2018 Joint Call

Closing the water cycle gap - Sustainable management of water resources

Research-based Assessment of Integrated approaches to Nature-based SOLUTIONS (RainSolutions)

Progress Report – Case Study 8: Igapó, a shallow tropical urban lake in the municipality of Londrina, Paraná state, Brazil

1. SUMMARY

The main goal of this case study is to deliver information that allows actions to make urban environment more resilient and cost effective by using NBS in the urban area of the Igapó lake watershed, Londrina, Brazil. To achieve this goal, we have developed a strategy based on a set of actions axis dedicated to water quality analysis, hydro-climatology, land cover, and NBS interventions. Two additional axis involving environmental services, financial sustainability, stakeholders, and regulations were also planned to a second phase of the project. For the axes foreseen in the context of the RainSolutions consortium, the deliverables were as follows:

D-01 Trend analysis for precipitation rates performed by the Mann-Kendall and Pettitt tests

D-02 The rainfall intensity-duration-frequency (IDF) curves

D-03 Water Quality Index (IQA) for two different rainfall regimes

D-04 Adequacy of hydrological model to assess the effectiveness of NBS-interventions

D-05 High resolution map of land cover classes

D-06 Systematic literature review on NBS interventions in urban stormwater drainage

D-07 Ranked potential benefits of NBS to control stormwater drainage

D-08 Flood risk map for Igapó lake basin

D-09 Potential NBS spatial allocation

2. CASE STUDY STRATEGY

As soon as the RainSolutions proposal was submitted, in 2018, we tried to identify what would be the most effective strategy to contribute to the Consortium, considering the limitations imposed by the small financial resources made available by the funding agency here in the state of Paraná, Brazil. In such initial phase of strategy survey, several components that represent challenges for nature-based solutions (NBS) interventions were evaluated. For example, tools and methods for mapping and assessing benefits, indicators to measure NBS effectiveness in providing solutions/benefits, ecosystem disservices that may emerge from NBS interventions, weak knowledge of NBS design, implementation, evaluation, and monitoring over time, human nature relationships and conflicts, society participation, stakeholders, assign monetary values to environmental resources, time/spatial scale mismatch between governance, built infrastructure, natural processes and NBS-interventions. It is in this context that our case study (Lake Igapó) appears, a shallow tropical urban lake in the municipality of Londrina, Paraná state, Brazil.

Once this first stage of discussions, debates, and summaries of existing knowledge on the topic was completed, we moved on to the second phase, which was precisely the elaboration of the case study proposal, that was presented at the first consortium meeting, and whose results achieved so far are the subject of this report. During the execution of the project, we seek to identify the best way to approach stakeholders safely and permanently. To be a little more assertive in this stakeholder approach, we sought to identify the spatial limits of the proposal and identify the most emerging environmental issues that could be benefited by NBS interventions in the chosen basin. Among the environmental problems faced by the lake that could be benefited by NBS-type interventions, we identified: the silting - accelerated by human activities in the drainage area and intense building in the coastal zone – not sustainable; water supply in the lake basin strongly dependent from watersheds that are far beyond the city limits; untreated or not fully treated sewage, chemicals, waste, plastics and other pollutants, causing high water-treatment costs due to the watershed degradation and its practically uselessness to Londrina citizens.

After the above-mentioned issues, the most obvious conclusion was that there would be no conditions to address all the challenges in this case study proposed for investigation. So, it was decided to develop a strategy based on methodologies that could provide answers to the most urgent questions and that would allow stakeholders to start moving towards NBS-type interventions. At the same time, other actions necessary, but not possible within the timeframe and funds available, were also included in the scope, but reserved to become part of the project in due course. To achieve our goal, we divided our action plan into several cells (Figure 01). Each cell of Figure 01 offers interfaces for interacting with other RainSolutions case studies. A small group of young engineering professionals was hired, under the supervision of professors from the Campus Londrina of the Federal University of Technology - Paraná (UTFPR).

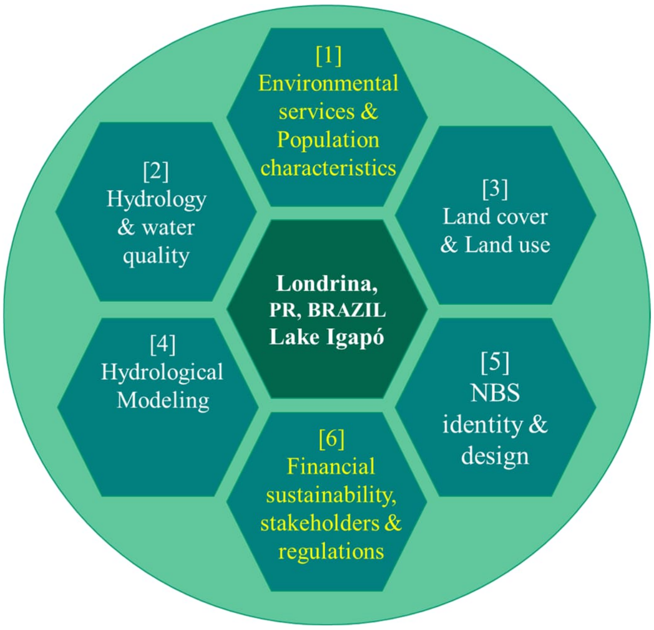


Figure 01 - Diagram representing the main actions expected in the strategy set up for the case study

The actions expected in each cell were executed by one or more professionals. Cells [1] and [6], even if presented in this section, were planned to be executed in the future, with a new source of funding. They will no longer be included in the sequence of sections of this document. Among the main goals of this axis formed by these two cells is the understanding of the social dimensions of the project (business, arts, sports, leisure, rest, gastronomy) which are related or dependent on environmental conditions of the lake (the lake value). Develop an economically viable strategy to fund the proposed NBS (how far it can go in terms of space and time), estimating costs, co-benefits, level of stakeholder's involvement, and changes in regulations, are also actions that will be duly addressed in this axis. The effectiveness of implementing this axis depends on the success of the other four cells. In fact, the vertical axis begins to take shape as the deliverables from the other cells begin to appear. And what are the findings of these other base cells? This is what we will discuss in the coming sections. They basically were planned to: [2] Analyze the water quality of the lake and tributary streams, as well as the hydrology of the study area, including increased frequency of extreme events; [3] Map the land cover by identifying the classes and especially the permeable and non-permeable areas of the watershed; [4] Model the hydrology of the basin with high spatial and temporal resolution, and; [5] Identify the NBS with the greatest potential for the region, including creating useful indicators for decision makers when implementing NBS.

3. WORK PERFORMED AND THE RESULTS ACHIEVED

3.1 Hydrology and water quality (cell 2)

3.1.1 Rainfall regime and IDF curves

Nature-Based Solutions (SBN) interventions are highly dependent on knowledge of the rainfall regime of the study area. However, in addition to not having any precipitation data series in the Igapó lake basin, most data series in the vicinity are short and/or incomplete, with many ranges of missing data. Among the closest stations, only one data series offered minimal conditions for the study. This is the station belonging to the Paraná Institute of Agronomy, which is a few km from the Igapó lake dam. Monthly rainfall observed in this station is showed in the Figure 02, the vicinity of Lake Igapó. As suggested by the monthly rainfall, in the Igapó area, rainfall events are distributed throughout the year, but more concentrated in the warm months. However, extreme events displaced from the warm months is not uncommon. The highest value among the annual precipitation totals occurred in 2015 (2449 mm). The three highest daily accumulated rainfall were observed in June 1997 (161.0 mm), June 2012 (200.5 mm), and January 2016 (223.6 mm).

