MULTISOURCE

Establishment of an international knowledge base on NBSWT and ENTS

Deliverable 4.2

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EXECUTIVE SUMMARY

The MULTISOURCE project presents a groundbreaking initiative in the realm of nature-based solutions for urban water management. This comprehensive report outlines the project's overarching objective: to streamline citywide planning through the integration of enhanced natural treatment systems and decision-support tools. At its core, the project establishes a robust knowledge base, spanning 53 technologies, with a focus on urban water treatment, storage, and reuse.

The Nature-Based Solution (NBS) technology selection tool, a key deliverable of MULTISOURCE, emerges as a pivotal asset. By combining data from experts and from literature into a knowledge base, this tool empowers stakeholders and decision-makers to make informed choices tailored to specific water scenarios. Factors such as cost, environmental impact, and operational needs are considered, ensuring a holistic approach to decision-making.

Data collection methods employed in the project include elicitation workshops, expert assessments, literature review and data analysis. A notable inclusion is the database of scientific publications, boasting 894 entries and providing a dynamic reference point for technology insights. Users can actively contribute to the database, ensuring its continuous enrichment and relevance.

Modelling of the required surface for different water treatment technologies reveals insights from 647 sampling campaigns, shedding light on NBS technology performance. Challenges, including data imbalances and missing values, are acknowledged, emphasizing the need for careful interpretation.

In line with principles of transparency, the knowledge base, API, and raw data files are made readily accessible following the FAIR principles. The MULTISOURCE project not only advances the understanding of nature-based solutions but also establishes a collaborative framework, fostering collective progress in water treatment and stormwater management.

1. INTRODUCTION

The overarching goal of the MULTISOURCE project is to facilitate the systematic, citywide planning of nature-based solutions for urban water treatment, storage, and reuse. To realize this objective, the project comprises two primary components: the implementation of pilots featuring enhanced natural treatment systems and the development of tools to assist stakeholders and decision-makers in adopting nature-based solutions. The selection, (pre)design and assessment of NBS technologies for water management require decision is a complex problem where decision support tools can help offering quick, consistent, and qualified solutions.

Among the tools created within MULTISOURCE, the Technology Selection Tool serves as a decision-support system, aiding users in choosing the most suitable NBS, including enhanced natural treatment systems (ENTS), for a specific water treatment, storage, or reuse scenario. In this context, a water scenario encompasses inflow conditions, outflow requirements, space availability, and other considerations such as the provision of specific ecosystem services or the skills required to operate the technology.

The NBS Technology Selection Tool not only guides users in choosing and pre-designing the most adequate technology for the water scenario but also considers various other variables of interest, including cost, surface requirements, environmental impact, co-benefits (multifunctionality), and operational needs. This multiple criteria assessment allows a comparison and overall ranking of all viable technologies for a given scenario.

All algorithms and models executed by the tool to make decisions are fuelled by two types of data: data obtained from experts and data from literature. The expert-based data is a catalogue of nature-based solutions for water treatment and stormwater management, which includes the ENTS pilots of MULTISOURCE. Similarly, the data obtained from literature consists of two tables. The first table contains scientific publications focused on one or several technologies included in the knowledge base. The second table is specific for publications about natural treatment systems, it contains additional data about the samples mentioned in the publication, such as inflow, pollutant concentrations, surface area, etc.

This deliverable introduces and describes the knowledge base and the database curated to feed the algorithms and models of the Technology Selection Tool within MULTISOURCE. Detailed information about the tool is provided in Deliverable 4.4.

2. DATA COLLECTION METHODS

2.1. KNOWLEDGE BASE

The construction of the knowledge base within MULTISOURCE involved three distinct stages. These stages are delineated as follows:

1. Upgrade of the legacy from the SNAPP Project: The initial stage of knowledge base development is inherited from the SNAPP project "Guidance on evidence based practices for improved sanitation, water security and ecological health, with a focus on nature-based solutions". This project was international and funded by the National Center for Ecological Analysis and Synthesis (NCEAS, UC Santa Barbara).

2. Addition of ENTS from MULTISOURCE Pilots: The second stage incorporates information from the MULTISOURCE pilots, expanding the scope of the knowledge base by including enhanced natural treatment systems.

3. Inclusion of Nature-Based Solutions for Stormwater Management: The third and final stage integrates nature-based solutions specifically tailored for stormwater management into the knowledge base.

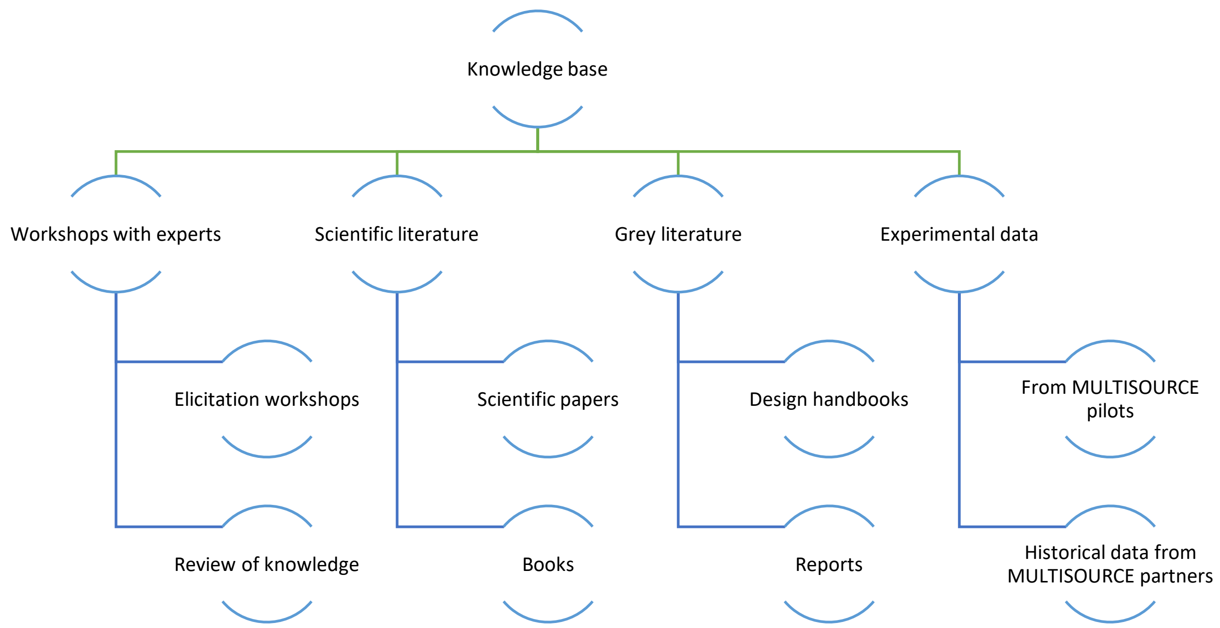

Figure 1. Sources of data used to compound the knowledge base.

2.1.1 SNAPP PROJECT

The SNAPP project played a pivotal role in establishing the foundation for the knowledge base within MULTISOURCE. The development of this knowledge base occurred through a series of elicitation workshops, primarily employing the IDEA protocol (Hemming et al., 2018) – a modified Delphi method. The workshops, conducted in Santa Barbara (22-24 May 2018), Vienna (Feb 11th, 2019) and Girona (Nov 8th, 2019), aimed to harness expert knowledge on the most suitable Nature-Based Solutions (NBS) for diverse socio-environmental contexts and needs. These workshops involved more than 40 experts worldwide, covering international representation (America, Europe, Asia, and Africa) and expertise in all types of NBS.

Workshop Methodology:

During the workshops, more than international experts, covering international representation (America, Europe, Asia and Africa) and expertise in all types of NBS, engaged in a structured process. Firstly, they collaboratively identified nine major types of NBS and 26 associated sub-types, encompassing different varieties and combinations. Subsequently, participants addressed several key aspects to define the decision-making table.

Key Workshop Topics:

NBS Characteristics: Participants detailed the characteristics of NBS for domestic wastewater treatment, considering various sub-types and their applicability.

- Wastewater Types and Treatment Targets: Discussions covered the types of wastewaters to be treated, main treatment targets, common climate categories, and categories of co-benefits.
- Pollutant Removal and Spatial Scale: For each NBS, experts assessed its capacity to treat different types of domestic wastewater and targeted pollutants. They also determined the spatial scale for installation, distinguishing between household/building and community-scale.
- Surface Requirements: Participants defined the required surface area for each NBS to treat one population equivalent (≈ 60 grams of BOD/day) under different climates (square meter per PE ratio).
- Technical Requirements: Consideration was given to whether each NBS requires external energy, with responses categorized as yes or no.
- Labor, Skill Requirements, and Biohazard Level: Discussions encompassed the labour and skill requirements for each NBS, along with categorizing associated biohazard levels as low, medium, or high.
- Co-Benefits: Experts evaluated the levels of various co-benefits associated with each NBS, including biodiversity (fauna and flora), temperature regulation, flood mitigation, storm peak mitigation, carbon sequestration, biomass production, aesthetic value, recreation, pollination, food source, water reuse, and biosolids provisioning. The levels for the cobenefits were defined in a qualitative scale of none, low, medium, and high.

