

Survey and calculation documentation

Supplementary Materials 1

This document describes the expert questionnaires, variable coding and spreadsheet calculations accompanying the manuscript.

1 Expert questionnaires

The study used a purposively assembled panel of 30 experts. The shared files comprise 30 FDM questionnaires, 25 DEMATEL questionnaires and 28 VIKOR questionnaires. Expert identifiers are specific to each stage and should not be treated as a cross-stage person identifier. Expert names and affiliation fields are omitted from the shared copies.

FDM participants assessed the importance of 37 candidate indicators for university building public spaces, rather than the condition of an individual campus. Each item requested a conservative lower rating (L), a most-likely rating (M) and an optimistic upper rating (U), each from 1 (very unimportant) to 10 (very important). The instructions recommended $L \leq M \leq U$. Item wording, definitions and instructions are retained in every completed FDM questionnaire.

DEMATEL participants assessed how a change in one criterion directly influences another. The row criterion is the influence source and the column criterion is the recipient. The 0–4 scale denotes no, weak, moderate, strong and very strong direct influence. The diagonal is fixed at zero. The instrument explicitly distinguishes direct influence from criterion importance, a particular campus, or a specific rainfall event.

VIKOR participants assessed five case universities against six criteria. Each questionnaire contains 30 performance ratings on a 0–10 scale, with higher values indicating performance closer to the ideal stormwater-resilience state. The case descriptions and scale instructions are included in the completed questionnaires and the separate VIKOR instrument.

2 Variable definitions and coding

Variable or code	Definition
I1–I37	Initial indicators, defined with source references in Supplementary Table S1. FDM questionnaire rows 28–64 follow this order.
C1–C6	Risk Identification and Grading; Stormwater Protection Facility Support; Runoff Drainage Performance; Pedestrian Space Performance; Water-Sensitive Retention Capacity; Recovery Assessment and Feedback.
D1–D6	Completed DANP/VIKOR workbook labels corresponding to C1–C6 in the same order. The separate VIKOR instrument uses C1–C6 for criteria and D1–D3 for the three process stages.
A1–A5	The five case universities, in the order used in the VIKOR questionnaires and performance matrix.
L, M, U	Individual FDM lower, most-likely and upper ratings. The most-likely field is distinct from the derived spread M in manuscript Table 3.
S, R, Q	VIKOR aggregate weighted gap, maximum weighted gap and compromise-ranking value, respectively. Lower values indicate better performance.

The 18 retained indicators and their assignment to the six criteria are listed in manuscript Table 4. All six VIKOR criteria are benefit criteria. Numerical ratings are retained at their recorded precision; displayed summaries are rounded only from the underlying values.

3 FDM data and calculation

FDM 结果.xlsx contains the collected ratings in 数据汇总 and the analysis matrix in FDM 大小数据筛选.

In both sheets, rows 3–39 contain the most-likely ratings, rows 44–80 the lower ratings, and rows 85–121 the upper ratings.

For each indicator, lower and upper ratings in the analysis matrix are separately summarized by their minimum, geometric mean and maximum to form conservative and optimistic triangular fuzzy numbers. The crisp score G is calculated by manuscript equation (2), using the conservative and optimistic parameters. The individual most-likely ratings do not enter this formula. Spreadsheet locations AE44:AJ80 contain fuzzy parameters, and AL44:AR80 contain derived spreads and crisp scores. The G sheet stores the descending scores.

The cutoff is the stored score of I25 (8.50468810866266), displayed as approximately 8.505. Retaining scores at least equal to that cutoff yields 18 indicators. The I25–I35 difference is approximately 0.333786, displayed as 0.334. This is a selected separation boundary, not the global largest adjacent difference.

4 DEMATEL and DANP calculation

DANP 结果.xlsx, Sheet1, contains the 25 individual matrices in B2:G7 and subsequent blocks at eight-row intervals. J2:O7 is their arithmetic mean. P40 contains the maximum-column-sum normalization factor, J42:O47 the normalized matrix, and J74:O79 the total-influence matrix. P74:S79 report dispatch, reception, prominence and relation.

The gap statistic compares the first 24 questionnaires with all 25. For each of the 30 off-diagonal entries, it takes the absolute difference between those two means relative to the 25-response mean, then averages those relative differences. The result is 0.823463220767%, displayed as 0.82%. Diagonal comparisons are set to zero and excluded from the denominator.