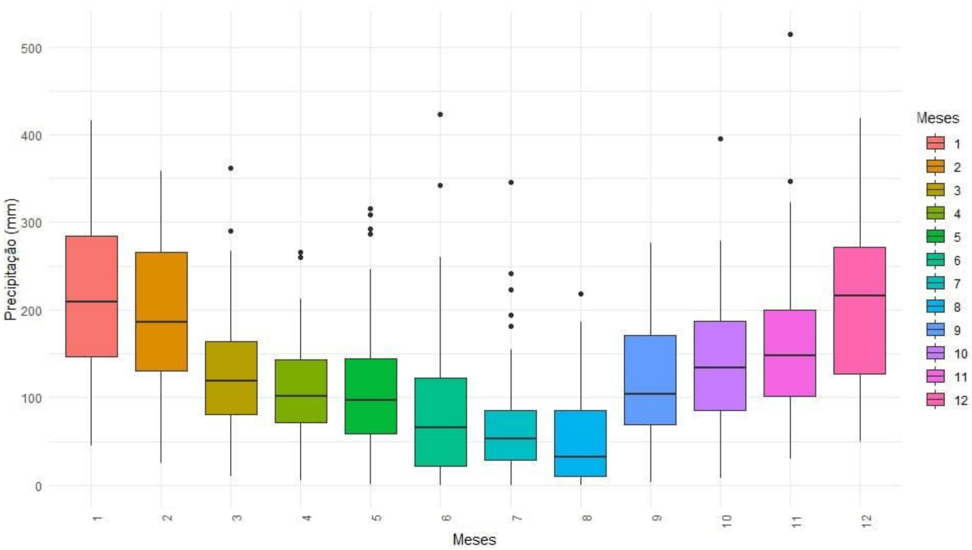


Figure 02 - Monthly rainfall observed in the vicinity of Lake Igapó.

The adaptation and minimization of the impacts inherent to extreme rainfall events depends on a rigorous statistical analysis of the intensity and frequency of their occurrences. In this context, the main deliverables of this section was to identify trends in extreme precipitation events in the

Igapó basin and derive the rainfall intensity–duration–frequency (IDF) curves. For the annual trend analysis, a decrease was observed for all indices analyzed at a significance level of 1%. With regard to the analysis of trends in monthly rainfall, only a few indices among those analyzed showed statistically significant trends. The IDF equation was fit from the Gumbel maximum distribution and the CETESB Disaggregation Method (1986). The coefficient of determination (R^2), obtained from the relationship between observed and estimated rainfall intensities by the IDF equation, was 0.998, which allows its reliable use for the design of infrastructures that are directly impacted by precipitation events in the region. These information is showed in a usable way by the Deliverables D-01 and D-02 (Section of Deliverables).

3.1.2 Water quality

In this deliverable, we proposed to the public agent that the actions aimed at monitoring the effectiveness of NBS should be carried out through the Water Quality Index (WQI). The assessment of water quality has become an essential activity in the face of the constant population increase and the growing rate of urbanization that directly impact water of the Igapó lake. The water quality was evaluated through fieldwork, divided in two campaigns with 15 collection points distributed between the source of the Ribeirão Cambé microbasin and the Igapó I lake dam in the city of Londrina/PR (Figure 04). The campaigns were carried out in the year 2021, in the months of January and August, as they are periods with different climatic characteristics, with rainfall in January, and drought in August. Eleven physicochemical and microbiological parameters were evaluated: temperature, electrical conductivity (EC), hydrogenic potential (pH), turbidity, dissolved oxygen (DO), total solids, total nitrogen, total phosphorus, biochemical oxygen demand (BOD), fecal coliforms and Escherichia coli. The water quality index (WQI) was calculated, and multivariate data analysis was performed using Principal Component Analysis (PCA). The results were compared to the limit values of CONAMA Resolution Nº 357/2005. The study showed that in the first campaign, in January during the rainy season, the site was heavily impacted by the sediment transport process, which has led to its advanced current conditions of silting. The runoff and the excess amount of organic matter, demonstrated by the high values of BOD, turbidity, and fecal coliforms are consistent with the current state of the lakes. In August, during the dry season, the contamination was more localized at specific points, but the water is also impacted by the accumulation of contaminants. This is verified by the high concentration of salts due to the lower water flow. Parameters such as EC, total phosphorus, and total solids confirm the role of contaminants present in the sediment. WQI values are presented in the Deliverable D-03.

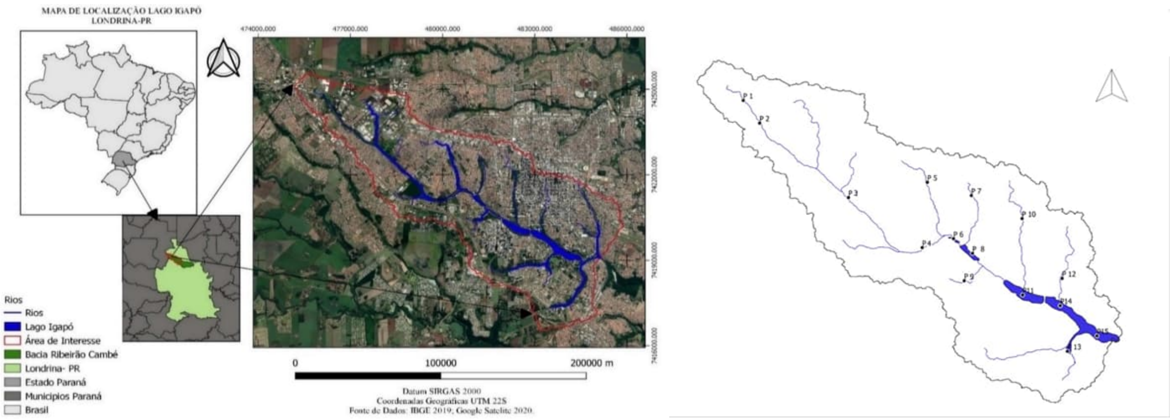


Figure 03 - Spatial distribution of sampling points along the basin

3.2 Hydrological modeling (cell 4)

Runoff estimates and dimensioning of the water retention capacity by NBS depend on hydrological models. A hydrological model, duly calibrated and validated for the basin, will be an essential tool to assess the effectiveness of the NBS interventions. For example, simulations with a hydrological model could show the flood response to a given rainfall event before and after the implementation of an NBS. In another example, in an urbanized scenario, but with greater water retention (via intervention by NBS), it is expected that the lake reaches its peak flood level more slowly and with less frequency and severity than without the presence of NBS distributed over the drainage area. In this specific objective, the focus was the identification of a hydrological model that would meet the specific needs of urban drainage. The calibration and validation of the model, although essential for its use, is not part of this stage of the work and will be planned in a subsequent stage of the project, even because there are data not yet available for the lake drainage area. Several hydrological models were evaluated regarding their suitability for urban areas and the parameterizatons associated with NBS. Deliverable D-04 represents the results of such evaluation.

Only a few hydrological model meets the necessary requirements for its application in urban drainage. For the Igapó lake, we are suggesting the adoption of the SWMM (Storm Water Management Model) is proposed. The model was developed by the U.S EPA (Environmental Protection Agency) in 1971 and has been continually improved. It is a dynamic rainfall-runoff model, used for urban drainage management, which allows calculating the different water flows across the basin. The SWMM has a history of numerous applications and will be fundamental for evaluating the effectiveness of interventions associated with NBS. Figure 03 shows the preliminary result of the simulated streamflow for the Igapó basin. In the example illustrated in the figure, scenarios of increase (+25%) and decrease (-25%) in the impermeable area of the basin were considered. It is just an experiment to control and learn the parameters of the model.