This comprehensive approach ensured that the knowledge base derived from the SNAPP project incorporated expert insights on diverse dimensions of NBS.

Notably, a modification to the knowledge base structure was made during the first annual meeting of MULTISOURCE in Lyon on June 27th, 2022. There, in a workshop dedicated to co-designing the workflow of the technology selection tool, a decision was reached to incorporate the design or recommended organic loading rate for all NBS technologies (in grams of BOD per square meter). Since these values was not provided by the experts, it was calculated for existing technologies by dividing 60 by the square meter per person equivalent (PE) ratio. This assumption was based on the idea that one PE produces 60 grams of BOD per day [1]. Likewise, one person producing raw domestic wastewater is equivalent to one PE, but this is not equivalent with other types of water. For instance, in greywater, one person is equivalent to 0.3 PE.

[1] Directive 91/271/EEC. *Concerning urban wastewater treatment*. European Council. http://data.europa.eu/eli/dir/1991/271/2014-01-01

2.1.2 INTEGRATION OF ENTS FROM MULTISOURCE PILOTS

The second stage in building the knowledge base involved the inclusion of the innovative NBS (or enhanced natural treatment systems, ENTS) studied in the MULTISOURCE pilots into the roster of available technologies. The gathering of the data and knowledge for this integration took place during a workshop held at the second annual meeting of the MULTISOURCE project in Leipzig on June 5th, 2023.

The workshop consisted of two rounds. In the initial round, all project partners were tasked with providing data for all pilots, along with indicating their confidence level in supplying this information. This approach mirrored the knowledge base structure established during the SNAPP project.

In the second round, MULTISOURCE partners were organized by pilots, collaborating to achieve consensus on the data for their respective pilot projects (i.e. responsible partners for one pilot worked out consensus for only the ENTS of that pilot). All collected data were summarized and weighted based on the confidence levels reported by users. The workshop aimed to reach a consensus decision, ensuring the integration of pilot data into the knowledge base.

For a detailed report of the outcomes of this workshop, please refer to the linked document.

2.1.3 INCLUSION OF NATURE-BASED SOLUTIONS FOR STORMWATER MANAGEMENT

The SNAPP project did not encompass technologies for stormwater management (SWM). Therefore, the first step in including SWM was to establish a structured framework for the knowledge base. All existing fields related to co-benefits and barriers in the knowledge base were retained, and new values concerning the water scenario were collaboratively defined with WP5 to ensure seamless interaction with the tools developed in that work package.

Structural enhancements:

1. **Introduction of New Water Types:** Two new water types, rainwater and runoff, were introduced. Notably, runoff water requires some form of treatment before infiltration or release into the environment.
2. **Assimilation of Combined Sewer Overflow (CSO) Technologies:** Previously to the consideration of SWM, three technologies were designated for combined sewer overflow (CSO) discharge. These technologies were assimilated into the SWM module. A field labelled “module” was introduced to differentiate between technologies for water treatment and those for SWM.
3. **Additional Fields for SWM Technologies:** To model the surface required by SWM technologies, new fields were added, including infiltration (yes or no), storage capacity (m3/m3), and depth or height of the technology (m).

Data Collection and Sources: The data collection for SWM technologies primarily relied on grey literature combined with expert knowledge. Desk work, as opposed to elicitation workshops, was the primary method for data collection. The main information source was Woods Ballard et al. (2015) by CIRIA.

Review and Validation: Following the collection and curation of all data, it underwent a review process conducted by WP5 partners (UFZ and INSA) to ensure accuracy and completeness.

2.2. COLLECTION OF SCIENTIFIC PUBLICATIONS

Similar to the knowledge base, the collection of scientific publications underwent a two-stage process. The initial batch of publications was collated during the SNAPP project, focusing solely on water treatment technologies appearing on scientific journal papers (until 2019). Subsequently, within the MULTISOURCE project, the database was updated to include new scientific publications for water treatment (2020-2022), data from grey literature (mainly design handbooks and databases with experimental data from project partners) and expanded to encompass stormwater management (SWM) technologies.

First Stage: SNAPP Project Publications (Water Treatment).

Scientific studies pertaining to the utilization of Nature-Based Solutions (NBS) in domestic wastewater systems constituted the first stage of publication collection. Using the Web-of-Science database, a comprehensive search was conducted on May 23rd, 2019, encompassing studies published in any year. Nine distinct searches, one for each type of NBS, were executed, with search terms strategically chosen to ensure the inclusion of all potentially relevant studies. Eligibility criteria were established, requiring full-text availability, English language, exclusion of laboratory case studies, prioritization of full-scale or pilot-scale studies, exclusion of reviews, and the inclusion of articles providing information on at least three selected variables characterizing NBS (Acuña et al., 2023).

Upon identifying potentially relevant articles, a meticulous selection process ensued. To ensure consistent choices, 30% of the articles underwent a dual review (title and abstract) by two researchers. The final inclusion in the database was contingent on meeting the eligibility criteria outlined above.

During the abstract review, reviewers introduced additional information for each case study in the spreadsheet. These fields, organized into six domains—removal efficiencies, water sources/types, sustainability indicators, co-benefits, elements of the urban wastewater system, and design and operational settings (see Figure 2)—were filled in by extracting information from the abstract or, if necessary, by downloading and reviewing the full text of the article. This information is used for the NBS technology selection to train regression models that estimate the surface required for a specific technology and specific water characteristics.

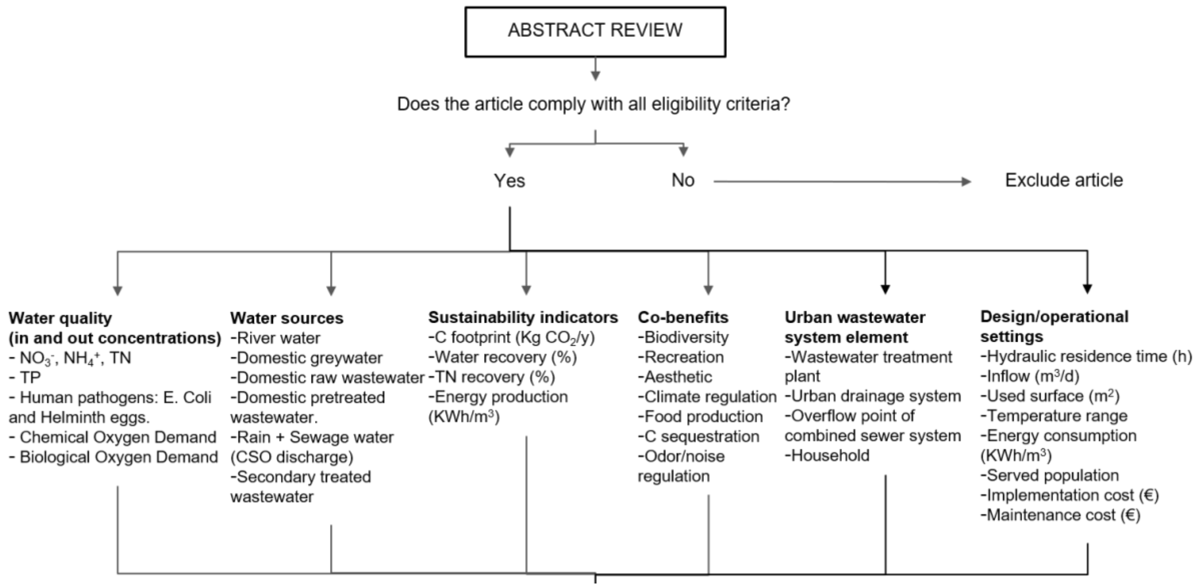

Figure 2. Data extracted from scientific publication about water treatment technologies.

Second stage: Additional data inclusion.

Within the MULTISOURCE project, the same methodological approach utilized during the SNAPP project was applied to update the database for water treatment technologies, extending the data collection until the year 2022.

In the context of stormwater management (SWM) technologies, the objective was to compile a list of pertinent publications for each technology, facilitating future reference for tool users. As the technology selection tool does not rely on data-driven models to estimate the surface of SWM technologies, there was no additional data sought within the gathered publications.

Search Strategy: To gather relevant publications, the SCOPUS database was employed. Specific queries were crafted for each technology, combining the technology name with “runoff” or “stormwater” in the title or abstract.

Publication Curation: The list of obtained references underwent careful curation to exclude publications not directly related to the technology or its ability to manage stormwater. This curation process relied on a filter based on the title and abstract.

This focused approach ensures that the compiled list of publications for SWM technologies remains relevant and directly applicable for user consultation within the technology selection tool.

