Research on Benefit Simulation and Management Optimization of Urban Landscape Pattern Based on an Eco-Socio-economic Model.

A report on Urban ecosystem services modelling in Chengdu. Collaboration between UK Centre for Ecology & Hydrology, UK, and Sichuan Academy of Environmental Sciences, China.

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Contents

1. Background

There is a good scientific understanding of the benefits of planting trees and maintaining green spaces such as parks and rivers in cities. For example, trees and rivers provide urban cooling, and all vegetation removes air pollutants, with trees being particularly effective at removing particulate pollution such as fine particulate matter ($PM_{2.5}$), which is the most damaging to human health. Trees can reduce the effect of traffic noise, and green space can also reduce flood risk, and provide opportunities for recreation and relaxation, so improving human health and wellbeing.

However, there is not always good understanding that the amount of benefit provided will depend on where this green infrastructure is located (Fletcher et al. 2022). The same size park can provide very different levels of benefit in one location, compared with another. In particular, there is a lack of knowledge transfer between scientists and city officials and planners. Having access to good information can help city officials evaluate the best locations to create or improve green infrastructure to provide multiple benefits to residents both in cities and the surrounding areas. There is therefore a need to provide robust scientific guidance, and decision-support tools which are easy to use and understand, so that the maximum benefit can be achieved when creating new green infrastructure.

Previous research has shown that the challenges in each city may be different (Banzhaf et al. 2022). The type and level of benefit that green infrastructure provides will also be different in each city, due to factors such as climate and the intensity of urban pressures such as flood risk, local climate, air pollution, etc. So far, UKCEH has worked in four cities in China: Beijing, Shanghai, Ningbo and Suzhou, and the services provided are different in each (Wu et al. 2022). In order to understand each city, it is necessary to quantify the various urban pressures and then apply scientifically-informed spatial models to calculate optimum locations for green infrastructure. Each city is different. There are also important gaps in knowledge around the equity of access to the benefits from green infrastructure (Yao et al. 2022), and spatial models are ideally suited to understand and solve these issues – for example the elderly are more at risk of heat stress, so planning green infrastructure to alleviate hot-day temperatures can prioritise locations with a greater elderly population. Therefore, there is considerable opportunity to conduct research in Sichuan to use the latest scientific approaches and models, bringing together experts from the UK and from China to quantify and solve these issues, and to develop and test urban decision tools which have not yet been applied in China. Sichuan can be a leader in this field and provide example case studies for other Chinese cities and locations to follow.

Research led by UKCEH has developed a suite of ecological, social and economic models, which calculate the benefits of using natural approaches to help address air pollution, carbon sequestration, heat island, flooding and noise mitigation measures.

These models have been developed to support UK government in natural capital assessment, and for government decision-making. For example, decisions within cities on where to introduce flood mitigation measures to achieve maximum benefit, and decisions on land-use such as tree planting inside and outside cities to achieve the optimum reduction of air pollutants such as $PM_{2.5}$, O_3 and NO_2 to benefit city residents. The basic approaches underlying the dynamic use of models and the spatial assessment of pressures, supply and demand are described in Jones et al. (2019) and Hutchins et al. (2021).

The models have now been extended and have been used to guide urban decision-making at sub-city scale in Birmingham and Paris (e.g. Fletcher et al. 2022), and particular models have also been used to assess land use management at national scale for Wales (21,000 km^2) and for the whole of the UK (242,000 km^2). They have showed for example that the health improvements of vegetation in removing air pollutants in the UK lead to an economic benefit of £1.03 billion per year. These benefits depend on air pollution concentrations, but also the type of vegetation and where it is located, as well as the locations where people live. All these factors need to be modelled to calculate the accurate economic benefits.

UKCEH has developed these models into a decision support tool called the City Explorer Toolkit which can be used to create and evaluate new scenarios very quickly using an on-line interface. The City Explorer Toolkit has already been demonstrated at the climate summit COP26 in Glasgow, UK, and has operational versions for Paris and for Birmingham. A new module on reducing surface flooding has just been created for the toolkit (Miller et al. 2023).

The project will benefit academics in both UK and Sichuan by sharing the latest world-leading expertise of each partner. The project will also benefit administrative officials by providing them with the latest scientific advice, which will support decision making to identify the optimum locations to develop new green infrastructure (or modify existing green infrastructure) to address a range of challenges. The tool will allow users to create new scenarios so they are able to evaluate a range of different planning options, and can produce solutions for different types of environmental challenge.

Through this improved planning and design of green infrastructure solutions, the local population will also benefit from reduced flood risk, lower air pollution concentrations, cooler temperatures and improved health and wellbeing.

2. Aims and objectives

The project objectives are to i) introduce two models which calculate the environmental, social and economic benefits of the ecological services provided by the environment, and ii) to develop outputs which can support decision making, for use by Sichuan officials and academics.

These models have been developed by the UK Centre for Ecology and Hydrology (UKCEH). The models will calculate benefits from air pollution removal, and heat island mitigation. It is important to consider both urban and rural areas when managing natural areas to provide the maximum benefit to the population. The project will select the key urban areas and rural hinterlands in Sichuan Province (focusing mainly on one show-case research area). The results of the introduction of technology and intelligence will provide decision-making support to form typical demonstration research results, which may be promoted to other provinces in Sichuan Chongqing.

3. Methodology

3.1 City Selection

In discussion among UKCEH and SCAES colleagues, it was decided to choose the city of Chengdu as the focus for this study.

3.2 Datasets needed to run the models

In order to run the ecosystem service models for air pollution removal and for hot-day cooling, we referred to the list of potential datasets (see Annex 1) needed. Table A1 (Annex 1) lists all datasets that might be useful for running a wider suite of models as part of the City Explorer Toolkit. Since the funding available for this project was more limited, it was agreed to run just two service models to illustrate the potential for this approach. Those datasets needed to run the modelling are shown in bold in Table A1.

An important component of the input data is the land cover. For this we used ESA WorldCover 2021 at 10 m resolution. The land cover classes were simplified to the following: trees, grass, urban, water and bare/other (i.e. bare soil, rock, and very sparsely vegetated areas). Cropland was aggregated into the grass class, as the cooling model doesn't contain a coefficient for crops – only grass, trees and water. See Annex 2, Table A2 for details of land cover data thematic aggregation. Additional data needed to calculate ecosystem service potential, and the beneficiaries is a data layer for population. For this we used data from Worldpop 2020 at 100 m resolution, resampled to 10 m resolution.

Input data to run models and calculate outputs for the air pollution removal require input data on $PM_{2.5}$ concentration. This was sourced from https://sedac.ciesin.columbia.edu/data/set/sdei-global-annual-gwr-pm2-5-modis-misr-seawifs-aod-v4-gl-03, and resampled to 10 m to match the land cover data.

The input data to run heat calculations was sourced from Landsat-8 Band 10; median value for summer months (June through August) 2017. Data were converted to Celsius and resampled to 10 m, to match the land cover data.