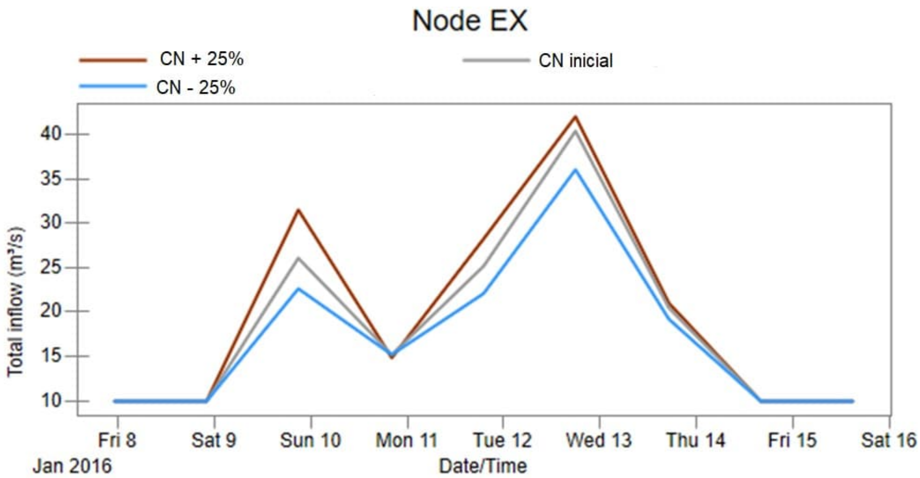


Figure 04 – Total inflow into the Igapó lake, considering scenarios of increase (+25%) and decrease (-25%) in the impermeabe area of the basin.

3.3 Land cover & land use (cell 3)

With urbanization, the original land cover is replaced by elements that prevent or hinder the infiltration of rainwater. Nature-based solutions have proved to be a viable alternative for dealing with problems associated with urban drainage. However, the success of interventions is highly dependent on an understanding of the elements that predominate on the urban surface. In this sense, the main objective here was the application of machine learning algorithms in high resolution satellite images to classify land use and occupation in the drainage area of the Igapó lake. Images of the Pleaides satellite constellation, with a high level of spatial resolution, were used for the classification (Figure 05). Twelve specific thematic classes were established for classifying land cover. Supervised classification was applied, and the following Machine Learning algorithms were evaluated: Decision Tree (DT), Randon Forest (RT), Support Vector Machine (SVM), K-Nearest Neighbors (KNN) and Normal Bayes. DT was the classifier that presented the best performance, both for the global classification and for the individual classes. The values for the Kappa, Precision, Recall, and F1-Score indices were between 90% and 100% for the DT classifier. The Deliverable D-05 represents a DT-based high resolution map of land cover classes, which are available to stakeholders at various file formats.

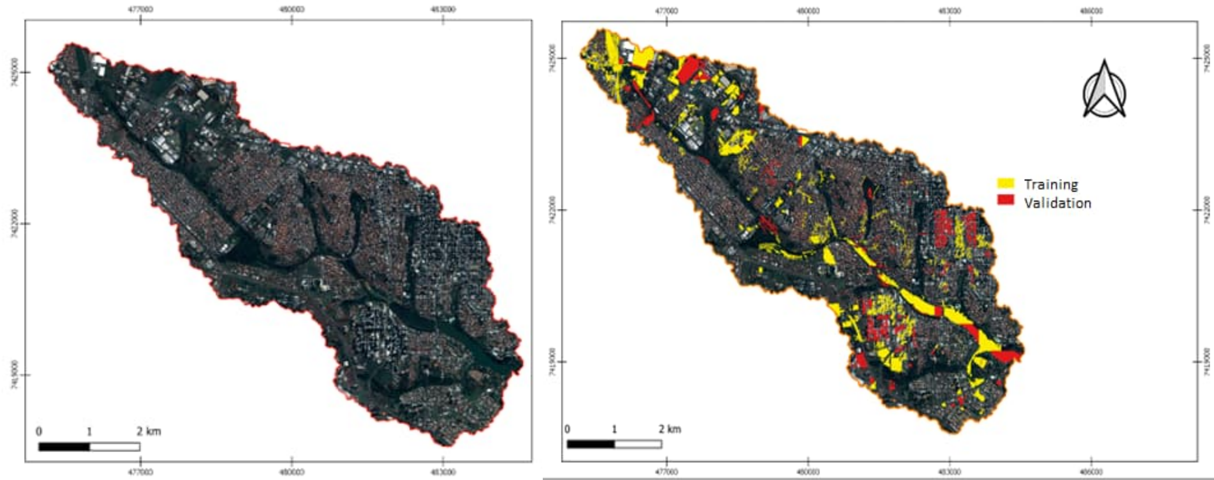


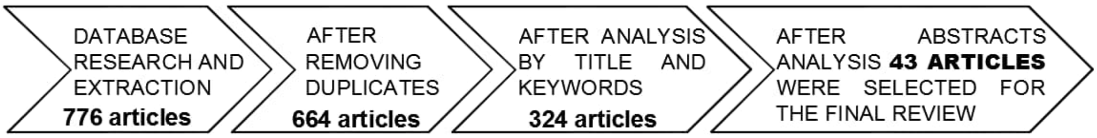
Figure 05 – High resolution image for the Igapó lake drainage area, obtained by the Pleiades constellation (left), showing the areas used for training and validation.

3.4 NBS identity & design (cell 5)

3.4.1 Bibliometric review

This section aims to assess the state of the art in using NBS for stormwater management in urban areas. The starting point of this working cell was an extensive literature review focusing on those solutions applied in stormwater management that have passed through an evaluation period.

The steps used to conduct the selection of articles can be seen below in Figure 06. As shown in the figure, 776 scientific papers were initially selected through the databases used. After removing duplicates using the Endnote and Mendeley libraries, a total of 664 scientific articles were selected for initial evaluation. The steps of the methodology applied to select the articles to be used in the systematic review, were:



NBS tools found in the analyzed studies seek to reduce rainwater flow volume, retaining it close to where it fell. They emphasize rainwater and wastewater management, ecological connectivity, and/or health and well-being applications, which are subjects intrinsically related to the Igapó lake emergences. The main solutions described in the case studies for rainwater management are presented in decreasing order according to the number of occurrences in the articles (Table 1).

Table 1 - Total number of occurrences of NBS in articles.

	Main Techniques		Occurrence Number in Articles
	Green roofs	16	17
A	Blue roof	1	
	Bioswales (with vegetation)	14	16
B	Bioswales (without vegetation)	2	
C	Rain garden		13
D	Permeable pavement		13
E	Dry detention basin		12
F	Retention pond		10
G	Tree pits		6
H	Infiltration trench / Detention		4
I	Constructed wetland		5
J	Rain barrel/cistern		3
K	Renaturalization of channels		2
L	Vertical gardens		1

Source: own author (2022)

Based on the identified articles (664), the VOSviewer software was used to graphically represent the strength of the links between the papers and the keywords of interest (Figure 06). In this tool, the similarity, the number of occurrences, and co-occurrences of the keywords are used to generate the density visualization diagram. Based on the list of keywords, the VOSviewer software organized the map where the sentences were grouped based on their co-occurrence in a single document. That is, if the words appear, then they are defined as co-occurring. All associated keywords are manually labelled based on the keywords observed in a cluster. Thus, this scientific panorama of research on sustainable urban drainage was finally generated from the perspective of NBS.

In general, through Figure 06, it is observed that, among the selected articles, the words with the greatest weight were “storms” and “water quality”. About the formation of clusters, groups of words with the greatest connection with each other, the terms were categorized into four groups, with each color representing a different cluster: cluster 1 (runoff, geological engineering, rain, storm sewers, and sustainable development); cluster 2 (storms, floods, climate change, and renewal); cluster 3 (monitoring, paving and sustainable drainage systems); cluster 4 (water quality, water management, and drainage). The word “storms” was the one that obtained the strongest link among the whole set. In addition to having the highest number of mentions, it is related to all other terms and clusters, whether in a greater or lesser degree of connection. This finding suggests that storms are at the center of the problem when NBS is considered in urban drainage.