3. CATALOGUE OF NBSWT AND ENTS

The knowledge base for NBSWT and ENTS comprises 53 technologies, with 31 dedicated to water treatment for various water types and 22 for stormwater management, encompassing rainwater, runoff water, and combined sewer overflow discharge water. The information is organized in tabular form, presenting details for each technology across 49 features. Of these, 32 features are common to all technologies, while 13 are specific to water treatment technologies and 4 are specific to SWM technologies (

Table 1). In the table, *active* means that the technology is suitable for that type of water of to remove that pollutant, *inactive* means the contrary and *not ideal* means that the technology can but it is not designed or optimized to do that.

Table 1. Description of the features of the knowledge base

Variable	Description	Values or units
GENERAL INFORMATION		
name	The name of the technology	--
type	The group of the technology	CW: Constructed wetlands GR: Green roofs GW: Green walls HA: Hydroponics and Aquaponics I-SRS: In-stream restoration systems MS: Multi-stage systems NW: Natural wetlands PL: Ponds and lagoons SIS: Soil infiltration systems WS: Willow systems BS: Bioretention systems DB: Detention basins

Variable	Description	Values or units
		FS: Filter strips IS: Infiltration systems PP: Pervious pavements PO: Ponds SW: Swales TR: Trees
description	A brief description of the technology	--
vertical	Is the technology a vertical structure (i.e., a green wall)?	1 (yes) – 0 (no)
module	Is the technology for water treatment of for stormwater management?	treatment – SWM
TYPES OF WATER		
raw_domestic_wastewater	Is the technology appropriate (active) for treating raw domestic wastewater?	1 (active) – 0 (inactive) – 2 (not ideal)
pretreated_domestic_wastewater	Is the technology appropriate (active) for treating pretreated domestic wastewater (primary treated effluent)?	1 (active) – 0 (inactive) – 2 (not ideal)
greywater	Is the technology appropriate (active) for treating greywater?	1 (active) – 0 (inactive) – 2 (not ideal)
secondary_treated_wastewater	Is the technology appropriate (active) for treating secondary treated wastewater?	1 (active) – 0 (inactive) – 2 (not ideal)
cso_discharge_water	Is the technology appropriate (active) for treating water from CSO discharge?	1 (active) – 0 (inactive) – 2 (not ideal)
river_diluted_wastewater	Is the technology appropriate (active) for treating river diluted wastewater?	1 (active) – 0 (inactive) – 2 (not ideal)
offices_wastewater	Is the technology appropriate (active) for treating wastewater from offices?	1 (active) – 0 (inactive) – 2 (not ideal)
camping_wastewater	Is the technology appropriate (active) for treating wastewater from camping sites?	1 (active) – 0 (inactive) – 2 (not ideal)
rainwater	Is the technology appropriate for storing or infiltrating rainwater?	1 (active) – 0 (inactive) – 2 (not ideal)
runoff_water	Is the technology appropriate for storing or infiltrating runoff water doing a primary treatment?	1 (active) – 0 (inactive) – 2 (not ideal)
POLLUTANTS REMOVAL	**(for water treatment technologies)**	1 (active) – 0 (inactive) – 2 (not ideal)
c_removal	Is the technology actively removing organic matter?	1 (active) – 0 (inactive) – 2 (not ideal)
n_removal_nitrification	Is the technology actively doing nitrification of ammonium?	1 (active) – 0 (inactive) – 2 (not ideal)
n_removal_nitrateremoval	Is the technology actively doing denitrification (removing nitrates and nitrites)?	1 (active) – 0 (inactive) – 2 (not ideal)
p_removal	Is the technology actively removing total phosphorus?	1 (active) – 0 (inactive) – 2 (not ideal)

Variable	Description	Values or units
pathogens_reduction	Is the technology actively removing pathogens, such as *E. coli* or Helminth eggs?	1 (active) – 0 (inactive) – 2 (not ideal)
SURFACE RATIOS	**(for water treatment technologies)**	
m2_pe_tropical	How many square meters are needed to treat one person equivalent (60 gr of BOD) in a tropical climate	m^2 / pe
m2_pe_dry	How many square meters are needed to treat one person equivalent (60 gr of BOD) in a dry climate	m^2 / pe
m2_pe_temperate	How many square meters are needed to treat one person equivalent (60 gr of BOD) in a temperate climate	m^2 / pe
m2_pe_continental	How many square meters are needed to treat one person equivalent (60 gr of BOD) in a continental climate	m^2 / pe
gr_bod_m2_tropical	How many grams of BOD5 can be treated by square meter in a tropical climate?	grams / m^2
gr_bod_m2_dry	How many grams of BOD5 can be treated by square meter in a dry climate?	grams / m^2
gr_bod_m2_temperate	How many grams of BOD5 can be treated by square meter in a temperate climate?	grams / m^2
gr_bod_m2_continental	How many grams of BOD5 can be treated by square meter in a continental climate?	grams / m^2
HYDRAULIC FEATURES	**(for SWM technologies)**	
Hydraulic conductivity	How much water can be stored by time?	mm / s
storage capacity	How much water can be stored by the technology?	m^3 water/m^3 capacity of the technology
depth	What is the default depth / height of the technology?	m
infiltration	Does the technology allow to infiltrate water into the ground?	0 (no) – 1 (yes)
COBENEFITS AND ECOSYSTEM SERVICES		
es_biodiversity_fauna	To what extent is the technology increasing the variability among living organisms from all sources, including diversity within species, between species and of ecosystems. Fauna including animals, fungi and various groups of bacteria.	0 (none) – 1 (low) – 2 (medium) – 3 (high)
es_biodiversity_flora	To what extent is the technology increasing the variability among living organisms from all sources, including diversity within species, between species and of ecosystems. Flora includes any organism in the kingdom *Plantae.*	0 (none) – 1 (low) – 2 (medium) – 3 (high)
es_temperature_regulation	To what extent the technology provides the regulation of humidity and localised temperatures during hot weather conditions, including through ventilation and transpiration.	0 (none) – 1 (low) – 2 (medium) – 3 (high)
es_flood_mitigation	To what extent the technology provides mitigation or prevention of potential damage to human use, health or safety caused by stormwater.	0 (none) – 1 (low) – 2 (medium) – 3 (high)
es_cso_mitigation	To what extent the technology helps to reduce the combined sewer overflows produced by storm events.	0 (none) – 1 (low) – 2 (medium) – 3 (high)
es_carbon_sequestration	To what extent the technology is removing carbon from the atmosphere and depositing it in a carbon sink, such as oceans, plants or soils.	0 (none) – 1 (low) – 2 (medium) – 3 (high)

Variable	Description	Values or units
es_biomass_production	To what extent the technology is providing above-ground (i.e., not roots) plant material trough regular harvesting and removal.	0 (none) – 1 (low) – 2 (medium) – 3 (high)
es_aesthetic_value	To what extent the technology is aesthetically pleasant as a component of the landscape.	0 (none) – 1 (low) – 2 (medium) – 3 (high)
es_recreation	To what extent the technology is providing recreation opportunities to citizens, such as walking or relaxing.	0 (none) – 1 (low) – 2 (medium) – 3 (high)
es_pollination	To what extent the technology is providing a habitat for pollinators, mainly insects, but also birds and bats.	0 (none) – 1 (low) – 2 (medium) – 3 (high)
es_food_source	To what extent the technology is providing food from wild plants and animals, including parts of the standing biomass that can be harvested and used for the production of food.	0 (none) – 1 (low) – 2 (medium) – 3 (high)
es_water_reuse	To what extent the water treated by the technology is appropriate for beneficial purposes such as irrigation, drinking water supplies, groundwater recharge, industrial processes, and environmental restoration.	0 (none) – 1 (low) – 2 (medium) – 3 (high)
es_biosolids	To what extent the technology is providing sludge that is rich in nutrients and can be reused as fertilizer.	0 (none) – 1 (low) – 2 (medium) – 3 (high)
FEATURES AND BARRIERS		
household_building_solutions	Is the technology appropriate (active) to be built for a single household or building? Or, on the contrary, it needs a bigger scale?	1 (active) – 0 (inactive) – 2 (not ideal)
energy	Is the technology using energy for its normal operation? Does it need water or air pumps? Any other kind of similar energy demand?	yes-no
inv_es_manpower	What level of manpower is required for its operation? Including all kinds of regular works required to keep the technology working.	0 (none) – 1 (low) – 2 (medium) – 3 (high)
inv_es_skills	What level of skills are required to operate the technology?	0 (none) – 1 (low) – 2 (medium) – 3 (high)
inv_es_biohazard	To what extent the technology presents biohazard risks, including microorganisms, virus and toxins that can affect human health?	0 (none) – 1 (low) – 2 (medium) – 3 (high)
cost	How much does the construction of the technology cost?	€/m^2

The technologies in the knowledge base are designed to address all water types considered in the tool. Additionally, they offer a diverse range of co-benefits in the form of ecosystem services (Figure 3). Some co-benefits are not applicable to all technologies, as they represent the primary objectives of specific technologies. For instance, flood mitigation and CSO mitigation are considered co-benefits only for water treatment technologies, as these outcomes are the primary goals of SWM technologies. Including them as co-benefits across all technologies could lead to double-counting in subsequent analyses, such as multicriteria decision analysis.