3.3 Calculations to run air pollution removal model

The equations used to calculate the quantity of $PM_{2.5}$ pollution removed by woodland (1) and the change in $PM_{2.5}$ concentration as a result of woodland cover (2) were taken from Fletcher et al. (2020), defined as follows:

$$PM\_removal\_rate = 1.1664 * PM\_conc + 0.4837 \quad (1)$$

Where PM_removal_rate is quantity of $PM_{2.5}$ removed per unit area of woodland per year (kg ha^{-1} yr^{-1}), and PM_conc is the concentration of $PM_{2.5}$ (µg m^{-3})

$$Change\_PM\_conc = -0.0318 * PM\_conc - 0.1112 * Log10WoodPC - 0.054 * PMxLogWood + 0.0832 \quad (2)$$

Where Change_PM_conc is the change in $PM_{2.5}$ concentration (µg m^{-3}), PM_conc is the initial $PM_{2.5}$ concentration (µg m^{-3}), Log10WoodPC is the Log10 of the percentage of woodland (percentage +1%, to avoid very low values) in the relevant area, and PMxLogWood is PM_conc multiplied by Log10WoodPC. This change in PM concentration is calculated using a kernel-based approach, within a circular kernel (moving window) of 1 km^2.

3.4 Calculations to run cooling model

The simplified land cover data were used as a template to create a cooling layer, by substituting land cover classes for corresponding cooling coefficients, following those in eftec et al., (2017). The cooling opportunity layer was created by subtracting the cooling layer from the maximum cooling coefficient value (3.5°C, for woodland), then multiplying by a heat-weighting layer. The heat-weighting layer was created by isolating areas of the city over 25 °C (a threshold of temperature, over which harm to human health can occur), then rescaling values in these areas from zero to one.

4. Results

The simplified land cover map for Chengdu, used as input to the models, is shown in Figure 1. Of particular interest for interpreting the ecosystem services outcomes is the location and extent of wooded land, and the large areas of grassland/agriculture surrounding the built area. Population density is shown in Figure 2 and this influences the 'opportunity mapping' to show which services can benefit the largest number of people through spatial targeting of interventions.

For each of the ecosystem services, we present three sets of outputs. These are a map of the pressure (air pollution, hot day temperature), a map of the service provided (air pollution removal, cooling) and an opportunity map showing where the best locations for interventions will occur, taking into account both the pressure and also the potential benefitting population.

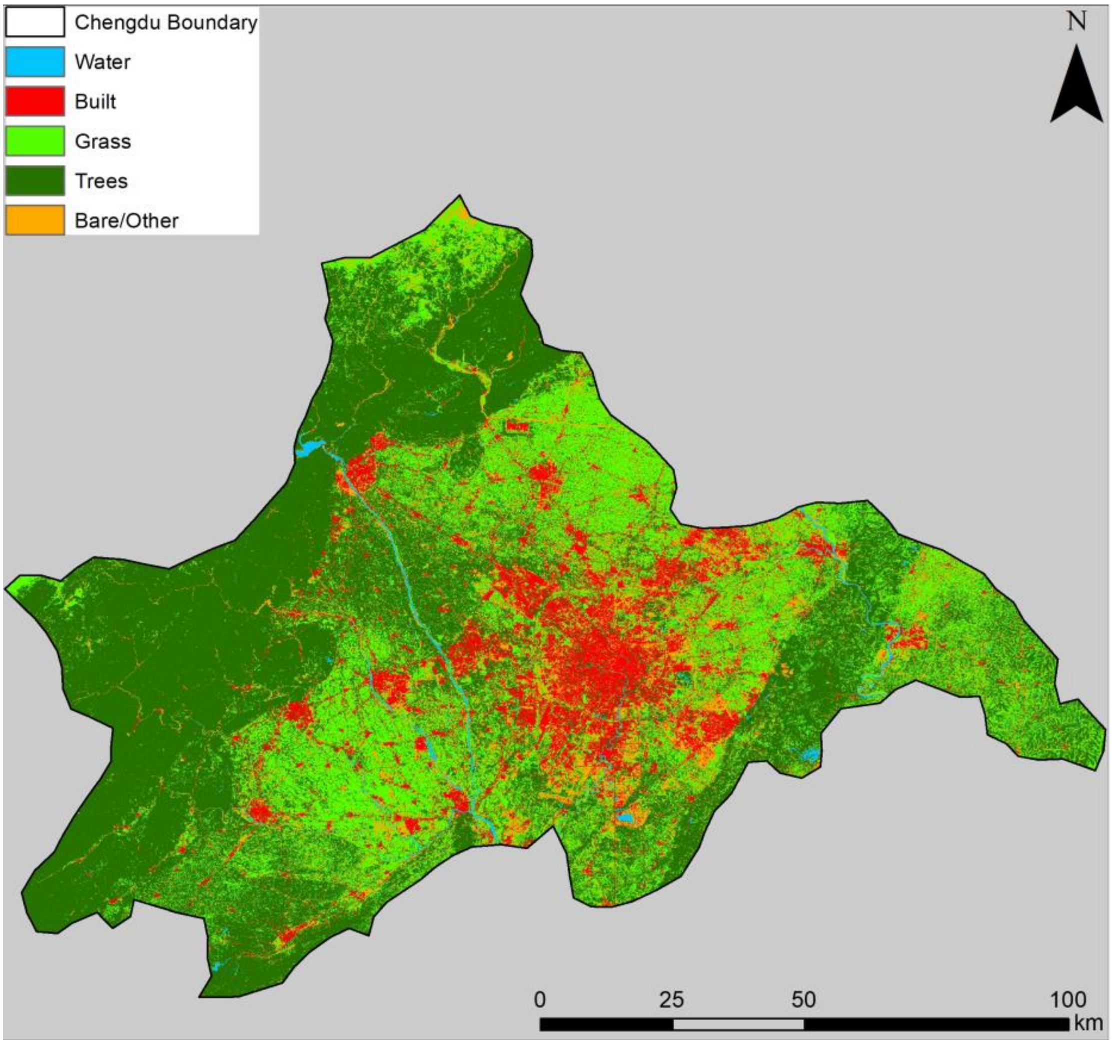

Figure 1. Land cover input used for ecosystem services modelling in Chengdu, reclassified from ESA Worldcover 2021.

