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EXECUTIVE SUMMARY

Collecting evidences about the effectiveness of NBS is increasingly recognized as key for enhancing the social acceptance of these measures and, thus, for facilitating their implementation. Past experiences demonstrated that, besides the NBS effectiveness in reducing climate-related risks, increasing interest has been gained by the NBS capabilities to produce socio-economic and ecosystem-related co-benefits. In many cases, those co-benefits represented the actual driver for taking initiative in dealing with climate-related risks. However, three key issues related to the information production process need to be addressed in order to make information capable to boost learning processes about NBS effectiveness and, in doing so, enhance NBS social acceptance: i.e. the credibility, the saliency and the legitimacy of the collected information. Credibility refers to the quality and reliability of the information. Saliency refers to the capability of the produced information to meet the decision-makers' information needs. Finally, the legitimacy refers to the need to account for the diversity of knowledge in the information production process.

This work describes the activities carried out in two of the NAIAD demos - i.e. the Lower Danube and the Glinčiska – aiming at designing innovative monitoring systems for the assessment of the NBS effectiveness, addressing the three above mentioned issues. Specifically, the credibility issue has been addressed by integrating different kinds of data in the monitoring activities. The saliency issue has been addressed by eliciting and structuring decision-makers' and stakeholders' information needs and designing the monitoring system accordingly. Finally, the legitimacy issue has been addressed by integrating local knowledge in the monitoring system.

A community-based monitoring system was designed and partially implemented in these two demos. The analysis of the experiences carried out allowed us to draw some important lessons. Firstly, NBS social acceptance is affected by the availability of data and information about its effectiveness in producing the expected co-benefits. Therefore, monitoring system for NBS effectiveness should not be focused exclusively on the reduction of the water-related risks. Evidences about the co-benefits production play are required. To this aim, the elicitation and structuring of stakeholders' perception of and preferences over the co-benefits could play a key role. Secondly, the engagement of stakeholders in the definition of the indicators for NBS assessment could have a positive impact on the level of trust of the stakeholders toward the produced information.

However, some limitations of the adopted approach were detected. Firstly, further efforts are required to integrate the community-based indicators for NBS assessment with the scientific ones. Secondly, the platform for feeding back the information toward the community (FreeStation) should be improved making it capable to meet the users' information needs.



1. INTRODUCTION – NBS SOCIAL ACCEPTANCE AND CO-BENEFITS MONITORING AND EVALUATION

In the last decades, the most common approach to reduce flood impacts has been related to the use of ‘grey’ solutions (e.g. dams, embankments, levees, etc.). Nevertheless, grey infrastructures alone demonstrated to have several limitations (EEA, 2017), for instance they are capital intensive, often responsible for damage or elimination of biophysical processes necessary to sustain both people and ecosystems, and even associated to a misleading sense of security that might condition communities’ behaviour (Palmer et al., 2015).

Nature-based solutions (NBS) have become a valid alternative for grey infrastructure development for coping with climate-related risks in urban and rural areas alike (Calliari et al., 2019; Frantzeskaki, 2019). Nevertheless, in order to be preferred over other conventional grey and hybrid interventions, comprehensive assessments are needed to prove NBS effectiveness in dealing with climate-related risks while capturing the diverse benefits they provide to the economy, society and ecological systems (Calliari et al., 2019). NBS have the capability to reduce disaster vulnerability, but also a potential for nature conservation, natural resources management and for supporting the mitigation of and adaptation to the disturbances generated from climate extremes and urbanization (Dong et al., 2017; European Commission, 2016; Liu et al., 2015; Nesshöver et al., 2017). NBS bring together multidimensional benefits that integrate technical, economic, governance, regulatory and social innovation (European Commission, 2015; Raymond et al., 2017b).

There is an increasing number of evidences on the positive effects of NBS on risk reduction and climate change adaptation (Kabisch et al., 2016), especially if they are strategically planned and managed, and spatially interconnected in a network of solutions, including a synergistic combination with grey solutions (Albert et al., 2019; Palmer et al., 2015; Raymond et al., 2017b). The increasing interest in NBS by policy-makers triggered an increasing interest in mapping and collecting evidences of their effectiveness and multiple benefits (Frantzeskaki, 2019; Raymond et al., 2017). Several approaches have been developed and implemented to assess the NBS effectiveness in reducing risks and producing co-benefits (see next section). However, most of the cited works seem to neglect the role that the communities can play in facilitating/hampering the NBS implementation. The integrated frameworks developed for the assessment of the NBS effectiveness were mainly designed for supporting decision-makers and scientists, whereas communities have been mainly considered as having a passive role. Moreover, these methods did not account for the three key characteristics of effective information collection, capable to affect the NBS social acceptance, i.e. **credibility**, **saliency** and **legitimacy**. Most of the existing efforts aimed exclusively to enhance the credibility of the information by improving the quality of the collected information. This work has the ambition to enhance the saliency of the collected information, making it relevant for both decision-makers and communities and, thus, capable to



assess the NBS effectiveness and to enable a collective learning process for NBS social acceptance. We also aim at enhancing the legitimacy of the information collection process. The current approaches consider scientific and technical knowledge as the only legitimate form of knowledge, disregarding the many meanings and interpretations, and ways of framing risk management issues that exist in the multi-actor setting, failing to empower stakeholders to participate meaningfully in the design and application of NBS.

To address the above-mentioned issues, efforts have been carried out in two NAIAD demos – i.e. Glinčiska and Lower Danube – for designing and deploying a community-based monitoring system aiming at engaging stakeholders and communities in collecting and analysing data and information related to NBS effectiveness in producing benefits and co-benefits. To this aim, the usability of crowdsourcing approaches for environmental data gathering and sharing – e.g. community-based monitoring, citizen science – was investigated. As discussed further in the text, two different engagement approaches were adopted in this work. On the one hand, stakeholders were engaged in the design of the NBS monitoring and evaluation system. To this aim, the elicited risk perceptions (see D3.1 of NAIAD) were accounted for. On the other hand, stakeholders and communities' members were involved in collecting data about NBS effectiveness. To this aim, NAIAD tested the potentialities of the FreeStation as crowdsourcing support tool.

This work is organized as following. Sections 2 and 3 describe the results of the literature review concerning the existing approaches for supporting the assessment of the NBS effectiveness, and the methods and tools for engaging citizens in crowdsourcing activities. Section 4 describes the activities carried out in the two NAIAD demos. The lessons learnt are discussed in section 5.

2. ASSESSING NBS EFFECTIVENESS: AN INTRODUCTION TO THE STATE-OF-THE-ART

As stated in the previous section, collecting evidences about NBS effectiveness and enhancing the communication towards communities and stakeholders is the key for boosting social acceptance and, thus, facilitating NBS implementation. To this aim, frameworks and tools for monitoring and evaluating NBS effectiveness play an important role. The growing interest around the NBS inspired several attempts to analyse their principles and qualities within comprehensive and structured evaluation systems, in order to support proving the superior performance of 'working with nature'. In an effort towards operationalizing the concept, several frameworks have recently been proposed to characterize the scope of NBS and assess their effectiveness (Calliari et al. 2019). A key element to consider in these analysis is the recognition that nature can play a fundamental role in tackling multiple major societal challenges, including climate change adaptation and mitigation, and disaster risk management. A distinctive aspect is related to the capacity of NBS to deliver simultaneous benefits for the society, economy and the



environment (Albert et al., 2017), i.e. their “multi-functionality” (see figure 1). An effective assessment framework must therefore take into account the NBS capacity to deliver simultaneous benefits for the society, the economy and the environment, and the associated direct benefits/costs and co-benefits/ costs.

Additionally, both the spatial (e.g. a larger planning process of multiple measures) and temporal (e.g. the evolution of external pressures and internal processes) dimensions must be carefully accounted for.

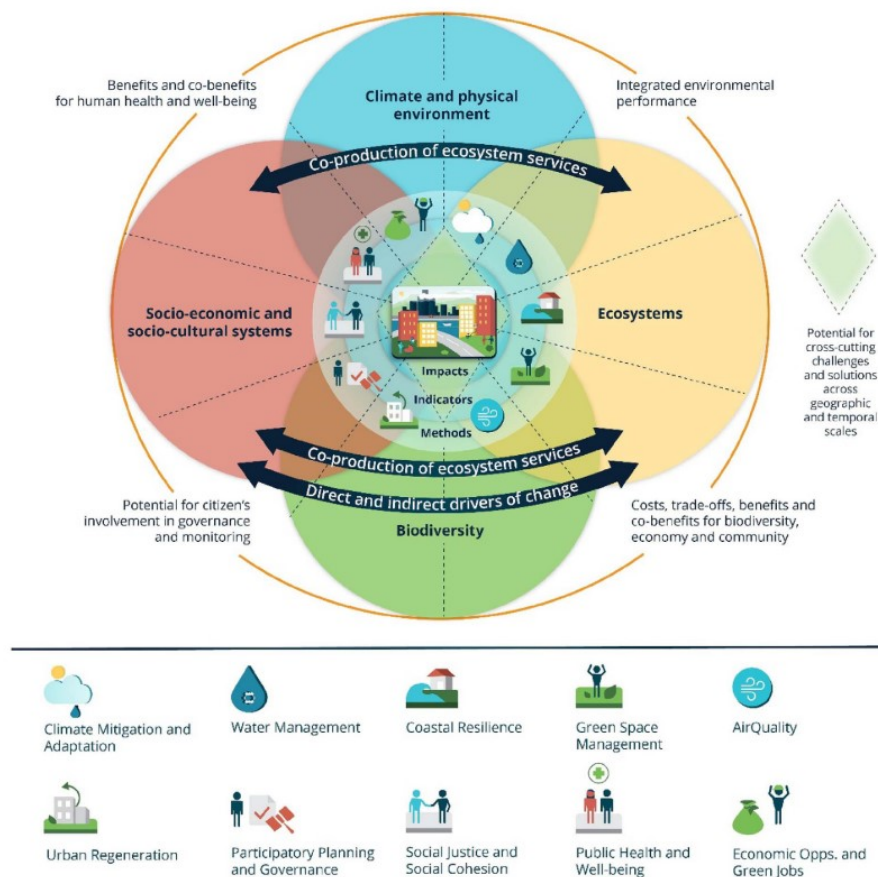


Figure 1. The NBS assessment framework considering different elements of the system, the 10 challenge areas and indicators and methods for assessing NBS impacts within and across challenge areas. (taken from Raymond et al. 2017b).

The issue of co-benefits assessment is central in the framework proposed by Raymond et al. (2017a, 2017b), i.e. the **EKLIPSE** framework. EKLIPSE is based on the design of a holistic framework that systematically identifies how NBS may provide both synergies across ecosystem



services, but also co-benefits (or costs) in other different elements (socio-cultural, socio-economic system, environment, biodiversity, ecosystems, and climate) particularly in urban areas. It includes four dimensions that are related to NBS implementation, i.e.:

- co-benefits for human health and well-being;
- integrated environmental performance (e.g. the provision of ecosystem services);
- trade-offs and synergies to biodiversity, health or economy;
- potential for citizen's involvement in governance and monitoring

The framework aims at supporting the design, implementation, monitoring and evaluation of NBS. It provides a globally applicable approach for multiple stakeholders that can lead and/or be used in the NBS action planning process.