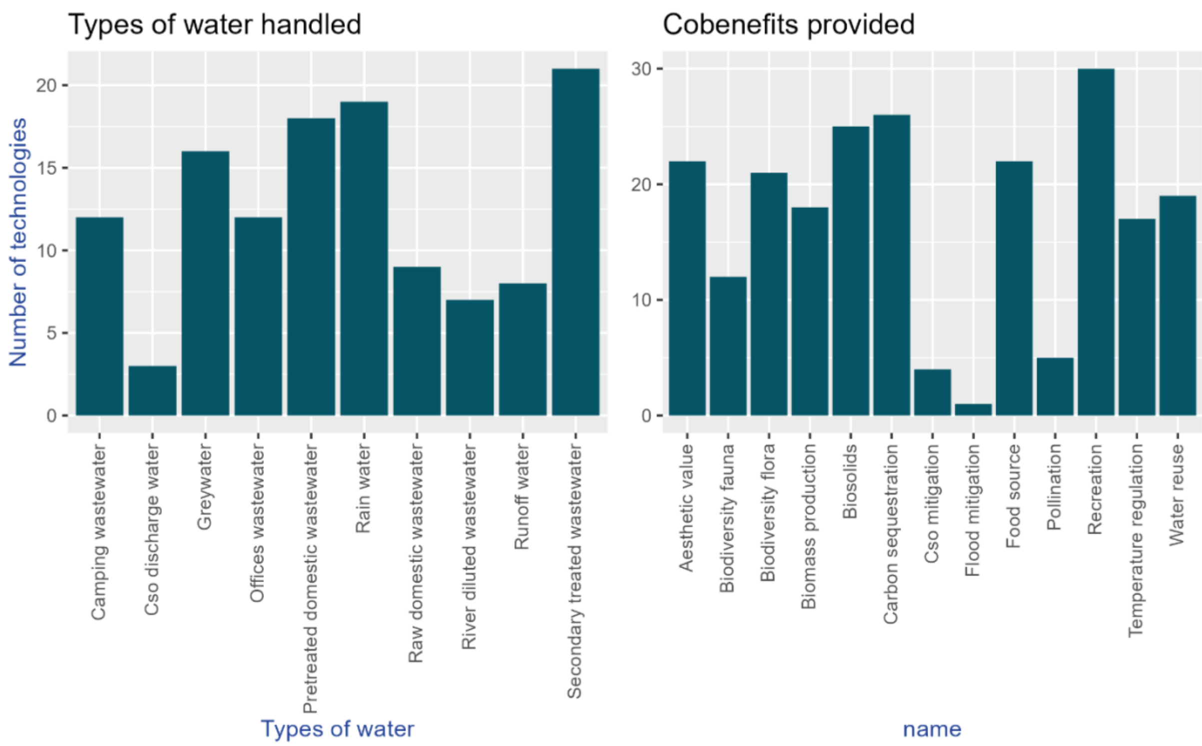

Figure 3. Types of water handled by technologies (left) and cobenefits provided (right).

The knowledge base incorporates three barriers to implementation: biohazard risk, required manpower, and necessary technical skills. Few technologies pose a high biohazard risk, and the majority necessitate low technical skills. The most common requirement for manpower is at a medium level (Figure 4).

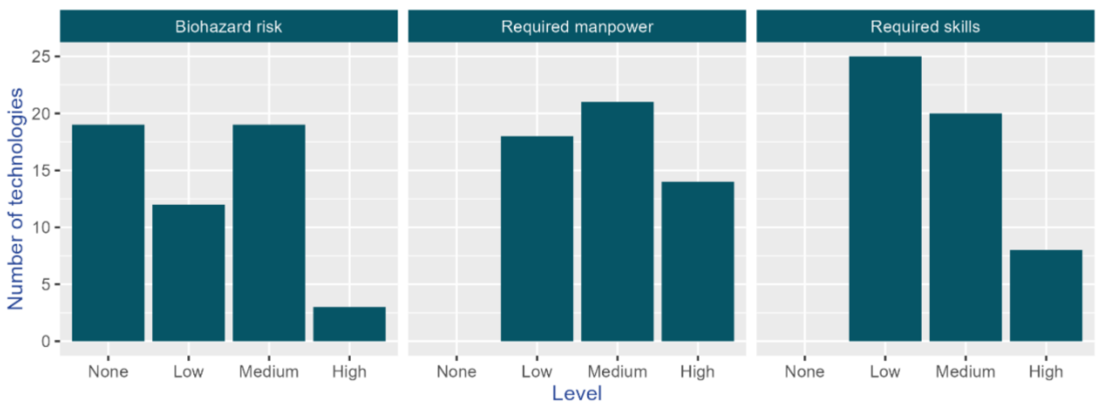

Figure 4. Barriers to implementation of technologies in the knowledge base

The knowledge base also provides values, derived from expert assessments, to estimate the required surface area for a given water scenario, taking into account the climatic context for treatment performance. Concerning SWM technologies, it is also considered whether they can infiltrate water or only retain it (Figure 5).

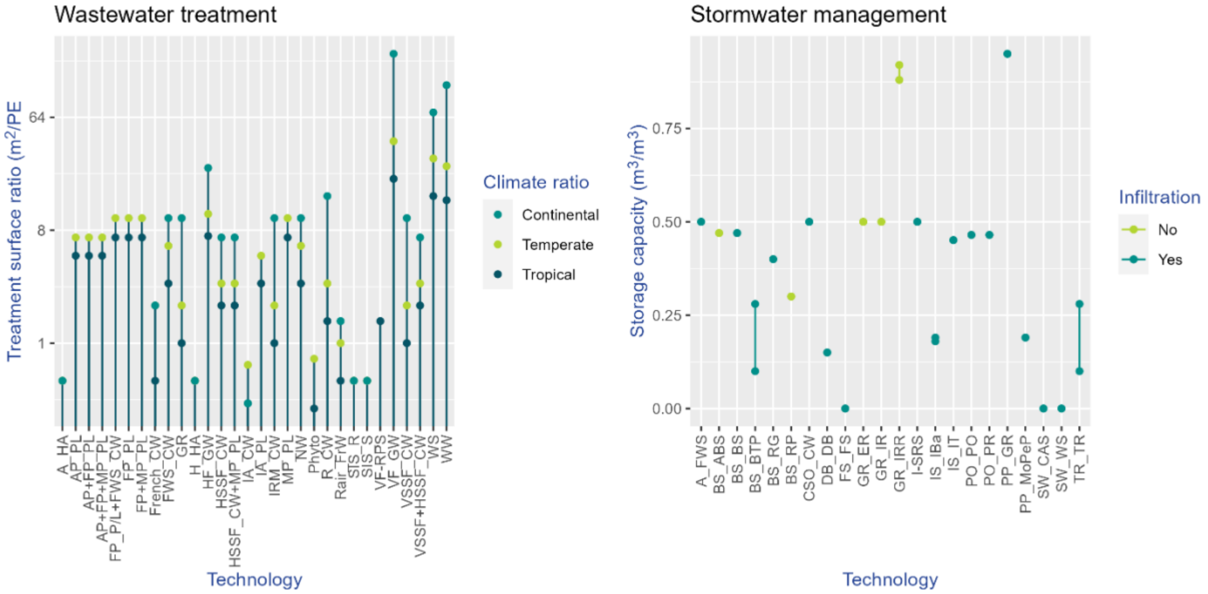

Figure 5. Expert-based data used to estimate the required surface for wastewater treatment (left) and stormwater management (right) technologies. Note that the scale in left panel is in $\log_2$. The acronyms description can be found in Appendix 1.

The knowledge base is accessible through the API developed within the MULTISOURCE project. This REST API delivers the knowledge base in JSON format via the following endpoint: https://snappapi-v2.icradev.cat/technologies/technologies. The endpoint supports a query parameter, allowing users to download information for a specific technology using its 'id.' For instance, to retrieve details for horizontal flow treatment wetlands, one can use the technology's id as a query parameter in the URL: https://snappapi-v2.icradev.cat/technologies/technologies?id=HSSF_CW. Additionally, the raw knowledge base is available as a CSV file at this URL: https://snappapi-v2.icradev.cat/technologies.csv."

A static version of the knowledge base has been deposited on ZENODO: https://doi.org/10.5281/zenodo.10401963.

4. DATABASE OF SCIENTIFIC PUBLICATIONS

The database of scientific publications comprises 894 publications related to the technologies in the knowledge base. Among these, 636 publications are dedicated to technologies for water treatment, while 258 focus on technologies for stormwater management (SWM). Constructed wetlands with horizontal (HSSF_CW) and vertical flow (VSSF_CW) are the technologies with the highest number of publications, followed by ponds and wetlands (PO_PO) specifically for stormwater management (Figure 6).