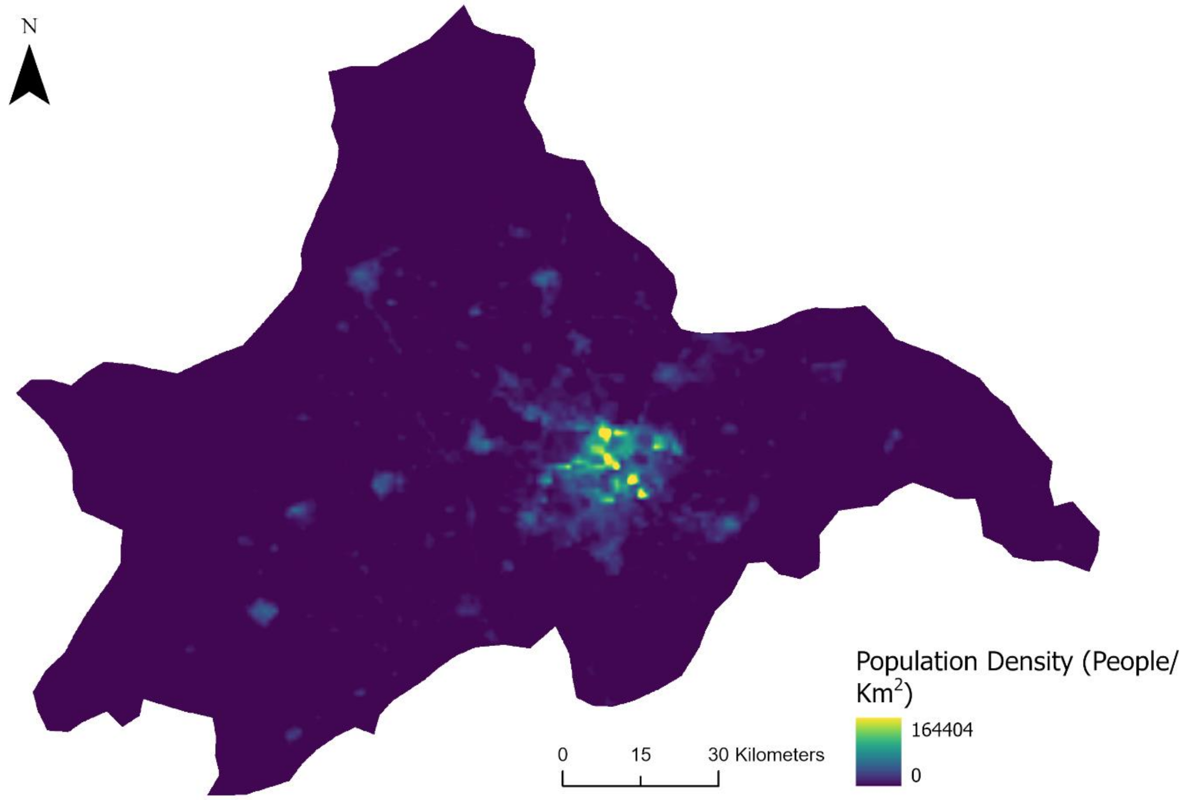

Figure 2. Map showing population density for Chengdu.

4.1 Air pollution removal

The map of $PM_{2.5}$ concentrations is shown in Figure 3. The highest concentrations reflect sources focused around the urban areas. For the outputs of ecosystem service provided, two metrics are calculated: the change in pollution concentrations due to removal by woodland, and the resulting, and the quantity of pollution removed. The map of change in $PM_{2.5}$ concentration is shown in Figure 4. The areas of greatest change in concentration reflect areas where there is a combination of high levels of tree cover, and where baseline $PM_{2.5}$ concentrations are also high. These areas occur most extensively to the south west of the city. Figure 5 shows the quantities of $PM_{2.5}$ removed per 10 m by 10 m grid cell, with the spatial patterns reflecting again where trees occur and where $PM_{2.5}$ concentrations are highest. Lastly we show the areas which provide the greatest potential for maximising the ecosystem service of air pollution removal by vegetation (Figure 6). Here, the highest areas reflect a combination of where people are located and where the highest $PM_{2.5}$ concentrations occur within the city.

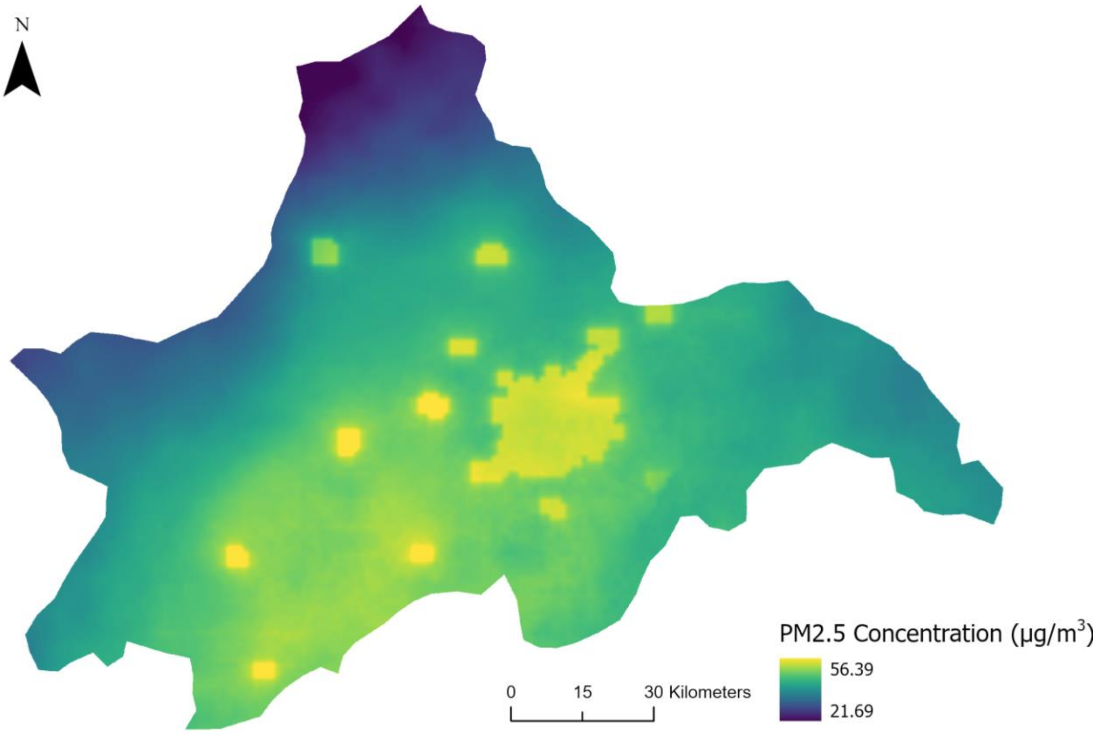

Figure 3. Map of $PM_{2.5}$ concentration (μg/m^3), Chengdu.

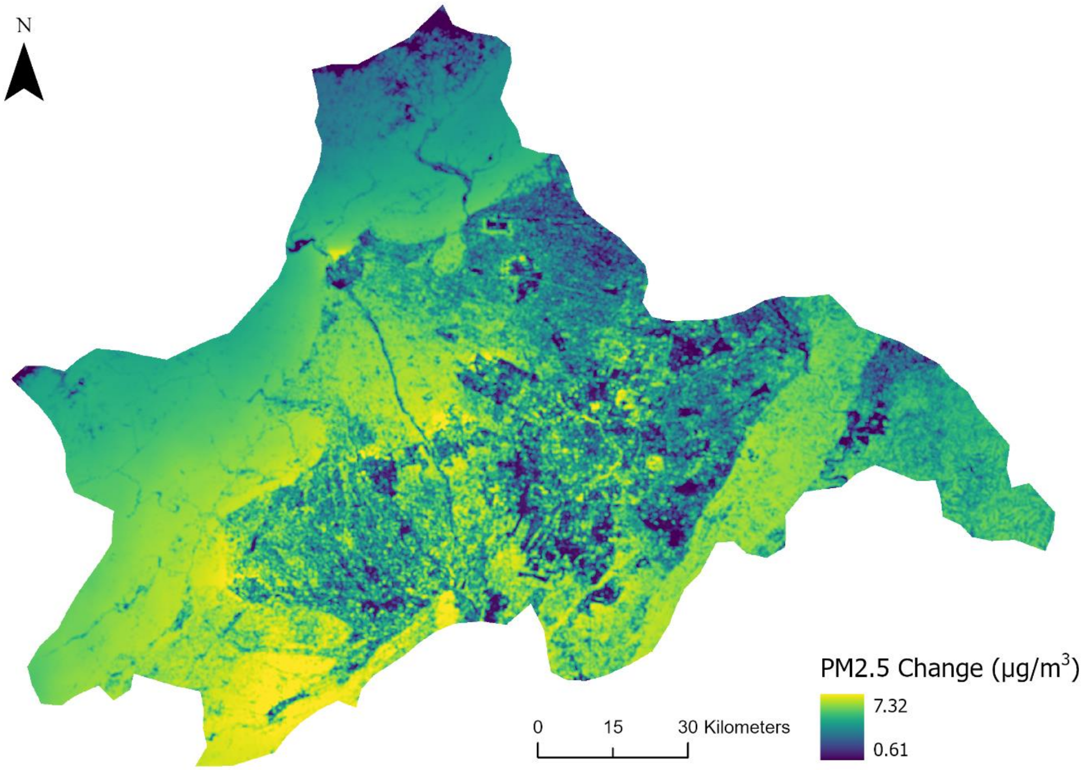

Figure 4. Change in $PM_{2.5}$ concentration (μg/m^3) as a result of pollution removal by trees, Chengdu.