The six criteria form a single network. The total-influence matrix is normalized by row and transposed to obtain the column-stochastic supermatrix W . Two successive matrix squarings produce W^4 . J138:J143 stores its first column, which supplies the reported weights. Its maximum absolute difference from the stationary solution is approximately 4.72×10^{-7} ; both yield the same weights to four decimal places.

5 VIKOR calculation and supporting materials

VIKOR 结果.xlsx assembles the 840 individual scores in 评分明细. VIKOR 绩效矩阵!C2:H6 contains the arithmetic mean of 28 ratings for each campus–criterion combination. The calculations use the DANP weights, benefit directions for all six criteria, and $v = 0.5$. Ideal and negative-ideal values are the observed criterion maxima and minima across the five campuses. Normalized gaps, weighted gaps, S , R and Q are retained as formulas in VIKOR 计算.

The performance ordering is $A5 > A2 > A1 > A3 > A4$, and improvement priority follows the reverse order. The acceptable-advantage threshold is $1/(5 - 1) = 0.25$. The acceptable-advantage condition fails and acceptable stability holds, yielding the compromise set $\{A5, A2, A1\}$.

Supporting case photographs appear in manuscript Table 1, and case descriptions are included in the VIKOR instrument. The shared calculation workbooks contain no separate adjustment matrix linking photographs, campus plans or meteorological measurements to changes in expert scores. The revised quantitative description therefore identifies the questionnaire means as the performance inputs.

Supplementary Table S1.

Supplementary Table S1. Initial FDM Indicator Pool and Literature Sources

Code	Indicator	Definition	References
I1	Flood-prone space identification	Identifies flood-prone spaces such as building entrances, low-lying plazas, and underground-space entrances.	[1,4,9,13,22,51,75,76,79]
I2	High-risk path identification	Identifies frequently used rainy-day routes vulnerable to ponding, slipperiness, detours, or interruption of rain-sheltered continuity.	[4,9,12,13,18,75,76]
I3	Historical stormwater-event record	Records previous stormwater events, including ponding, backflow, slipping incidents, temporary closures, complaints, and maintenance actions.	[4,25,27,38,42,43,68,75]
I4	Stormwater Risk Grading Representation	Represents stormwater risk points, risk routes, and risk grades through drawings, GIS, or risk maps.	[4,11,42,73,74]
I5	Rainstorm warning and notification	Provides timely risk reminders and rainy-day mobility advice to students and staff before rainstorm events.	[13,18,25,38,42,75]
I6	Alternative route guidance plan	Specifies recommended rainy-day routes, detour routes, restricted areas, and safety information.	[13,18,25,38,42,75,76]
I7	Emergency plan for key nodes	Develops rainy-day evacuation and guidance plans for high-frequency nodes such as canteens, teaching buildings, dormitories, and libraries.	[4,11,13,20,27,38,42]
I8	Coordinated response mechanism	Defines response responsibilities across logistics, security, property management, and dormitory management units.	[4,12,19,20,25,38,42,48,49]
I9	Drainage facility maintenance	Ensures that inlets, drainage ditches, linear drains, and roof downpipes remain unobstructed before rainstorm events.	[42,44,45,48,49,50,51,76]
I10	Entrance waterproofing and anti-slip measures	Reduces backflow and slipping risk at entrances through elevation control, interception, water barriers, anti-slip paving, and emergency facilities.	[4,11,12,19,42,45,74,76]
I11	Rain-shelter connection provision	Provides continuous or semi-continuous rain-shelter connections between frequently used building nodes.	[11,13,18,19,20,76]
I12	Water-sensitive facility provision	Provides rain gardens, sunken green spaces, permeable pavement, and related facilities in flood-prone and high-pedestrian-flow areas.	[42,44,45,48,49,50,51,76]
I13	Ponding extent and depth	Evaluates whether the spatial extent and depth of ponding at entrances, plazas, and corridor nodes affect safe passage.	[4,9,28,42,45,48,74,76,79]
I14	Runoff conveyance organization	Assesses whether runoff is organized away from pedestrian routes and building entrances and conveyed through drainage facilities or green spaces.	[4,9,18,28,42,45,48,49,74,79]
I15	Drainage operation	Assesses whether inlets, drainage ditches, and linear drainage facilities operate effectively during rainstorm	[4,9,18,28,42,45,48,49,74,79]