Notably, 12 technologies lack corresponding scientific publications. Six of them pertain to the six pilots of MULTISOURCE for water treatment (excluding the green roof, which is for SWM). This is anticipated as these innovative technologies are likely to have publications, potentially after the MULTISOURCE project. The remaining six technologies consist of two multi-stage technologies (facultative pond + free water surface flow constructed wetland and Horizontal flow treatment wetland + maturation pond), reactive media in treatment wetland (a type of constructed wetland), and three SWM technologies (anaerobic bioretention system, grass reinforcement and conveyance, and attenuation swale).

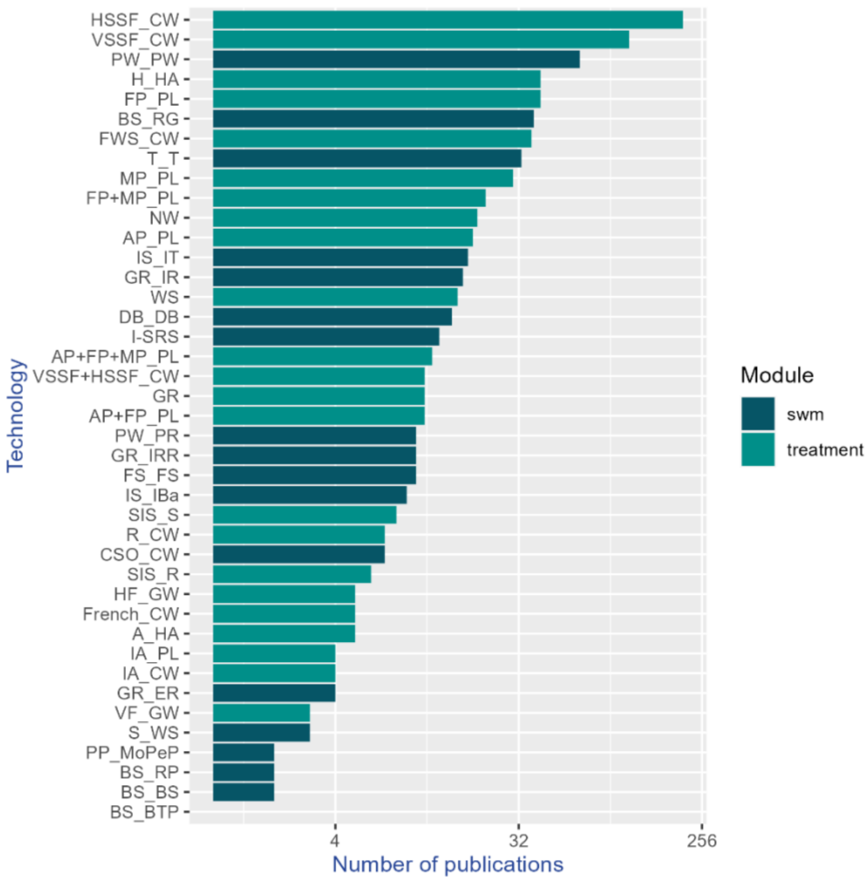

Figure 6. Number of scientific publications by technology. Note that the scale is in $\log_2$.

The structure of the database encompasses all necessary information for identifying and retrieving publications, including title, DOI, year of publication, authors, journal, issue, and pages. Users of the tool have the capability to update the database with new publications, and for traceability, each publication includes details about the uploading user: username, email, and company (which is not publicly available). A field named 'validation_status' indicates whether a publication has been accepted after peer review, with only accepted publications being publicly available.

To retrieve scientific publications, users can use the following API endpoint: https://snappapi-v2.icradev.cat/sci-studies/sci-publications, providing access to all scientific publications in JSON format.

In a separate table within the database, information is stored for modelling the surface in water treatment technologies. Both tables are linked using a common ID. A single scientific publication may contain data from various sampling campaigns or different technologies. In such cases, each campaign is treated as a distinct observation, represented by a separate row in this table. The information in this table includes details about water characteristics (inflow rate, pollutant concentration, type of water, temperature) and technology attributes (surface, urban water system, people served, and year of operation) (Table 2).

Table 2. Features of water treatment technologies in scientific publications

Variable	Description	Values or units
type	Type of technology	Types in the knowledge base
sub_type	Sub-type of technology, also referred as technology in the knowledge base	Technologies in the knowledge base
water_type	Water type treated by the technology	Water types of the knowledge base
uws	Urban water system where the technology operates	WWTP-Household-River
population	Population served by the technology	Number of people
surface	Surface of the technology	m^2
inflow	Inflow rate of wastewater	m^3/day
hrt	Hydraulic retention time	days
water_temp	Temperature of wastewater	ºC
air_temp	Temperature of air during the sampling	ºC
year_operation	Year of the sampling	year
bod_in, bod_out	Biological oxygen demand concentrations in the inflow and the outflow	mg O_2/L
cod_in, cod_out	Chemical oxygen demand concentrations in the inflow and the outflow	mg O_2/L
tn_in, tn_out	Total nitrogen concentrations in the inflow and the outflow	mg N/L
no3_in, no3_out	Nitrate concentrations in the inflow and the outflow	mg N/L
nh4_in, nh4_out	Ammonia concentrations in the inflow and the outflow	mg N/L
tp_in, tp_out	Total phosphorus concentrations in the inflow and the outflow	mg P/L
po43_in, po43_out	Phosphate concentrations in the inflow and the outflow	mg P/L
ecoli_in, ecoli_out	Escherichia coli concentrations in the inflow and the outflow	cfu/L
heggs_in, heggs_out	Helminth eggs in the inflow and the outflow	eggs/L

This table encompasses 647 sampling campaigns sourced from 191 publications. Constructed wetlands, particularly horizontal and vertical flow wetlands, showcase the highest number of observations, with hydroponic systems also contributing significantly. As mentioned earlier, the six pilots from MULTISOURCE and three other technologies lack related publications and, consequently, do not appear in this table detailing treatment performance (Figure 7).

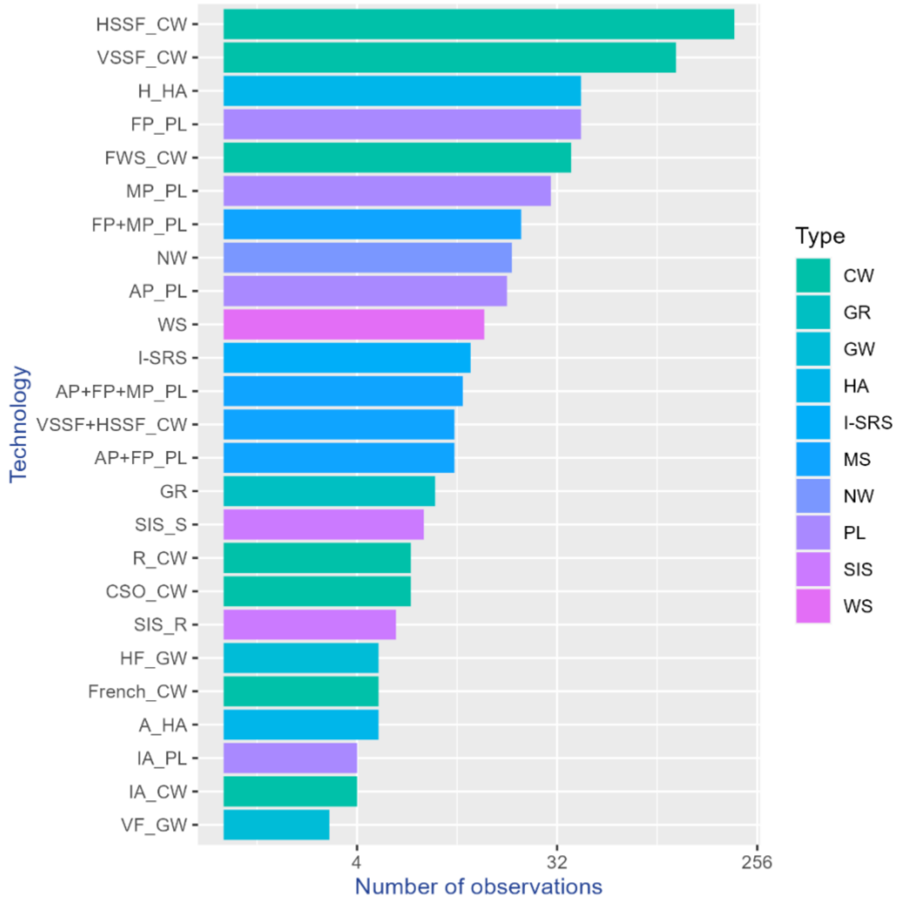

Figure 7. Number of observations by technology with information on treatment performance

However, not all information was consistently available in every scientific publication, resulting in varying numbers of missing values in the table. Consequently, certain analyses can only be conducted using a subset of the observations. The variables with the highest number of missing values are the count of Helminth eggs, followed by concentrations of *E. coli*. In contrast, the dataset is most complete for BOD concentrations, followed by COD and ammonia. Both inflow rate and surface variables have no missing values, as their availability was a prerequisite for inclusion in this table. Similarly, the year of operation has no missing values; when information was absent in the paper, the year of publication was used instead (Figure 8).

