Nature-based solutions for urban resilience:

A citizen science-based research programme

January 2022

EXECUTIVE SUMMARY

This report showcases research into urban nature-based solutions - **solutions that are supported and inspired by nature** - as a sustainable tool for building resilient cities. The report highlights how science and community engagement can provide key answers to support a sustainable future, providing the first insights for urban planners, councils and businesses.

Urban life can provide many social and economic advantages, but as the number of people working and living in cities increases and cities expand, urban nature is at increasing risk.

- **A predicted 68% of the global population will live in cities by 2050[1].**
- **Over half of the world's total GDP ($44 trillion USD) is moderately or highly dependent on nature and the services it provides[2].**
- **A lack of urban green space and waterbodies means fewer vital habitats for wildlife, and increases our vulnerability to flooding, pollution and heat stress - all of which are predicted to worsen as climate change progresses.**

To tackle the climate crisis and mass biodiversity loss, it is imperative that towns and cities embed the protection and restoration of nature into the heart of urban planning. Nature-based solutions (NbS) offer a powerful way to create healthier urban areas that enhance the health and wellbeing of people and contribute to climate resilience.

RESEARCH OUTPUTS

Through citizen science-based research, Earthwatch explored a variety of urban NbS, creating an innovative international research programme that:

- Comprised of eight research projects in 17 cities spanning the globe focused on local environmental issues with people and places in mind.
- Filled knowledge gaps to better understand the function and management of various NbS for climate resilience in four areas: carbon capture, flood mitigation, thermal comfort and water quality.
- Provided insights into the important trade-offs in ecosystem services that NbS can provide.
- Actively engaged 28 local academics and 1,955 non-expert participants through citizen science, collecting 80,000 data points in total.

As final data analyses proceed, the research outputs are being presented in scientific publications that aim to fill knowledge gaps in the use and management of several urban NbS. A large part of the research has been published in the journal Sustainability in the Special Issue ***"Citizen Science for Sustainable Cities: Investigating Nature Based Solutions".***

Crucially, this knowledge can be shared with relevant stakeholders and ultimately integrated into policy, such that evidence-based change can be realised on the ground.

1. UN, 2018: www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html
2. World Economic Forum, Nature Risk Rising Report, 2020: www.weforum.org/reports/nature-risk-rising-why-the-crisis-engulfing-nature-matters-for-business-and-the-economy

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INTRODUCTION

As the proportion of the global population living in cities expands, it is imperative that we live sustainably and adaptively to confront the challenges of climate change. From water pollution to biodiversity loss, heat waves to flooding, greenhouse gas emissions to degraded human health and wellbeing, the consequences of climate change are complex and diverse.

Incorporating nature into the built environment is an important part of the solution to climate change adaptation. Nature-based solutions (NbS) are supported and inspired by natural processes to provide cost effective strategies that help address the consequences of the climate crisis[3]. Their multi-functionality means they can deliver numerous environmental benefits as well as social and economic advantages.

The placement and ongoing management of urban NbS can have a huge impact on their functionality and the benefits they provide, as well as trade-offs between benefits. In order to support integration of NbS in urban planning, more quantitative evidence is needed on their benefits and the impact of different management strategies.

Since 2017, Earthwatch Europe has led a global citizen science-based research programme to address knowledge gaps in the use and management of urban NbS for climate resilience. Delivered in 17 major cities around the world, each regional research project has focused on solutions to local urban environmental challenges.

The projects have been conducted in collaboration with scientists from 14 different research institutes and delivered through our HSBC Water Programme partnership[4]. Through the research, 1,955 HSBC employees were trained as citizen scientists to collect data. These data are now being used to build and test solutions and protocols that address critical challenges faced in urban areas across the world.

This report provides a summary of our research to date on the benefits and complexities of implementing urban NbS in different regional contexts. It demonstrates how citizen science has contributed to our understanding underpinning how NbS can contribute to urban design and best practice for regional and national policy.

3. *European Commission. Nature-based solutions. [online - accessed 13/12/2021]. Available from: ec.europa.eu/info/research-and-innovation/research-area/environment/nature-based-solutions_en*

4. *HSBC Water Programme: www.waterprogramme.org/*

RESULTS SUMMARY

This research is helping to improve our understanding of the function of urban green and blue spaces, necessary to inform policy on the value of integrating NbS into urban design.

The key messages from the analyses are outlined below.

CARBON CAPTURE

- The management regime of **urban trees** and their surrounding soil has implications on their sequestration and storage of carbon. Early analysis shows that trees in managed contexts (located along streets, or in open parks) have higher vitality than trees left unmanaged (in more natural conditions, high undergrowth and vegetation density), and therefore may *capture* more carbon. However, the soil surrounding trees in unmanaged contexts is able to *store* more carbon. The data will be used to provide clearer guidance on the effects and trade-offs of the different urban land managements to achieve carbon capture objectives.

- **Rivers** receive and transform carbon from their surroundings, usually acting as a net source of carbon dioxide and methane, therefore contributing to climate change. However, this is accentuated when rivers receive high inputs of pollutants and nutrients from their catchment. Preliminary results suggest that minimising nutrient pollution and creating green buffer areas can help reduce emissions.

FLOOD MITIGATION

- **Bioswales** (small, artificially constructed urban wetlands) are an effective NbS in mitigating urban flood risk. Studies across North America show they successfully retain and slowly release water following rain events.

- The maintenance, age, size and soil type of bioswales varies significantly, and influences their hydrological function. The establishment of a Green Infrastructure Rapid Assessment (GIRA) protocol is helping citizen scientists to monitor bioswales and the information produced is informing urban planners and other stakeholders in future bioswale design and maintenance.

- The magnitude of flood mitigation by **urban green space** and **urban trees** is strongly influenced by factors such as management, season and soil characteristics. Due to the largescale nature of citizen science data, it was possible to create a model from which urban soil permeability can be estimated around green areas. Further, citizen science data can be used to refine computer simulations, allowing the flood mitigation effect of urban green space in various contexts to be modelled. These results will provide an invaluable tool for stakeholders to manage this NbS.

THERMAL COMFORT

- Urban vegetation plays an important role in regulating microclimates, even in temperate regions. Midday temperatures are significantly lower in the vicinity of **urban trees** as compared to asphalt and other built surfaces, indicating the value of NbS in combating extreme temperatures in urban environments at a local scale.

- Models based on citizen scientist-collected data, can determine **urban tree** planting configurations that maximise cooling in residential areas. This methodology, developed for Abu Dhabi, can be applied to any region to support urban planning that helps mitigate the urban heat island effect.

- This research will provide insights into the best urban planning for street trees where the aim is to improve social aspects of urban living as well as urban energy consumption.

WATER QUALITY

- **Vegetation buffers** around river ecosystems as well as urban lakes improves water quality, particularly reducing contaminant loads originating from non-point sources such as agricultural run-off and urban discharge. This research provides simple solutions for better water management supply.

- Novel forms of NbS such as **floating floriculture beds** are a valuable tool for removing sediments and pollutants from urban lakes and provide additional benefits to urban wildlife such as birds. This research presents these simple nature interventions as low-cost solutions to closed urban waterbodies.

- Maintaining **wetlands** as natural ecosystems (as opposed to using them for agriculture or as tourist parks) has the greatest benefit for water quality, by reducing nutrient pollution and suspended sediment. This simple approach is low-maintenance and has multiple benefits for biodiversity and urban ecosystem wellbeing.

CARBON CAPTURE

THE CHALLENGE: Tackling global increases in carbon dioxide: a primary driver of climate change

Since the Industrial Revolution, the concentration of atmospheric carbon dioxide (CO_2) has increased by 47%[5]. It is primarily emitted by the burning of fossil fuels (such as coal and oil) for energy production, but is also influenced by other human-driven activities including land use change (e.g. urbanisation, agriculture and deforestation) and industrial processes (e.g. cement production)[6].