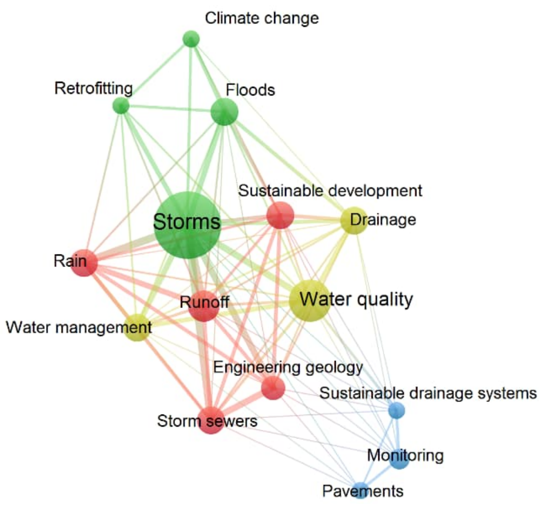


Figure 06 - VOSviewer graph-based showing the network and the clusters between the evaluated articles.

Based on the information collected in this in-depth bibliometric review, two deliverables proved to be useful to stakeholders. The first one (Deliverable D-06) is given by a data sheet indicating which sustainable drainage tools (e.g., green roofs, rain gardens, bioswales, retention ponds, infiltration trenches) were were correlated with each expected benefit. The second one (Deliverable D-07) was based on the BeST tool (Benefit of the SuDS tool), and determine which NBS tools and which benefits have the greatest weights.

3.4.2 Flood risk map

The use of NBS to mitigate flood risks is one of such pratical interventions in urban areas. Therefore, in this deliverable, the work advances in identifying flood risks in the Igapó Lake basin, wich is surrounded by the urban area of Londrina city. The methodology proposed for this research is based on multi-criteria analysis in a Geographic Information System (GIS) environment. The information layers were referenced by the Brazilian Geodetic System, which adopts the Reference System for the Americas (SIRGAS – 2000). All acquired data were organized in layers, sharing the same database for geospatial compatibility, according to Howard *et al.* (2008). The steps followed here are represented in the diagram of Figure 07, which integrates the primary data used, its manipulation in the GIS environment, and the multiparameter method "*Analysis Hierarchical Process" (AHP)* proposed by Saaty (1977). The results were integrated into a flood risk map (Deliverable D-08), which shows the areas likely to be flooded. About 3.1 km² (10.3%) of the basin is exposed to a high or very high risk of flooding, strengthening the importance of implementing NBS in the area.

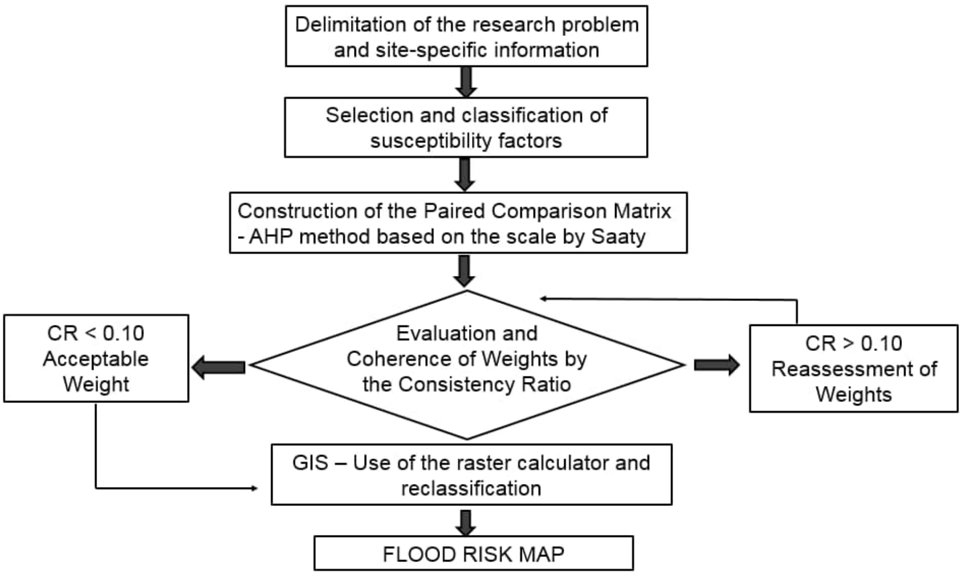


Figure 07 – Flow chart describing the processes involved in the modeling of the flood risk map.

3.4.3 NBS suitability index

Here we developed a criteria-based selection for application of NBS over the investigated urban area and the feasibility of implementing the 10 NBS ranked in the bibliometric review. The public and private spaces analysis was conducted based on the following criteria: slope, distance from the groundwater level, hydrological type of soil, infiltration rate, and distance from building structures. The results show that all NBS proposals were considered suitable for implementation in the study area, whether on a larger or smaller scale. The general percentage of the analyzed classes and the respective proportions of appropriate spaces are shown in Figure 08. The solution that showed the most significant potential for implementation in relation to the basin's total area was rain barrels, about 37.1% of the basin area, followed by tree pits and rain gardens, with a potential for implementation of 27.9% and 25.4% of the area, respectively. Spatial distributions of areas of potential NBS interventions are given in Deliverable D-09, separated by NBS type.