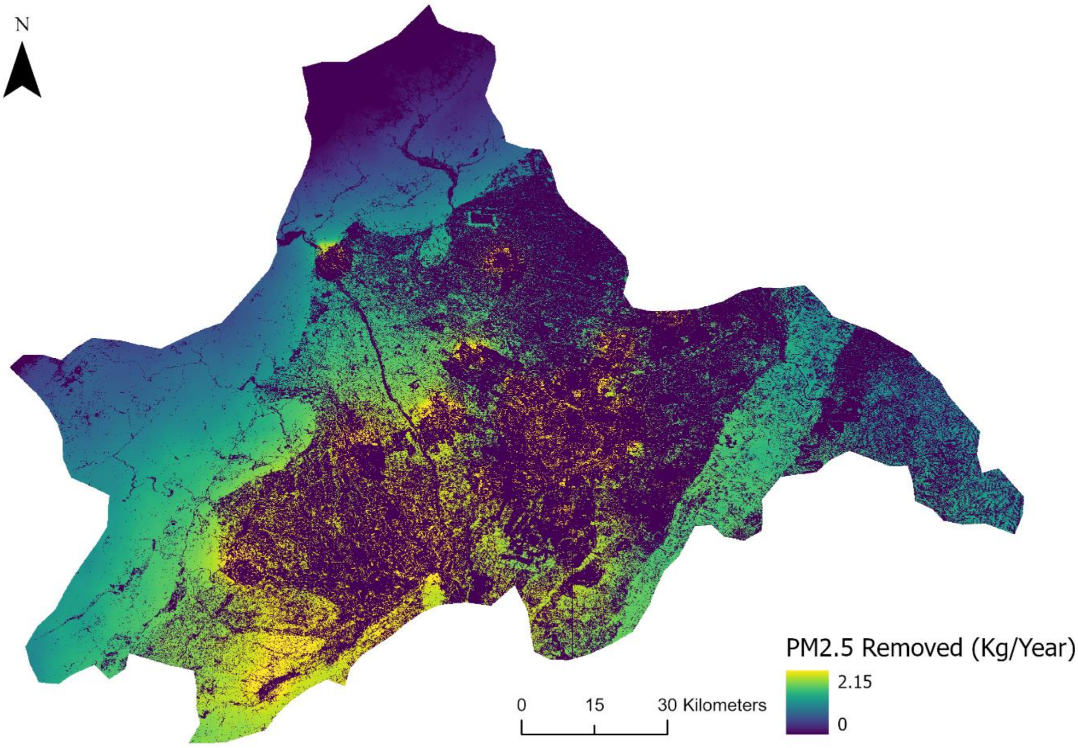

Figure 5. Map of quantity of $PM_{2.5}$ removed by trees (kg yr^{-1} per 10x10m cell), Chengdu.

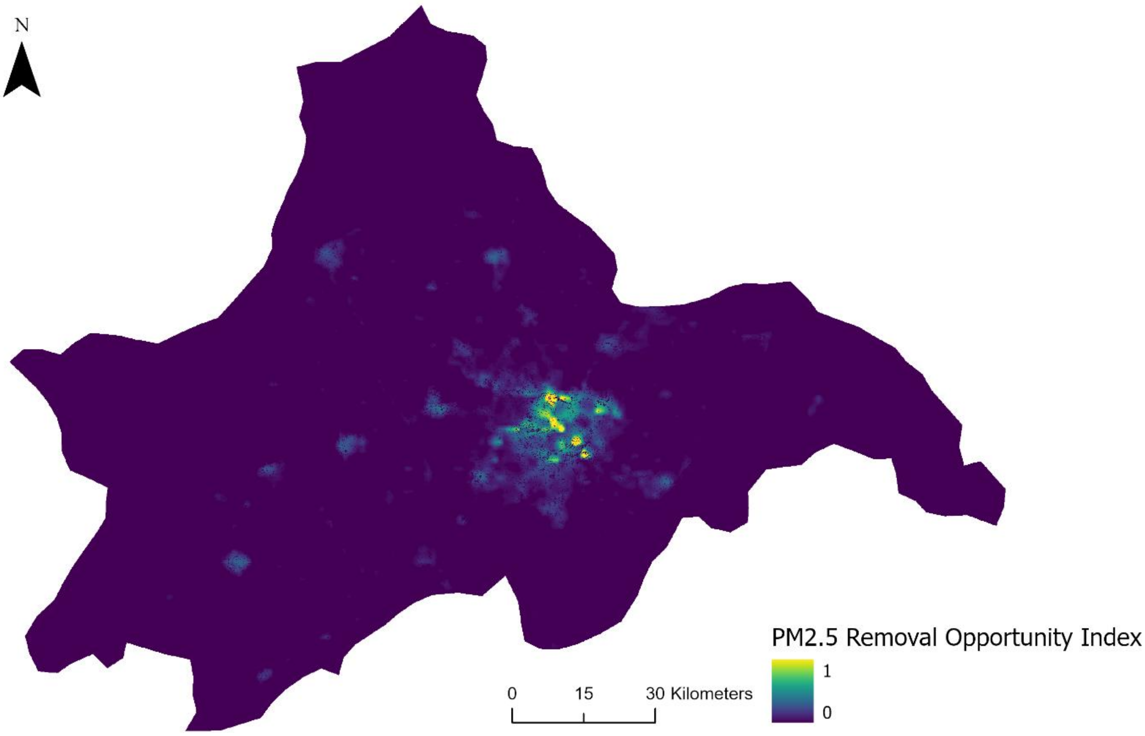

Figure 6. Opportunity map for $PM_{2.5}$ removal by vegetation, Chengdu. A value of 1 indicates greatest potential.

4.2 Hot-day cooling

Land surface temperature (LST) was used as a proxy for hot-day air temperature pressure in summer, shown in Figure 7. The hottest areas with the highest heat pressure tend to be urban and built up areas, but also include bare land and some agricultural land. Cooler areas with lower heat pressure are found in the mountainous areas and the more forested areas. Figure 8 shows the cooling service provided by land cover for Chengdu. The greatest levels of cooling are provided by tree cover, with much less cooling provided by grass/agriculture. Figure 9 shows the opportunity mapping for cooling. This reflects the combination of where the greatest heat pressure occurs, and where the most people live who will potentially benefit from that service.