Urban areas are at the heart of CO_2 emissions, accountable for over 70% of the total anthropogenic production of this climate-altering gas[7]. At the same time, urban inhabitants are frequently the most vulnerable to the impacts of climate change.

Greenhouse gases, including CO_2, trap energy within the Earth's atmosphere. Incoming energy from the sun is either absorbed or reflected by the Earth's surface. Some of this energy is then re-emitted as infrared radiation, and absorbed by greenhouse gases, increasing the temperature of the atmosphere[8]. As a result, the world becomes warmer, sea temperatures increase, polar ice caps melt and global weather patterns change. Extreme weather becomes more common, with severe heat and drought as well as more frequent storms. These factors increase the frequency of flooding, the urban heat island effect and loss of water quality and biodiversity. According to the European Commission, urban areas are particularly poorly prepared for climate change, with four out of five Europeans living in places exposed to these challenges[9].

PART OF THE SOLUTION: Increasing urban green space and providing green buffers to blue infrastructure

The most efficient and successful way to tackle climate change is by engaging with the root of the problem. That is, reducing the emission of CO_2 and other greenhouse gases by replacing fossil fuels with renewable energy sources and making the shift to a circular and low carbon economy.

To support the shift to a low carbon economy, increasing urban green space can help reduce CO_2 emissions and improve carbon capture. Vegetation and soils are natural carbon stores, therefore increasing urban green space can help reduce the amount of CO_2 in the atmosphere. Vegetation sequesters carbon via photosynthesis, the process by which plants convert solar energy in order to grow. In doing so, CO_2 is removed from the atmosphere and locked away in plant biomass.

Plants are dependent on healthy soils to survive, while at the same time they play a fundamental role in the amount of carbon present in the soil. In fact, soil organic matter derives from the activities of soil microbes, plant roots and decaying plant and animal material and is a large carbon store. Of all terrestrial carbon, 80% is stored in soils[10].

Waterbodies, or blue infrastructure, are also important within the carbon cycle. Rivers collect carbon from the watershed via plant, soil and rock erosion, and then act as vectors, transporting carbon between land and the oceans. However, rivers can also act as carbon sources, releasing carbon dioxide and methane back into the atmosphere. How much carbon is emitted from rivers depends on how the river catchment is managed; factors such as the amount of vegetation and pollution occurring in the watershed are key.

The management of vegetation and soils plays an important role in carbon storage and release in urban environments. While the study of forest and ocean carbon dynamics is ongoing, our understanding of carbon cycles in urban green and blue spaces is very limited. These spaces are increasingly under pressure, yet they can provide essential benefits to the overall carbon balance of a city, as well as other important advantages related to flood mitigation, thermal comfort, water quality, biodiversity, reduction in air and noise pollution and improved human health and wellbeing.

5. *IPCC (Intergovernmental Panel on Climate Change). 2021. Climate Change 2021: The Physical Science Basis, Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Available from: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf*
6. *CO_2 Human Emissions. 2017. Main sources of carbon dioxide emissions. Available from: https://www.che-project.eu/news/main-sources-carbon-dioxide-emissions*
7. *International Energy Agency. 2021. World Energy Outlook 2021. Available from: https://iea.blob.core.windows.net/assets/888004cf-1a38-4716-9e0c-3b0e3fdbf609/WorldEnergyOutlook2021.pdf*
8. *NASA. 2020. The causes of Climate Change. [Online]. [Accessed: 02/10/2020]. Available from: https://climate.nasa.gov/causes/*
9. *European Commission. [no date]. Climate change consequences. [Online]. [Accessed: 02/10/2020]. Available from: https://ec.europa.eu/clima/change/consequences_en*
10. *Ontl, T.A. and Schulte, L.A. 2012. Soil Carbon Storage. Nature Education Knowledge. 3(10), pp. 35*

Figure 1: Citizen scientists measuring chlorophyll content in study trees of the European project. This is a simple yet innovative technique to measure tree productivity with non-expert citizen scientists (Photo credit: John Hunt)

RESEARCH PROJECT FINDINGS:
France, Hong Kong and the UK

Through our research projects in France, Hong Kong and the UK, researchers and citizen scientists gathered data on trees, soil and rivers in urban areas. The data collected are being used to help researchers better understand the effect of both management practices and external environmental factors on different stages of the carbon cycle (sequestration, storage and emission) associated with green and blue infrastructure in cities.

European research project:

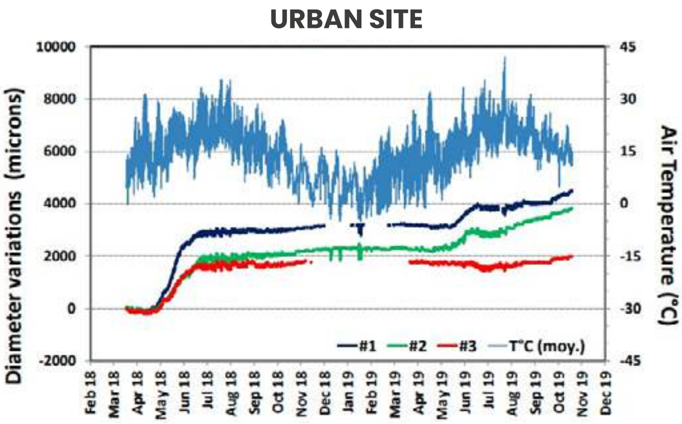
In Europe, urban trees and soil across six locations (three parks) in Birmingham, London and Paris were studied to understand how the management of urban green spaces affected tree and soil health, and therefore the sequestration and storage of carbon (see Methods 1). The collaborative project involved researchers from Earthwatch, Imperial College London, University of Reading and Institut National de la Recherche Agronomique who guided a team of citizen scientists to collect in-field soil and tree measurements (Figure 1) as well as take soil and leaf samples to be later analysed in the lab and by computer software.

METHODS 1. Tree and soil health in the UK

Tree vitality and productivity: Citizen scientists collected branch length, leaf number, leaf area and leaf chlorophyll content data to estimate tree growth and vitality of each study tree. Meanwhile highly sensitive automatic micro-dendrometers recorded the intricate changes in tree diameter that can be used to deduce growth, transpiration, phenology, mobilization of reserves and health status as well as atmospheric temperature. These sensors took measurements every 30 minutes for 20 months and showed how each tree changed its growth in relation to local environmental conditions.

Soil health: Citizen scientists measured soil colour as a proxy for soil organic matter, as well as taking soil samples for laboratory analysis. Soil colour was measured by taking a handful of soil and comparing its colour against the chart 7.5YR of the Munsell chart. The colour that was the closest in the chart to the soil sample was the value recorded.

Interestingly, both the citizen scientist-collected data and that from the micro-dendrometers concurred that trees in managed conditions showed the strongest growth (managed sites are where trees are pruned, soil cleared of fallen leaves and grass kept short if present) (Figure 2). For example, trees located along streets and trees in open parks showed a high growth rate, compared to trees in more natural (and crowded) settings. Project scientists associated this improved productivity to a lack of competition from other trees for resources such as light. These findings have important implications for park management to maximise carbon capture and highlight the importance of trees across the urban landscape.



