

MAPPING CLIMATE RISK AND VULNERABILITY WITH PUBLICLY AVAILABLE DATA

Several factors affect climate risk. What these are and the extent of their influence varies from place to place. Therefore, climate action is needed on all fronts: “everything, everywhere, all at once.”¹

A guidance document from the WM-Air project

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No two places are affected by climate change in the same way. Socio-economic and environmental decisions, past and future, lead to variances in the vulnerability of people to the impact of climate change. These decisions impact land use, inequity, marginalisation and governance².

Why map climate risk and vulnerability? A climate risk and vulnerability assessment (CRVA) map is a tool to communicate climate risk and identify potential impacts on society. CRVA maps help prioritise, target and plan adaptation investments to the needs of a place.

This guidance document describes a new CRVA approach that can be easily updated from readily available datasets. Figure 1 describes the conceptual methodology used in this project. This is a working document **and will continue to be updated.**

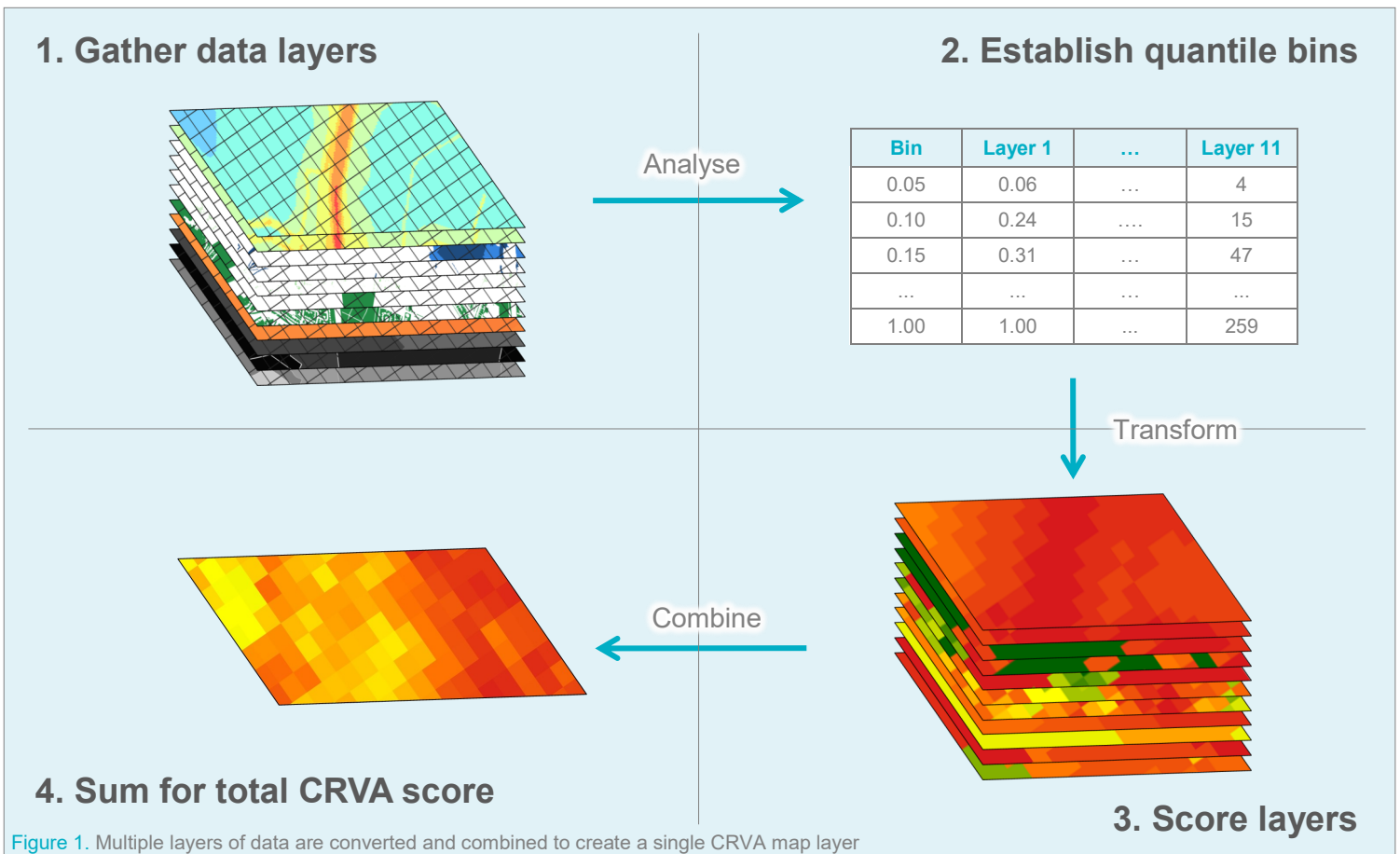


Figure 1. Multiple layers of data are converted and combined to create a single CRVA map layer

References

- United Nations (2023) Secretary-General's video message for press conference to launch the Synthesis Report of the Intergovernmental Panel on Climate Change: Available at: <https://www.un.org/sg/en/content/sg/statement/2023-03-20/secretary-generals-video-message-for-press-conference-launch-the-synthesis-report-of-the-intergovernmental-panel-climate-change> (last accessed 19/04/2023)
- IPCC (2022) Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the IPCC. Available at: https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_FullReport.pdf (last accessed 13/03/2023)

PRODUCING A CLIMATE RISK AND VULNERABILITY ASSESSMENT (CRVA) MAP FOR BIRMINGHAM

This guidance document describes the GIS techniques used to develop a CRVA map for Birmingham; co-created by the WM-Air project group and Birmingham City Council.

How is a CRVA map built?

A CRVA map requires several layers of data that would contribute to climate risk. The data parameters could include: **Physical**, e.g. urban form, flood zones; **Environmental**, e.g. temperature, air quality; and **Social**, e.g. health, social deprivation. Each data layer is standardised in terms of both spatial scale and values. Then, they can be easily combined into one single layer that represented the total climate risk across the map. Therefore, it is important to note that this CRVA map is not an absolute assessment of climate risk and vulnerability, but only relative within the boundary of the area being assessed, which in this case, is the Birmingham city boundary. This means that it cannot be directly compared with another city or region.