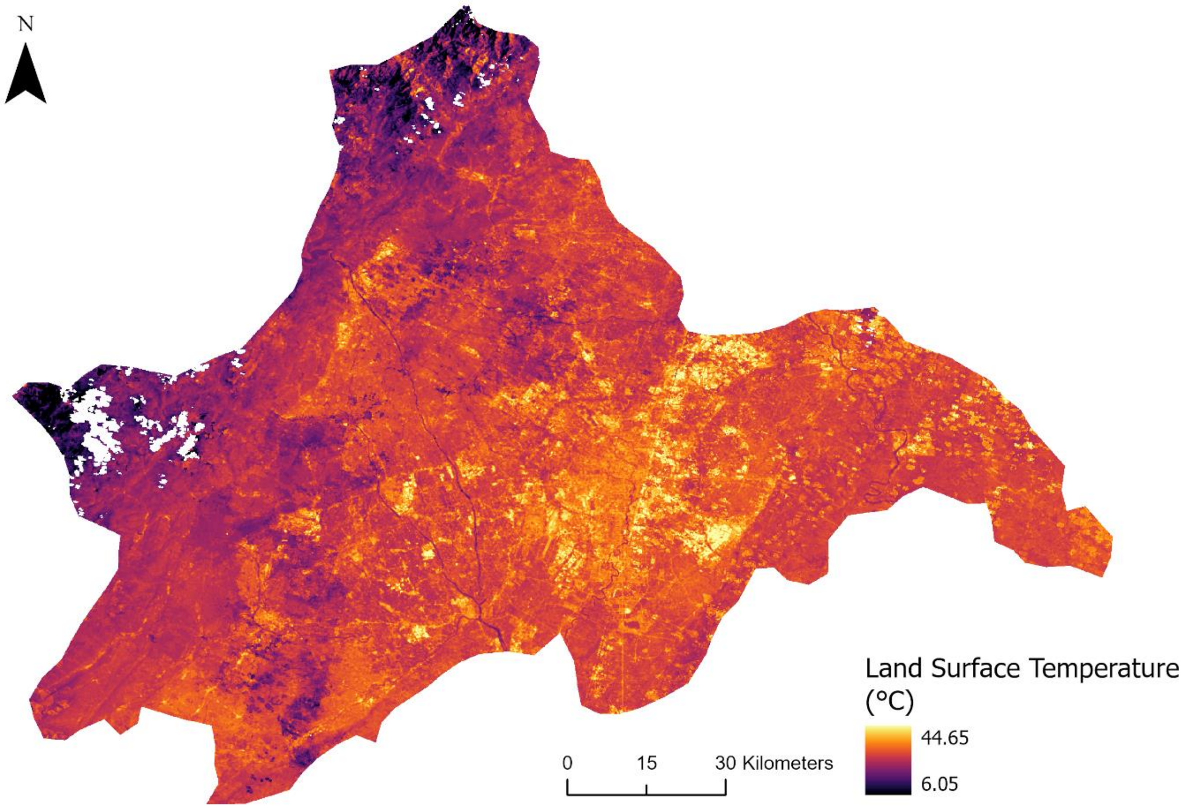

Figure 7. Land surface temperature (°C) calculated as the median across the summer months of June to August 2017, for Chengdu. White areas show no data.

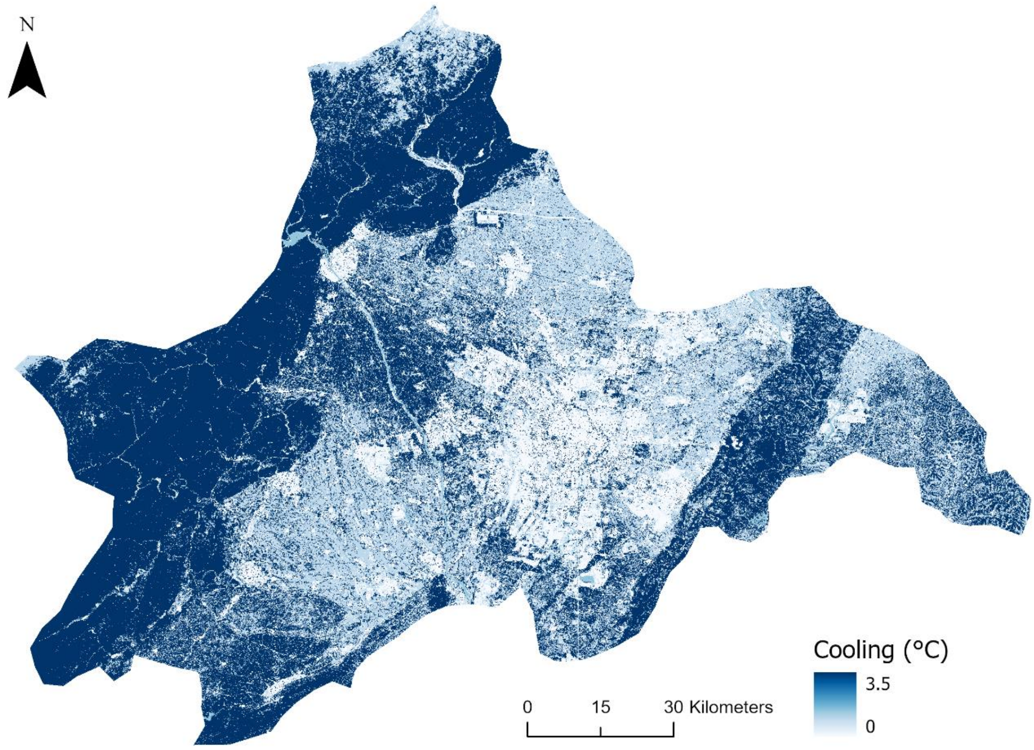

Figure 8. Cooling service (°C) provided by vegetation in Chengdu.

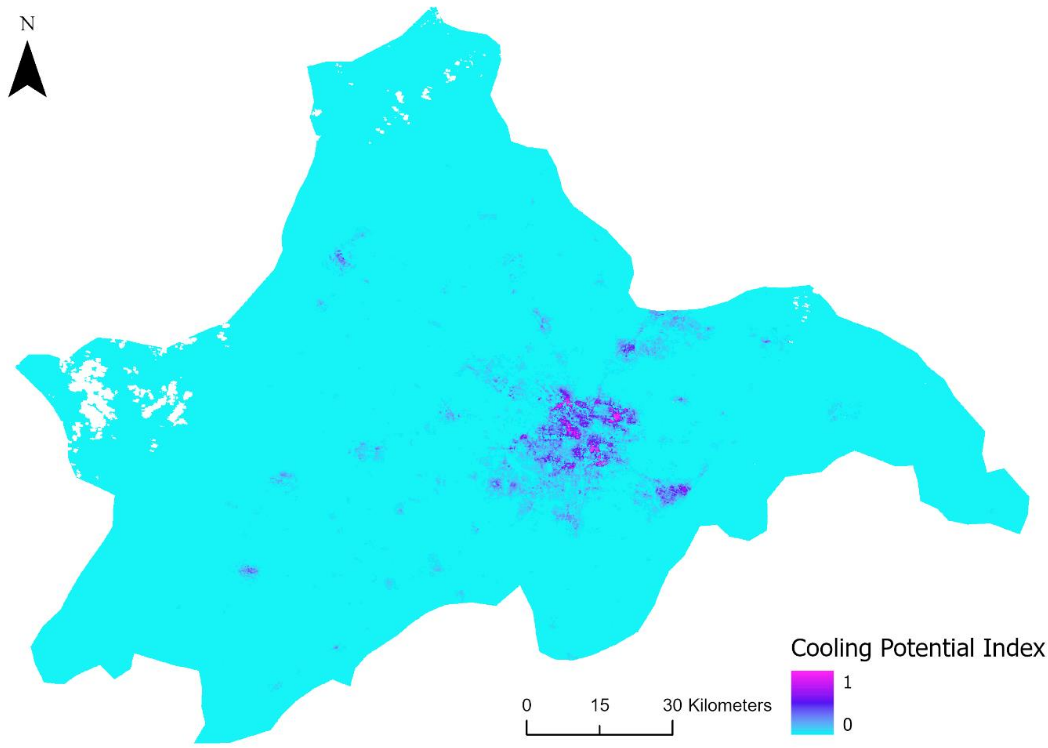

Figure 9. Opportunity map for cooling potential in Chengdu.