EKLIPSE has a threefold objective: 1) To develop an impact evaluation framework with a list of criteria for assessing the performance of NBS; 2) To prepare an application guide for measuring how NBS projects fare against the identified indicators in delivering multiple environmental, economic and societal benefits; 3) To make recommendations to improve the assessment of the effectiveness of NBS projects, including the identification of knowledge gaps. With specific reference to the point 1, 10 societal challenges have been identified, based both on the scientific literature and on expert knowledge. EKLIPSE underlines the multiplicity of dimensions and scales that are impacted by NBS, stressing the importance of defining critical thresholds and a relevant number of indicators that can be considered important for assessing key impacts of specific NBS actions. Some success and limiting factors are identified as well. The following societal challenges are identified in the EKLIPSE framework: 1) Climate mitigation and adaptation; 2) Water management; 3) Coastal resilience; 4) Green space management (including enhancing/conserving urban biodiversity); 5) Air/ambient quality; 6) Urban regeneration; 7) Participatory planning and governance; 8) Social justice and social cohesion; 9) Public health and well-being; 10) Potential for new economic opportunities and green jobs. The starting point is that a NBS targeted towards a specific societal challenge is likely to produce co-benefits, costs and neutral effects in other challenges. For example, flood peak reduction actions are likely to have co-benefits also for quality of life by improving urban living conditions (Raymond et al. 2017a,b).

Given that NBS seek to address multiple challenges (economic, environmental and social), the role of indicators is important for assessing the potential performance and the actual effectiveness of NBS. The process of indicators identification is just indicative and far from being exhaustive, since the selection of appropriate indicator(s) will depend on several factors such as the type and objective of the action, the potential expected impacts (both direct and indirect, positive and negative), the resources and skills available, the scale of analysis.



It is also worth mentioning another relevant framework developed at EU level, specifically for developing a common classification of Ecosystem Services, that is **CICES** (<https://cices.eu/>). Ecosystem Services are defined as the contributions that ecosystems make to human well-being, and distinct from the goods and benefits that people subsequently derive from them. CICES stems from the need for a common international classification, because it was recognised that if ecosystem accounting methods were to be developed and comparisons made, then some standardisation in ecosystem services description was needed, especially in economic accounting. Mapping and valuing ecosystem services and ecosystems assessments would benefit from more systematic approaches.

CICES identifies three main classes of ES, namely: Provisioning (all nutritional, non-nutritional material and energetic outputs from living systems as well as abiotic outputs, including water); Regulation and maintenance (All the ways in which living organisms can mediate or moderate the ambient environment that affects human health, safety or comfort, together with abiotic equivalents); Cultural (All the non-material, and normally non-rival and non-consumptive, outputs of ecosystems (biotic and abiotic) that affect physical and mental states of people). CICES uses a five-level hierarchical structure. Each level is progressively more detailed and specific: Section, Division, Group, Class, Class type.

Some research (e.g. Kabisch et al., 2016; Xing et al., 2017) examined indicators of NBS effectiveness at the urban scale, although with a level of abstraction that does not support a comparison with different alternatives. A guidance on NBS for flood risk management, as alternative or complementary to conventional engineering measures was proposed by the World Bank (2017). The document starts from the assumption that NBS have been already identified as the best option, and the activities needed for their implementation are described, thus focusing on several factors which are specific to them. In particular, the additional economic, environmental and social benefits associated with a NBS are highlighted since they allow a more holistic comparison with traditional engineering approaches (Calliari et al. 2019). The guidance comprises multiple steps and, besides, the identification of the flood hazard(s), the main stakeholders, the scale of the system, suggests the identification and analysis of different management options through an estimation of the costs, benefits and effectiveness of the measure. The process, which has an attention to the dynamic issues (e.g. the changing external conditions), is concluded with the implementation and monitoring phases.

Participatory Multi-Criteria Analysis was used to identify and analyze the multiple benefits of a NBS in an ex-post assessment, starting from the analysis of stakeholders' preferences (Liquete et al., 2016). A novel method was proposed to support selection of both green and grey measures, including the definition of preferences over a broad range of co-benefits. The method, in its current form, is still limited in the possibility of performing the analysis with



multiple measures and in including stakeholders (Alves et al., 2018). The assessment of co-benefits in different scenarios is also central in the framework proposed by (Lanzas et al., 2019), although additional investigation is needed in the characterization of the potential conflicts and/or co-benefits between different objectives.

Calliari et al. (2019) proposed a framework for an ex-ante assessment of the direct benefits/costs and co-benefits/costs of NBS. This allows assessing NBS suitability with specific reference to the societal challenges identified in the EU Research and Innovation agenda on the environment. It is designed to account for the constitutive elements of NBS, i.e.: multifunctionality; simultaneous delivery of economic, environmental and social benefits; multi-stakeholder engagement. Evolving conditions are analysed as well, since NBS must be analysed as 'living' solutions operating in an evolving environment.

Existing frameworks have some limitations that require further research efforts. Firstly, some of them have a limited capability to fully analyse the NBS potential for producing **co-benefits** (e.g. Kabisch et al., 2016), being limited to the analysis of a subset of impacts (mainly environmental), rarely addressing the cross-sectoral ones. More specifically there is a gap in the process of understanding the interface between environmental, economic and social dimensions related to NBS planning and implementation. In particular, there are some aspects such as the socio-cultural, economic and ecosystem interactions, that require further consideration (Raymond et al. 2017a,b). Additionally, it must be taken into account that trans-disciplinary and multi-sectoral knowledge and tools are typically required for such purpose.

Secondly, it should be considered that they are generally **static**, i.e. the analysis of NBS is performed assuming that both the NBS and the conditions in which they are set to operate (e.g. climate, urbanization, etc.) are immutable and not affected by any change (Calliari et al. 2019). Building a dynamic framework would be crucial, in order to take into account both the changing 'external' conditions (eg. climate change) and the 'internal' evolution of NBS (e.g. some time is required to become fully effective).

Thirdly, the role of **indicators** should be carefully valued. Despite the identification of a set of widely accepted and common indicators would be highly useful, indicators often need to be selected according to the specific spatial and temporal scale of analysis, must be relevant for the site conditions, and must take adequately into account the key aspects belonging to the social domain.

Lastly, most of the existing frameworks are limited in terms of **stakeholders' involvement** (Calliari et al., 2019; Narayan et al., 2017). An active stakeholders' involvement throughout the whole process of NBS design, implementation and evaluation, is fundamental in order to elicit and structure the local knowledge as well as to support raising awareness on the multi-



dimensional benefits associated to NBS. It is widely acknowledged that specific types of knowledge (e.g., indigenous, local, tacit) require consideration in NBS impact assessments, and this still represents an important gap in current research and practice, along with the issue of identifying a proper way to ‘communicate’ about NBS.

NAIAD aims at overcoming these limits by enabling the involvement of local communities in monitoring and evaluating NBS. In doing so, NAIAD has threefold goals. Firstly, it aims at improving the identification of benefits and co-benefits to be produced through the NBS implementation, accounting for the stakeholders’ perception and understanding. Secondly, it aims at facilitating the collection of evidences concerning the NBS effectiveness, by enlarging the monitoring network through the direct involvement of local communities. Thirdly, it aims at filling the gaps between the scientific and local knowledge concerning NBS role and effectiveness, by involving communities in a citizen science experiences. In doing so, NAIAD aims at enabling collective learning processes concerning the NBS effectiveness and, thus, to enhance social acceptance.

3. CITIZEN SCIENCE AND COMMUNITY-BASED MONITORING: SOME EXAMPLES FROM THE LITERATURE

Citizen science and, generally, the involvement of citizens in research activities has become increasingly important in different discipline, such as, conservation science and disaster management, just to mention two of them. This is mainly due to the widening up of the issues to be addressed and the failure of the resources for monitoring to match the scale of the question at hand. Engaging citizens in monitoring activities is often the only practical way to achieve the geographical extent and the distribution of information required to address specific issues, such as document ecological patterns, assess the impacts of environmental processes like climate change, monitor the evolution of a natural disaster.

The present section aims at providing an overview of the key features and potential applications of Citizen Science and Community Based Monitoring Systems to support the analysis of complex environmental problems, with specific attention to the issue of water-related risk analysis.

3.1. Generalities and definitions

There is not a single definition or methodology of citizen science. The concept stems from two origins, one in the social sciences and one in the natural sciences and subsequently touching the issues of public engagement itself as well as the collection and analysis of large data sets through public participation. Currently, one of the key aspects of citizen science is related to environmental monitoring and to Ecosystem Services assessment (Schröter et al. 2017).



Community-Based Monitoring (CBM) approaches are based on the involvement of volunteers, either non-experts or trained scientists, in one or more stages of collecting, analyzing, and using data with the aim to answer locally-relevant questions. CBM can be implemented with varying degrees of community participation and collaboration with governments, industry, academic institutions and/or civil society. CBM is generally compatible with the concepts of citizen science, community science, crowd-sourced data collection and participatory monitoring (Carlson and Cohen 2018) and is marked, in general, by an emphasis on community- driven motivations for generating environmental data.

There has been a recent growth in experiences with CBM, which can be attributed to many factors including: the limited capacity and scope of monitoring conducted by scientists in government and academia; the growing concerns of communities regarding the health of their local environment; the rise of affordable and simple technologies for crowdsourcing data and undertaking robust and accurate water monitoring (Carlson and Cohen 2018). More specifically, recent technological advances led to growth in popularity of citizen science by facilitating participation (see e.g. Schröter et al. 2017). The internet helps to reach broader audiences, allowing interested participants to find topics or projects. Further, the development of social media, mobile devices (incl. sensors), powerful (online) networks and computational facilities multiplies the capacity for data collection, storage, integration, analysis and dissemination. Therefore, data collected through CBM are filling gaps in environmental monitoring, promoting sustainable natural resource management, and engaging communities in the conservation of ecosystems. However, besides the capability to provide data and information on environmental aspects, there are several additional reasons for actively engaging communities in the collection and use of data. First, motivations can stem from a desire to generate community awareness, increase scientific literacy, and contribute to scientific research (EPA 2016). Second CBM may help filling gaps in ‘institutional’ monitoring activities, identifying (and tracking) local concerns about ecosystem and human health. Third, CBM can support to leverage scientific knowledge to inform and improve policy and decision-making at various scales of governance and to promote better compliance with environmental laws. Focusing specifically on the last point, CBM is a relevant motivation for the community involved and several case studies demonstrated that when data is stored and analysed within local communities, CBM can have a more powerful impact in local decision-making scenarios.