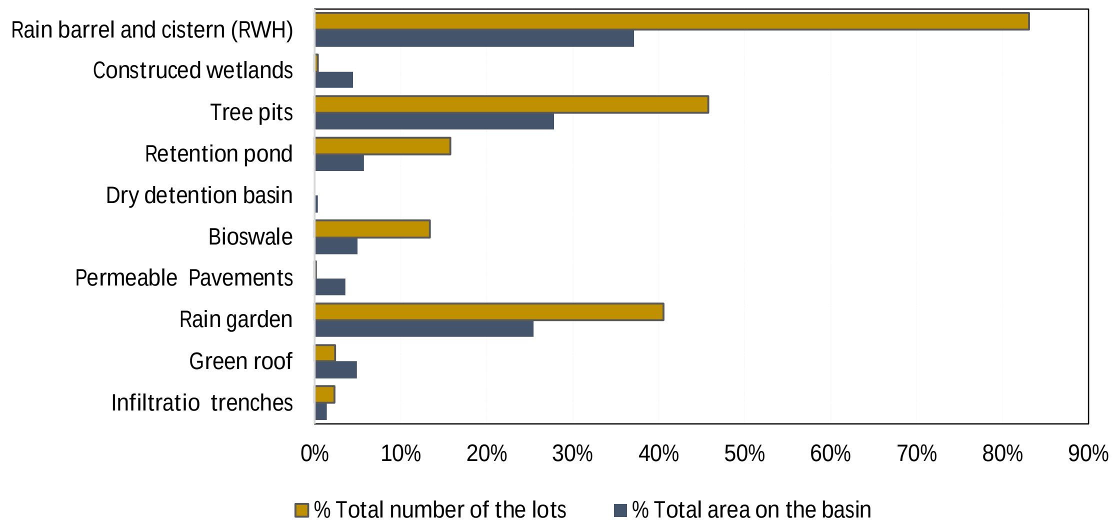


Figure 08 - Percentage of areas suitable for the evaluated NBS types

4. COLLABORATION, IMPACT ON SOCIETY AND STAKEHOLDER ENGAGEMENT

4.1 Partnerships and collaborations

From the point of view of collaboration within the scope of RainSolutions, exchanges of experience have taken place through regular meetings promoted by the Consortium's coordination. Unfortunately, the pandemic prevented the organization of most face-to-face meetings. Anyway, even though remote meetings, participation in discussions involving the experience of each partner was fundamental throughout the development of the activities in our case study. It is worth mentioning the experience in urban lakes of the partners from Danube Delta National Institute, especially in terms of rehabilitation of urban lakes, which is closely related to the challenges we face for Igapó lake in Londrina, Brazil. The way in which the Romanian local authorities participate and the vision of how to deal with the protection and restoration of aquatic ecosystems are experiences already well matured by the Romanian partners and this has made us move more quickly here, mainly avoiding experimental steps that may not be effective in the search for solutions. The University of Pretoria's experience with hydrological modeling and flow forecasting has also helped us to specify and choose a hydrological model for the drainage area of the Igapó lake. According to our expectations, the next steps here will be driven towards the modeling of rainwater flows and wastewater treatment, which suggests that we should expand the interaction with the experiences of the Wageningen University & VESI Environmental groups. Unfortunately, until the beginning of this consortium, our stage of involvement with NBS-related issues was too elementary to interact more strongly with these two groups, which are dealing with very advanced issues. We hope that from now on, this experience can be better used in the actions planned for the coming years. The experiences of VESI International, for example, will be essential when resources are available and the executive projects for installing the NBS are effectively contracted for the Igapó lake area. The other partners also have valuable experiences for the success of our case study, but many of them will be coming to our focus of attention in later stages of our case study.

At the local level, over the last two years, we have built a close collaboration with stakeholders, with the dialogue being mediated by IPPUL - Institute of Research and Urban Planning of Londrina, which manages the schedule of meetings and the exchange of data with the Secretariat of Government, the Civil Engineering Works Department, the Environment Department, the Londrina Municipal Transit and Urbanization Company (CMTU) and the Paraná Sanitation Company (SANEPAR). It is also important to highlight the collaboration with the EnvCity project, which deals with the development of an environmental quality monitoring network in Smart Cities. The project proposes the development of an air & water quality monitoring network using low-cost sensors and real-time data transmission, for later availability to society in the form of maps and/or via applications, in line with the concept of smart cities. Londrina is one of the pilot cities for the development of the project and two RainSolutions researchers are already integrated into EnvCity.

4.2 Stakeholder engagement

The main stakeholder in the contributions of our case study (Igapó lake) is the urban planning sector of the Municipality of Londrina. In this sense, in 2021 a working group was created involving researchers from UTFPR-RainSolutions team and engineers/architects from IPPUL. The priority actions of this working group have focused on the most urgent demands, which are: i) understand the hydrology of the lake; ii) mapping the entire network of stormwater drainage system, including the outfall points in the lake, for the purpose of calculating the volume of water, especially in situations of extreme events; iii) monitoring of areas that are disproportionately generating diffuse pollution; iv) identify priority NBS to contribute to the reduction of water velocity and sediment retention; v) elaboration of a project for dredging (removal and safe destination of sediments currently deposited in the lake). Although these actions are under the responsibility of the municipal administration, it will be monitored by UTFPR researchers. Among the actions foreseen in the dredging stage are: a) removal of a sediment sample and disposal in the vicinity of the lake, in a minimally adequate amount for monitoring its physicochemical properties, including analysis of the sediments to be removed (dehydration time, soil compaction behavior and tests of its use as a substrate for SBN settlement, landscaping elements and walking and cycling tracks; b) monitoring of odors from the organic decomposition process, dilution capacity in the atmosphere and ways of mitigation; c) testing the use of sediments as a substrate for plants and corrections that allow reaching the appropriate condition for landscaping; d) identification and quantification of adjacent areas able to receive the removed sediment without having to transport it out of the lake margins; e) carrying out the removal of sediment, in the proportions recommended for each lake in the Igapó system.

4.3 Knowledge output

We understand that the deliverables listed in this work correspond to the knowledge outputs of this project. They will be dealt with in an exclusive section following this text. However, the actions resulting from the involvement with public administration bodies, listed above, represent the main contribution, as they are a straight output of the RainSolutions that demonstrates its importance in the urban planning and environmental management sector of the city. This involvement also indicates that stakeholders have identified results of interest to them. In a practical way, the greatest contribution of the knowledge produced by our case study at the moment is its subsidy for the elaboration of a wide project, led by the public power, and that was presented to the Ministry of Regional Development, entitled "Strategies for the NBS interventions in the dredging of the Igapó lake, in the city of Londrina", whose objective is to recover and maintain the capacity of the Igapó lake to receive and flow rainwater in situations of extreme and prolonged rainfall. The actions aim to increase the resilience of the Igapó basin to extreme rainfall events, protect the lakebed from future silting processes, and guarantee an alternative source of water resources. The proposal is guided by the application of NBS and will rely on collaborative action between various entities and civil society, to generate a perspective of sustainable use of water resources.

5. DELIVERABLES

This section summarizes all the identified deliverables and include an illustration of the product. It should be remembered that supplementary information (figures, tables, maps, projects), as well as details of the methodology, will also be forwarded to stakeholders. All these additional information can gather a few dozen pages and are in Portuguese. However, if a RainSolutions partner is interested in a specific part, it will be provided in English.

Deliverable D-01

Trend analysis for precipitation rates performed by the Mann-Kendall and Pettitt tests considering a significance level of 5%. The selected indices were those that are associated with extreme rainfall events: daily rainfall, daily mean rainfall, monthly mean rainfall, number of wet days, average precipitation from wet days, wet period, percentiles of specific daily rainfall. The definition of each index is given in the supplementary list to the table.

	MANN KENDALL			PETTITT	
	Kendall's Tau	p-value	Trend	p-value	Changing point
Rx1day	-0,39	P<0,0001	Decrease	0,003	2008
Rx5day	-0,381	P<0,0001	Decrease	0,047	1988
SDII	-0,395	P<0,0001	Decrease	0,003	2011
R10mm	-0,385	P<0,0001	Decrease	0,034	1995
R20mm	-0,392	P<0,0001	Decrease	0,002	2008
R99p	-0,406	P<0,0001	Decrease	0,048	1998
R95p	-0,404	P<0,0001	Decrease	0,002	1998

CDW	-0,404	P<0,0001	Decrease	0,036	1984
CDD	-0,391	P<0,0001	Decrease	0,037	2001
PRCPTOT	-0,394	P<0,0001	Decrease	0,002	2008
Maxim	-0,39	P<0,0001	Decrease	0,002	2008
Mean	-0,395	P<0,0001	Decrease	0,003	2008

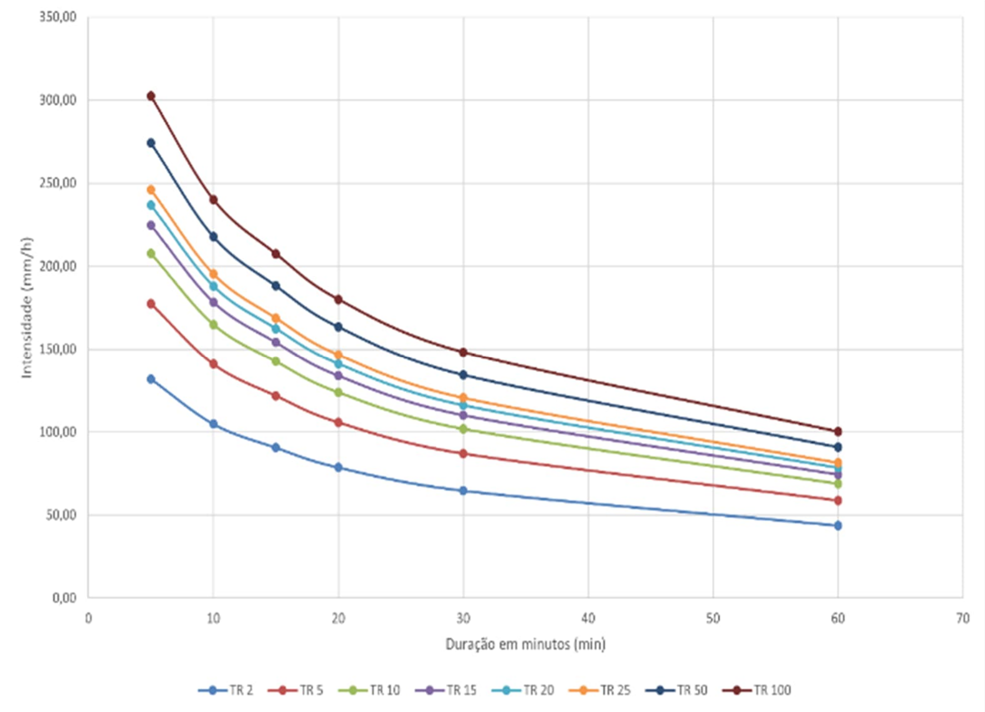
List of precipitation indices used to characterize rainfall in the Igapó lake region.