5. Discussion of findings, and conclusions

The outputs from this project show in detail the spatial patterns of where the pressures lie, and where the amount of service is currently provided, as an output of the City Explorer Toolkit models used in this study.

Although much of the service benefit for both air pollution removal and cooling is provided outside of the built areas, there are also substantial areas within the built environment where these services are also provided, and the greatest level of service does not always occur in the same locations for these two pressures.

The opportunity mapping highlights the most important areas to target for new interventions designed to address those pressures. Since the higher opportunity scores are, to a large extent, a function of the potential population that would benefit from the service, the underlying population map is a key factor in the distribution of potential. Nonetheless, there are differences as well as synergies in the specific locations which deliver the most opportunity for air pollution removal and for cooling.

These key opportunity areas can be targeted by decision-makers as the best places to make changes to improve the extent and quality of green and blue infrastructure (or nature-based solutions). Figure 10 and Figure 11 show the combined opportunity layer for the two services, with Figure 11 focusing in more detail on the urban extent. This shows specific parts of the city where interventions to address air pollution or hot-day temperatures are likely to be most effective. Once key locations are identified, decision-makers can also make use of recently published assessments of multi-functionality and performance of individual green and blue infrastructure types (Jones et al. 2022) to help decide which nature-based solutions to implement in those locations (Figure 12). If the key pressures are air pollution removal and cooling, then the nature-based solutions which deliver the most service for both these pressures are likely to be those which contain many trees (Figure A1 – Annex 1). However, water bodies would also be a good option to provide cooling, but they provide very little removal of air pollution.

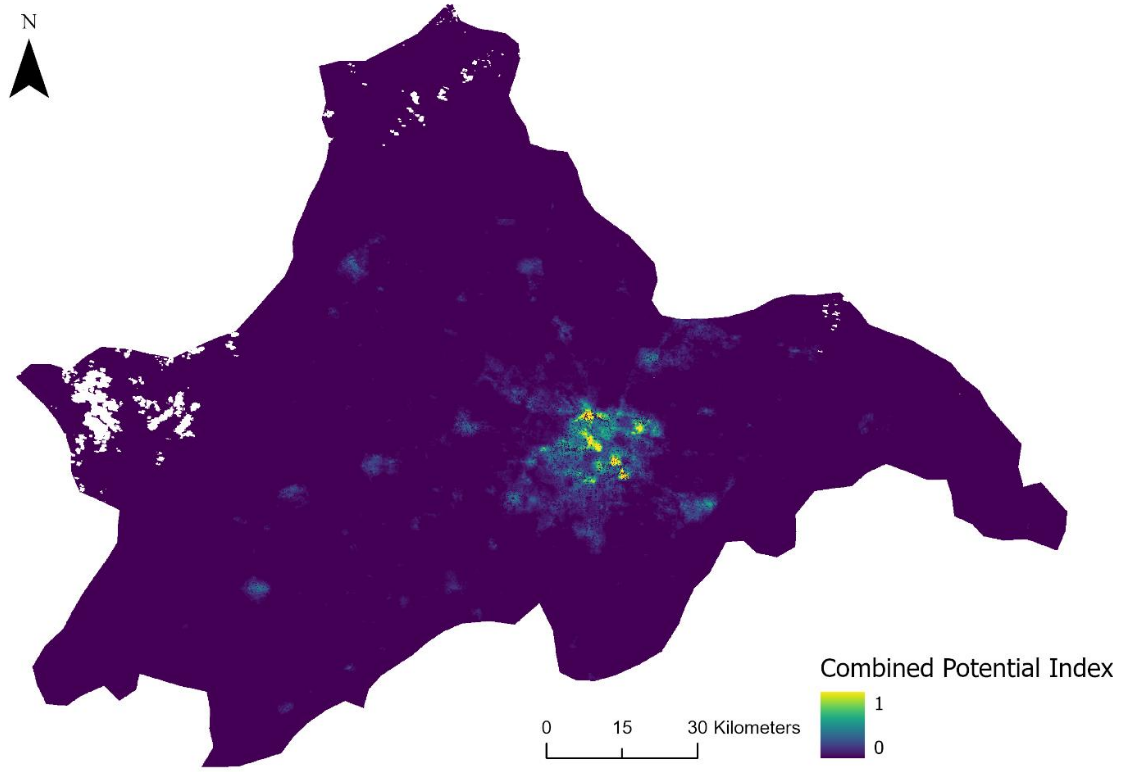

Figure 10. Combined opportunity scores for air pollution removal and cooling potential for Chengdu.

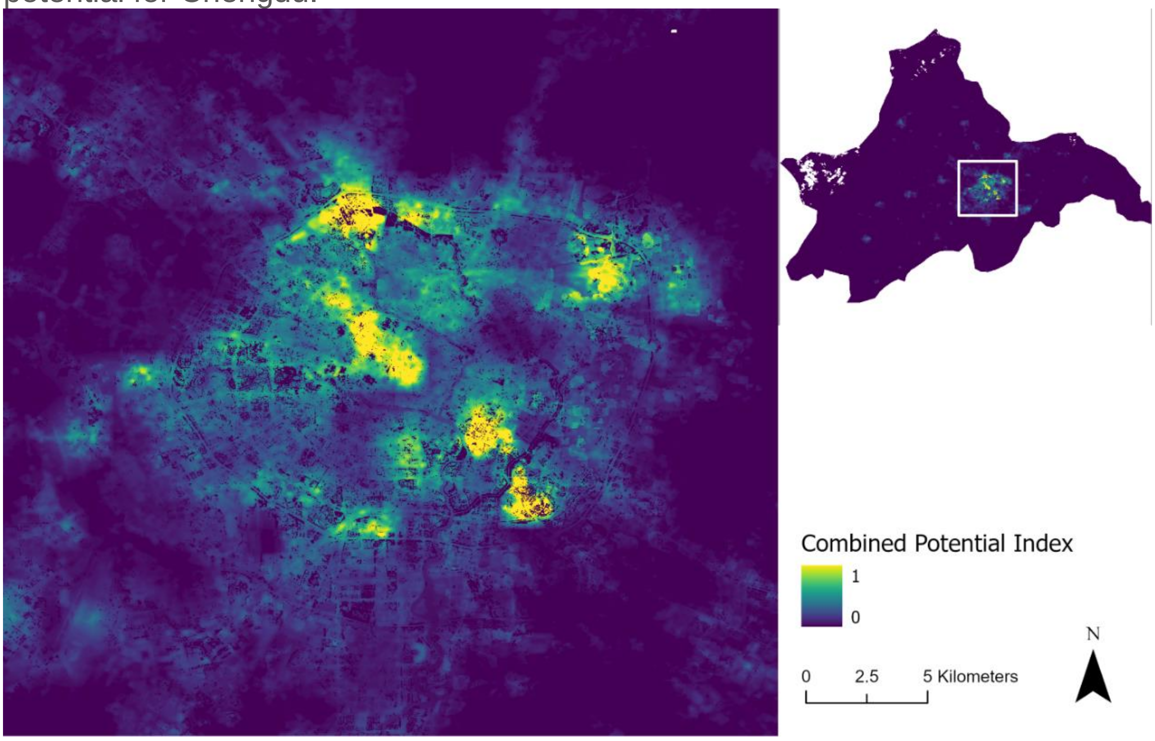

Figure 11. Combined opportunity scores for zoomed in central urban area within Chengdu.