What tools and functions are required for a CRVA map?

A Geographic Information System (GIS) application is required to build a CRVA map. Throughout this guidance document, the Quantum GIS (QGIS)³ free, open-source application was used; the approach is also compatible with ArcGIS. Several functions are used, but the main CRVA build uses raster (or matrix) algebra. Data layers are divided into small grids (cells) of equal dimension, with each cell comprising a single value.

Why produce a CRVA map of Birmingham?

Birmingham is part of the West Midlands conurbation; the

largest metropolitan county in the United Kingdom⁴. Birmingham's city centre has undergone significant transformation in recent decades, attracting unprecedented levels of investment, development, and opportunities. At the same time, the city faces the challenges of climate change, increased economic disparity, and socio-environmental change⁵. Future developments must consider these challenges from their inception to reduce climate risk and vulnerability. A CRVA provides the means to understand and address these challenges, direct service priorities for the Levelling Up agenda, and help achieve the city's stated ambitions around a Just Transition. Its adoption would position Birmingham City Council as a A-class city and a global leader in transparency and bold climate action⁶.

Data used for this CRVA map of Birmingham

This CRVA map used 11 datasets, shown in Table 1. They include physical, environmental and social data that represent climate risk as a hazard, vulnerability or exposure. Most data are open source or publicly available, so it is a replicable process for other regions to produce a similar CRVA map. It also means that when future revisions of data are available, they can be loaded in as a means of monitoring and evaluating processes in reducing climate risk.

Putting the final CRVA map together

In Table 1, the required score ranges are described per layer. They were converted from the original data forms they were downloaded in, to a standardised format and score to be summed up easily - where for each layer, a **score near to 0 represents lower risk** and a **score near to 1 represents higher risk**. Table 2 shows the conversion processes undertaken in GIS to conduct this standardisation process per layer. Once these were ready, the raster calculator was used to sum all the layers together. Currently, the layers have equal weighting for they are assumed to be of equal importance to the overall CRVA scores.