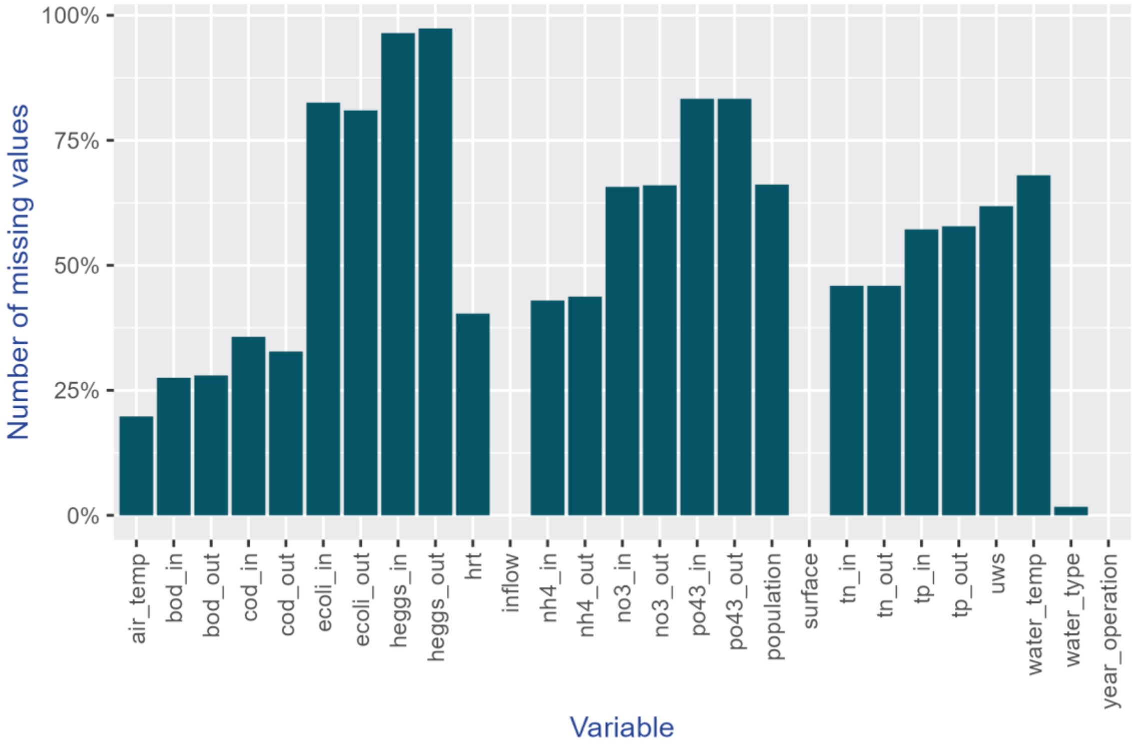

Figure 8. Number of missing values for each variable in the dataset

Once viable technologies are identified, the WP4 tool also allows to carry out a preliminary design by estimating the required surface. Thus, we can explore the BOD removal as a function of the surface used at the technology level, calculated as:

$$BOD_{REMOVAL} = BOD_I Q_I - BOD_O Q_O$$

where *Q* means flow *I* means inflow rate and *O* means outflow rate (and assuming $Q_I = Q_O$).

The primary issue to note is the imbalance among technologies, with some having more than 100 observations for BOD, while others have only 2 or 3. It's important to mention that in Figure 9, technologies without information on BOD concentrations or those with zero variance in BOD removal or surface were excluded. These technologies include in-stream restoration (no BOD information), slow-rate soil infiltration system (no BOD information), horizontal flow green wall (no BOD information), French constructed wetlands (5 observations with the same surface), constructed wetlands for CSO discharge (2 observations with the same surface), vertical flow green walls (3 observations with the same surface), aquaponic systems, and willow systems (1 observation).

For technologies with proper information on BOD, most exhibit expected positive slopes in modelling BOD removal as a function of surface (note that the figure depicts power models, i.e., log-log linear models). However, natural wetlands and aerated treatment wetlands deviate from this trend, showing negative slopes, indicating that larger surfaces decrease BOD removal, which is not possible from a mechanistic point of view (Figure 9).

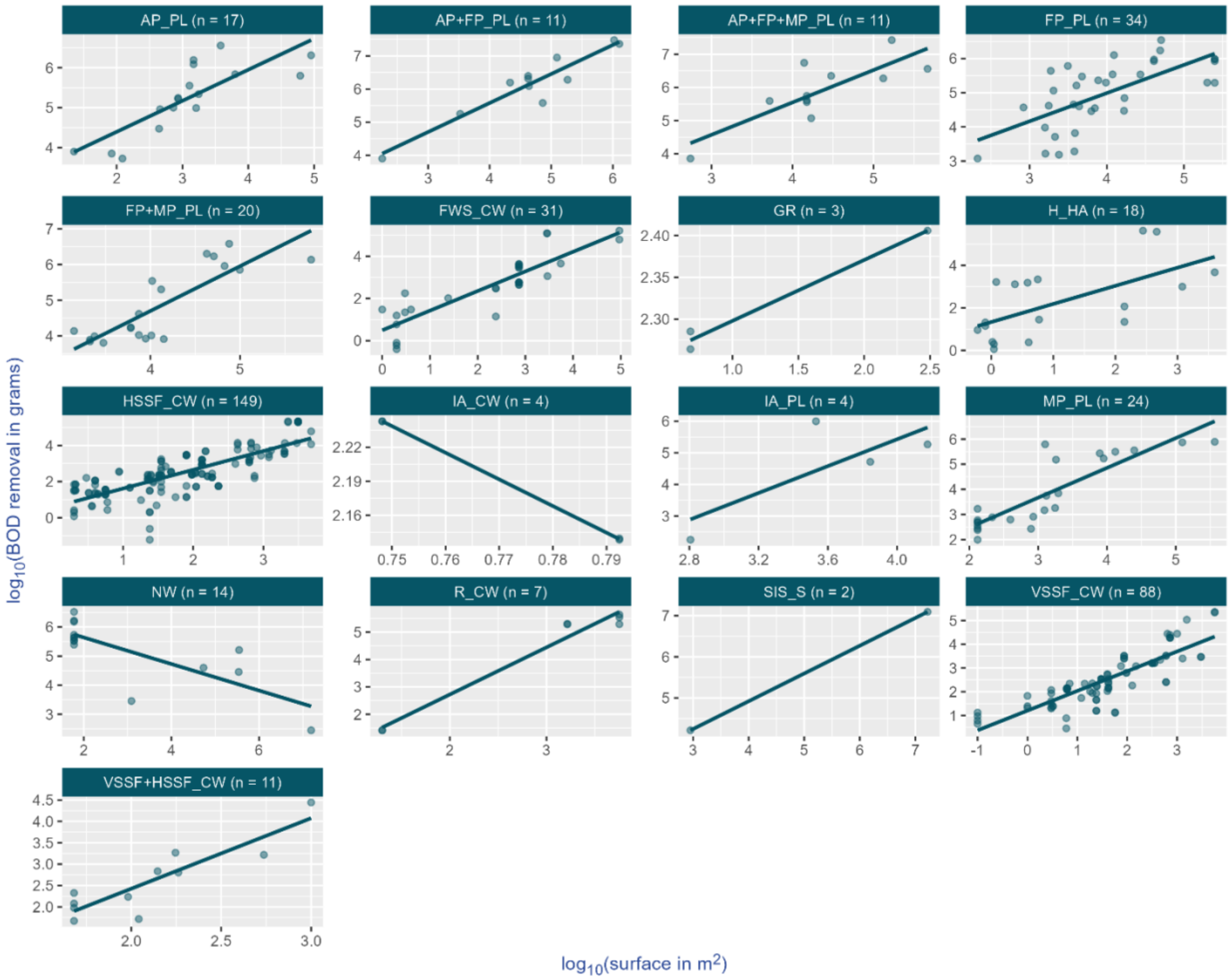

Figure 9. BOD removal as a function of surface using power models.

We can replicate the same analysis for COD (Figure 10). Six technologies are excluded: French vertical wetlands, green walls, aquaponics, and in-stream restoration are omitted for the same reasons explained above. Additionally, aerated treatment wetlands and natural wetlands are excluded due to a lack of COD information in either none or just one observation. Examining the slopes in the power models, only one technology, surface aerated ponds (with only two observations), exhibits negative slopes.