Common forms of citizen science participation comprise (i) contributory projects, led by scientists, involving volunteers mainly in the collection of data or samples, (ii) collaborative projects, that also include joint analysis of data or dissemination of results, (iii) co-created designs, i.e. the joint development of a study or (iv) citizen-led research or so-called collegial approaches where professional researchers are only involved secondarily, e.g. by being consulted for advice or specific analyses (Shirk et al. 2012, Schröter et al. 2017). A similar



classification, considering an increasing level of engagement, was proposed by Haklay (2013). The author built a model that has four levels, in which the first one refers to the participation of citizens only as data collectors, passing through a second level in which citizens are asked to act as interpreters of data, going towards the participation in definition of the problem in the third level and finally, being fully involved in the scientific enterprise at hand.

However, there are still barriers that limit the adoption and effectiveness of community-based approaches in environmental monitoring. Particularly, skepticism is often directed toward issues of data accuracy and biases and scientists have expressed concern about the capacity of non-experts to limit errors, calibrate equipment, and undertake robust data analyses. However, most biases in data interpretation are found equally among both professional scientists and citizen scientists (Kosmala et al. 2016), and the increasing use of automatic sensors and statistical analysis, as well as of specific protocols, could be highly beneficial. The positive evidences on the validity and suitability of CBM refer particularly to ecological studies and environmental monitoring, which are also highly accessible and engaging for citizens. Thus, the lack of awareness within the scientific community of the credibility of CBM is currently the larger barrier to CBM, more than the technical issues (Burgess et al. 2017). Additionally, it should be considered that CBM activities are data intensive, and issues of data quality may arise when monitoring programs have inadequate funding and resources. It may also be difficult to match monitoring protocols with different cultural contexts, language issues and locally-specific motivations for monitoring.

As far as the level of involvement of citizens in monitoring programs is concerned, they usually participate only as data collectors whereas professionals determine monitoring objectives, methodology, and data use. In contrast, monitoring programs initiated at the community-level often entail community members taking a leading or collaborative role in data collection, analysis, and usage. The degree and quality of community participation in CBM have relevant implications on a program's outcomes and potential policy impact.

3.2. An overview of the main experiences

Citizen science in dealing with water-related risks

Novel and more affordable technologies are allowing new actors to engage increasingly in the monitoring of hydrological systems and the assessment of water resources. This trend may shift data collection from a small number of mostly formal institutions (e.g. monitoring authorities, water companies) toward a much more dynamic, decentralized, and diverse network of data collectors (including citizens and other non-specialists). Such a move toward a more diverse and polycentric type of monitoring may have important consequences for the generation of knowledge about water resources and the way that this knowledge is used to govern these



resources (Buytaert et al. 2016). On a technical level, this ‘polycentric’ approach may lead to improve availability of, and access to, data. Furthermore, the opportunity for actors to design and implement monitoring may lead to data collection strategies that are tailored better to locally specific management questions. However, in a policy context the evolution may also shift balances of knowledge and power. For example, it will be easier to collect data and generate evidence to support specific agendas, or for non-specialists to challenge existing agreements, laws, and statutory authorities (Buytaert et al. 2016).

In recent years, the interest in citizen science and the number of citizen science studies in the water-related risks context has risen considerably. The main factors affecting its use in flood modelling are the degree of how difficult it is to acquire and evaluate these data and their integration into the models. The key opportunities are related to the need to: explore and improve the existing methods to obtain water velocity and topography from videos; explore calibration and validation employing data collected through social media in urban environments; explore the possibilities of setting up the models with the use of land cover maps validated with citizen science; make use of apps/websites already developed for citizen science (Assumpção et al. 2018). There are several classes of flood-related data that can be obtained by crowdsourcing (Assumpção et al. 2018), i.e. rainfall, water level, velocity, flood extent, land cover/use, topography

The role of CBM is becoming increasingly relevant for the analysis of many smaller catchments, which remain ungauged despite the existence of well-established meteorological and hydrometric monitoring networks. Community-based observations can be highly relevant for modelling and understanding catchment response as a contribution to catchment science (Starkey et al. 2017). The paper suggests the use of community-based rainfall, river level and flood observations, to build and run a physically-based, spatially-distributed catchment model. The results show how the local network of community-based observations alongside traditional sources of hydro-information supports the characterization of catchment response more accurately than using traditional observations alone over both spatial and temporal scales. Community-derived datasets are most valuable during local flash flood events, particularly towards peak discharge. This information is often missed or poorly represented by ground-based gauges, or significantly underestimated by rainfall radar. While community-based observations are less valuable during prolonged and widespread floods, or over longer hydrological periods of interest, they can still ground-truth existing traditional sources of catchment data to increase confidence during characterization and management activities. Involvement of the public in data collection activities also encourages wider community engagement, and provides important information for catchment management (Starkey et al. 2017).



The opportunities and challenges of citizen science for flood analysis are summarized in the following tables, taken from Paul et al. (2018):

Table 1. Overview of the commonly measured variables in hydrological risk reduction, along with related opportunities and challenges (taken from Paul et al. 2018)

Variable	Opportunities	Challenges
Precipitation	Cheaper equipment (e.g., electronic tipping bucket rain gauges). Bulk analysis of environmental influences on rain capitation. Merging with remotely sensed observations.	Long-term data collection. Proper installation, maintenance, and documentation of local environmental conditions.
Soil moisture	Automatic measurements (e.g., Time domain reflectometry) becoming increasingly affordable.	Relationship to other soil properties; high spatial variability; dependence on local agricultural practices.
River level/stage	Low-cost, robust, and accurate measurements using latest range-finding technology (e.g., radar and lidar).	Proper maintenance and data download. Conversion to real-time transfer and display. Potential human interference with exposed sensors.
Streamflow (volume per unit time)	Collection of calibration data; cheap measurement technology; emerging image analysis techniques for stage and flow measurements	Proper installation and maintenance; technical support
Water use	Availability of electronic sensors; convenient data communication via the Internet in urban areas	Interpretation and extrapolation of generated data; potential human interference
Vegetation dynamics	Cheap and readily available technology (e.g., GPS, photography; remote identification	Hard to process and combine with remotely sensed data; systemization

Table 2. Overview of the recent examples of CBM in hydrological risk reduction (taken from Paul et al. 2018)



Study	Location(s)	Nature of hazard/ program objectives	Activities/innovations	Citizen scientist engagement	Professional scientist role
Buytaert et al. ¹	Peruvian Andes, Lake Tana (Ethiopia), Mustang (Nepal)	Impact of changing land use	Rainfall, river level, soil moisture and stream flow data coupled to modeling approach	Hydrological monitoring	Design of monitoring program, training, data analysis
Malakar ⁵⁸	Central Nepal	Rainfall and landslide monitoring	New sensor networks installed at community level	Rainfall monitoring; geological studies	Enunciation of major landslide causes; training and data interpretation
Oven et al. ⁵⁹	Nepal	Flood, landslide, earthquake risk reduction	Community-based disaster risk reduction intervention	Semi-structured interviews and focus group discussion	Problem definition; design of engagement program
Borga et al. ⁶⁰	n/a	Resilience to flash floods	Integration of hydrological data with citizen science	Collection of eyewitness accounts and observations	Problem definition; design of interviews; data interpretation
Kattelmann ⁴⁸	East Nepal	Glacial lake outburst floods	Drainage and automatic warning systems	Soliciting political interest and funding	Design of drainage projects
Lane et al. ⁶¹	Ryedale, North Yorkshire, UK	Building flood resilience	Improvements to local flood knowledge	Extensive engagement with scientists and policy makers	Extensive engagement with citizen scientists
Liu et al. ⁹	Champaign, IL (testing)	Emergency management; urban flood response	New integrated Mapster app	Twitter and access to maps (two-way information flow)	Data protocol design only
Robson ¹⁰	San Jose, CA	Building flood resilience	'Creek Watch': app and website	Simple observation of water level and flow rate; time-stamped photos	Top-down approach: complete oversight of program
Le Coz et al. ¹³	Argentina/ France/New Zealand	Building flood resilience	New crowd-sourced data sets	Photos and videos for flow estimation	Training, design of monitoring system, data dissemination
Uson et al. ¹⁴	Santiago, Chile	Urban flood risk reduction	Role of citizen science on governance structures	Social media content, photos	None
Rosser et al. ¹⁵	Oxford, UK	Flood probability mapping	Citizen science and remotely sensed data	Geotagged photos from social media	No active contact with citizens
Horita et al. ¹⁶	Sao Carlos, SE Brazil	Integrated river flood risk management	Combination of wireless sensor network and citizen observatories	Observational monitoring	Provision of participatory website only

However, there are a number of issues that should be taken into account to identify some potential limitations or drawbacks associated to CBM. Just to provide a few examples, catchments are spatially and temporally complex, and flash floods, while of particular interest and importance to both hydrologists and communities, are hard to characterize given that they are rare, spatially localized, short lived and often occur in locations without formal monitoring (Starkey et al. 2017). One of the most relevant aspect, is that activities should be designed to encourage long-term monitoring even beyond the lifetime of the project and for citizen scientists to physically observe and learn about their weather and water environment themselves, rather than simply distributing automatic sensors.

There are aspects of the integration of crowdsourced data into flood modelling that are still challenging. These are as follows: exploring the use of citizens as data interpreters; improving



methods to estimate water level from pictures; harmonising the time frequency and spatial distribution of models with the ones of crowdsourced data; quantifying uncertainty; increasing the volume of data gathered, mainly in non-urban environments; the temporal and spatial scale of analysis.

3.3. The relevance of ‘citizen science’ to support Ecosystem Services assessment

In parallel to the interest in Ecosystem Services, citizen science has gained increasing attention as an approach that aims to strengthen bonds between science and society by engaging citizens in research (e.g. Haklay 2013, Schröter et al. 2017). With specific reference to the issue of ES analysis, despite there has been a limited involvement of citizens in such topic, it can serve as an entry point for more strongly engaging citizens. Particular, this could happen for the ES that have direct relation to people’s everyday life (e.g. opportunities for recreation, water quality) or those that can be reasonably assessed only through beneficiaries or ‘the eye of the beholder’ (such as sense of place, aesthetics, aspects of social cohesion) (Schröter et al. 2017). A recent review of the experiences of citizen science in ES assessment is summarized in the following Table 3.

As far as the level of participation is concerned, all studies included in the Table involved citizens in data collection, and nearly half of them required knowledge and advanced skills (e.g. assessment of ecosystem condition according to a protocol, or more in-depth procedures). Most of the studies can be classified as contributory, i.e. designed by scientists while citizens primarily contributed data or samples. Some studies also showed aspects of collaborative design, as citizens were engaged also in more advanced analyses of samples or also active dissemination of findings. Only one study could be classified as a co-created project employing deeper citizen involvement including study design, data analysis and interpretation (Nicosia et al., 2014).