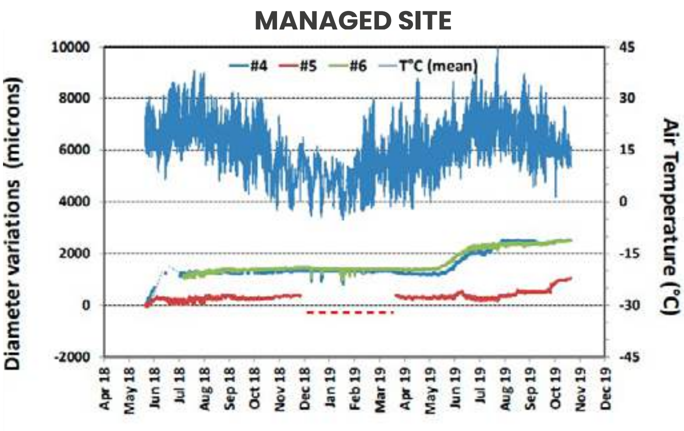


Figure 2: *Daily changes in branch diameter (μm) of three study trees in an Urban Site (top graph), where trees are growing in soil pits surrounded by concrete ("line or street trees", during two years (x axis shows day/month), and three trees in a Managed Site (bottom graph), where leaf litter and ground vegetation are periodically removed. Thin blue line shows air temperature while the coloured lines show the daily change in branch diameter of each tree. Taken from: Institut National de la Recherche Agronomique. 2020. Field Report Final Supplementary Material. Unpublished*

Importantly, the results show how tree location and management impacts carbon capture and storage, with the highest carbon capture in managed trees and the highest soil carbon storage in unmanaged areas (see Ferrando et al 2021 in this section, and Ngao et al 2021 at the thermal comfort section). Understanding how soil, hydrology, climate and management affect trees is paramount to minimise dieback and maximise health of urban trees. Thus, the data collected by citizen scientists are helping to understand the complex relationships that exist.

The researchers highlighted the strong relationship between data obtained by the citizen scientists and the sensors (dendrometers) and lab analyses. This provides further evidence of the scientific value of communities monitoring their local green spaces as well as the value of green areas in improving carbon capture and storage in urban settings.

Sustainability Special Issue: *"Ferrando Jorge et al. 2021. Measuring Soil Colour to Estimate Soil Organic Carbon Using a Large-Scale Citizen Science-Based Approach."*

***Figure 3:** Citizen Scientists in Hong Kong monitoring greenhouse gas saturation levels in urban watercourses. Photo credit: Earthwatch Hong Kong*

Hong Kong research project:

In Hong Kong, green buffers around urban waterbodies were studied in order to investigate the environmental factors influencing the emission of greenhouse gases from rivers (Figure 3). Researchers from the Chinese University of Hong Kong, with the help of citizen scientists, compared the amount of available carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) in 15 urban rivers in Hong Kong (see Methods 2). Each river was subject to a different amount of pollution from its surrounding catchment.

METHODS 2. Greenhouse gas emissions in Hong Kong

Citizen scientists took water samples (Figure 3) from 15 rivers in Hong Kong to determine the quantity of nutrient pollution and carbon present in each site. The citizen science research included the quantification of the magnitude and seasonal variability of dissolved CO_2, CH_4, and N_2O fluxes from eight selected river sites, three times a year in Hong Kong.

This information allowed researchers to examine the link between river catchment conditions, in particular the presence of green buffer areas, and the carbon emission of rivers and how this fluctuated with seasons.

The preliminary results suggest that all of the sites measured were supersaturated with CO_2, CH_4 and N_2O, indicating that the rivers acted as net emitters of greenhouse gases, confirming the significant role that rivers have in the global carbon cycle. Importantly, it was found that rivers with better water quality and lower pollution loads had lower available greenhouse gases and therefore were less likely to emit as much CO_2, CH4 and N2O back into the atmosphere. In particular, high CO_2 emissions were correlated with high ammonia, nitrogen and phosphorus concentrations, typical for rivers with low vegetation cover and high pollution sources. This nutrient enrichment is thought to increase the amount of microbial activity in rivers, thus leading to greater CO_2 production.

Therefore, the results suggest that improving water quality and reducing nutrient loads in rivers could limit the amount that a river acts as a carbon source, along with improving the riverine ecosystem for aquatic life and other users and stakeholders. Vegetated river catchments could help to keep carbon and nutrients in soils rather than leaching them into water courses. By trapping sediments and pollutants, urban green infrastructure helps reduce the emission of greenhouse gases from blue infrastructure.

Climate change needs to be addressed across different scales and ecosystems. These two projects demonstrate how citizen scientists can support innovative and alternative approaches to increasing carbon storage and reducing carbon emission in urban green and blue spaces. As urban areas continue to grow, proper planning of green and blue infrastructure and the integration of NbS in urban design provide opportunities for planners and stakeholders to address this challenge.

FLOOD MITIGATION

THE CHALLENGE: Urban flooding

Pluvial flooding is associated with rain events, typically following short, intense downpours. In the UK, these short, intense downpours are the cause of one-third of all flooding events[11], and are particularly difficult to predict due to their highly localised nature and fast initiation times.

Urban areas are particularly prone to the effects of extreme rainfall events due to their largely impermeable surface cover. Intense rainfall hits tarmac or paving slabs and then this stormwater runs straight to drainage channels, carrying with it pollutants picked up as it flows across the urban landscape. With this limited opportunity for stormwater to infiltrate naturally into soil, urban drainage systems can quickly become overwhelmed. This fast-moving water can then lead to local and sometimes large-scale flooding events that are difficult to prepare for and can be damaging to communities and businesses (Figure 4).

Climate projections predict that the intensity and severity of extreme weather events, including precipitation, will increase in the near- and long-term. Consequently, there is a rising number of urban inhabitants, properties and infrastructure as well as economies that are threatened by more frequent and more intense urban pluvial flooding.

Figure 4: *Recent flooding (February 2021) in the UK Midlands generated after two days of rain, highlighting the negative impact it can have for communities and businesses (Photo credit: Macarena L. Cárdenas)*

PART OF THE SOLUTION: Bioswales and urban trees

In many cities, concrete drainage pipes and channels referred to as 'grey' infrastructure typically handle urban rainwater, carrying run-off and pollutants from the streets and impermeable areas to local rivers and ponds. This grey solution may resolve problems related to removing water from some urban areas, but can create other problems (pollution transport) and does not resolve the core issue: impermeable surfaces dominate the urban landscape.

Bioswales and urban parks with trees address these challenges and provide a number of other important services to the local population. Both of these NbS break up the impermeable landscape by adding water absorbent plants and soils to the urban landscape. These solutions help to attenuate the intensity of pluvial flooding by slowing and storing water during intense rain events, contributing to a greener strategy of Sustainable urban Drainage Systems (SuDS)[12].

Bioswales are small, artificially constructed urban wetlands placed along streets and urban areas to act as infiltration basins (Figure 5). They contain porous soils that are planted with vegetation that are both water and drought tolerant. The combination of the porous soils and plants increases the rate of infiltration into soils and promotes groundwater recharge.

Bioswales are strategically placed in low-lying areas, in the course of water drainage pathways to slow the downstream movement of stormwater allowing it to be filtered, removing sediment and pollution. Bioswales are a form of multifunctional green infrastructure that, in addition to flood and pollutant mitigation, perform multiple ecosystem services. For example, they can also contribute to carbon sequestration and urban temperature regulation as well as provide an aesthetically pleasing place for local residents and a refuge for biodiversity.