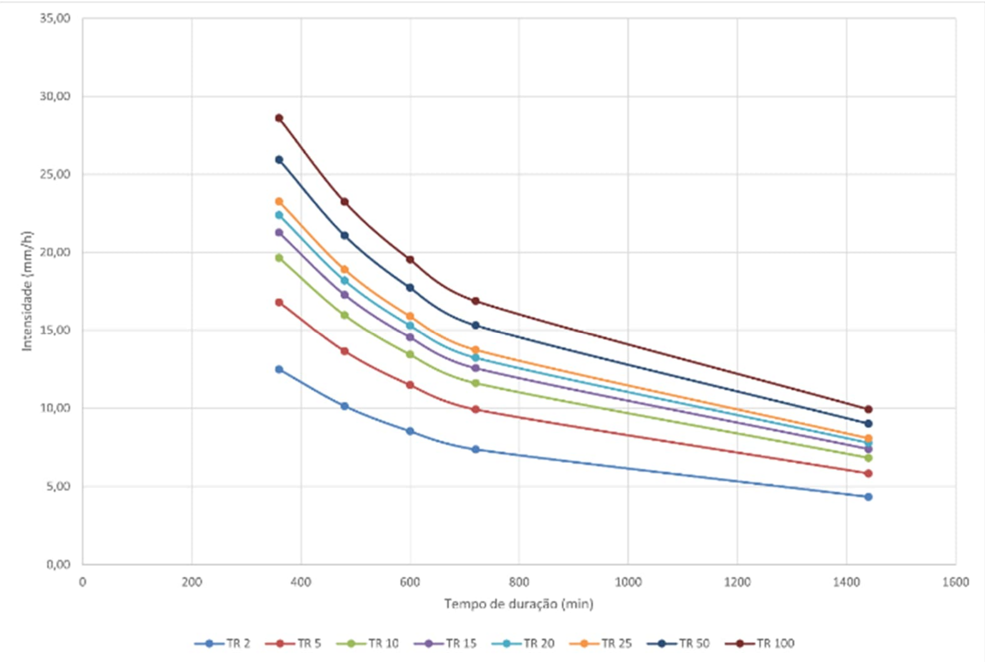
Symbol	Definition	Unit
RR	Daily rainfall: Observation of the total precipitation for the preceding 24 hours made at 7 a.m. local clock time.	mm
DR	Daily mean rainfall: The total amount of precipitation recorded during a period divided by the number of days of the period.	$mm.day^{-1}$
MR	Monthly mean rainfall: The total amount of precipitation recorded at a specific month divided by the number of months of the period.	$mm.month^{-1}$
WD	Wet days: Number of days with RR ≥ 1 mm	day
R_{a-b}	Annual count of days when $a \leq RR < b$	day
RWD	Average precipitation from wet days	$mm.day^{-1}$
WP	Wet period: Number of consecutive WD	day
RXP	Precipitation when RR > X^{th} percentile of the data series	mm
RX	Annual max consecutive X-day precipitation	mm

Deliverable D-02

The rainfall intensity-duration-frequency (IDF) curves are fundamental for the design of the urban drainage system and, therefore, if properly known for the lake Igapó area, they will be important for an effective management of the NBS interventions. The figure shows the IDF curves for the area of the lake, considering the durations of 5, 10, 15, 20, 25, 30, 60, 360, 480, 600, 720 and

1440 minutes and the return periods of 2, 5, 10, 15, 20, 25, 50 and 100 years. The data will be delivered to stakeholders in the form of tables, as well as methodology used in the construction of the curves.





Deliverable D-03

The results suggest that the contamination of anthropic origin is present in both sampling campaigns. In general, the lake's WQI could be rated as "good", and, in addition to the PCA analysis, show that the water quality of the micro basin, when evaluated in an integrated manner by the WQI, is independent of the seasonal effect. The invariability of the WQI demonstrates that changes in environmental conditions, from one season to the other, promote the intermittence of parameters, so that the degraded nature of the water bodies prevails over seasonality. In view of this, for the planning of the NBS intervention, it is highly recommended to pay close attention to the parameters implicit in the calculation of the WQI. What the findings indicate is that part of the pollutants comes from surface runoff and part comes from sediments already deposited at the bottom of the lakes. We will make available to the stakeholders both the methodology involved and the collection protocol for analysis of all parameters involved in the WQI calculation.

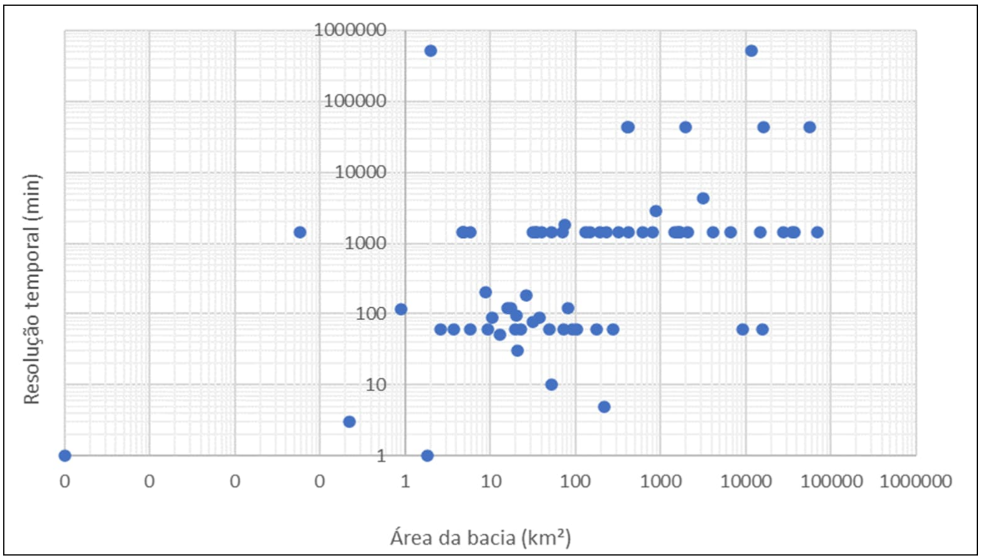
Water Quality Index (WQI)

Collection Sites	Description of Collection Sites	Values	
		Rainy Season	Dry Season
P1	Source of Ribeirão Cambé	77,00	76,00
P2	Lake near the source of Ribeirão Cambé	73,00	77,00
P3	Site in the Ribeirão Cambé bed	76,00	66,00
P4	Mata stream	59,00	79,00
P5	Baroré stream	73,00	70,00
P6	Igapó Lake IV	50,00	76,00
P7	Rubi stream	83,00	68,00
P8	Igapó Lake III	69,00	73,00
P9	Colina Verde stream	81,00	68,00
P10	Água Fresca stream	75,00	61,00
P11	Igapó Lake II	71,00	82,00
P12	Leme stream	51,00	68,00
P13	Capivara stream	78,00	78,00
P14	Igapó Lake I (collect point 1)	85,00	80,00
P15	Igapó Lake I (collect point 2)	80,00	80,00
Average		72,10	73,50