Table 1. Key information on each layer used to build the CRVA map

Layer	Data type	Layer score parameters
Fluvial flood risk (Flood zones 2 & 3) ^{7,8}	Physical	% coverage of a grid square by flood risk; grouped by 5%ile bins
Pluvial flood risk (3.3 year return period) ⁹	Physical	% coverage of a grid square by flood risk; grouped by 5%ile bins
Open green space deficit ¹⁰	Physical	% coverage of a grid square by green space; grouped by 5%ile bins
Other green space deficit ¹¹	Physical	% coverage of a grid square by green space; grouped by 5%ile bins
Tree canopy cover deficit ¹²	Physical	% coverage of a grid square by tree canopy; grouped by 5%ile bins
Local climate zones ¹³	Physical	0 = completely open space, 1 = most densely built-up, high-rise*
Nitrogen dioxide (NO ₂) concentration**	Environmental	Mean annual concentration per grid square; grouped by 5%ile bins
Annual fine particulate (PM _{2.5}) concentration**	Environmental	Mean annual concentration per grid square; grouped by 5%ile bins
Surface temperature (summer daily max) ¹⁶	Environmental	Temperature per grid square; grouped by 5%ile bins
Indices of Multiple Deprivation (IMD) ¹⁷	Social	Decile ranking per grid square
Excess years life lost ¹⁸	Social	Total years per grid square; grouped by 5%ile bins***

* See Table 3 for the local climate zone breakdown and assigned CRVA scores

** Data layers are a 2019 update of Zhong et al.¹⁴ created by the WM-Air project. Lower resolution open data is available from DEFRA¹⁵.

*** Data provided are available to UK local authorities

References

- QGIS: A Free and Open Source Geographic Information System. Available at : <https://www.qgis.org/en/site/> (last accessed 16/03/2023)
- ONS (2022) Estimates of the population for the UK, England, Wales, Scotland and Northern Ireland. Available at: <https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/populationestimatesforukenglandandwalescotlandandnorthernireland> (last accessed 27/02/2023)
- Birmingham City Council (2021) Our Future City Plan 2021. Available at: https://www.birmingham.gov.uk/downloads/file/18590/our_future_city_plan_2021_print_version (last accessed 31/01/2023)
- CDP (2022) Cities A list 2022. Available at: <https://www.cdp.net/en/cities/cities-scores> (last accessed 27/02/2023)