11. Houston, D., Werritty, A., Bassett, D., Geddes, A., Hoolachan, A and McMillan, M. 2011. Pluvial (rain-related) flooding in urban areas: the invisible hazard. [Online]. Joseph Rowntree Foundation. [Accessed 02/10/2020]. Available from: http://eprints.gla.ac.uk/162145/7/162145.pdf

12. Susdrain. [no date]. Delivering SuDS. [Online]. [Accessed 02/10/2020]. Available from: https://www.susdrain.org/delivering-suds/

Figure 5: *American and Canadian citizen scientist teams in New York City (left) and Vancouver (right) assessing bioswale features and measuring soil infiltration rates. (Photo credit: Earthwatch US)*

Likewise, urban trees and the green areas that surround them can provide significant pluvial flood mitigation as well as many other benefits. Trees play an important role in a larger green infrastructure network (parks), as part of bioswale design, or as stand-alone street trees. Trees and the soil they need to take root and grow can improve infiltration of water into the ground, whilst their branches and leaves intercept rainfall and evapotranspirate water back into the atmosphere.

RESEARCH PROJECT FINDINGS: North America and Europe

Across nine cities spanning North America and Europe, citizen scientists have contributed data to improve our knowledge of the functionality, costs and benefits of green infrastructure in urban flood mitigation. These projects have provided evidence and tools to local authorities and stakeholders that are being used to improve the management of urban green spaces and support alternative flood mitigation strategies.

North America research project:

In six cities across North America, 71 bioswales were studied to assess how their design, the environment and the climate affected their functionality (See Methods 3). Collectively, the results of the study showed that hydrological functionality of bioswales was strongly influenced by their management, age, size and initial soil type. These results have important implications on how new bioswales should be designed as well as how they should be maintained to ensure consistent and long-term functionality.

A great variety in the size of bioswale was found. The sizes varied from an average of 8m^2 in New York City to 56 m^2 in San Francisco, due to the nature of the roads they serviced. Vegetation cover also varied; in Chicago, on average >75% of a bioswale was bare soil, whilst in Vancouver, San Francisco and Toronto >80% of the ground cover was vegetated.

These physical bioswale features subsequently influenced their perceived positive amenity. When asked to rate the bioswales, citizen scientists attributed blocked inlets, presence of rubbish and poor plant health as negative factors. This highlights the importance of maintenance of green infrastructure for ensuring the continued provision of ecosystem services, including those services related to social benefits such as wellbeing. Regardless of the physical discrepancies between different bioswales observed above, all showed a positive response to rainfall events; exhibiting capacity of improved drainage and water storage.

METHODS 3. Urban flood management with bioswales

Citizen scientists measured infiltration rate and classified soil type, as well as assessed and mapped bioswale features.

In addition to these on-site measurements, they also installed soil moisture sensors which allowed research teams to accurately capture how local rain events affected bioswale functionality in real time. Citizen scientists were able to track the amount of time a bioswale took to absorb and filter stormwater and return to pre-rain soil moisture levels (Figure 6).

The powerful information provided by low cost, effective soil moisture sensors showed city managers how real time information could improve decisions on maintenance and placement of bioswales, improving flood mitigation performance and reducing water requirements for irrigation in dry periods.

The bioswale evaluation methodology developed as part of the research project and tested by citizen scientists to quickly and consistently assess bioswales - the Green Infrastructure Rapid Assessment (GIRA) protocol - has already been distributed to multiple city authorities to guide their policies and green infrastructure strategies. See Box 1 for a summary of how this citizen science project has had a positive impact on the ground.

Sustainability Special Issue: *"Meixner et al. 2021. Rapid Assessment and Long-Term Monitoring of Green Stormwater Infrastructure with Citizen Scientists."*

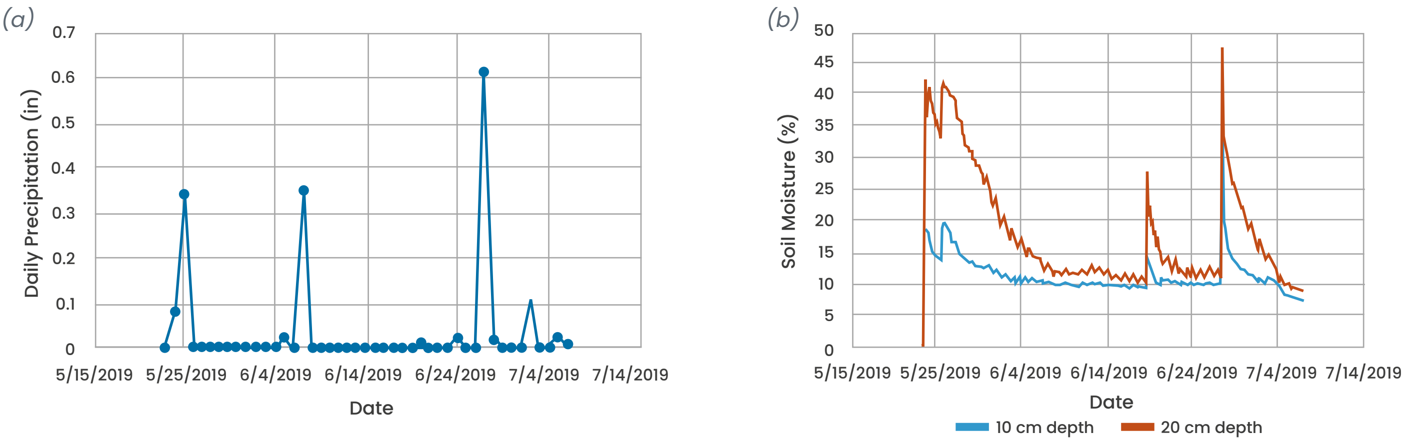


Figure 6: *(a) daily precipitation (inches) in the North American study, showing significant rain events and its impact on (b) soil moisture (%) readings from Arduino sensors installed at 10cm (blue) and 20cm (orange) below ground by citizen scientists. Peaks reflect the rainfall events, with subsequent steady drainage to pre-rainfall soil moisture levels. There is an anomalous peak on 18/06, thought to be associated with other local run-off, unrelated to weather, such as someone washing a car or watering the bioswale vegetation. Adapted from: Cherrier et al., 2020. 2019 Summary of Scientific Progress. Rapid Assessment and Long-Term Monitoring of Urban Green Infrastructure with Citizen Scientists. Unpublished*

BOX 1. GIRA: MANAGING STORMWATER CHALLENGES THROUGH CITIZEN SCIENCE IN THE US

The research project led by Professor Jennifer Cherrier from the Department of Earth and Environmental Sciences, Brooklyn College, City University, and Professor Thomas Meixner from the Department of Hydrology and Water Resources, University of Arizona, in collaboration with Earthwatch Europe, generated an open-source, transferable Green Infrastructure Rapid Assessment (GIRA) protocol for studying the performance of bioswales with citizen scientists.

GIRA was a highly successful protocol, tested in six North American cities (New York City, Toronto, Vancouver, Chicago, San Francisco, and Buffalo). It is a simple, low-cost, time-efficient method, which allows collecting data by any non-expert or scientist. It combined the physical assessment of the performance of bioswales, as a NbS for storm water management, by citizen scientists, with small and affordable Green Infrastructure Sensor Boxes (GIBoxes) to determine longer-term function across rain events.

The results of the research demonstrate that GIRA has benefits for scientists, people, and municipalities. Data collected by citizen scientists helped determine the status of the bioswales (Figure B1.) across the studied cities which were equivalent to laboratory measurements. Moreover, the effort also showed that citizen scientists experienced changes in understanding of urban stormwater challenges and the role that green infrastructure can play in solving these problems.

Finally, it created a reproducible and consistent approach for data collection for municipalities, as well as the development of an informed public that can better partner with cities in the implementation of solutions that reduce public risks to stormwater-related flooding and run-off pollution.