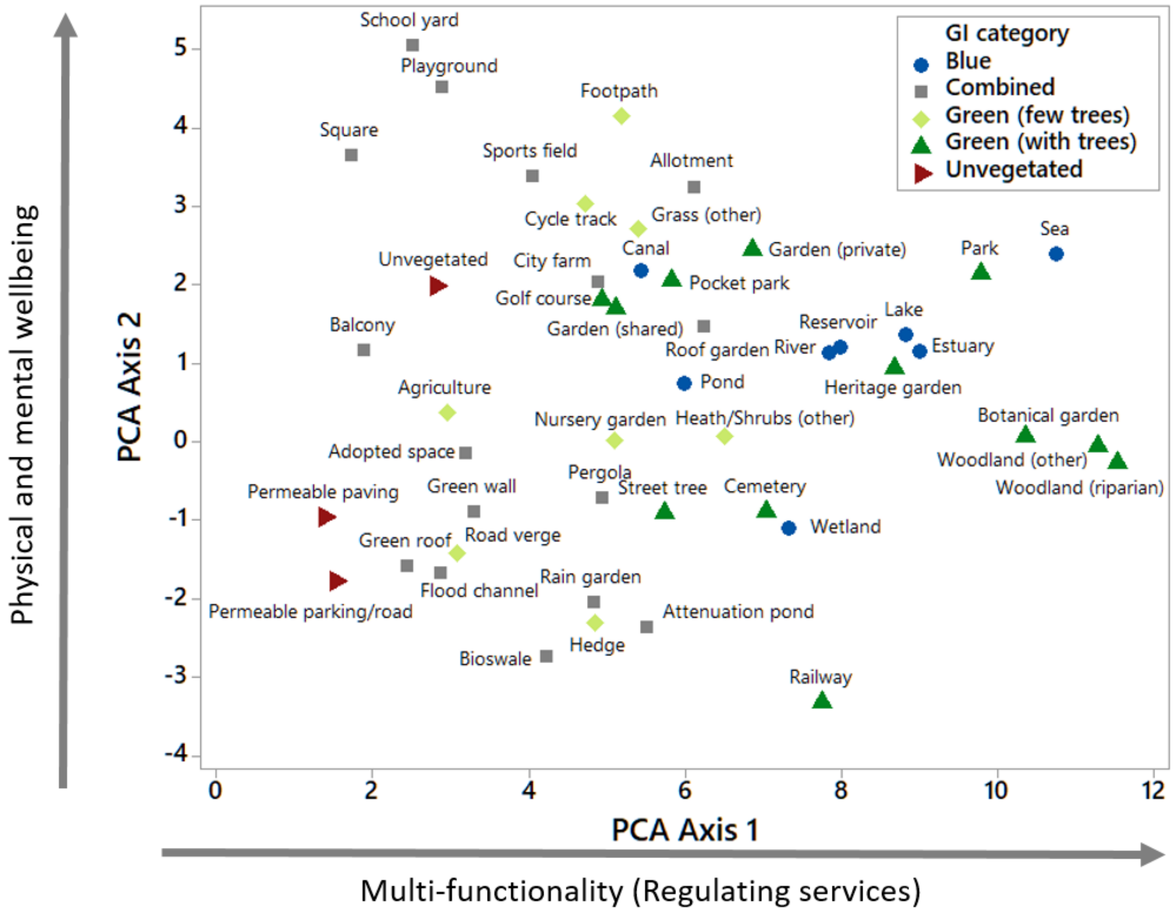

Figure 12. Multifunctionality of green and blue infrastructure for nature-based solutions. Adapted from Jones et al. (2022).

6. Conclusions

- We have demonstrated the potential of using ecosystem services models for two services (air pollution removal, and cooling) to calculate benefits of green and blue infrastructure for the city of Chengdu and its surrounding administrative area.
- There is spatial variation in the amount of ecosystem service provided for each of these services within Chengdu, and they differ from each other. The spatial variation reflects patterns in the pressure and patterns in the location and type of natural and semi-natural land cover types which provide ecosystem services.

- Opportunity mapping has revealed the best places for new green or blue infrastructure types, and the opportunity layers can be combined to reveal optimum locations to achieve the most multi-functionality.
- These outcomes illustrate the potential for enhanced spatial models and information to inform city planning and decision making for Chengdu.
- These example outcomes can be further developed by incorporating other ecosystem service models, such as water quality, carbon, biodiversity or flood risk, to give a more complete understanding of the benefits provided by green and blue infrastructure.
- Combining multiple models into a single online interface would provide decision-makers with a tool that they can use to plan and design nature-based solutions to achieve maximum benefit for the city.

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8. Annex 1

Supporting information tables and figures

Table A1. Data sources required for City Explorer Toolkit, and potential datasources identified for Chengdu

Name	Type	Minimum Spatial Resolution	Notes	Data source (for Chengdu, the capital city of Sichuan province)
Land Cover	Raster	10m	Thematic resolution is dependent upon which modules/models are being used in the Toolkit. Suggested minimum would be: Trees, Grass, Water, Impervious, Buildings. Additional classes may be added within the editor tab of the app, for scenario creation (e.g. for adding green roofs, rain gardens, etc).	ESA WorldCover 10 m 2021, Including tree, shrub, grass, crop, built-up, bare, water bodies and so on. raster file (Zanaga, D., Van De Kerchove, R., Daems, D., De Keersmaecker, W., Brockmann, C., Kirches, G., Wevers, J., Cartus, O., Santoro, M., Fritz, S., Lesiv, M., Herold, M., Tsendbazar, N.E., Xu, P., Ramoino, F., Arino, O., 2022. ESA WorldCover 10 m 2021 v200. https://doi.org/10.5281/zenodo.7254221)
PM2.5 Concentration	Raster	1000m	This should be an annual mean PM2.5 concentration. Prefereably, this layer should be much higher resolution, however not all citites have custom air pollution models, so it may be necessary to obtain this fom global datasets. Some of these are available at approx. 500m resolution, but not for every year.	1 km Ground-level PM2.5 (μg/m3) Dataset for China 2021, raster file (Jing Wei, & Zhanqing Li. (2019). ChinaHighPM2.5: Big Data Seamless 1 km Ground-level PM2.5 Dataset for China (Version 4) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.6398971.)
Temperature	Raster	10m	This should be an estimate of air temperature, rather than LST, for an expample "hot day". The LC data should, for preference, be from as close in time to the LC as possible.	0.1° x 0.1°, 2 m air temperature, monthly and annually
DEM/DSM	Raster	10m	Hydro-correct DEM covering the whole catchement, from which to construct a flow accumulation raster.	8 m DEM, raster file