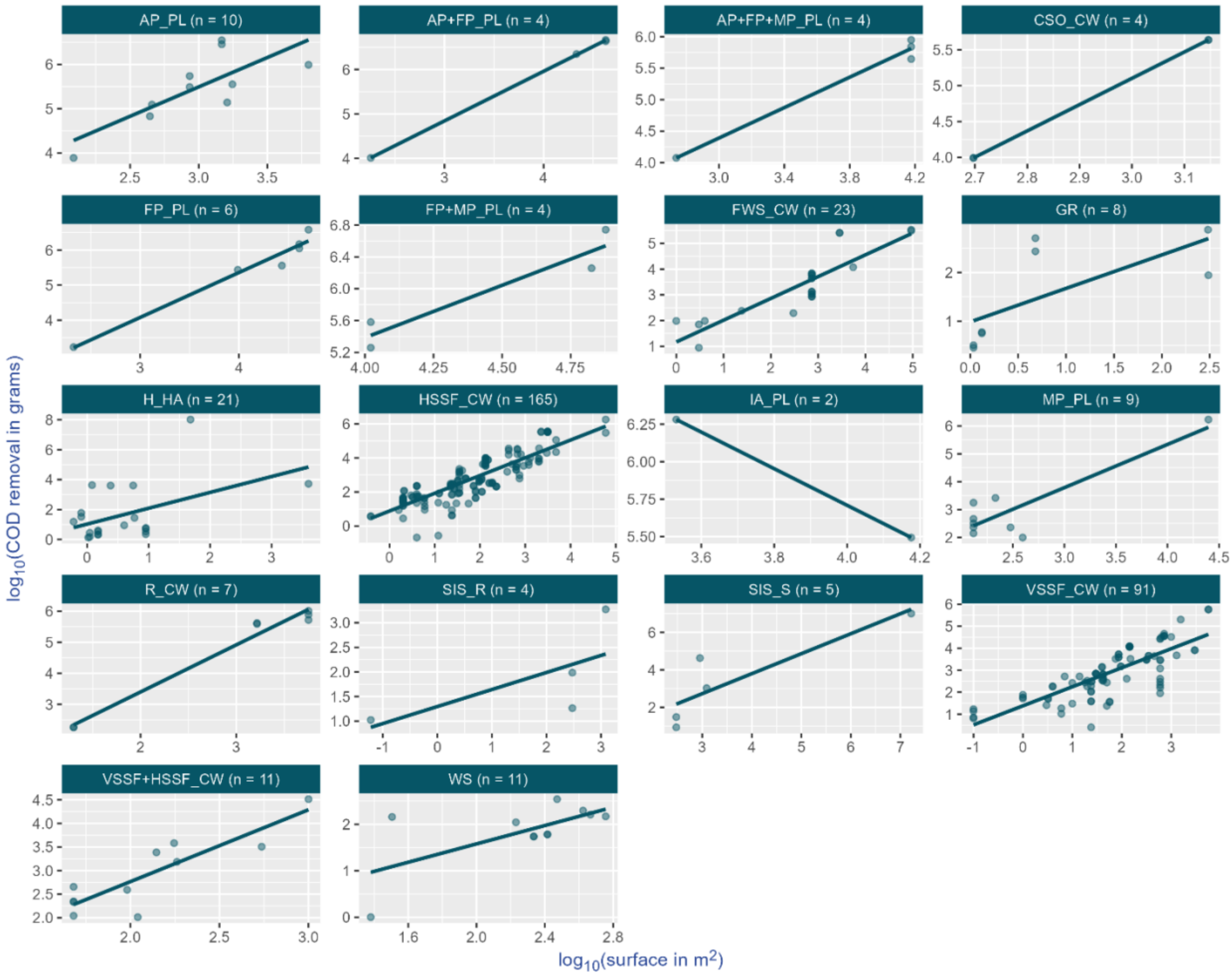

Figure 10. COD removal as a function of surface using power models.

We replicate the analysis for ammonia, the third most observed pollutant and a significant parameter in water treatment (Figure 11). In this case, six technologies are excluded. Like in BOD and COD analyses, French constructed wetland, vertical flow green wall, and aquaponics are omitted, i.e., all observations present the same surface and it is not possible to calculate the regression parameters. Additionally, natural wetlands, willow systems, and surface aerated ponds are excluded due to a lack of information on ammonia removal. Similar to previous examples, a couple of observations show negative slopes, specifically for horizontal flow green walls and aerated treatment wetlands.

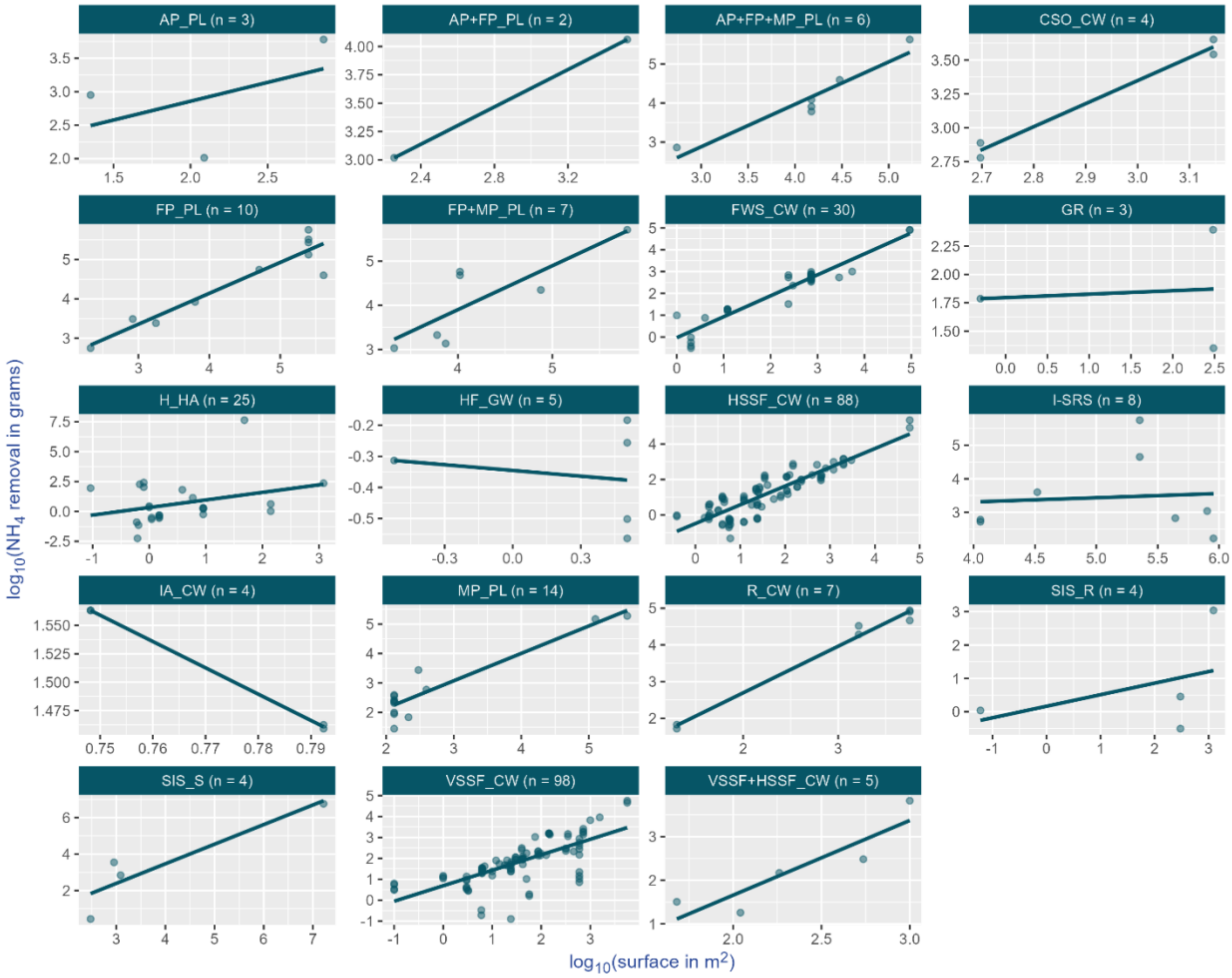

Figure 11. NH_4 removal as a function of surface using power models.

To retrieve all water performance data obtained from scientific publications, users can use the following API endpoint: https://snappapi-v2.icradev.cat/sci-studies/sci-studies?records=true, providing access to all sampling data in JSON format.

As mentioned above, a static version of the knowledge base has been deposited on ZENODO: https://doi.org/10.5281/zenodo.10401963.

CONCLUSIONS

In this comprehensive study of nature-based solutions for water management, the MULTISOURCE project has developed an extensive knowledge base encompassing 53 technologies, focusing on water treatment, storage, and reuse. The project's objective includes citywide planning facilitated by enhanced natural treatment systems and decision-support tools.

The technology selection tool, a key component of MULTISOURCE, integrates a knowledge base and a database, aiding stakeholders and decision-makers in choosing and pre-designing optimal natural treatment systems based on specific water scenarios. Notably, the tool considers various variables, including cost, environmental impact, and operational needs.

The data and information of the knowledge base is gathered through distinct stages, including the SNAPP project, MULTISOURCE pilots, and the incorporation of nature-based solutions for stormwater management. The SNAPP project utilized elicitation workshops, employing the IDEA protocol, while the MULTISOURCE pilots and stormwater management solutions were integrated through workshops and desk work.