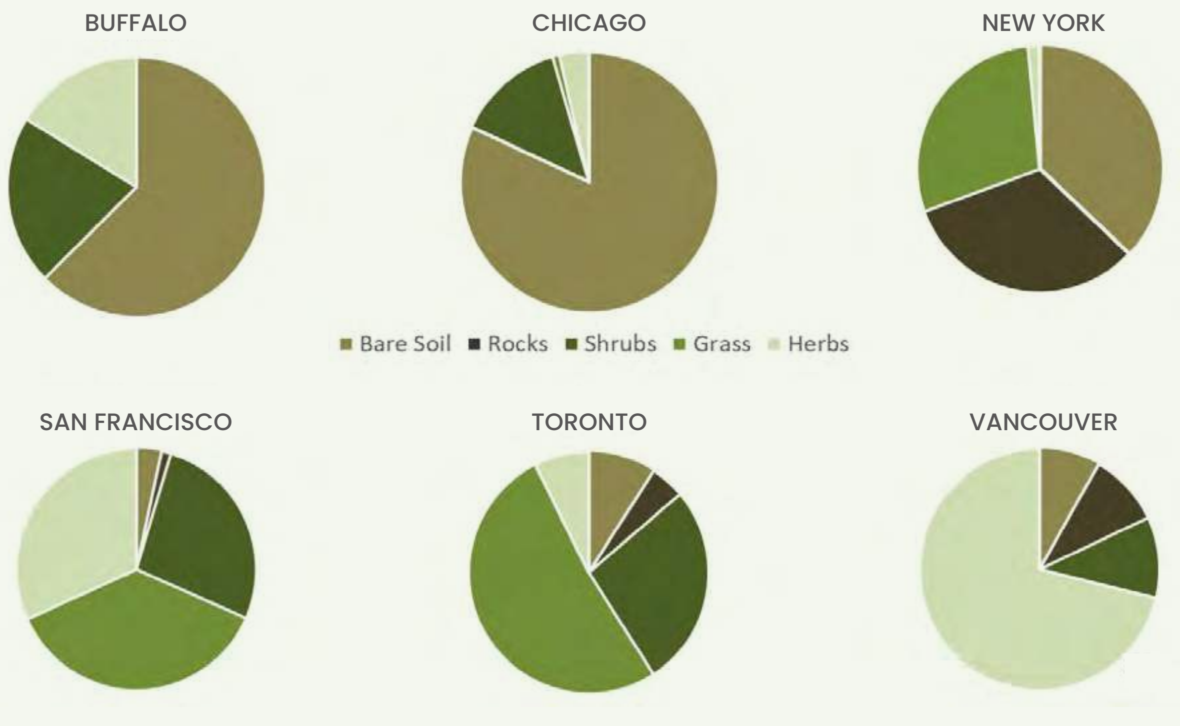


***Figure B1:** Average % cover estimates in bioswales in six North American cities. Results of the assessment done by citizen scientists on the bioswales using the GIRA protocol in 2019. (**www.mdpi.com/2071-1050/13/22/12520/htm**)*

Figure 7: *Citizen scientists collecting field measurements regarding soil characteristics during the European project on urban trees and green spaces. Photo credit: Earthwatch Europe*

European research project:

In Europe, research with the help of citizen scientists aimed to provide evidence of how green spaces with urban trees absorb rainfall and therefore reduce flood risk (Figure 7 and Methods 4).

The preliminary results show significant differences amongst the studied land management around urban trees. The research highlights the greater effectiveness that urban green spaces could have for flood management when the right management factors are considered. The impact of this research could be translated in helping to define the best management practices of urban green areas for economic and environmental efficiency.

The results of the citizen science field data collection will be used in a model that will integrate the laboratory analyses in the samples collected by the participants. The purpose of the model is to inform management decisions, to ensure the efficacy of existing green infrastructure, and contribute to cost-benefit analyses of potential NbS. The project is already working with an array of stakeholders, including the UNESCO International Hydrology Programme and government advisory bodies such as the UK Committee on Climate and Policy.

Frontiers in Water scientific publication:
"Pudifoot et al. 2021. When It Rains, It Pours: Integrating Citizen Science Methods to Understand Resilience of Urban Green Spaces."

METHODS 4. Understanding the impact of land management around urban trees for flood management

Citizen scientists measured soil characteristics in 36 locations and collected over 520 samples in three urban parks in the UK and France. The metrics included soil texture, soil colour, soil infiltration and soil moisture using traditional methods as well as hand-held meters.
Each one of the metrics was taken with four replicates around the urban trees in three land managements: street trees, trees in managed areas (manicured, with pruned trees, where fallen leaves are cleared out and grass cut) and in unmanaged areas (not manicured, trees and grass left to grow naturally around them).

These metrics are being used to calibrate a model of the infiltration capacity of soil and the reduction in run-off in order to minimise urban flood risk, in close cooperation with park and local authorities.

By providing science-backed evidence, the research from the US and European projects has provided new insights to improving the planning and management of urban NbS. As climate change creates increasing challenges to urban communities, the utilisation of NbS provides an opportunity for planners and policy makers to improve the resilience of our cities and urban areas.

Figure 8: *Citizen scientists in the UK taking infrared images from and around urban trees to understand the cooling effect (Photo credit: John Hunt)*

THERMAL COMFORT

THE CHALLENGE: Keeping cities cool as climate changes - combatting the Urban Heat Island effect

By 2050, a projected 1.5ºC increase in global temperatures could expose an additional 350 million people living in megacities to deadly heat[13]. Urban populations are particularly prone to heat stress due to the Urban Heat Island effect (UHI), a phenomenon whereby the built environment (cities) experiences significantly warmer temperatures than its rural counterparts. Driven by a high density of impermeable, dark surfaces (buildings) and increased energy consumption for cooling, transport and related infrastructure, the UHI can significantly impact the sustainability and quality of life in metropolitan areas.

In most cities, domestic and industrial activities utilise energy to function, generating heat as well as other kinds of pollution. In addition, the high density of large buildings with absorbing surfaces traps and stores heat energy within city streets. Typically, warm temperatures are overcome using air conditioning to cool indoor spaces. However, air conditioning is extremely energy demanding and functions by pumping warm air outside to make indoor air cooler, further exacerbating the problem they are intended to solve.

PART OF THE SOLUTION: Urban Trees

Incorporating trees in urban landscape design is a NbS that provides an alternative means to mitigate the UHI effect. Trees cool their surrounding local environment via evapotranspiration and shading.

In warm conditions, water taken up by trees evaporates through their leaves, and in doing so removes heat energy from the immediate environment. As this evapotranspiration increases, the tree and its surrounding environment stay at a lower temperature. Tree canopies also provide shade, improving the ambient temperature for humans as well as preventing solar radiation from heating external building walls, therefore reducing the need for other cooling systems such as air conditioning. Leaves on a healthy tree can reflect and absorb a large percentage of the incoming solar radiation, both visible and infrared.

However, tree type, placement and management have important impacts on their capacity to keep us cool. Local conditions of climate, building stock and urban landscape influence the efficiency and feasibility of trees and green spaces to mitigate the UHI effect.