Lden_Noise	Raster	10m	This should be annual mean of A-weighted Lden annual average noise (dBA) from major road traffic. For Europe, this is the European Noise Directive statutary modelled noise data, which doesn't factor in effects of vegetation. If noise data are not available, traffic data could potentially be used to create something similar.	road data from Open Street Map, 2023, shape file
Population density	Various	10m (if raster, but see notes>)	Population density. If we have building footprints and heights, along with use-type (e.g. commercial, residential, inditrial) we could use census data at a more coarse resolution (e.g. electoral wards) and then use a dasymetric disaggregation approach to create a raster dataset at high resolution.	①100 m from WorldPop (https://www.worldpop.org/), the number of people per pixel, 2020, raster file ②10 m building height, 2020, raster file (Wanben Wu. (2023). CNBH-10 m: A first Chinese building height at 10 m resolution[Data set]. In Remote Sensing of Environment (Updated in April 2023, Vol. 291, p.113578). Zenodo. https://doi.org/10.5281/zenodo.7827315.)
Social	Various	10m (if raster, but see notes>)	Ideally these data should match the population density and should comprise various relevant descriptors of the population, e.g. age (in age-bands), poverty (and/or maybe deprivation indices). These can be recorded in the form of absolute numbers (i.e. number of individuals within, e.g. age-band) or proportional data (i.e. % within, e.g. age-band).	statistics tables of population at district and county level (there are 20 districts/counties in Chengdu city): including total population, gender, urban and rural population, etc. 2020

Table A2. Land cover look-up table for mapping land cover in Chengdu, as input to the ecosystem services models.

Worldcover2020 Class	Simplified class
Trees	Trees
Shrubs	Grass
Grass	Grass
Crops	Grass
Built	Built
Bare/sparse veg	Bare
Snow/Ice	Water
Water	Water
Herbaceous wetland	Grass
Mangroves	Trees
Moss/Lichens	Grass

Description	Object type	Object category	Food provision	Air pollution removal	Noise mitigation	Heat mitigation	Water quality mitigation	Water flow manageme nt	Maintainin g carbon stocks	Supportin g physical activity	Supporting social interactions	capacities - stress reduction and cognitive restoration	Supporting biodiversity
Mainly public space, but some access restrictions may apply	Parks	Pocket park	Low	Low	Low	Low	High	Medium	Low	Medium	Very high	High	Medium
		Park	Low	High	High	High	High	Medium	High	Very high	Very high	Very high	High
		Botanical garden	Low	High	Very high	Very high	High	Medium	High	Medium	High	Very high	Very high
		Heritage garden	Medium	Medium	High	High	High	Medium	Medium	Medium	High	Very high	High
		Nursery garden	Medium	Medium	Low	Low	High	Medium	Medium	Low	Medium	Medium	Low
Areas designed primarily for specific amenity uses	Amenity areas	Sports field	Negligible	Low	Low	Low	Low	Low	Low	Very high	High	Medium	Negligible
		School yard	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Very high	Very high	Medium	Negligible
		Playground	Negligible	Negligible	Negligible	Negligible	Low	Low	Negligible	Very high	Very high	Medium	Negligible
		Golf course	Negligible	Medium	Low	Low	Negligible	Medium	Low	Medium	High	High	Medium
		Shared open space (e.g. square)	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Medium	Very high	Low	Negligible
Areas designed primarily for specific uses (not leisure); some access restrictions may apply	Other public space	Cemetery	Negligible	Medium	Medium	Medium	Medium	Medium	High	Low	Low	Very high	High
		Allotment/other growing space	Very high	Medium	Low	Low	Negligible	Medium	Negligible	High	High	Very high	High
		City farm	Very high	Medium	Low	Low	Negligible	Medium	Negligible	Medium	Medium	High	Medium
		Adopted public space	Low	Medium	Low	Low	Low	Low	Negligible	Negligible	Low	Medium	Low
Linked to routeways, geographical features and boundaries	Linear features/routes	Street tree	Low	High	Low	High	Low	Low	Medium	Negligible	Low	High	Medium
		Cycle track (as green/blue corridor)	Low	Low	Low	Low	Low	Low	Low	Very high	Medium	High	Low
		Footpath (as green/blue corridor)	Low	Low	Low	Low	Low	Low	Low	Very high	Very high	High	Low
		Road verge	Low	Low	Low	Low	Medium	Medium	Low	Negligible	Negligible	Low	Low
		Railway corridor	Negligible	Very high	Very high	Very high	Low	Medium	High	Negligible	Negligible	Low	Very high
		Riparian woodland	Low	Very high	Very high	Very high	Very high	High	Very high	High	High	Very high	Very high
		Hedge	Low	Medium	Low	Low	High	High	Medium	Negligible	Negligible	Medium	Medium
Constructed green and blue space, added to infastructure	Constructed GI on infrastructure	Green roof	Negligible	Low	Negligible	Low	Low	High	Low	Negligible	Negligible	Low	Low
		Green wall	Negligible	Medium	Medium	Low	Negligible	Low	Low	Negligible	Negligible	Medium	Low
		Roof garden	Medium	Medium	Low	Medium	Low	Low	Medium	Low	High	Very high	Medium
		Pergola (with vegetation)	Negligible	Medium	Low	High	Low	Low	Medium	Negligible	Low	High	Low
Infrastructure designed to incorporate some GBS components	Hybrid GI (for water)	Permeable paving	Negligible	Negligible	Negligible	Negligible	High	High	Negligible	Low	Negligible	Negligible	Negligible
		Permeable parking/roadway	Negligible	Negligible	Negligible	Negligible	High	High	Low	Negligible	Negligible	Negligible	Negligible
		Attenuation pond	Negligible	Low	Low	Low	Very high	Very high	Medium	Negligible	Low	Medium	High
		Flood control channel	Negligible	Low	Negligible	Low	Low	Very high	Low	Negligible	Low	Negligible	Medium
		Rain garden	Low	Medium	Negligible	Low	High	High	Medium	Negligible	Negligible	High	Medium
		Bioswale	Negligible	Medium	Low	Low	Medium	Very high	Medium	Negligible	Negligible	Low	Medium
Bluespace features	Waterbodies	Wetland	Negligible	Medium	Low	Medium	Very high	Very high	Medium	Low	Medium	Very high	High
		River/stream	Low	Low	High	High	Medium	High	Low	Medium	High	Very high	High
		Canal	Low	Low	Low	Medium	Low	Medium	Low	Medium	High	Very high	Low
		Pond	Negligible	Low	Low	Low	Low	High	Medium	Low	High	Very high	High
		Lake	Medium	Low	Medium	High	High	High	Medium	High	High	Very high	Very high
		Reservoir	Low	Low	Medium	High	High	Very high	Medium	High	High	Very high	Medium
		Estuary/tidal river	High	Low	High	High	High	N/A	Medium	Medium	High	Very high	Very high
		Sea (incl. coast)	High	Low	High	Very high	High	N/A	Very high	Very high	Very high	Very high	Very high
Other un-sealed features without specified use, often on private land	Other non-sealed urban areas	Woodland (other)	Low	Very high	Very high	Very high	High	High	Very high	High	High	Very high	Very high
		Grass (other)	Low	Low	Low	Low	Medium	Medium	Low	Very high	High	Medium	Medium
		Shrubland (other)	Low	Medium	Low	Low	High	High	Medium	Medium	Medium	High	High
		Arable agriculture	Very high	Medium	Low	Low	Negligible	Low	Negligible	Low	Negligible	Low	Low
		Sparsely vegetated land	Negligible	Negligible	Low	Negligible	Low	Low	Negligible	Medium	Medium	Medium	Low

Figure A1. Matrix of ecosystem service delivery, by green and blue infrastructure type. Adapted from Jones et al. (2022).

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