Table 3. review of scientific articles assessing ES with citizen science (from (Schröter et al. 2017)).



Ecosystem service assessed (P-Provisioning, R-Regulating, C-Cultural)	Approach of assessment	Study reference	Study location/ Spatial scale	Time scale	No. of participants	Study description	Acronym
P- Honey production	Experiment	Sponsler and Johnson (2015)	Ohio, U.S.A.	2012–2013	32 and 18	The influence of landscape composition and beekeepers experience on bee colony success assessed	Sp
P- Fish harvest	Environmental Monitoring scheme	Fairclough et al. (2014)	West coast of Australia	2007/2008-ongoing	>350 / year	Recreational fishers send fish skeletons of three fish species from their catch, needed for stock assessments	Fa
P- Drinking water	Environmental Monitoring scheme	Little et al. (2016)	Rocky View County, Alberta, Canada	2007–2012 (partly 2013)	39 (wells)	Monthly water level measurements in privately owned wells using a water level sounder	Li
R- Water quality regulation	Environmental Monitoring scheme	Lottig et al. (2014)	3,251 lakes in the upper midwest of U.S.A.	1972–2012	not indicated	Water transparency measurements with Secchi-disks	Lot
R- Pollination	Experiment	Birkin and Goulson (2015)	80 sites across the U.K.	2014 (growing season)	173	Participants germinate seeds of <i>Vicia faba</i> L. and grow 4 plants with 3 treatments and record flower visitors	Bi
R- Pollination	Service-providing unit assessment	Pauw and Louw (2012)	46 gardens in Cape Town, South Africa	2002–2003	46	Presence/absence of four pollinating hummingbird species (<i>Nectarinia famosa</i> , <i>Cinnyris chalybea</i> , <i>Anthobaphes violacea</i> , <i>Proserpops cafer</i>) in urban gardens	Pa
R- Pest control	Service-providing unit assessment	Roy et al. (2012)	Belgium and U.K.	1990–2010	~67000 (BE) / 90000 (U.K.)	<i>Coccinellidae</i> recording scheme (in Britain since 1971, in Belgium since 1999) surveying eight endemic and one invasive species	Ro
R- Pest control	Service-providing unit assessment	Weed and Schwarzländer (2014)	38 observation sites within the state of Idaho (U.S.A.)	2007–2011	30	Effect of stem miner insects (weevil <i>Mecinus janthiniformis</i>) on invasive plant species (<i>Linaria dalmatica</i>) estimated at 38 sites (6 three minute counts and 10 sampling plots at each site)	We
R- Carbon storage	Environmental Monitoring scheme	Butt et al. (2013)	Wytham Woods, Oxford, southern England, U.K.	2008–2012	260	Volunteers measured tree breast-height diameter and tree height with dendrometer bands	Bu
R- Bio-remediation	Experiment	Kaartinen et al. (2013)	82 cattle farms across Finland	2011 (growing season)	79	Dung decomposition experiment with five different treatments: exclusion of dor beetles (Geotrope) and/or earthworms (Oligochaeta)	Ka
C- Multiple cultural ES	Service-providing unit assessment	Bruce et al. (2014)	Jervis Bay, New South Wales, Australia	2007–2011	not indicated	Migration patterns and behavior of humpback whales in Jervis Bay, Australia were assessed by trained volunteers and Crew of whale-watching boats	Bru
C- Multiple cultural ES	Service-providing unit assessment	Bramanti et al. (2011)	western Italian coastline	Spring 2008–June 2009	616 questionnaires	locations, and ecological conditions of red corals (<i>Corallium rubrum</i>) were reported by SCUBA-Divers	Lor
C- Multiple cultural ES	Service-providing unit assessment	Sequeira et al. (2014)	Adelaide and the Mount Lofty Ranges region of South Australia	28.11.2012	not indicated	Koala (<i>Phascolarctos cinereus</i>) assessment during fixed time period using a standardized sampling scheme (presence/absence, location, validation photo)	Se
C- Multiple cultural ES	Service-providing unit assessment	Williams et al. (2015)	Inhambane Province, Mozambique	2008–2011	918	Sightings of three sea turtle species (<i>Caretta caretta</i> , <i>Chelonia mydas</i> , <i>Eretmochelys imbricata</i>) by recreational SCUBA divers	Wi
C- Multiple cultural ES	Participatory GIS	Newton et al. (2012, 2013)	Frome catchment, county of Dorset, southern UK (480 km ²)	2010	~200	The non-marked value of cultural, aesthetic and recreational ES was elicited from local stakeholders using a web-mapping tool.	Ne
Multiple ES (water quality, soil retention, habitat provisioning, recreation)	Survey	Nicosia et al. (2014)	Barnegat Bay watershed, New Jersey, U.S.A. (~1,500 km ²)	2010–2011	33	Survey on willingness to pay (WTP) for four ES related to water among 1000 randomly selected residents	Ni
Multiple ES	Participatory GIS	Brown (2013), Brown et al. (2014)	3 California forest sites: Sierra National Forest, Sequoia National Forest, Inyo National Forest, U.S.A.	Feb.-Apr. 2012	84	Public participation GIS was used to identify locations for 14 ES in three National forests in California.	BrO

The Table above includes also a characterization of the citizen science studies, according to their approach for assessing ES, as surveys, experiments, environmental monitoring, service-providing unit assessments and participatory GIS schemes. The following Figure 2 proposes a summary of the main opportunities and challenges associated to the implementation of citizen science to ES assessment. The main **opportunities** include the facilitation to collect larger amounts of data over broader temporal and spatial ranges, the cost advantages through citizen science projects (e.g. low or no staff cost), the educational objectives and the capability to promote the value of nature, which could be also relevant to allocate funds or select strategies (Schröter et al. 2017). Additional benefits could be related to environmental literacy, awareness raising or establishing collaborations, along with the possibility of integrating knowledge about the coupled socio-ecological system of interest, which provides opportunities to better inform policy-makers. The **challenges** include the existence of complicated protocols that may give rise to bias, the adequacy of training and problems in applying the scientific study design (e.g. incomplete observation protocols). Furthermore, citizen science approaches are not generally



suitable or useful for all types of ES assessments, particularly when other high quality data are sufficiently available

	Type of opportunity/challenge	Related study (for acronyms cf. Table 3)												
OPPORTUNITIES	Bigger data amount, better spatial/temporal coverage	Bi	Ka		Fa	Li	Lot	Bru	Lor	Ro	Se	Wi	Ne	
	Good quality of data, low sampling errors			Bu									Ne	
	Cost advantage	Bi	Ka		Fa						Se	Wi	Ne	
	Sustainability education/stewardship	Ni			Fa	Li			Lor					
	Public involvement/place-based value elucidation	Ni										Bro	Ne	
	Establishing collaborations/strengthening community	Ni											Ne	
	Generate locally relevant data for decision-making	Ni											Ne	
CHALLENGES	Complicated protocol/observer bias	Ni	Bi	Sp	Bu			Bru	Lor			Wi	Ne	
	Restricted standardized design			Ka									Ne	
	Spatial bias (sampling effort, sparse, patchy)	Ni	Bi				Li	Bru			Se	Bro	Ne	
	Interest bias in mobilisation											Bro	Ne	
	Presence only, no absence data									Ro			Ne	
	Overall sample effort not recorded											Wi		
	Initial costs					Fa								

Figure 2. Opportunities and challenges of the citizen science approach. Figure from (Schröter et al. 2017).

Going further into details, CBM can contribute to biodiversity monitoring by providing information on species distribution and population abundance, and ecosystem function variables, at a scale that would be difficult or impossible for researchers. It has enabled consistent progress in several study fields, and particularly supports dealing with large-scale quantitative approaches to investigate questions about the distribution and abundance of organisms across space and time associated with current habitat and climate change (Rae et al. 2019).

Some research also underlines the relevance of citizen science in the field of Nature Based Solutions assessment. Particularly, (Rae et al. 2019) refer to the analysis of a specific class of SuDS (Sustainable Drainage Systems), i.e. the small ponds. SuDS, indeed, demonstrated the capability to provide multiple benefits within the urban environment: providing a place for wildlife, supplying environmental services, and promoting the health of human inhabitants. The



proximity to communities and schools makes them a potential tool for educating local people about ecosystem services and ecosystem health, which may support an improved protection and understanding of nature. However, it is well-known that SuDS vary greatly in their value for biodiversity and conservation. They include standalone ponds, as well as integrated systems which act as a water management chain and support ecological connectivity. These assessments of biodiversity values have used a variety of methods, many of which are unsuitable for citizen.

4. CITIZEN SCIENCE FOR BENEFITS AND CO-BENEFITS MONITORING AND EVALUATION: THE NAIAD DEMOS

Starting from the results of the literature review, NAIAD aimed at engaging communities and stakeholders in collecting data and information for assessing NBS effectiveness. This activity aimed at contributing to the enhancement of the NBS social acceptance. Therefore, the three key features of an effective information production process related to NBS effectiveness – i.e. credibility, saliency, and legitimacy – were accounted for. Specifically, the activities carried out in NAIAD aimed at improving the credibility of the information by integrating traditional monitoring system with the FreeStations, i.e. low-cost sensors to be used and managed by the community. NAIAD aimed also at enhancing the saliency of the information through the elicitation of the main stakeholders' information needs and concerns. Finally, NAIAD aimed at enhancing the legitimacy of the information production process by integrating stakeholders' knowledge in the monitoring activities.

4.1. Addressing the credibility issue – the FreeStation approach

The credibility of monitoring data is often affected by gaps in the data production. This is specifically true in data poor areas where, due to budget limitation, the network of the monitoring stations is not adequately spatially dense. The availability of low cost monitoring stations could allow decision-makers to expand the monitoring coverage without increase too much the monitoring costs. NAIAD aimed at demonstrating the usability of the FreeStations for flood monitoring.

The Eco:Actuary toolkit allows assessing different types of NBS at scales from small to large, and is specifically designed for locations where there is little or no pre-existing data available to support assessments, which is often the case for non-engineered solutions, like NBS. One of its key components is the FreeStation. These systems are called FreeStationLive (connected to the internet) or FreeStationLocal (for areas with no reliable GSM coverage) stations. They can be used to monitor (a) subsurface storage created by an in-line storage intervention or (b) soil storage resulting from a land management intervention. Two stations can be deployed to monitor the differential between two land management interventions (for example



conservation agriculture vs. conventional tillage) or to monitor river stage on either side of an intervention such as a leaky dam.

//SmartRiver: is developed for monitoring and assessing the effectiveness of inline storage NFM such as retention ponds, leaky dams, beaver dams etc. It combines the FreeStation stage gauge (FreeStage) and subsurface (soil) storage (moisture) sensors with specific serverware for analysis of inline storage by such interventions. A //SmartRiver sensor uses a low-cost sonar to measure the distance from the sensor to the water surface and thus changing river stage. The solar-powered device measures 6 times per hour, averages hourly and sends data every hour or once per day to the FreeStation servers.