Water Quality Index Level	Water Quality Status	
	Excellent	90 < WQI ≤ 100
	Good	70 < WQI ≤ 90
	Moderate	50 < WQI ≤ 70
	Bad	25 < WQI ≤ 50
	Very Bad	0 < WQI ≤ 25

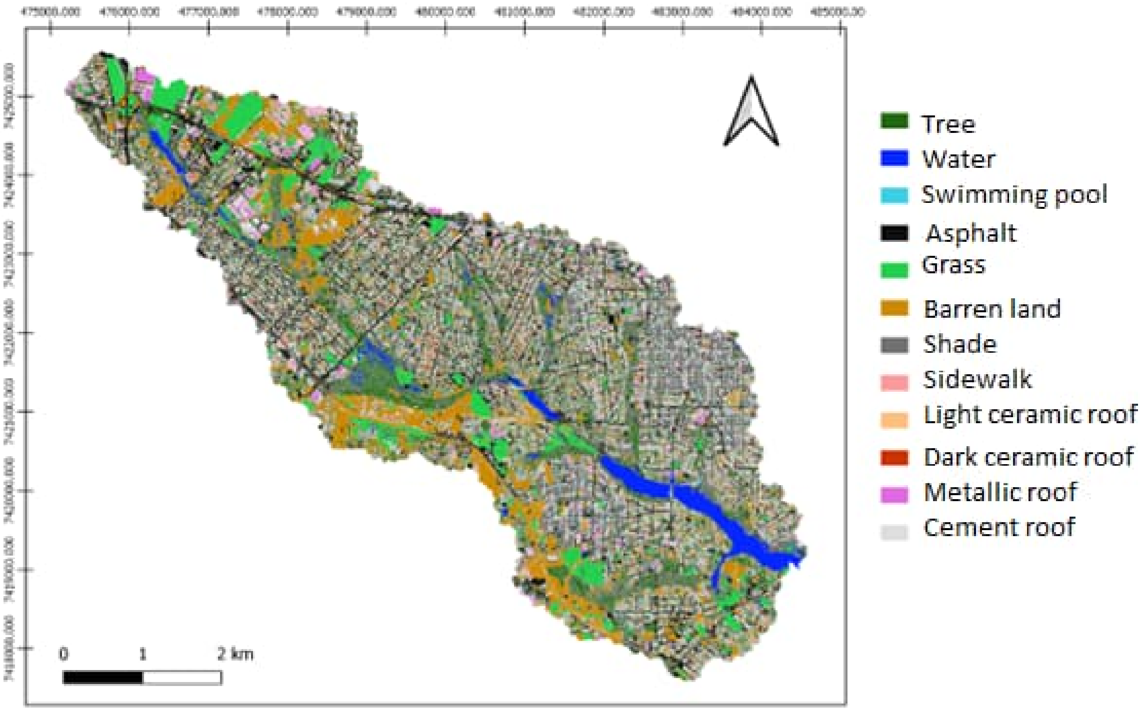
Deliverable D-04

The purpose of this deliverable is support the decision makers in choosing the suitable hydrological model to assess the effectiveness of NBS-interventions. The temporal/spatial scale of resolution of the models are the first step in order to organize/acquire input data. The relationship between the basin area (km²) and the temporal resolution (min) of the input data, for a great number of aplication was evaluated and are displayed in an statistical base. It is possible to observe that, for basins between 10 and 100 km² (case of Igapó lake), the most used temporal resolution is hourly. For basins with larger areas, the tendency is to use daily data. Therefore, the drainage area of the Igapó lake, with about 32 km², requires information with hourly temporal resolution for the input data, which are not yet available.



Deliverable D-05

This deliverable comprises a high resolution map of land cover classes, available at various file formats, with high accuracy, representing 100% of the drainage area of the Igapó lake.The green areas, represented by Trees/bushes and Grass, together with roofs, represent the majority classes, with 24% and 23% of the total drainage area, respectively. Asphalt and pavement, with 19% of the area, and barren land, with 14%, were also classes with expressive participation. The remaining fraction consists of water (including swimming pool surface) and shaded areas. This deliverable can be a very useful tool for NBS-intervention projects to solve urban drainage problems.



Deliverable D-06

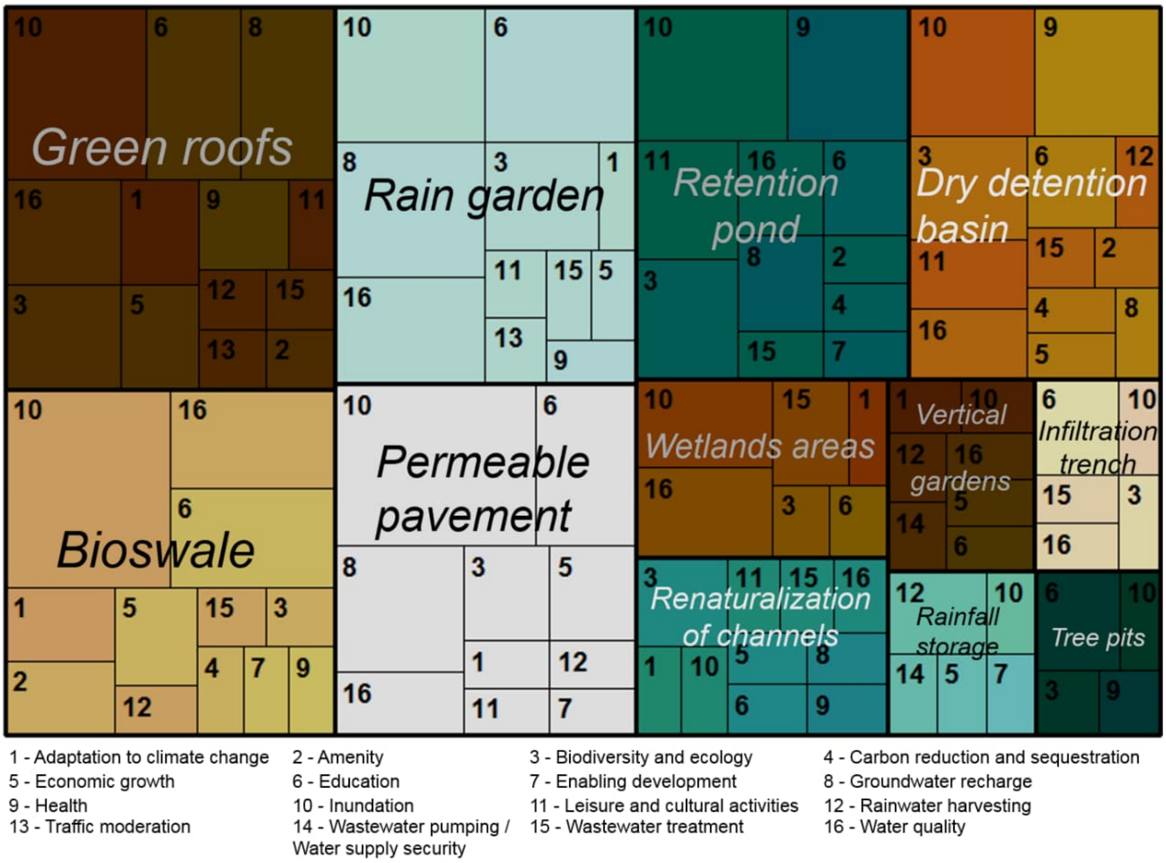
This deliverable was built based on the systematic NBS literature review. All these documents share practical implementation experiences of NBS worldwide and reveal numerous essential findings, with key ecosystem benefits. A tool to help professionals and customers assess the benefits of sustainable drainage systems was launched in 2015 by CIRIA (Construction Industry Research Information Association). It is the BeST tool (Benefit of the SuDS tool), and we used here to produce this deliverable. The tool presents summary tables in an ecosystem service structure (ESS), and has helped decision-makers investigate future options with relative robustness and flexibility. Therefore, we elaborated a table that connects the benefits of the BeST assessment tool with the NBS tools evaluated in each description of the articles. The investigation allowed the wider benefits to be captured. The scheme below follows a logical and simplified evaluation process. It indicates which services were most listed in the articles and their correlations with each specific sustainable drainage tool (e.g., green roofs, rain gardens, bioswales, retention ponds, infiltration trenches). This means that in each manuscript examined, occurrences/frequency of each listed benefit were counted.