The database of scientific publications, comprising 894 entries, provides a robust foundation for referencing technologies in the knowledge base. This resource, accessible through a REST API, ensures traceability and user involvement in updating new publications. The inclusion of information about the user who uploaded publications adds an additional layer of accountability.

Surface modeling for water treatment technologies involves two interconnected tables, offering insights from 647 sampling campaigns. The analysis reveals imbalances among technologies, influencing the availability of observations. While most technologies exhibit positive slopes in BOD removal modelling as a function of surface required, natural wetlands and aerated treatment wetlands deviate with negative slopes. Similar analyses for COD and ammonia underscore the varying performance of different technologies.

The study acknowledges challenges such as data imbalance among technologies, missing values, and the exclusion of certain technologies due to insufficient data or variance. Additionally, the observed negative slopes in natural wetlands and aerated treatment wetlands in BOD removal raise considerations for further investigation.

The knowledge base, API, and raw data files are made accessible following the FAIR principles, ensuring transparency and fostering collaboration within the research community. Likewise, it must be noted that the knowledge base is in continuous construction and review. New data can be provided at any moment to supply the current weaknesses. Especially regarding treatment performance for some technologies. Within the MULTISOURCE project this database will be enlarged with data from partners, historical data as well as experimental data carried out in the MULTISOURCE pilots.

In conclusion, the MULTISOURCE project's comprehensive approach to data collection, analysis, and transparency contributes valuable insights into nature-based solutions for water management. The knowledge base, supported by user-friendly tools and openly available data, provides a foundation for informed decision-making in urban water treatment and stormwater management.

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APPENDIX 01: NAME AND DESCRIPTION OF TECHNOLOGIES

ID	NAME	TYPE	DESCRIPTION
A_FWS	Aerated + free water surface wetland	MS	Combination of aerated and free water wetland designed for CSO wastewater
A_HA	Aquaponic system	HA	Aquaponics
AP_PL	Anaerobic pond	PL	Wastewater stabilization ponds/lagoons - Anaerobic
AP+FP_PL	Anaerobic + facultative pond	MS	Multistage Wastewater stabilization ponds/lagoons - Anaerobic+Facultative
AP+FP+MP_PL	Anaerobic + maturation pond	MS	Multistage Wastewater stabilization ponds/lagoons - Anaerobic+Facultative+Maturation
BS_ABS	Anaerobic bioretention system	BS	A bioretention system that has the outlet pipe designed so that there is a permanent water level within the drainage layer to create an anaerobic environment at the bottom of the system.
BS_BS	Bioretention swale (or trench)	BS	A bioretention swale is a shallow and vegetated depression with sloped sides that is located within the base of a swale.
BS_BTP	Bioretention tree pit	BS	A bioretention tree pit is a street tree pit with enhanced performance achieved through extra surface planting and soil amendments.
BS_RG	Rain garden	BS	Rain gardens are small bioretention systems that serve part of a single property.
BS_RP	Raised planter	BS	Raised planters are boxed systems constructed above the surrounding ground surface with a planted soil mix and an underdrain to collect the filtered water.
CSO_CW	Treatment wetland for CSO	CW	CW - Subsurface flow - CSO wetlands
DB_DB	Detention basin	DB	Detention basins are landscaped depressions that are normally dry except during and immediately after storm events.
FP_P/L+FWS_CW	Facultative pond + Free water surface flow constructed wetland	MS	Multistage Facultative pond + Free Water Surface Constructed Wetland
FP_PL	Facultative pond	PL	Wastewater stabilization ponds/lagoons - Facultative
FP+MP_PL	Facultative + maturation pond	MS	Multistage Wastewater stabilization ponds/lagoons - Facultative+Maturation
French_CW	French vertical flow treatment wetland	CW	CW - Subsurface flow - French reed beds
FS_FS	Filter strips	FS	Area uniformly graded and gently sloping strips of grass or other dense vegetation that are designed to treat runoff from adjacent impermeable areas.
FWS_CW	Free water surface treatment wetland	CW	CW - Surface flow - Free water systems
GR	Rooftop treatment wetland	GR	CW - subsurface flow - Rooftop wetlands
GR_ER	Extensive green roof	GR	Roofs that are covered with a lightweight layer with a shallow growing medium.
GR_IR	Intensive green roof	GR	Roofs that have deep that can support a wide variety of plantings.

This project has received funding from the European Union's Horizon H2020 innovation action programme under grant agreement 101003527.

ID	NAME	TYPE	DESCRIPTION
GR_IRR	Intensive green roof with retention layer	GR	Roofs that have deep substrates that can support a wide variety of plantings and incorporate an extra retention layer.
H_HA	Hydroponic system	HA	Hydroponics
HF_GW	Horizontal flow green wall	GW	GW - Green wall with horizontal flow
HSSF_CW	Horizontal flow treatment wetland	CW	CW - Subsurface flow - Horizontal flow
HSSF_CW+MP_PL	Horizontal flow treatment wetland + maturation pond	MS	Multistage Wastewater Subsurface horizontal CW + Maturation pond
IA_CW	Aerated treatment wetland	CW	CW - Intensified wetlands - Aerated engineered wetland
IA_PL	Surface aerated pond	PL	Wastewater stabilization ponds/lagoons - Intensified aeration
IRM_CW	Reactive media in treatment wetland	CW	CW - Intensified wetlands - Reactive Media
IS_IBa	Infiltration basin	IS	Flat-bottomed shallow landscape depressions that store runoff before infiltration into the subsurface soils.
IS_IT	Infiltration trench	IS	Linear excavations filled with gravel or stone that create temporary subsurface storage of stormwater runoff.
I-SRS	In-stream restoration	I-SRS	Instream retention systems
MP_PL	Maturation pond	PL	Wastewater stabilization ponds/lagoons - Maturation
NW	Natural wetland	NW	Natural Wetland
Phyto	Phytoparking	CW	Underground natural wastewater treatment combined with parking space on top
PO_PR	Pond retrofits	PO	It is the improvement or adaptation of an existing pond to function as a Sustainable Urban Drainage System (SUDS).
PO_PW	Pond	PO	Ponds are features with a permanent pool of water that provide both attenuation and treatment of surface water runoff.
PP_GR	Grass reinforcement	PP	A type of ground protection that uses plastic or concrete grids infilled with grass or gravel to create a load-bearing grass reinforced surface.
PP_MoPeP	Modular permeable paving	PP	A type of permeable paving that consists of modular units that are laid on a permeable base and sub-base.
R_CW	Reciprocating treatment wetland	CW	CW - Intensified wetlands - Recirculation/Tidal
Rair_FrW	Rhizosph'air aerated french wetland	CW	Rhizosph'air aerated french wetland
RG-T	Rain garden with treatment	CW	Bioswale to collect and treat road runoff
S_CAS	Conveyance and attenuation swale	SW	Conveyance and attenuation swales act similar to a pipeline in that they collect and carry surface water to the next stage in the SuDS management train.
S_WS	Wet swale	SW	Wet swales are specifically designed to provide wet or boggy conditions at their base.
SIS_R	Slow-rate soil infiltration system	SIS	Infiltration or soil-based treatment systems - Rapid

ID	NAME	TYPE	DESCRIPTION
SIS_S	Rapid-rate soil infiltration system	SIS	Infiltration or soil-based treatment systems - Slow
TR_TR	Trees	TR	Trees detain water in their canopies and enhance infiltration in their pits.
VF_GW	Vertical flow green wall	GW	GW - Green wall with vertical flow
VF-RPS	Vertical flow wetland with recycle and partial saturation	CW	Vertical flow wetland with recycle and partial saturation
VSSF_CW	Vertical flow treatment wetland	CW	CW - Subsurface flow - Vertical Flow
VSSF+HSSF_CW	Vertical flow + Horizontal flow treatment wetland	MS	CW - Subsurface flow - VSSF+HSSF
WS	Willow system	WS	CW - zero discharge - Willow systems
WW	Hybrid living wall	GW	Modular green wall combining vertical and horitzonal flow treatment units

The overall goal of MULTISOURCE is to, together with local, national, and international stakeholders, demonstrate a variety of about Enhanced Natural Treatment Solutions (ENTS) treating a wide range of urban waters and to develop innovative tools, methods, and business models that support citywide planning and long-term operations and maintenance of nature-based solutions for water treatment, storage, and reuse in urban areas worldwide. The project includes seven pilots treating a wide range of urban waters. Two individual municipalities (Girona, Spain; Oslo, Norway), two metropolitan municipalities (Lyon, France; Milan, Italy), and international partners in Brazil, Vietnam, and the USA will contribute to each of the main project activities: ENTS pilots, risk assessment, business models, technology selection, and the MULTISOURCE Planning Platform. The use of urban archetypes in the Planning Platform will enable users to quickly classify regions (in both developed or developing countries) suitable for the application of nature-based solutions for water treatment (NBSWT) and compare scenarios both with and without NBSWT.

MULTISOURCE
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