As far as the Glinščica catchment is concerned, the utilization of the FreeStation approach was initially suggested to collect the reference data for improving the hydrological/hydraulic models used in assessment of the NBS solutions, but the stakeholder participation process revealed that it can also be used to monitor the impact in case of implementation of the selected NBS and to establish a remote sensing location to support civil protection service of the City Municipality of Ljubljana in monitoring water levels and issuing flood warnings.

The FreeStation open source initiative enables different stakeholders and communities to build and deploy reliable environmental data loggers with the lowest cost and easiest DIY build possible. Its modular design allows the user to select and install the assortment of sensors most suitable for their specific purpose. In the City Municipality of Ljubljana, the Department for civil protection is, among other, responsible to monitor, report and issue early warnings in cooperation with the national civil protection agency (URSZR) in case of natural disaster. Since there was no gauging station on the Glinščica stream (and other streams in the municipality) before the NAIAD project, the department personnel were required to regularly monitor the water levels during high rainfall events in person, or by deploying personnel of other available civil protection departments or services (e.g. local volunteer firefighter community personnel). Needless to say, in either case, the personal field observation in time of emergency is a waste of valuable and limited time that the personnel could be using to organize and implement mitigation and/or rescue activities.

Therefore, the first FreeStation monitoring station was installed on a suitable bridge over the Glinščica stream upstream from the vulnerable urban area to test its efficiency and usefulness for the above-mentioned purposes. The data collected from the Glinščica monitoring station will be incorporated into the existing flood monitoring system of the MOL, available online to the general public and used in various analyses and forecasts. Besides water level, the station is also collecting data on air temperature, humidity and pressure, but it can be upgraded with modules for rainfall and wind speed monitoring if requested by the stakeholders. The solar panel powered FreeStation is completely independent and requires minimal maintenance. It is thus



not surprising that the City Municipality of Ljubljana is already considering deployment of additional FreeStations to the different observation locations throughout the municipality.

4.2. Addressing the saliency and legitimacy issues

This phase of the NAIAD activities aimed at designing an NBS monitoring system capable to produce information that is relevant for the decision-maker, in order to support the assessment of the NBS effectiveness, and for the communities as well, to enable collective learning and enhancing social acceptance. We aimed at overcoming the information gaps, hampering the actual usability of the produced information. To achieve this objective, this work aims to enhance the legitimacy of the information production process as well. To this aim, the stakeholders' knowledge was integrated with the scientific ones for assessing the NBS effectiveness.

To design the community-based monitoring systems for NBS evaluation, a multi-steps methodology has been developed within the NAIAD framework:

1. Elicitation of stakeholders' problem understanding and co-benefits perceptions;
2. Definition of a set of indicators for the assessment of the co-benefits production;
3. Development of the community-based monitoring system.

Concerning the first point, the basic assumption here is that an information is considered as relevant by a decision-maker/stakeholder if it could be used by her/him to address key issues or for enhancing her/his understanding. The definition of locally-based and community-driven indicators allowed us to integrate stakeholders' knowledge in the monitoring process.

The activities have been carried out in two of the NAIAD demos, namely the Lower Danube and the Glinčiska demo. In both cases, in order to facilitate the actual engagement of the local communities in the monitoring activities, we decided to narrow down the WP3 activities and to focus on specific issues related to the NBS design and implementation in the two demos, as described in the following sections.

4.2.1. Lower Danube - Wetland restoration in the Potelu area

The demo activities related to T3.4 were focused on the monitoring and evaluation of a wetland restoration project in the Potelu area (figure 3). Key stakeholders were involved in the early stages of the CBMS development, i.e. the local branch of the WWF, the Romanian National Agency for Fishing and Aquaculture (ANPA), and the mayors of the villages in the study area.

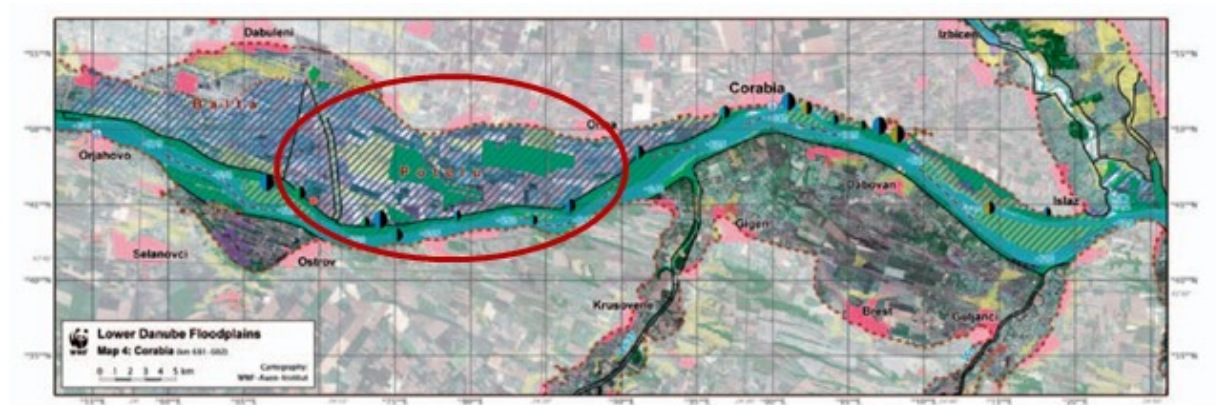


Figure 3. The area interested by the wetland restoration project

Individual interviews and a workshop were carried out to define the stakeholders' perceptions about NBS effectiveness and how to assess it. During the early phase of this process, most of the engaged stakeholders identified in the co-benefits production – and specifically the socio-economic ones - the most important goal to be achieved through the NBS implementation.

Figure 4 shows the discussion occurred during the workshop.



Figure 4. Potelu stakeholders' workshop for the identification of the most important co-benefits due to the wetland restoration project.

At the end of the discussion, the following list of co-benefits was agreed upon:



- Increasing fishing productivity: the renovated wetland will be used for fishing activities and fish farming;
- Enhance local biodiversity: flora and fauna are expected to benefit from the implementation of the restoration project;
- Combat soil degradation and desertification: the availability of water for irrigation and the positive impact on the local climate is expected to reduce the soil degradation phenomenon;
- Attract eco-tourisms: the wetland restoration is expected to produce socio-economic benefits, such as the increase of the eco-tourism;
- Combat depopulation: the population living in the local villages is constantly decreasing. Migration toward the main cities is the most evident demographic phenomenon. The economic activities connected to the restored wetland are expected to reduce the depopulation process.

Therefore, to produce information that could be relevant for the involved stakeholders and to affect the NBS social acceptance, the community-based monitoring system should be focused on the above-mentioned elements. Moreover, a round of semi-structured interviews were carried out with key local stakeholders in order to define the main characteristics of the CBMS, enhancing its saliency.

The second issue to be addressed in NAIAD concerned the legitimacy of the information production process. Therefore, efforts were carried out to integrate local knowledge in the monitoring activities. To this aim, stakeholders were involved in an exercise aimed at co-defining a set of community-driven and locally-based indicators for the monitoring of the co-benefits production. Not all the listed co-benefits are suitable for being monitored through the direct involvement of local communities in the monitoring activities. E.g. evidences concerning the increase of the eco-tourism and the improvement of the demographic dynamic (stop the depopulation process) can be collected referring to the institutional data collection systems (e.g. demographic census). The remaining co-benefits can be successfully monitored through the engagement of local citizens.

This phases involved the Romanian branch of the WWF, the Romanian National Agency for Fishing and Aquaculture, and the majors of the local villages. The results of the interviews were, then, analysed and summarised, in order to identify the main system requirements, as shown in table 4.

Table 4. main requirements for the Potelu wetland CBMS

ID	System requirement
R1	The system should allow citizens to send photos



R2	The system should support citizens in evaluating the level of soil degradation
R3	The system should support non-expert volunteers in taking part in the monitoring activities
R4	The system should allow the integration between crowdsourced information and remote sensing data (soil quality)
R5	The system should allow crowdmapping activities
R6	The system should allow individual inputs to be recognized

The users' requirements were, then, used to define the tasks users will be required to carry out in order to achieve a specific goal, e.g. to crowdsource data about the lake biodiversity. The Hierarchical Task Analysis (HTA) was implemented in this phase (Annett, 2003). The HTA allows to decompose high level tasks into a hierarchy of sub-tasks. The development of an HTA involves breaking a main task into sub-tasks and, later, grouping them as they should be performed in actual situation. HTA can include tasks that are both related or not to computer interaction. The following figure shows the HTA developed for the biodiversity monitoring, accounting for the defined requirements.

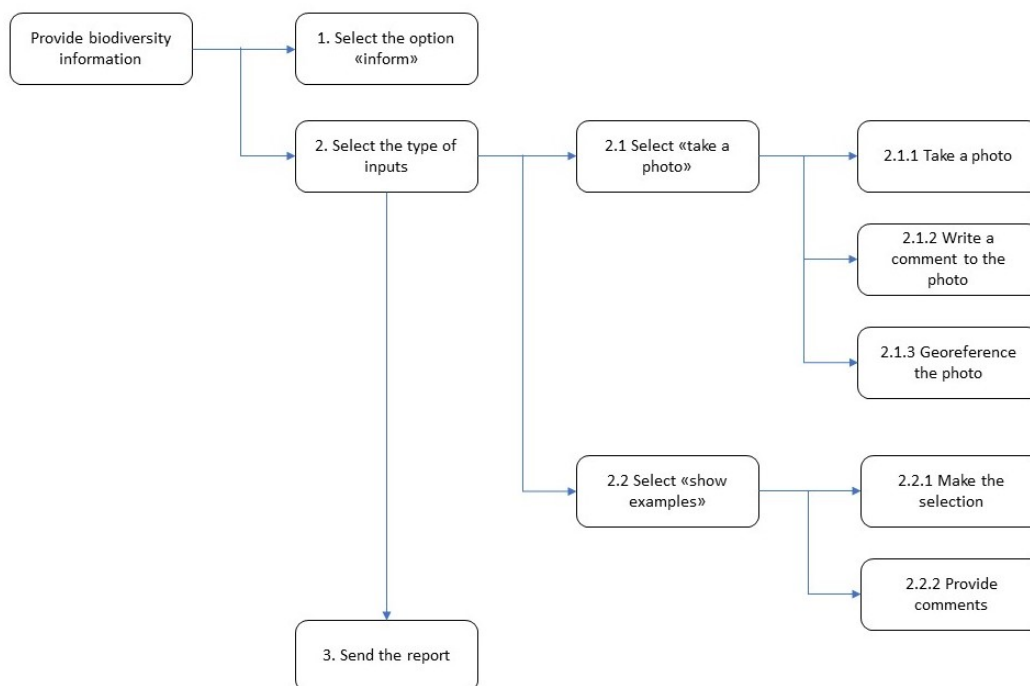


Figure 5. HTA for the Potelu platform – biodiversity monitoring.