13. Rosenzweig, C., Solecki, W., Romero-Lankao, P., Mehrotra, S., Dhakal, S. and Ali Ibrahim, S. ed(s). 2018: Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network. Urban Climate Change Research Network. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, pp. 811

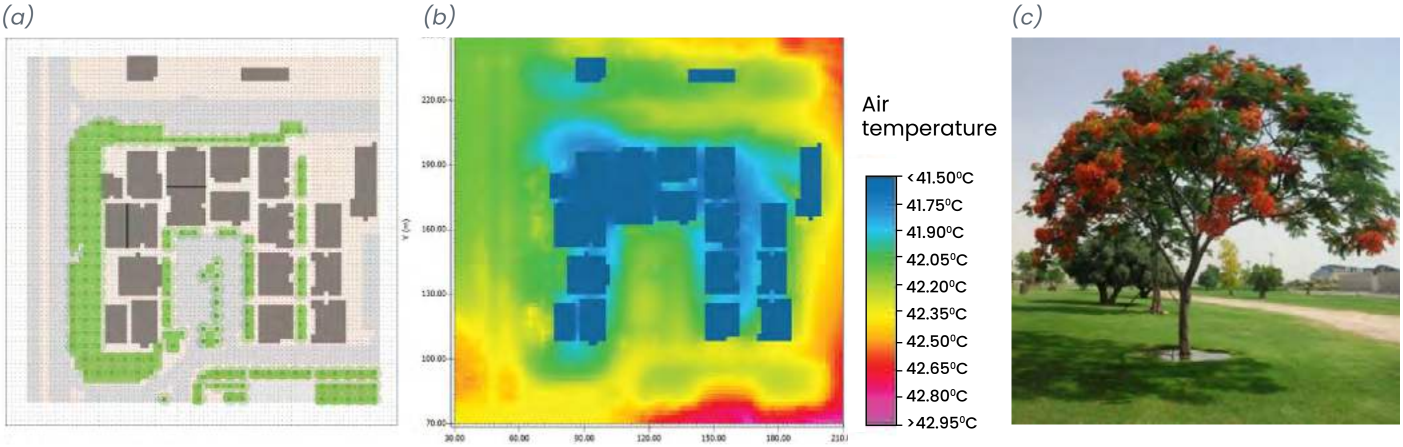


Figure 9: *(a) suggested configuration of Poinciana trees 6m apart at residential site in Abu Dhabi and (b) the simulated resultant air temperature (oc) of this tree planting plan, (c) a Poinciana tree. Adapted from Alawadi, K., and Abu Ali, M. 2020.* 2019 Final Field Report. Green Infrastructure in Abu Dhabi Neighbourhoods. *Unpublished*

RESEARCH PROJECT FINDINGS: Europe and United Arab Emirates (UAE)

Through our research projects in France and the UAE, researchers from the French National Institute for Agricultural Research (INRA), French National Centre for Scientific Research (CNRS) and Kalifa University of Science and Technology, with the support of citizen scientists, have explored the opportunities and limitations of using trees to influence urban air temperatures.

By measuring tree parameters, citizen scientists have collected data that have helped to fine-tune and validate models used to quantify the amount of cooling provided by urban trees (Figure 8). This contributes to a knowledge base that will facilitate future integration of trees into urban planning and design. In both projects, placement and management were key to maximising benefits.

UAE research project:

With summer heat often exceeding 40°C and a population surpassing 1.45 million, Abu Dhabi, the capital of the UAE, faces up to a 2.5°C increase in temperature by 2050. With limited protection, inhabitants of the city find it difficult to go outdoors.

The research was performed in a low-density residential neighbourhood of Abu Dhabi, consisting of 160 residential buildings of three to five stories (Methods 5). The results showed that in a low-rise Abu Dhabi neighbourhood, planting Poinciana trees six metres apart on pathways and in open areas could reduce air temperatures by up to 0.9°C (Figure 9). This translates to a major reduction in energy usage for air conditioning (the largest energy requirement in the UAE[14]), and most importantly, creates better conditions for residents to socialise outside of their home.

Whilst this was the most desirable arrangement for Abu Dhabi specifically, the methodology could be applied to any city. Although the researchers highlight the importance of an in-depth knowledge of the location and potential plant species so that costs, associated with water consumption, root disruption to infrastructure and other maintenance, are limited.

METHODS 5. Thermal comfort in Abu Dhabi

For this research, citizen scientists assisted researchers in collecting over 3,000 weather data points, 1,000 tree height measurements and locations as well as more than 2,500 infrared images. These data points were used in thermal model simulations to identify the most beneficial tree planting and green space configurations for minimising the UHI effect in Abu Dhabi's residential areas.

Sustainability Special Issue: *"Abu Ali et al. 2021. The Role of Green Infrastructure in Enhancing Microclimate Conditions: A Case Study of a Low-Rise Neighborhood in Abu Dhabi."*

14. Shanks, K., and Nezamifar, E. 2013. Impacts of climate change on building cooling demands in the UAE. In: SB13 Dubai: Advancing the Green Agenda Technology, Practices and Policies, 8-10 December 2013, Dubai.

European research project:

In the Northern France research, temperatures were measured in the immediate vicinity of trees and compared to temperatures in close proximity to building walls and asphalt (Methods 6). There was a maximum difference of 11.5°C, recorded at midday, between sensors located under urban trees and those next to a south facing building wall. This clearly demonstrates the benefits of urban trees in alleviating the UHI effect in temperate climates. Meanwhile, infrared pictures of microclimates around trees taken by citizen scientists were used to help refine models that map high-resolution thermal comfort zones.

METHODS 6. Thermal comfort in France

In Northern France, sensitive grey globe temperature sensors were installed in the study sites to assess extremely fine scale warming patterns. Temperature measurements were taken in the immediate vicinity of trees as compared to in proximity to building walls and asphalt. Over 48,000 measurements were taken over two years. Citizen scientists also took infrared pictures of microclimates around trees in parallel to the grey bulb measurements.

The results of these studies demonstrate the large thermal impact of grey infrastructure and the cooling effect of street trees. At the same time, the process of data collection highlighted the challenges of accurate data to assess thermal comfort and improvements were identified.

These results have been communicated to multiple local authorities through workshops and presentations to educate and advise planning officials and landscape engineers in the value of incorporating green infrastructure, such as trees, in future housing developments. Importantly, their work can help to direct tree planting in an orientation that optimises the efficacy of cooling in the most cost-efficient manner. The dedication and enthusiasm of the researchers and citizen scientists alike has provided a firm scientific basis that can provide the foundations for collaborative discussions with the aim of implementing more suitable, sustainable and liveable urban solutions.

These two projects have shown how modelling, management and planning can be supported by citizen scientists and the potential benefits from NbS to mitigate the urban heat island effect.

Sustainability Special Issue: *"Ngao et al. 2021. Implications of Urban Land Management on the Cooling Properties of Urban Trees: Citizen Science and Laboratory Analysis."*

WATER QUALITY

THE CHALLENGE: Water quality degradation

Water is an essential requirement for human survival and economic development, but is an increasingly limiting factor in areas undergoing climate change and increased urbanisation. The situation is made even more critical as many of the available freshwater resources are undergoing degradation due to poor management and the introduction of pollution from direct and indirect (diffuse) sources.

Every day, two million tonnes of sewage drain into freshwater ecosystems globally. Whilst every year nearly 400 megatonnes of industrial waste are discharged into rivers, lakes and canals[15] around the world, limiting the capacity of these ecosystems to provide resources for local communities and a healthy habitat for freshwater biodiversity.

In the world's megacities, there is growing pressure on freshwater environments to provide water resources for people, industry and energy. There is a further need to receive and treat wastewater from these same activities, yet available infrastructure is frequently insufficient or even absent, allowing wastewater and sewerage to contaminate freshwater sources. This is compounded by storm water that causes run-off from impermeable urban surfaces and into receiving lakes and rivers. Heavy metals, microbial contaminants, organic pollutants and pharmaceuticals are just a few of the harmful effluents that run-off during heavy rain events.

This combination of increased water use and increased water pollution leads to the loss and degradation of many of the freshwater environments on which we depend. While most cities have wastewater treatment plants to prevent sewage and contaminants from running directly into our waterbodies, these have high energy requirements and are limited in their capacity to treat increases in pollutants and flowrates. Furthermore, a large proportion of water pollution originates from non-point sources, from both urban and agricultural areas, which makes tackling the cause of the problem a challenge.