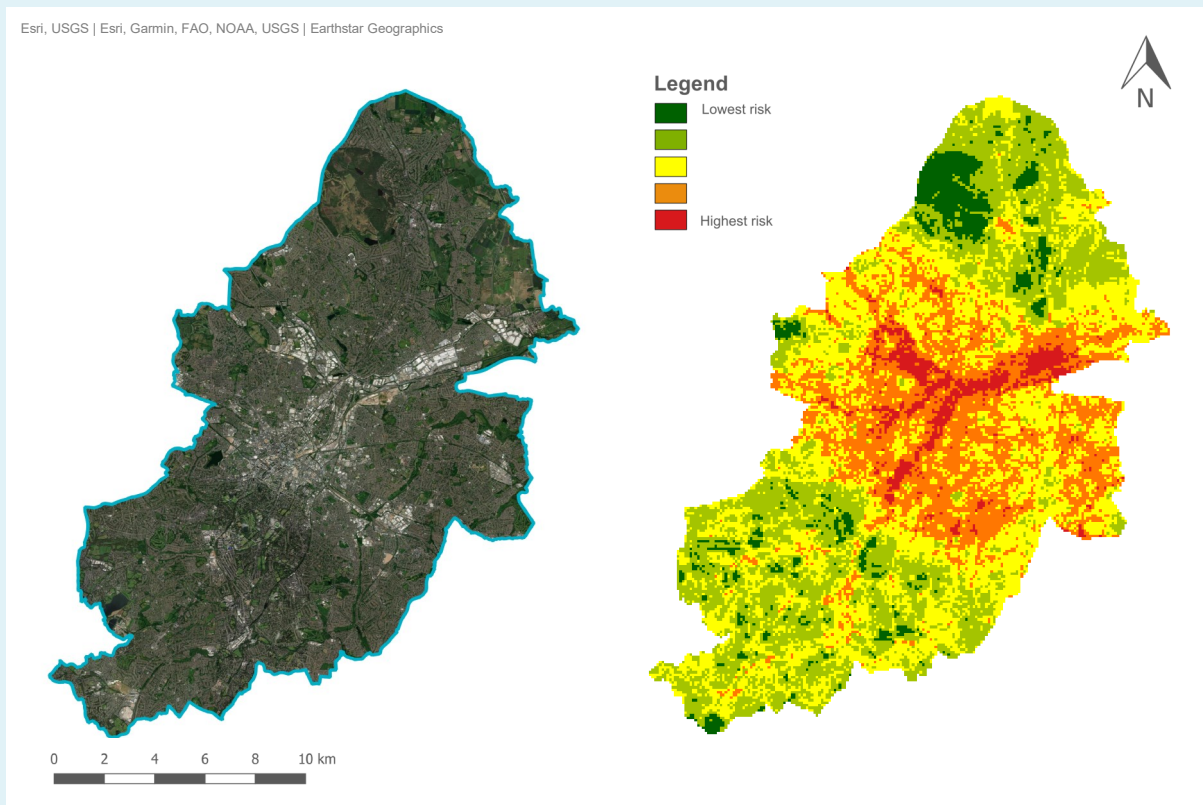


Figure 2. Aerial view of Birmingham (left)¹⁹, compared to the total CRVA score for Birmingham, at 100m raster cell resolution (right)

What does the CRVA map look like?

Figure 2 shows the CRVA map for Birmingham. CRVA scores vary across the city, with higher scores running through the city centre, and lower scores to the northeast and across parts of the southwest.

How can the CRVA influence future decision-making for Birmingham?

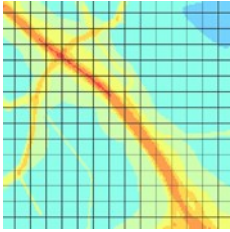
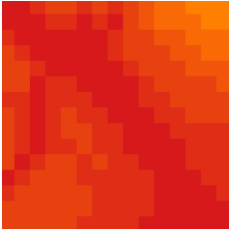
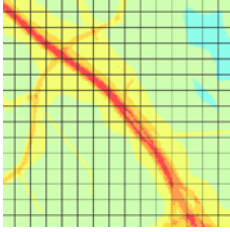
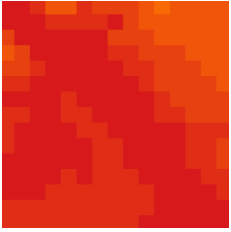
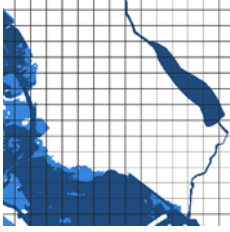
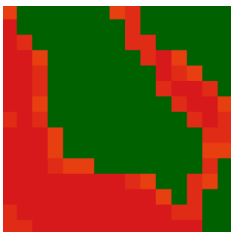
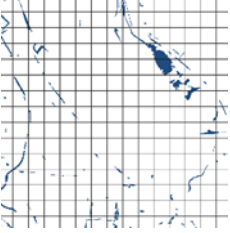
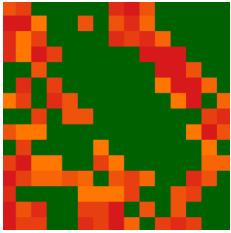
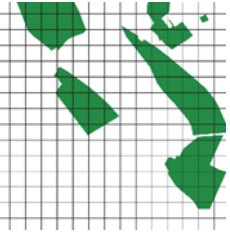
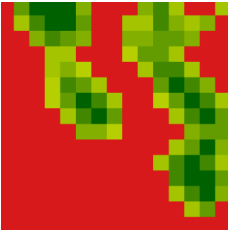
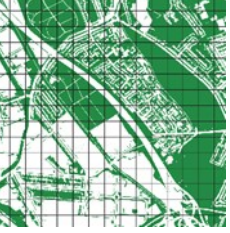
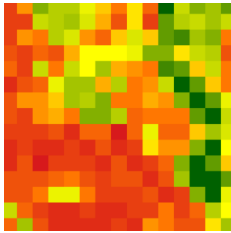
Birmingham is currently experiencing significant redevelopment; largely taking place around the city centre, where total CRVA scores are currently high. Including CRVA data at the inception of redevelopment plan-making has several benefits, including:

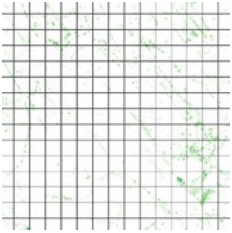
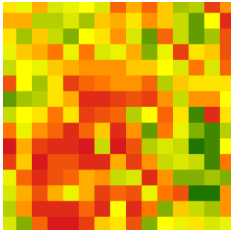
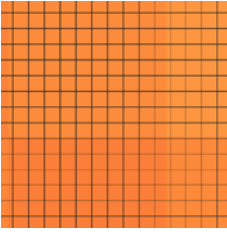

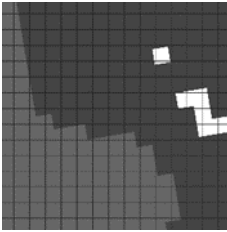
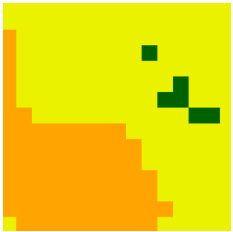
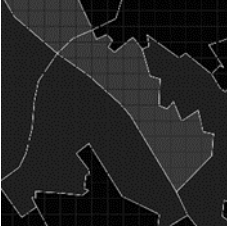
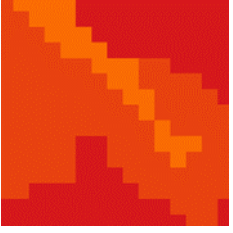
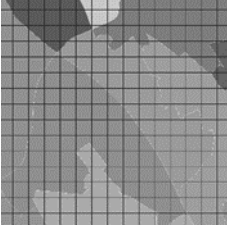

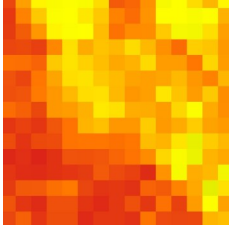
1. Identifying which climate risk or risks contribute greatest to the overall score in a development area before planning.
2. Scenario testing change in CRVA score by adjusting the values in a layer based on the development plans during the planning stages.
3. Monitoring and evaluating the resulting change in climate risk of a development from and after completion from the original baseline map data (Figure 2).