The HTA and the users' requirements were used to develop a paper prototype of the flood monitoring platform. To this aim, a citizen science project has been created and uploaded on the Zooniverse.org open platform (<https://www.zooniverse.org/>). This platform was selected because: i) it is freely available; ii) it is flexible enough to be adapted to the different needs related to the citizen involvement in monitoring activities; iii) the design of the citizen science project and the deployment of the platform is user-friendly and it does not require specific skills; iv) it allows to integrate different sources of data and information.

The following figure shows the introductory page of the citizen science project for the Potelu wetland.

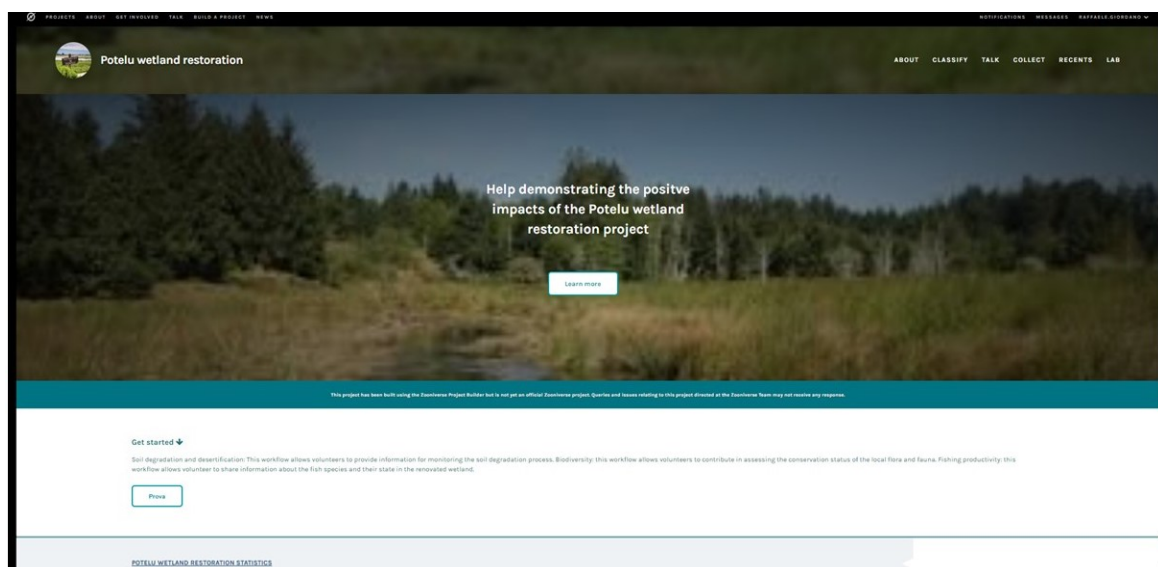


Figure 6. introduction to the Potelu Wetland citizen science project.

One of the key steps in the design of the citizen science platform is the definition of the workflow, that is the sequence of tasks that the volunteers are required to perform. Considering the HTA and the system requirements, multiple workflows have been defining in this project: i) Soil degradation and desertification; ii) biodiversity; iii) fishing productivity. The selected platform allows two main kinds of task, i.e. the “question” task, and the drawing task. In the first case, volunteers are required to answer specific questions concerning the main issue of the workflow. In the second case, participants are requested to mark specific features on already available pictures. For more details, a reader could refer to the online tutorial Zooniverse.org. This document aims at describing the stakeholders-driven process that lead us to define the workflow for the Potelu project.



For what concerns the soil degradation process, in order to guarantee the engagement of the local communities, efforts were carried out to keep the monitoring activities as simple as possible, and as similar as possible to the daily activities of the farmers and local citizens. In doing this, we were aware that if users would face difficulties in using the monitoring system, they might give up providing information or provide erroneous information. Therefore, interviews were carried out involving experienced citizens and farmers, in order to identify the elements used by local communities for assessing the state of the soil. The methods described in Giordano et al. (2010) was implemented at this stage. During the interviews we learned that two main elements are used for assessing the quality of the soil, i.e. the colour and the kind of vegetation. Concerning the first point, the colour is used by local communities for assessing the sand content in the soil. The colour ranges from brown to yellow, where brown means soil of good quality, and yellow determines a highly degraded soil (high sand content). The following figure shows the section “soil degradation and desertification” of the Potelu wetland monitoring project.

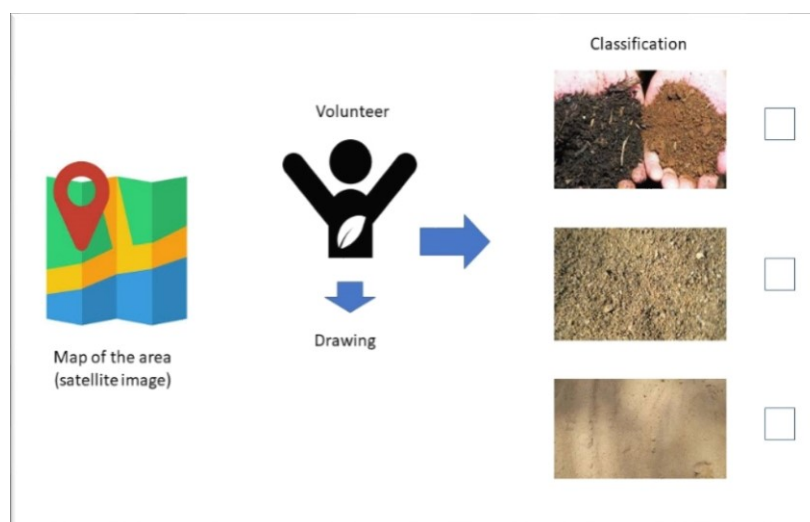


Figure 7. design of the soil degradation workflow for the citizen science project.

As shown in the figure 7, volunteers are requested to indicate on a map the point(s) where the provided information is referred to. Then, pictures of the different kinds of soil - i.e. different states of soil degradation - are shown to the volunteers. They are allowed to select the picture that, according to their own opinion, represents the actual situation. Similarly, information about the state of the vegetation covering the soil will be collected. To this aim, pictures will be presented to the volunteers, comparing the vegetation in degraded soils and good quality soils. Volunteers will be required to select the picture showing the kind of vegetation in the area. We



are currently working with local experts for defining the local types of vegetation. Unfortunately, we have not enough information on this element at this stage of the project implementation. Further details will be provided in the D3.6.

One of the most important steps for designing and implementing successful community-based monitoring system concerns the analysis of the data collected, and the definition of the feedback to be provided to the volunteers. Concerning the first point, the system is capable to keep track and to map the crowdsourced information. Therefore, two maps will be elaborated by the monitoring system, i.e. the soil colour and the vegetation maps. By aggregating these two maps and comparing the *ex-ante* and *ex-post* conditions, the system will be capable to assess the effectiveness of the wetland restoration project in combating desertification. The feedback to be provided to the volunteers play a key role in keeping them motivated and engaged in the monitoring activities. During the interactions with the members of the local communities we learned that the recognisability of the individual contributions to the monitoring activities was considered important by the participants. To this aim, the platform has been designed in order to keep track of the individual contributions, if allowed by the users, and to show these contributions on the map. Besides, the maps obtained through the analysis of the crowdsourced data will be freely available on the platform. To facilitate the volunteers in checking the status of the soil degradation process, *ex-ante* and *ex-post* evaluation maps will be available.

In order to make the crowdsourced information more reliable and usable for the monitoring of the NBS effectiveness, the data concerning the soil quality will be integrated with remote sensing technologies. To this aim, the experiences carried out within the LANDSENSE project (<https://landsense.eu/>) have been accounted for. The information freely available on the Copernicus Access Hub will be used to this aim.

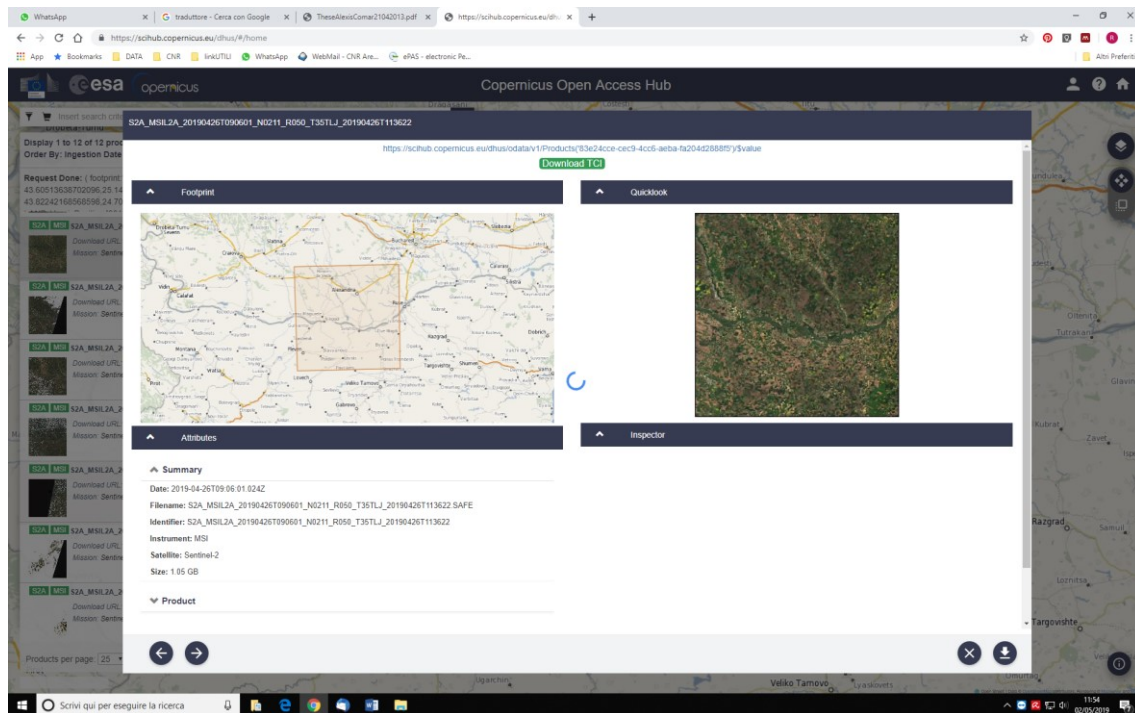


Figure 8. Copernicus Open Access hub for satellite images.

Free images from Sentinel 2A and B satellites¹ will be used to investigate the correlation between Soil Degradation indices (Dobovik, 2017; Chabrilat, 2006) and ground truth measurements and experiences. The spatial resolution of these data fully fits the dimension of the studied phenomenon, since it will be possible to have information every 10m, 20m or 60m in the visible range, every 5 days (with no cloudy sky). Therefore, the monitoring system will be capable to compare/integrate the maps obtained through the analysis of the crowdsourced data and the satellite information. Considering that the collection of data from the citizens has not started yet, the integration between the crowdsourced information and the remote sensing will be described in the D3.6, to be delivered in M40.