Code	Indicator continuity	Definition events.	References
I16	Control capacity for flood-prone locations	Evaluates whether low-lying areas, underground entrances, and roof-edge runoff points avoid backflow, concentrated discharge, or local water impact.	[4,9,13,42,45,74,76]
I17	Rainy-day main-route accessibility	Assesses whether high-frequency routes connecting dormitories, teaching buildings, canteens, and libraries remain accessible during rainfall.	[12,13,18,76]
I18	Continuity of rain-sheltered passage	Assesses whether corridors, canopies, pilotis, entrance porches, and related spaces form a continuous rain-sheltered passage system.	[4,11,12,13,18,19,20,22,33]
I19	Controllability of detour cost	Evaluates whether detour distance, travel time, and route complexity remain acceptable when main paths are ponded or closed.	[12,13,18,76]
I20	Peak-period path capacity	Assesses whether path capacity remains sufficient under umbrellas, bidirectional flows, carried objects, and concentrated peak-period pedestrian flow.	[4,13,76]
I21	Continuity of barrier-free passage	Assesses whether barrier-free ramps and gently sloped routes remain continuous and usable during rainstorm events.	[4,13,76]
I22	Pedestrian–vehicle conflict control	Evaluates whether conflicts among pedestrians, bicycles, electric bikes, and logistics vehicles remain controllable on rainy days.	[4,13,76]
I23	Rain-shelter buffer capacity	Assesses whether entrances to teaching buildings, dormitories, canteens, and libraries are prone to ponding or backflow under rain-shelter conditions.	[4,11,12,18,19,20,22,33,74]
I24	Sheltered waiting space at entrances	Assesses whether entrance areas provide sufficient sheltered space for umbrella handling, short waiting, queuing, and rain avoidance.	[4,11,12,18,19,20,22,33,74]
I25	Ground anti-slip safety	Evaluates whether entrance ground surfaces can control slipperiness caused by rainwater, sediment, and dripping umbrellas.	[4,19,42,45,55,58,74,76]
I26	Operational maintenance of core nodes	Assesses whether high-frequency nodes such as teaching buildings, canteens, dormitories, and libraries maintain use during rainy conditions.	[4,11,12,13,19]
I27	Support for ancillary service nodes	Assesses whether shuttle stops, bus stops, bicycle parking points, delivery nodes, maintenance points, and cleaning-service nodes maintain basic operation and safe transfer.	[4,13,19,20,38,42]
I28	Rainwater retention and peak attenuation	Assesses whether sunken green spaces, rain gardens, retention basins, and related facilities retain rainwater and attenuate runoff peaks.	[18,42,44,45,46,47,49,51,58,77]
I29	Infiltration and conveyance efficiency	Assesses whether permeable pavement, grassed swales, shallow channels, and related measures promote infiltration, organize surface runoff, and reduce local ponding.	[18,42,44,45,46,47,49,51,58,77]

Code	Indicator	Definition	References
I30	Facility-system coordination	Assesses whether green spaces, inlets, drainage ditches, rain gardens, and permeable pavement form continuous connections that prevent isolated facility failure.	[4,18,42,44,45,46,47,49,50]
I31	Differentiated mobility support	Assesses whether users with mobility limitations, users carrying objects, cycling-transfer users, and night-returning students receive safe, continuous, and legible mobility support.	[4,13,25,27,38,42]
I32	Drainage and functional recovery time	Measures the time required for main paths, entrances, plazas, and service nodes to recover to a condition without evident ponding.	[4,20,22,37,42]
I33	Recovery of spatial accessibility	Assesses whether spaces temporarily closed or suspended because of ponding, backflow, or control measures are reopened in a timely manner.	[4,19,20,22,37,42,48,49,77]
I34	Recovery of ground safety	Assesses whether post-rain safety hazards such as slippery surfaces, sediment, fallen leaves, and damaged pavement are addressed in a timely manner.	[4,19,22,42,48,49,58,77]
I35	Post-rain inspection and sediment removal	Assesses whether post-rain inspections identify ponding points, blocked facilities, and damaged locations, and whether drainage sediment is removed.	[4,25,38,42,47,48,49,53,77]
I36	Closed-loop maintenance and rectification	Assesses whether stormwater-related problems follow a closed-loop process of discovery, recording, dispatch, repair, review, and repeated-problem rectification.	[4,22,28,29,37,42,43,50,68]
I37	Review feedback and data accumulation	Assesses whether post-event reviews summarize spatial failure, route congestion, and facility performance while collecting feedback, ponding locations, drainage recovery time, and maintenance records.	[11,19,25,27,42,43,53,68]