References

7. Environment Agency (2022a) Flood Map for Planning (Rivers and Sea) - Flood Zone 2. Available at: <https://www.data.gov.uk/dataset/cf494c44-05cd-4060-a029-35937970c9c6/flood-map-for-planning-rivers-and-sea-flood-zone-2> (last accessed 19/01/2023)
8. Environment Agency (2022b) Flood Map for Planning (Rivers and Sea) - Flood Zone 3. Available at: <https://www.data.gov.uk/dataset/bed63fc1-dd26-4685-b143-2941088923b3/flood-map-for-planning-rivers-and-sea-flood-zone-3> (last accessed 19/01/2023)
9. Environment Agency (2021) Risk of Flooding from Surface Water Extent: 3.3 percent annual chance. Available at: <https://www.data.gov.uk/dataset/95ea1c96-f3dd-4f92-b41f-ef21603a2802/risk-of-flooding-from-surface-water-extent-3-3-percent-annual-chance> (last accessed 19/01/2023)
10. Ordnance Survey (2022a) OS Open Greenspace. Available at: <https://osdatahub.os.uk/downloads/open/OpenGreenspace> (last accessed: 04/10/2022)
11. Ordnance Survey (2022b) OS MasterMap Greenspace - Layer. Available at: <https://ordnancesurvey.co.uk/business-government/products/mastermap-greenspace> (Accessed: 6 December 2022)
12. Environment Agency (2022c) National LIDAR Programme Vegetation Object Model. Available at: <https://data.gov.uk/dataset/227ab487-e8f2-4cbb-b26a-9e6d3b662265/national-lidar-programme-vegetation-object-model> (last accessed: 24/01/2023)
13. Demuzere et al. (2019) European LCZ map. Available at: https://figshare.com/articles/dataset/European_LCZ_map/13322450 (last accessed: 24/01/2023)
14. Zhong et al. (2021) Using Task Farming to Optimise a Street-Scale Resolution Air Quality Model of the West Midlands (UK). *Atmosphere*, 12 (8): 983
15. DEFRA (2023) UK AIR: Air Information Resource. Available at: <https://uk-air.defra.gov.uk/data/gis-mapping> (last accessed 13/10/2023)
16. Met Office (2022) HadUK-Grid Gridded Climate Observations on a 1km grid over the UK: 20 year seasonal tasmax (1981-2000). Available at: <https://data.ceda.ac.uk/badc/ukmo-hadobs/data/insitu/MOHC/HadOBS/HadUK-Grid/v1.1.0.0/1km/tasmax/seas-20y/v20220310> (last accessed: 24/01/2023)
17. Ministry of Housing, Communities and Local Government (2019) Indices of Multiple Deprivation (IMD). Available at: <https://data-communities.opendata.arcgis.com/datasets/communities::indices-of-multiple-deprivation-imd-2019-1/explore> (last accessed: 13/10/2023)
18. Public Health England (2018) Excess years life lost by Lower Super Output Area. Data provided by Birmingham City Council
19. ESRI (2021) World Imagery. Available at: <https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9> (last accessed 16/03/2023)

Table 2. Conversion process of each layer that forms the final CRVA map

	Data layer	Converted layer	Conversion process
Annual NO ₂ concentration			<ul style="list-style-type: none"> • Convert using average resampling to 100m cell resolution, using the extent of the fishnet grid • Clip raster to the fishnet grid layer • Use quantile function to identify 5%ile bin values by setting 20 quantiles; an incremental score of 0.05 per bin • Reclassify raster by table according to bin values
Annual PM _{2.5} concentration			<ul style="list-style-type: none"> • Convert using average resampling to 100m cell resolution, using the extent of the fishnet grid • Clip to the fishnet grid layer • Use quantile function to identify 5%ile bin values by setting 20 quantiles; an incremental score of 0.05 per bin • Reclassify raster by table according to bin values
Fluvial flood risk			<ul style="list-style-type: none"> • Rasterise flood zone 2 and 3 layers to 100m cell resolution and fishnet grid extent • Replace null values with 0 in both rasters • Sum both rasters and divide by 2 • Clip raster to the fishnet grid layer • Use quantile function to identify 5%ile bin values by setting 20 quantiles; an incremental score of 0.05 per bin • Reclassify raster by table according to bin values
Pluvial flood risk			<ul style="list-style-type: none"> • Rasterise to 100m cell resolution and fishnet grid extent • Replace null values with 0 • Clip raster to the fishnet grid layer • Use quantile function to identify 5%ile bin values by setting 20 quantiles; an incremental score of 0.05 per bin • Reclassify raster by table according to bin values
Open green space deficit			<ul style="list-style-type: none"> • Rasterise to 100m cell resolution and fishnet grid extent • Replace null values with 0 • Use raster calculator to inverse values (1 - raster) • Clip raster to the fishnet grid layer • Use quantile function to identify 5%ile bin values by setting 20 quantiles; an incremental score of 0.05 per bin • Reclassify raster by table according to bin values
Other green space deficit			<ul style="list-style-type: none"> • Rasterise to 100m cell resolution and fishnet grid extent • Replace null values with 0 • Use raster calculator to inverse values (1 - raster) • Clip raster to the fishnet grid layer • Use quantile function to identify 5%ile bin values by setting 20 quantiles; an incremental score of 0.05 per bin • Reclassify raster by table according to bin values