The design of the biodiversity part of the monitoring system was carried out by involving experts of the Romanian branch of the WWF. Their involvement was considered a key for the success of the CBMS initiatives because of their experience in protecting and restoring natural areas and wetlands, and because of their role in enabling the implementation of the Potelu wetland restoration project. Semi-structured interviews were carried out with some of the WWF experts, aiming at defining a set of indicators for the assessment of the NBS impacts on the biodiversity.

¹ https://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-2



During this phase, we learned that three main elements need to be monitored in order to assess the NBS effectiveness for biodiversity enhancement, that is: i) new bird species in the area; ii) conservation status of the existing species; iii) quality status of the aquatic ecosystem.

Concerning the indicator “new bird species”, similarly to what has been described for the soil quality monitoring, volunteers will be required to select the species among those represented in pictures. This part of the monitoring system is still under development. We are currently working with the experts of the WWF in order to identify the new bird species that could populate the project area after the restoration of the wetland. It worth mentioning that, following the local experts’ opinion, this part of the CBMS will not be limited to the local community. Tourists and bird-watchers will be involved in the monitoring activities as well. In order to enhance the reliability of the crowdsourced information, WWF experts agreed on supporting awareness raising campaigns and training activities aiming at enhancing the capabilities of the local communities collecting data about the local biodiversity. Moreover, the Romanian branch of the WWF is willing to facilitate the engagement of tourists in the monitoring activities by preparing training materials describing the different bird species, to be distributed at the beginning of the touristic visits at the wetland.

Concerning the expected impacts on fishing activities and fish farming, WP3 involved the Romanian National Agency for Fishing and Aquaculture (ANPA). This actor is, among the other roles, responsible for collecting data about the fishing activities and the fish farming production at national level. Moreover, local experts in fishing production were involved in the co-development of the indicators to be used as basis of the CBMS for this co-benefit. It is worth mentioning that, according to the opinions of both the ANPA and the local experts, the most suitable indicators are those related to the fishing production – i.e. quantity and quality of fishing, presence of fish species vulnerable to stress conditions (drought) – and those related to the fish production and to the economic impacts at local level:

- tons of fish produced per year;
- Municipal income due to the fish permits;
- Community income due to fish activities;
- Number of new activities connected to the fishing.

These indicators will be collected through the institutional monitoring systems and organizations. Citizen science approach will be implemented for collecting data about the fish catching, that is, the quantity of fishing and the species. The project workflow for this part of the system will be similar to the one described for the biodiversity monitoring. Therefore, volunteers will be required to select the species among those shown in the system. We are currently working with the local experts, in order to develop the list of fish species that are expected to populate the restored wetland.



4.2.2. Integrating citizen science and low cost sensors for flood monitoring in the Slovenian demo

In the early phases of the task implementation in this demo, two key local actors were involved in order to co-design the NBS monitoring and evaluation system, i.e. the Department for Civil Protection and Disaster Relief of the Ljubljana municipality (MOL Civ), and the Civil initiative for flood protection (CIPV), a local NGO. Starting from the results of the previous stakeholders' workshops (please, refer to D3.3 for more details on the workshop) concerning the main benefits and co-benefits due to the NBS implementation, initial meetings were held with these actors in order to define the main goals to be achieved by designing the CBMS. At the end of this initial phase, three main goals were defined concerning the communities' engagement in monitoring activities, as shown in figure 9: i) enhance the reliability of the early warning system for flood; ii) enhance the effectiveness of the flood event monitoring (situational awareness); iii) enhance the capability of estimating flood damages. In both cases, the results and products of already existing research projects were accounted for. Contrary to what happened in the Romanian demo experience, the main Slovenian stakeholders focused more on the NBS effectiveness in reducing flood risk and impacts, rather than on the co-benefits production. The CBMS was designed accordingly in order to make the produced information relevant for the decision-makers and local stakeholders.

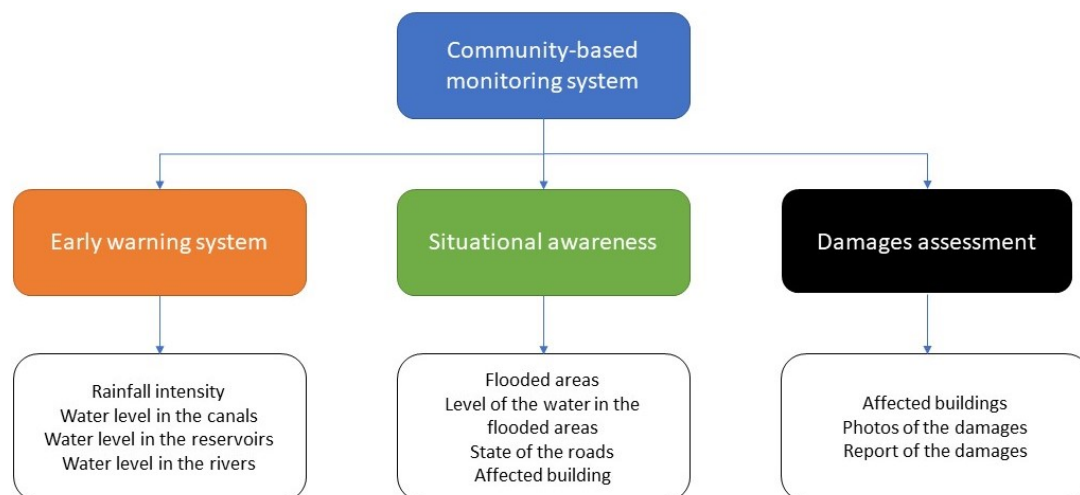


Figure 9. Role of the CBMS in the Slovenian demo.

Concerning the first objective, the monitoring and management of city flooding events are often in the hands of local government agencies, with citizens playing a passive role. T3.4 proposes an interactive and cooperative framework involving citizens and local authorities to improve the monitoring and management of urban flooding. In the adopted approach, citizens are no longer



considered passive, potential victims of flooding, but engaged and active contributors in the process of flood monitoring and mapping. This task aims at integrating crowdsourced hydrological data, collaboratively monitored by local citizens, and make use of low-cost sensors (FreeStation – WP2), and web-based platform for creating a flood early warning system. The activities related to the installation and use of the FreeStation have been already described in section 4.1. Thus, this section is mainly dedicated to describe the activities related to the design of a crowdsourcing system for flood monitoring.

Although the involvement of citizens in collecting data is already well established in biology, nature observation and protection, as already demonstrated in the previous section, water science is not an obvious discipline for the use of citizen science because many measurements are technologically demanding, and the data interpretation requires specific skills. Finally, hydrological measurements are often tailored to the professional needs of scientists, without accounting for the citizens' information needs.

Nevertheless, there are several good examples of citizen-led measurements of precipitation, river and lake levels. The rapid technological development has greatly aided this process. Beyond smartphones, that can be effectively used for scientific observations, citizen science can benefit from other newly emerging technologies, such as cheap rainfall stations to be used for crowdsourcing rainfall data, and the online platform for sharing geographical information – e.g. crowd-mapping.

Starting from these premises, an integrated platform for engaging citizens in monitoring flood events and, thus, assess the capabilities of the NBS to reduce flood risk was designed in the Ljubljana demo. The flood platform aimed at gathering information from citizens concerning the flooded – damaged – areas and the water level in the retention area developed for reducing flood risk in the urban area. We did not consider the citizen science tools for collecting data on the rainfall intensity, because the actors involved in the co-design phase were not interested in using crowdsourced rainfall data.

The results of the interviews carried out in the previous phases, and those with the two key actors, were used to identify the users' needs and to define the requirements of the platform. The table below shows the main system requirements:

ID	System requirement
R1	The system should allow citizens to send photos
R2	The system should support citizens in evaluating the level of the water in the retention area during rainfall event.
R3	The system should support citizens in evaluating the level of the water in the canals during rainfall event



R4	The crowdsourced data concerning the level of water in the retention area should be used for the flood early warning
R5	The system should be capable to integrate crowdsourced data and the data from the FreeStations
R6	The system should allow users to provide information about the observed damages
R7	The system should allow users to obtain timely information about the flood events

Table 5. users' requirements for flood monitoring platform.

The HTA approach was implemented. Figure 10 shows the tasks a user should perform for providing information about the level of water in the retention area and in the canals, and the report about the main damages.

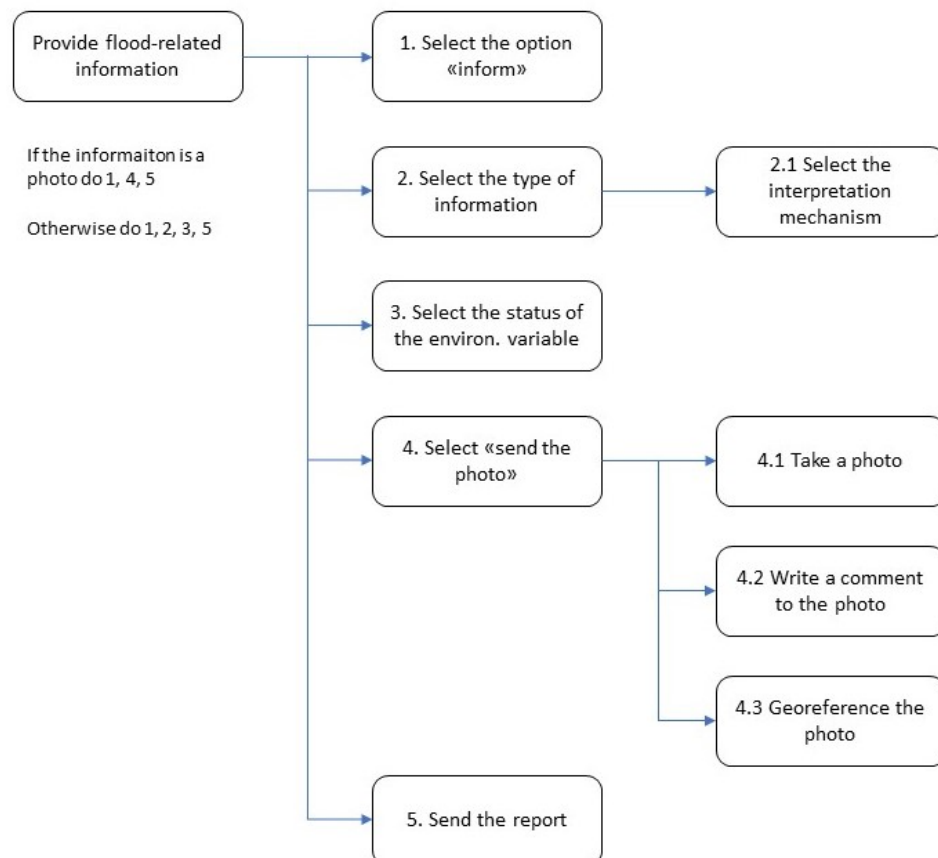


Figure 10. HTA for the flood monitoring platform.