Benefits Category	A	B	C	D	E	F	G	H	I	J	K	L
Air quality												
Amenity	✓	✓			✓	✓						
Biodiversity and ecology	✓	✓	✓		✓	✓	✓	✓	✓		✓	
Construction temperature												
Carbon reduction and sequestration	✓				✓	✓						
Crime reduction												
Economic growth	✓	✓	✓	✓	✓					✓	✓	✓
education	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Enabling development	✓			✓		✓				✓		
Adaptation to climate change	✓	✓	✓	✓					✓		✓	✓
Inundation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Groundwater recharge		✓	✓	✓	✓	✓					✓	
Health	✓	✓	✓		✓	✓	✓				✓	
Wastewater pumping / Water supply security										✓		✓
Rainwater harvesting	✓	✓		✓	✓					✓		✓
Leisure and cultural activities			✓	✓	✓	✓					✓	
Tourism												
Traffic moderation		✓										
Wastewater treatment	✓	✓	✓		✓	✓		✓	✓		✓	
Water quality	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓

Note: A - Green roofs/ Blue roof; B - Bioswales (with and without vegetation); C - Rain garden; D - Permeable pavement; E - Dry detention basin; F - Retention pond; G - Tree pits; H - Infiltration trench/ Detention; I - Constructed wetland; J - Rain barrel/cistern; K - Renaturalization of channels; L - Vertical gardens.
Source: Own author (2022)

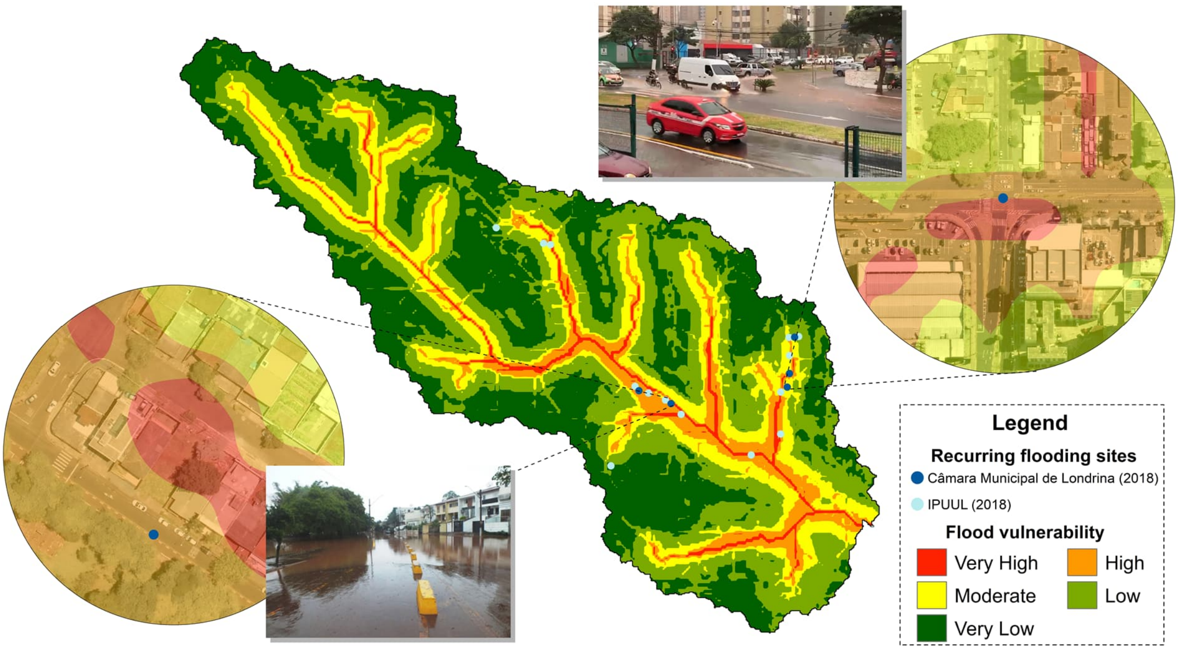
Deliverable D-07

In this deliverable, we do not include a detailed assessment of the impacts or monetized values of the benefits mentioned in the references. They are potential benefits since each location reserves its particularities and values could hardly be associated to a new application context. Therefore, the real objective here was to connect the tools based on principles of NBS and benefits that were somehow reported. For this purpose, the selected works were examined in depth. Each evidence of the various benefits reported was recorded in an Excel spreadsheet. In this way, it was possible to determine which NBS tools and which benefits have the greatest weights. The results are mainly based on the indicators described in the case studies and the potential benefits of each NBS tool. The score was assigned by multiplying the number of times a "benefit" was reported and recorded in the table (table with additional information will be delivered to stakeholders).



Link between the main NBS tools and the potential benefits reported in the reviewed articles. T**he top-level order corresponds to the rectangles with different colors representing each NBS and their respective names. The size of the colored rectangles reflects the number of benefits considered within each group. The figure illustrates that some groups showed several benefits (e.g., green roofs and bioswale), while others presented a lesser number (tree pits, rain barrel/cistern, infiltration trench). The second level (the rectangles within each group) represents the benefit intensities for each NBS tool. For example, studies on green roofs demonstrate 13 benefits, of which the Inundation (10), Education (6), and Ground recharge (8) proved to be the most recurrent benefits. On the other hand, Rainwater harvesting (12), Traffic moderation (13), Amenity (2), and Wastewater treatment (15) were the least cited benefits in the studies.**

This deliverable compris a map of vulnerability to flooding for the Igapó Lake basin. The flood risk map was divided into five classes, with different degrees of vulnerability: very low, low, moderate, high, and very high risk. The result of the evaluation of the area proved to be quite uneven. The area of greatest exposure to danger is concentrated in the central region of the basin. Recurring flood sites in the Igapó lake drainage area are also identified on the map. This product will be delivered with high resolution and accompanied by tables with complementary information to stakeholders.



Deliverable D-09

To identify locations for NBS implementation in the Igapó Lake basin, we also applied a methodology based on multiple criteria, using a GIS environment. This deliverable presents suitable sites for implementing ten types of NBS. The area shaded in light blue indicates the region with the lowest income family grouping[1] according to the 2010 IBGE census, which, in this sense, demands greater attention due to the implementation costs. A detailed table on the

[1]Clustering was calculated using the Local Indicator of Spatial Association, as shown in Rudke *et al.* (2021). The method allows the identification of clusters where regions of high values are close to regions of high values (HH), low values are close to low values (LL), high values are close to low values (HL) and low values are close to high values (LH). In this study, only the LL group was evaluated, since the aim was to evaluate urban agglomerations with lower household income.

potential application of NBS that considers the basin area, all lots, and public spaces is part of deliverable and will be made available to the stakeholders.