References for Supplementary Table S1

- [1] Miller, J.D.; Hutchins, M. The impacts of urbanisation and climate change on urban flooding and urban water quality: A review of the evidence concerning the United Kingdom. *J. Hydrol. Reg. Stud.* 2017, 12, 345–362, doi:10.1016/j.ejrh.2017.06.006.
- [4] Hammond, M.J.; Chen, A.S.; Djordjevic, S.; Butler, D.; Mark, O. Urban flood impact assessment: A state-of-the-art review. *Urban Water J.* 2015, 12, 14–29, doi:10.1080/1573062X.2013.857421.
- [9] Rosenzweig, B.R.; McPhillips, L.; Chang, H.; Cheng, C.; Welty, C.; Matsler, M.; Iwaniec, D.; Davidson, C.I. Pluvial flood risk and opportunities for resilience. *WIREs Water* 2018, 5, e1302, doi:10.1002/wat2.1302.
- [11] Dong, W.; Wu, J.; Chen, Y.; Zhou, X. A Bibliometric Review of Research on the Perceptions of Campus Public Spaces. *Buildings* 2023, 13, 501, doi:10.3390/buildings13020501.
- [12] Hajrasouliha, A. Campus score: Measuring university campus qualities. *Landsc. Urban Plan.* 2017, 158, 166–176, doi:10.1016/j.landurbplan.2016.10.007.
- [13] Zhang, Z.; Sun, T.; Fisher, T.; Wang, H. The relationships between the campus built environment and walking activity. *Sci. Rep.* 2024, 14, 20330, doi:10.1038/s41598-024-69881-8.
- [18] Gorzka, J.; Burda, I.; Nyka, L. Walkability and Flood Resilience: Public Space Design in Climate-Sensitive Urban Environments. *Urban Plan.* 2025, 10, 9561, doi:10.17645/up.9561.
- [19] Lau, S.S.Y.; Gou, Z.; Liu, Y. Healthy campus by open space design: Approaches and guidelines. *Front. Archit. Res.* 2014, 3, 452–467, doi:10.1016/j.foar.2014.06.006.
- [20] Bruneau, M.; Chang, S.E.; Eguchi, R.T.; Lee, G.C.; O'Rourke, T.D.; Reinhorn, A.M.; Shinozuka, M.; Tierney, K.; Wallace, W.A.; von Winterfeldt, D. A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities. *Earthq. Spectra* 2003, 19, 733–752, doi:10.1193/1.1623497.
- [22] Cimellaro, G.P.; Reinhorn, A.M.; Bruneau, M. Framework for analytical quantification of disaster resilience. *Eng. Struct.* 2010, 32, 3639–3649, doi:10.1016/j.engstruct.2010.08.008.
- [25] Sharifi, A. A critical review of selected tools for assessing community resilience. *Ecol. Indic.* 2016, 69, 629–647, doi:10.1016/j.ecolind.2016.05.023.
- [27] Meerow, S.; Newell, J.P.; Stults, M. Defining urban resilience: A review. *Landsc. Urban Plan.* 2016, 147, 38–49, doi:10.1016/j.landurbplan.2015.11.011.
- [28] de Brito, M.M.; Evers, M. Multi-criteria decision-making for flood risk management: a survey of the current state of the art. *Nat. Hazards Earth Syst. Sci.* 2016, 16, 1019–1033, doi:10.5194/nhess-16-1019-2016.
- [29] Huang, I.B.; Keisler, J.; Linkov, I. Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends. *Sci. Total Environ.* 2011, 409, 3578–3594, doi:10.1016/j.scitotenv.2011.06.022.
- [33] McFarland, A.L.; Waliczek, T.M.; Zajicek, J.M. The relationship between student use of campus green spaces and perceptions of quality of life. *HortTechnology* 2008, 18, 232–238, doi:10.21273/HORTTECH.18.2.232.
- [37] Kammouh, O.; Zamani Noori, A.; Cimellaro, G.P.; Mahin, S.A. Resilience Assessment of Urban Communities. *ASCE-ASME J. Risk Uncertain. Eng. Syst. Part A Civ. Eng.* 2019, 5, 04019002, doi:10.1061/AJRUUA6.0001004.
- [38] Cutter, S.L.; Burton, C.G.; Emrich, C.T. Disaster resilience indicators for benchmarking baseline conditions. *J. Homel. Secur. Emerg. Manag.* 2010, 7, 51, doi:10.2202/1547-7355.1732.
- [42] Barreiro, J.; Ferreira, F.; Brito, R.S.; Matos, J.S. Development of Resilience Framework and Respective Tool for Urban Stormwater Services. *Sustainability* 2024, 16, 1316, doi:10.3390/su16031316.
- [43] Folke, C. Resilience: The emergence of a perspective for social–ecological systems analyses. *Glob. Environ. Change* 2006, 16, 253–267, doi:10.1016/j.gloenvcha.2006.04.002.