The developed HTA shows that volunteers can provide two main kinds of information – i.e. the level of water in the canals and in the retention area, and the flood damages. Moreover, the HTA shows that two different kinds of report can be submitted by the volunteers – i.e. georeferenced photos with comments, and interpretation of water level. The HTA and the users' requirements were used to develop a paper prototype of the flood monitoring platform. The prototype allows users to select the kind of report they want to submit, i.e. water level or flood damages. In the first case, users could either send a georeferenced photo, or assess the level. In order to support volunteers in performing this task, a user-friendly interface has been designed. To this aim, we referred to the work done by Degrossi et al. (2018), as shown in figure 11.

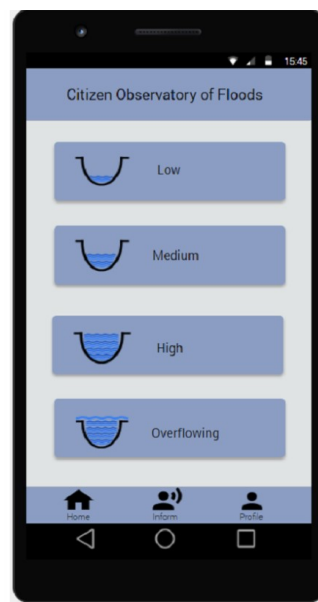


Figure 11. initial idea of the interface for collecting data about the water level in the canals (adapted from Degrossi et al. (2018)).

To facilitate the users' task, the platform will allow them to select among four possible states, i.e. low, medium, high and overflowing. Pictures will be provided by the interface.

If the users want to submit a report concerning the experienced flood damages, the interface allows them to send georeferenced photos. In the current version of the prototype, users are required to specify whether they are submitting a report about damages to the public spaces or private properties. The prototype allows to include comments to the photos, aiming at describing the damages.

The developed prototype must be validated. To this aim, meetings with members of the local community and representatives of the municipality were organized. Due to the difficulties in



finding a date suitable for the involved stakeholders, it was not possible to hold these meetings before the submission of this document. The results of the validation meetings will be described and discussed in the deliverable 3.5.

One of the key user's requirements for the Ljubljana CBMS platform regarded the integration with the FreeStations (WP2). These cheap sensors aimed at collecting data about the level of water in the retention area, making them available through the FreeStation platform. Figure 12 shows the FreeStation web platform.

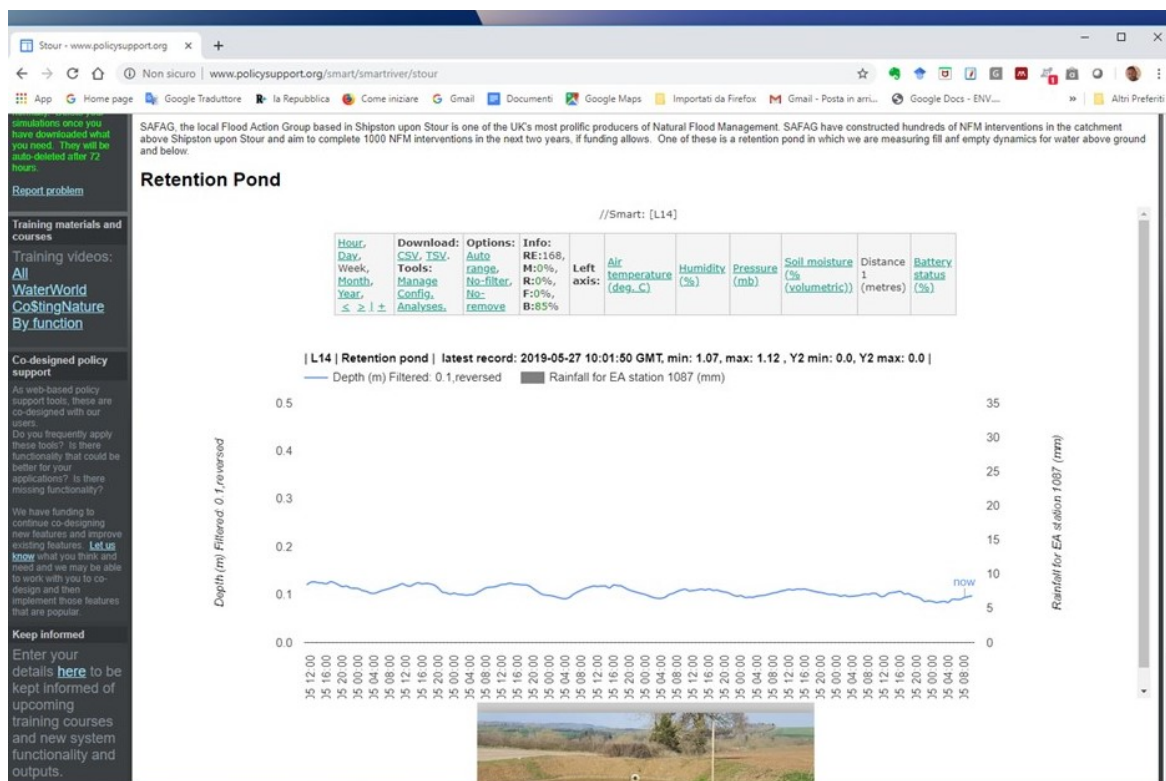


Figure 12. FreeStations web platform for sharing the data collected through the cheap sensors.

As shown in figure 12, the FreeStations are capable to collect data about the water level. Therefore, in order to integrate the crowdsourced data to those collected through the sensors, the citizen-based information should be translated into numerical values describing the level of water in the retention area according to the citizen evaluation. Figure 13 shows the integrated approach to CBMS development adopted in the Slovenian demo.



Figure 13. Integration of different sources of data for the NBS monitoring and assessment.

Concerning the data collected through the mobile app, the main local stakeholder clearly stated that, even if crowdsourced, quantitative data would make community's reports on the flood event stronger and likely to increase the authority confidence in the report itself. Therefore, participants will be allowed to attach a photo to the text report, in order to corroborate the assessment. Moreover, in order to facilitate the participants' tasks, the authority agreed to install water level gauge in different points in the retention area. By doing this, they would increase the validity of the citizens' report and the usability of the crowdsourced data to support the flood early warning system.

5. DISCUSSION AND CONCLUDING REMARKS

The activities described in this document aimed at contributing to the enhancement of the NBS social acceptance by improving the information production and sharing process concerning the NBS effectiveness. The basic assumption here is that, to enable individual and collective learning processes, monitoring information should be perceived as credible, salient and legitimate for a wide range of decision-makers and stakeholders. The NAIAD project aimed at addressing these issues by: i) integrating different sources of data in order to fill data gaps, with specific reference to data-poor areas (credibility); ii) elicit and structure stakeholders' information needs, using them as guideline for designing the monitoring system for the NBS effectiveness (saliency); iii) integrate stakeholders' knowledge into the monitoring system (legitimacy). This section is meant to critically analyse the lessons learned from the NAIAD implementation in the demo sites, highlighting pros and cons of the adopted approaches.

The credibility issue was addressed by enhancing the availability of reliable data concerning the effectiveness of the retention area for reducing the flood risk in the Gliciska demo site. The low-



cost sensors FreeStation were installed to this aim. The analysis of the experiences carried out in this demo demonstrated the usability of this tool. Decision-makers requires a wide set of data, geographically distributed, to take decisions and continuously assess the actual impacts and effectiveness of the implemented measures. However, extending the monitoring network is not always feasible due to budget constraints. Therefore, the availability of low-cost monitoring stations could support the decision-makers in collecting key data on NBS information with a rather low cost.

Two drawbacks can be identified in the adopted approach, both related to the ease of use of the tool by non-expert people. FreeStation tool has been designed to be installed and used by members of the community. However, improvements are needed in order to make the stations immediately operative without the intervention of an expert. Besides, the data are collected and showed in a web interface that cannot be adapted to the users' needs, concerning the kind of information to be showed and the format.

The saliency and legitimacy of the information production process were addressed in this work by engaging stakeholders and members of the community in the design of the monitoring system for NBS effectiveness. The experiences carried out demonstrated that engaging stakeholders in the design of the CBMS enhanced their understandings of the NBS benefits and co-benefits. The whole process – i.e. co-definition of benefits and co-benefits, indicators definition and CBMS design – contributed to make the involved stakeholders aware of the wide range of benefits that can be produced through the NBS implementation. This was particularly true in the Lower Danube demo. At the beginning of the process, stakeholders were mainly interested in assessing the NBS effectiveness in reducing flood and drought risks. During the next phases of the discussion, stakeholders became increasingly aware of and interested in the socio-economic co-benefits due to the restoration of the Potelu wetland. This, in turn, had a positive impact on the NBS social acceptance.

Many efforts have been carried out in research project aiming at developing indicators-based framework for monitoring and assessing the NBS effectiveness. The experienced carried out in the two NAIAD demos demonstrated that, in order to get the interest of the community and the keep them motivated in gathering and sharing information, making the monitoring activities as simple as possible and as close as possible to the community's daily activities is key for keeping low the efforts required and, thus, to guarantee the long-term community involvement. Moreover, the integration of the community-driven indicators in the designed monitoring system enhanced the legitimacy of the produced information and, consequently, the level of trust. The experiences carried out in the NAIAD demos showed some limitations of the adopted approach. Although, the integration of locally-based indicators in the monitoring system enhanced the community's trust toward the monitoring activities and, consequently, toward the



produced information, efforts are required to integrated the community-based indicators with the scientific-based ones.

The CBMS for NBS monitoring and evaluation should be designed as a two-way information platform. That is, allowing crowdsourcing of data and information on benefits and co-benefits could be not sufficient. The experiences carried out in the demos demonstrated that providing information back to the users – e.g. the results of the data analysis – capable to meet their actual information needs, and rewarding them for their contributions – e.g. making their contribution clearly recognizable in the results – play a key role in keeping the volunteers motivated and increase their willingness to be active in collecting data and information. Moreover, the interviewees gave significant importance to the possibility to communicate with the other participants through the CBMS platform.

The success of the CBMS activities is strongly affected by the capability to engage key local actors in the management of the CBMS. According to the experiences carried out in the two demos, community members – i.e. potential volunteers of the CBMS – would be more interested in taking part in the monitoring activities if they know that local authorities – and not exclusively scientists – would make use of the collected information. In the Lower Danube demo, the involvement of the WWF greatly facilitated the discussion with the mayors and the local communities. In the Ljubljana demo, the interest of the Civil Protection department of the Municipality in using the crowdsourced data enabled the involvement of the other stakeholders as well.

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