PART OF THE SOLUTION: Green-blue infrastructure

A complementary solution to traditional water treatment methods is the use of vegetation to slow flowrates and remove contaminants from freshwaters. Aquatic vegetation can filter and absorb particulates and dissolved pollutants, while their roots take up excess nutrients and other contaminants. The overall effect is improved water quality, reduced pollution and increased sedimentation. Incorporating and protecting green areas alongside blue areas also provides other advantages such as increased biodiversity, cooling and social benefits.

15. UNESCO. 2019. The global water quality challenge & SDGs. [Online]. [Accessed 02/10/2020]. Available from: https://en.unesco.org/waterquality-iiwq/wq-challenge

RESEARCH PROJECT FINDINGS: Mexico, China and India

Across three countries, researchers investigated the opportunities of blue-green infrastructure as a means to improve freshwater environments and the services they provide. These initiatives focused on resolving major local challenges for important cities such as Bengaluru, Hyderabad and Mumbai (India), Mexico City (Mexico) and Guangzhou and Shanghai (China). The approaches addressed the major drivers for water degradation in each location, which principally focused on uncontrolled urban discharge, and diffuse industrial and agricultural pollution. The outcome of the research showed that the utilisation of green infrastructure to protect blue resources across these very different contexts was widely positive.

The results of the research are now being used to support stakeholders in introducing and expanding eco-friendly practices to limit water pollution, encourage monitoring of water quality and develop alternative solutions to urban design and management.

Mexico research project:

In the Valle de Bravo watershed, Mexico, researchers investigated the efficacy of vegetation strips buffering the river and overall catchment forest cover in water purification. Here, citizen scientists contributed to chemical, bacteriological and nutrient monitoring at 18 sampling locations (Figure 11), none of which satisfied water quality standards for human consumption. Urban discharge and changes in agricultural activities from traditional maize production to potato and fava bean was seen to lead to an increase in pollutants in the receiving waters. These rivers are key to providing potable water to a large part of the population of Mexico City. The results of the research showed how high concentrations of *E.coli* and eutrophic conditions were compromising the quality of these important resources. However, the research also showed that vegetation buffering riparian ecosystems and native forest cover within the watershed could be used to improve water quality and freshwater ecosystem functioning.

Following the sharing of the project results, the local Government in Mexico committed to green infrastructure as a means for water quality regulation, establishing a constructed wetland and restoring local springs to reduce the impact of a local hospital on an important local river.

Sustainability Special Issue: *"Calderón Cendejas et al. 2021. Evaluation of the Impacts of Land Use in Water Quality and the Role of Nature-Based Solutions: A Citizen Science-Based Study."*

Figure 11: *Citizen scientists performing field analysis of bacteriological content as well as of nutrient content (phosphorous and nitrogen) from water samples they collected at the study site in Valle Bravo, Mexico (credit Earthwatch US).*

India research project:

The study of water and soil samples in Hyderabad, India, demonstrated clear evidence of urban expansion, loss of vegetated buffer areas and increasing eutrophication at 30 study sites (See Methods 7). Simultaneously, floating floriculture beds were deployed into one of their study lakes (Figure 12), to test the effectiveness of this novel technique in reducing elevated concentrations of nutrients and other pollutants.

The results show that one aquatic plant, canna lily, is particularly good at removing sediment and pollutants from the water, as well as providing a favourable breeding spot for local bird populations.

Elsewhere in India, the Mumbai research project also explored the benefits of floating constructed wetlands to regulate water quality. This was part of their larger study to identify potential benefits of integrating green and blue infrastructure to upgrade the city's lakes, reversing the ongoing degradation of these critical ecosystems due to pollution from untreated sewage, urban run-off and illegal disposal of industrial effluent.

By taking measurements across lakes with different green buffer areas and varying pollution loads, the project's citizen scientists helped demonstrate stark contrasts in water quality. At one location, water was classified as suitable for drinking, but elsewhere in the same ecosystem, the influx of urban wastewater and cultural practices such as idol immersion led to heavily compromised conditions, with low dissolved oxygen, and high pH and total dissolved solids. The study

Figure 12: *Floating floriculture beds in Swan Lake, Hyderabad, India. Photo credit: Jawaharlal Nehru Technological University Hyderabad. 2020. 2019 Field Report on spatiotemporal effects of urbanization on surface waterbodies and its impact on soil and vegetation ecosystem. Unpublished*

showed how lake water quality has deteriorated over time and highlighted the need for shared responsibility in gathering the information necessary to develop a suitable wastewater treatment strategy.

METHODS 7. Water quality in India

Hyderabad. Water and soil quality, as well as faunal and floral biodiversity, were investigated in a series of 30 lakes with and without vegetated buffers. A combination of in-field measurements alongside advanced hyperspectral remote sensing techniques were used to study the effect of domestic and industrial discharge into the lakes, as well as land use change over time.

In parallel, three floating floriculture beds were deployed into one of their study lakes (Figure 12). In this innovative form of green infrastructure, numerous plants are secured within a wire mesh attached to a floating frame, anchored to the lake bottom.

Bengaluru. The research team in the Bengaluru project surveyed more than 500 lake users and local community members to identify how users perceived the lakes and environmental issues associated with them.

The importance of lake water quality monitoring was further emphasised by the project carried out in Bengaluru, India. The 7,000 data points collected by citizen scientists helped provide a detailed picture of the associations between blue-green infrastructure and ecosystem resilience to anthropogenic stressors. Research findings showed that storm water run-off and sewage from old, leaky drains within the local catchments of the study lakes led to the formation of harmful algal blooms that subsequently kill aquatic life and render water unsuitable for human use.

In an effort to reduce this inflow of contaminants, new approaches to monitoring and managing these waterbodies and their catchment were explored. Citizen scientists helped researchers to identify parameters (chemical oxygen demand) and thresholds that could be used as a preventative early warning system and to support management decisions to protect these important ecosystems.

Equally as vital as understanding the physical consequences of freshwater degradation are the social and cultural implications. The project also included collecting information from lake users about their perception of the lakes and the environmental characteristics (See Methods 7). The results from the public survey were used to develop a framework (Figure 13) to highlight the most significant environmental pressures and recognise the interlinkages between these and the various stakeholders.

The positive impacts of the project in India extended to the citizen scientists and stakeholders. In Hyderabad, citizen scientists took the initiative to do additional water quality monitoring and educate their peers in the importance of sewage treatment. Moreover, the Mumbai project brought together regulatory agencies, public officials, NGOs and industry in yearly workshops and round table events, to achieve a sustainable business model for rejuvenating Mumbai's urban lakes.

