2022; Watkins et al., 2020)
Camera observations and image analysis (pyorc)	**Scale:** - NBS unit, - small scale. **Update frequency:** real time	**Data usage:** - flowrate, - water depth, - flood extent, - drought, - permeability and infiltration rate tests, - water quality observations, - precipitation intensity. **Limitations:** - requires calibration (setting up markers), - trackable particles needed, - availability of training data & measuring extremes - safety concerns - acceptance and integration by broader society,	(Boogard, 2015; Meier et al., 2022; Oberascher et al., 2022; Rainbow Sensing, 2023)

Type and methods	Scale and update frequency	Data usage and limitations	References
		- winter conditions.	
Ground based observations – installation of devices capable of collecting weather/water quantity-quality data.	**Scale:** - NBS unit, - small scale. **Update frequency:** real time	**Data usage:** - indirect measurements: ○ flow measurements (ultrasonic sensor + weir), ○ surrogate water quality parameters, ○ soil water content measurement via reflectometry. - Direct measurements: ○ level sensors, ○ flow meters, ○ infiltrometers, ○ rain gauges, ○ water quality sensors, sampling quipment, ○ soil moisture measurements. **Limitations:** - long term performance analysis (comparison with proven solutions), - performance under adverse weather conditions (needs validations) - cost of devices (non-commercial, self-made options), - utility for real-time operation and maintenance (parameters to measure, monitoring setup), - spatial resolution (representative coverage of a watershed), - knowledge and resources of the system managers (technological savviness), - frameworks to quantify the viability and performance of NBS solution (uniform solution), - synergies between different NBS/NBS train performance,	(Gobatti et al., 2022, Cherqui et al., 2019, Wendling et al., 2020, Raspati et al., 2019, Watkin et al., 2019, Wellmann et al., 2022, EC NBS handbook, 2021, Heckova et al., 2022, Liu et al., 2021, Oberascher et al., 2022, Bouzouidja et al., 2021, Cotterill et al., 2020)

Type and methods	Scale and update frequency	Data usage and limitations	References
		- baseflow estimation, subsurface flow, and groundwater level, - forecast accuracy.	
Commercial Microwave Links (Mobile Communication Towers)	**Scale:** - country-wide, - watershed, - catchment. **Update frequency:** near real time*** ****depends on computational load and analysis scale*	**Data usage:** - rainfall data (total precipitation, intensity etc.) estimation, - spatial and temporal variability assessment, - representation of rainfall patterns on a large area scale. **Limitations:** - data gaps in cases where not enough rain gauges pick up rainfall, - computational load required to analyze data, - accuracy of results based on accuracy of assumptions.	(Blettner et al., 2022; Polz et al., 2020)

Knowledge Gaps and Research Needs

Significant strides have been taken in the realm of monitoring Nature-Based Solutions (NBSs) for urban drainage, yet a landscape of knowledge gaps persists, warranting concerted research efforts for a comprehensive understanding. Standardization of protocols and methodologies for data collection and analysis emerges as a pressing need, facilitating consistent monitoring across diverse NBS types and geographical contexts. This is in line with recent studies highlighting the importance of standardized monitoring to enable meaningful comparisons and meta-analyses across different NBS implementations (Smith et al., 2020; Debele et al., 2021).

The temporal dimension remains a challenge, as the majority of existing studies offer insights over short durations. Long-term monitoring studies are crucial to unravel the evolving performance of NBS over extended time frames and under varying environmental conditions. Such studies would provide invaluable insights into the resilience and adaptability of NBS (Colding et al., 2020).

Beyond technical aspects, socio-economic considerations demand rigorous exploration. An inclusive evaluation should encompass cost-effectiveness assessments, community perceptions, and equitable distribution of benefits (García-Murillo et al., 2021). Notably, a recent study emphasized the importance of engaging stakeholders to ensure the success and longevity of NBS initiatives (Borgwardt et al., 2022).

The synergy between NBS and climate change also beckons further investigation. Understanding how NBS effectiveness might evolve in response to shifting precipitation patterns and increasing frequency of extreme events is a critical area of research (Mannini et al., 2020). Additionally, the integration of advanced technologies like remote sensing, sensor networks, and modeling techniques holds promise for real-time monitoring and decision support (Kessler et al., 2019; Wang et al., 2021).

In summary, addressing these knowledge gaps necessitates interdisciplinary collaboration and sustained research. By doing so, we can harness the full potential of NBSs in realizing resilient and sustainable urban drainage systems that align with the multifaceted challenges of contemporary urbanization.

The LATESTadapt project is at the forefront of addressing critical knowledge gaps in our understanding of sustainable solutions for environmental challenges. The project employs a multifaceted approach, leveraging various activities to comprehensively tackle these gaps. Notably, two international hackathons will be organized, to advance development and implementation of innovative and cost-effective monitoring methods. These hackathons not only generate novel ideas but also facilitate cross-pollination of expertise, contributing significantly to filling knowledge voids. Another pivotal aspect of the project involves the implementation and rigorous testing of innovative Nature-Based Solutions (NBS) across eight pilot sites. These on-the-ground trials not only provide invaluable empirical data but also establish real-world effectiveness and feasibility of NBS. By bridging the gap between theory and practice, the project contributes substantially to our understanding of sustainable environmental interventions.

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