	Data layer	Converted layer	Conversion process
Tree canopy cover deficit			<ul style="list-style-type: none"> • Use raster calculator to convert data to binary form: $((\text{merged raster} > 0) = 1) + ((\text{merged raster} = 0) = 0) / 2$ • Reproject raster using average resampling to 100m cell resolution, using the extent of the fishnet grid • Clip to the fishnet grid layer • Use raster calculator to inverse values $(1 - \text{raster})$ • Use quantile function to identify 5%ile bin values by setting 20 quantiles; an incremental score of 0.05 per bin • Reclassify raster by table according to bin values
Surface temperature			<ul style="list-style-type: none"> • Bilinear sampling interpolation to 100m cell resolution • Convert using average resampling to 100m cell resolution, using the extent of the fishnet grid • Clip raster to the fishnet grid layer • Use quantile function to identify 5%ile bin values by setting 20 quantiles; an incremental score of 0.05 per bin • Reclassify raster by table according to bin values
Local climate zone			<ul style="list-style-type: none"> • Reproject raster to the GB coordinate reference system (EPSG:27700/OSGB 1936) to 100m cell resolution, using the extent of the fishnet grid and resample using the nearest neighbour method • Clip raster to the fishnet grid layer • Reclassify raster by table (see Table 3 for reclassification values)
IMD			<ul style="list-style-type: none"> • Join attributes by location (summary) to fishnet grid • Rasterise fishnet with joined data to 100m cell resolution, using the decile majority value from the attribute table • Normalise raster layer 0-1 • Use raster calculator to inverse values $(1 - \text{raster})$
Excess years life lost			<ul style="list-style-type: none"> • Join attributes by location (summary) to fishnet grid • Rasterise fishnet with joined data to 100m cell resolution, using the total excess years life lost value from the attribute table • Use quantile function to identify 5%ile bin values by setting 20 quantiles; an incremental score of 0.05 per bin • Reclassify raster by table according to bin values
Total CRVA score	Not applicable		<ul style="list-style-type: none"> • Use raster calculator to sum the total scores of each layer

ADDITIONAL INFORMATION ON GIS TECHNIQUES

Some of the GIS techniques described in [Table 2](#) are explained in more detail here, so the processes can be replicated. This CRVA map used tools within the QGIS application (version 3.28.11 Firenze long-term release).

Creating a fishnet grid

[Vector > Research Tools > Create Grid](#)

A fishnet grid is a vector layer, which is a conversion of another vector file into gridded squares. It is used for the CRVA map as the reference layer to align all raster conversions. The conversion for Birmingham into its resulting fishnet grid is shown in [Figure 4](#). This same process could be used to create hex grids for zonal statistics.

Resampling: Bilinear interpolation

[Raster > Projections > Warp \(Reproject\)](#)

Resampling creates a new raster layer based on sampling from another raster layer. The reasons for doing this include reprojecting or aligning raster cells to a new grid size or position. Bilinear interpolation is a resampling method using the weighted four nearest cell centres²⁰.

Resampling: Nearest neighbour

[Raster > Projections > Warp \(Reproject\)](#)

Using the same process as bilinear interpolation, nearest neighbour resampling is determined by the nearest cell centre on the input grid²⁰.

Joining attributes by location (summary)

[Processing toolbox > Vector general > Join attributes by location \(summary\)](#)

This process takes vector attributes and assigns them to each grid square. It is therefore a step before converting vector data into a raster layer.

Identifying percentile values of continuous layer data

[Processing toolbox > GRASS > Raster > r.quantile](#)

This produces a table with the percentile boundaries of continuous raster data. To establish 5%ile bins, the number of quantiles is set to 20.