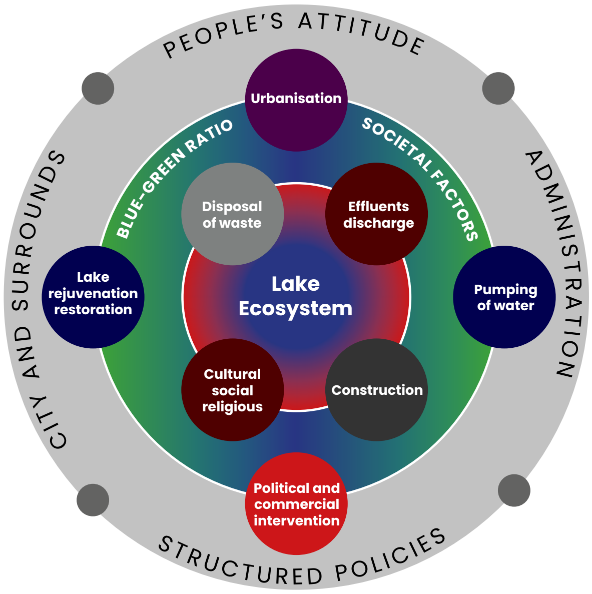


Figure 13: *Overview of a systems model to understand the interlinkages between lake pressures and various stakeholders. Taken from: Rao, S.M., Mani, M. and Aurora, M. 2020. 2019 Final field report. Lakes of Bengaluru as drivers of an enriched blue-green cityscape. Unpublished*

Sustainability Special Issue: *"Rao et al. 2021. New Classification Method to Evaluate Pollution Levels of Sewage Contaminated Lakes." and "Lekshmi et al. 2021. Science & Technology Agenda for Blue-Green Spaces Inspired by Citizen Science: Case for Rejuvenation of Powai Lake."*

China research project:

Wetland ecosystems in China have traditionally been multiuse blue-green systems. In this research three wetland practices were compared: natural (unmanaged) wetlands; wetlands managed for agriculture; and wetlands in tourist parks (see Methods 8, Figure 14), to test their capacity to trap sediment and remove pollutants from the local freshwater ecosystems.

All three types of wetland showed benefits to downstream water quality. After flowing through both wetland parks and agricultural wetlands, there was a clear reduction in nitrogen-related nutrient pollution, showing the benefit of NbS whereby excess nitrogen can be converted to vegetation growth and thus improve the overall water quality of receiving ecosystems. By comparing these management approaches, it was possible to demonstrate that wetland capacity to improve water quality was most powerful in natural wetlands, particularly in terms of removing nutrient pollution and suspended sediment.

The results of the study of wetlands in China by partners at the Chinese Academy of Sciences are used for daily on-the-ground management decisions at 56 Ramsar designated wetland sites through the project partner's outreach to wetland managers and provincial authorities.

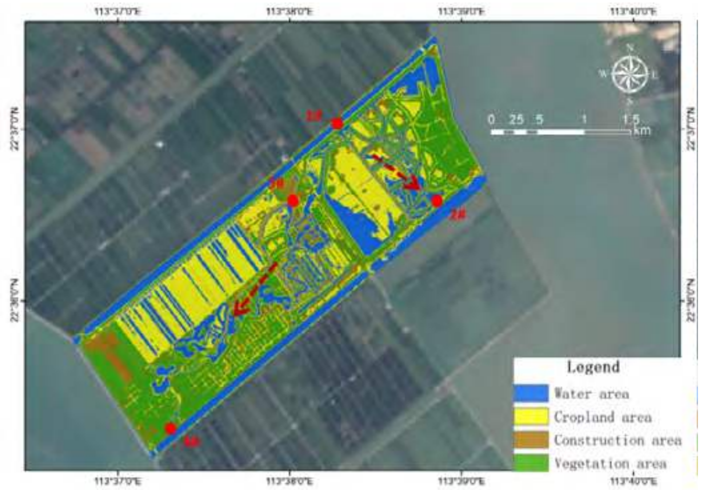


Figure 14: *Nansha wetland study site, Guangdong province, China. Red dots indicate monitoring sites and red arrows show water flow direction. Adapted from: Zhang, Y., and Sun, X. 2020. Scientific Analysis Report for 2018 & 2019. Unpublished*

METHODS 8. Wetlands in China

The researchers and citizen scientists involved in the projects near Shanghai and Guangzhou explored how different wetland uses could influence their capacity to protect lakes and rivers in these developing areas. Three different approaches to wetland management were explored with respect to their capacity to trap sediment and remove pollutants from the local freshwater ecosystems (Figure 14). The remediation capacity of natural (unmanaged) wetlands was compared to wetlands managed for agriculture or as tourist parks.

Sustainability Special Issue: *"Zhang et al. 2021. Comparing Wetland Ecosystems Service Provision under Different Management Approaches: Two Cases Study of Tianfu Wetland and Nansha Wetland in China."*

Maintaining our freshwater resources is a global challenge. These projects have exemplified how novel approaches, supported by citizen scientists, are finding alternative solutions that use green and blue infrastructure to guarantee this fundamental resource. As urbanisation shows no sign of slowing and climate change creates new challenges, the utilisation of NbS provides an opportunity for stakeholders and policy makers to address the challenge of water pollution.

Figure 14: *Citizen scientists collecting data on soil infiltration capacity at Kew Gardens (Photo credit: John Hunt)*

CITIZEN SCIENTISTS

The results from our urban NbS projects have been based on citizen scientist-collected data across 17 urban environments across the globe. Citizen scientists are non-professionals actively involved in scientific research, placed at the heart of Earthwatch's research activities. Over the course of the programme, there were a total of 1,955 HSBC employees trained by Earthwatch and research partners as citizen scientists.

HIGHLIGHTED BENEFITS FROM CITIZEN SCIENCE:

The benefits to be highlighted from citizen science engagement in this programme have important implications for urban resilience. One of them is the instrumental contribution of citizen scientists to **finding solutions for priority local environmental challenges**. The citizen scientists of the programme helped to collect more data, and from a greater temporal and spatial range, than would be possible using trained scientists alone. The citizen science approach resulted in new and robust information that is being used by planners, managers and policy makers to tackle the complex challenges in urban environments in the face of climate change. Most of the impactful findings from the research programme have now been published in a dedicated Special Issue in peer-reviewed Journal Sustainability: ***"Citizen Science for Sustainable Cities: Investigating Nature Based Solutions."***

The success from the data collection and involvement of citizens also resulted in the **creation of new methodologies** that have allowed the expansion of citizen scientist-based participation in research, urban design and policy. One interesting example was the Green Infrastructure Rapid Assessment protocol (GIRA) which was developed with citizen scientists through successive iterations of the methodology. The final product is being used by schools, researchers and other citizen scientists to examine bioswale functionality across the world. Alongside a first-of-its-kind database on green infrastructure function, these project outputs are striving to better inform stakeholders and make data open and accessible to all.

Another impactful benefit from the citizen science in this programme, was offering the space for individuals to **reconnect with nature**, identify new pockets of nature within their own neighbourhood and gain knowledge of how this contributes to their local community.

From changed personal opinions and everyday habits to actively implementing change in their professional lives, the majority of the citizen scientists experienced an increase in confidence and motivation to be more environmentally conscious, with 97% of participants reporting the training as professionally worthwhile. Individuals came away from the projects with an increased understanding of local environmental issues and expressing surprise towards the newly discovered benefits of NbS as a sustainable option to mitigate environmental threats in their city.

Aside from increased awareness in the participants themselves, 92% of citizen scientists reported that they **disseminated their experiences and knowledge throughout their own networks**. For example in Hyderabad, India, feedback from participants revealed that they were interested in monitoring water quality in their local community with the aim of informing better management of their freshwater resources.

Benefits for the research community were also highlighted. All of the researchers involved in the projects expressed their amazement at the **dedication, enthusiasm and engagement of the participating citizen scientists**. They also conveyed their appreciation for the insights provided by individuals from different personal and professional backgrounds, which allowed for the cultivation of ideas, broad discussions and new perspectives. A scientific publication about the benefits of engaging on citizen science, obtained from this international project, can be found at ***"Cárdenas et al. 2021. The Circular Benefits of Participation in Nature-Based Solutions."***

All the project outcomes were **widely disseminated** to local and state authorities, providing key evidence to inform stakeholder decisions regarding land use, urban planning and the management of NbS. This included recommendations for agricultural management, training local community leaders in water monitoring methods, as well as informing policy decisions at local, municipal and national level.

The greatest highlight is the positive change that comes from multiple stakeholder engagement. From this programme and so many others including citizen science, it becomes clear that each one of us human beings have a role to play, if we are to have a sustainable and liveable future.

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