[Processing Toolbox > Raster Analysis > Reclassify by table](#)

After identifying the boundary ranges, the percentile break ranges can be set using reclassify by table.

Normalising a raster layer 0-1

[Processing Toolbox > SAGA > Raster calculus > raster normalisation](#)

This process quickly normalises a raster layer, where the highest value is scaled to 1 and the lowest scaled to 0. This is used when rasterising a layer creates cell values between 0 and 255, reflective of colour band values.

Local climate zone scoring

[Processing Toolbox > Raster Analysis > Reclassify by table](#)



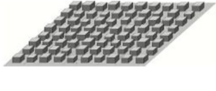



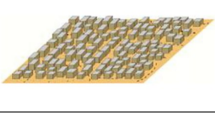
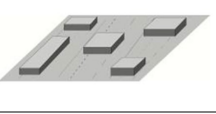

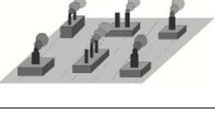
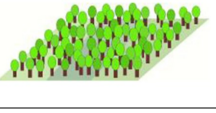
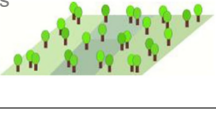
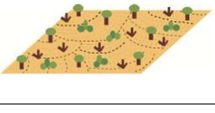

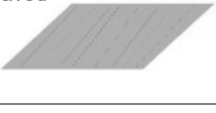
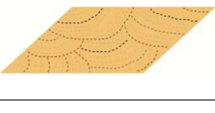
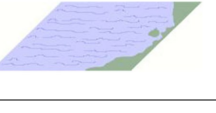
After resampling, values are converted using [Table 3](#).

Converting total CRVA scores to other geographic boundaries

[Processing toolbox > Raster Analysis > Zonal statistics](#)

CRVA score can be averaged in accordance with vector files that include smaller boundaries, such as wards or hex grids.

Table 3. Local climate zones and their CRVA scores. Graphics²¹ © American Meteorological Society. Used with permission.

<p>LCZ 1: Compact high-rise</p>  <p>CRVA score 1.0</p>	<p>LCZ 2: Compact mid-rise</p>  <p>CRVA score 1.0</p>	<p>LCZ 3: Compact low-rise</p>  <p>CRVA score 0.9</p>
<p>LCZ 4: Open high-rise</p>  <p>CRVA score 0.8</p>	<p>LCZ 5: Open mid-rise</p>  <p>CRVA score 0.7</p>	<p>LCZ 6: Open low-rise</p>  <p>CRVA score 0.4</p>
<p>LCZ 7: Lightweight low-rise</p>  <p>CRVA score 0.5</p>	<p>LCZ 8: Large low-rise</p>  <p>CRVA score 0.6</p>	<p>LCZ 9: Sparsely built</p>  <p>CRVA score 0.1</p>
<p>LCZ 10: Heavy industry</p>  <p>CRVA score 1.0</p>	<p>LCZ A: Dense trees</p>  <p>CRVA score 0.0</p>	<p>LCZ B: Scattered trees</p>  <p>CRVA score 0.0</p>
<p>LCZ C: Bush, scrub</p>  <p>CRVA score 0.0</p>	<p>LCZ D: Low plants</p>  <p>CRVA score 0.0</p>	<p>LCZ E: Bare rock or paved</p>  <p>CRVA score 0.0</p>
<p>LCZ F: Bare soil or sand</p>  <p>CRVA score 0.0</p>	<p>LCZ G: Water</p>  <p>CRVA score 0.0</p>	

References

20. ESRI (2023) FAQ: What is the difference between Nearest Neighbor, Bilinear Interpolation and Cubic Convolution? Available at: <https://support.esri.com/en/technical-article/000005606> (last accessed 20/03/2023)

21. Stewart & Oke (2012) Local Climate Zones for Urban Temperature Studies. Bulletin of the American Meteorological Society, 93(12): pp.1879-1900