- [44] Wong, T.H.F.; Brown, R.R. The water sensitive city: principles for practice. *Water Sci. Technol.* 2009, 60, 673–682, doi:10.2166/wst.2009.436.
- [45] Burns, M.J.; Fletcher, T.D.; Walsh, C.J.; Ladson, A.R.; Hatt, B.E. Hydrologic shortcomings of conventional urban stormwater management and opportunities for reform. *Landsc. Urban Plan.* 2012, 105, 230–240, doi:10.1016/j.landurbplan.2011.12.012.
- [46] Ashley, R.; Lundy, L.; Ward, S.; Shaffer, P.; Walker, L.; Morgan, C.; Saul, A.; Wong, T.; Moore, S. Water-sensitive urban design: opportunities for the UK. *Proc. Inst. Civ. Eng. Munic. Eng.* 2013, 166, 65–76, doi:10.1680/muen.12.00046.
- [47] Fletcher, T.D.; Shuster, W.; Hunt, W.F.; Ashley, R.; Butler, D.; Arthur, S.; Trowsdale, S.; Barraud, S.; Semadeni-Davies, A.; Bertrand-Krajewski, J.-L.; et al. SUDS, LID, BMPs, WSUD and more: The evolution and application of terminology surrounding urban drainage. *Urban Water J.* 2015, 12, 525–542, doi:10.1080/1573062X.2014.916314.
- [48] Barbosa, A.E.; Fernandes, J.N.; David, L.M. Key issues for sustainable urban stormwater management. *Water Res.* 2012, 46, 6787–6798, doi:10.1016/j.watres.2012.05.029.
- [49] McFarland, A.R.; Larsen, L.; Yeshitela, K.; Engida, A.N.; Love, N.G. Guide for using green infrastructure in urban environments for stormwater management. *Environ. Sci.: Water Res. Technol.* 2019, 5, 643–659, doi:10.1039/C8EW00498F.
- [50] Meerow, S.; Newell, J.P. Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit. *Landsc. Urban Plan.* 2017, 159, 62–75, doi:10.1016/j.landurbplan.2016.10.005.
- [51] Qin, H.P.; Li, Z.X.; Fu, G. The effects of low impact development on urban flooding under different rainfall characteristics. *J. Environ. Manag.* 2013, 129, 577–585, doi:10.1016/j.jenvman.2013.08.026.
- [53] Raymond, C.M.; Frantzeskaki, N.; Kabisch, N.; Berry, P.; Breil, M.; Nita, M.R.; Geneletti, D.; Calfapietra, C. A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environ. Sci. Policy* 2017, 77, 15–24, doi:10.1016/j.envsci.2017.07.008.
- [55] Demuzere, M.; Orru, K.; Heidrich, O.; Olazabal, E.; Geneletti, D.; Orru, H.; Bhawe, A.G.; Mittal, N.; Feliu, E.; Faehnle, M. Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *J. Environ. Manag.* 2014, 146, 107–115, doi:10.1016/j.jenvman.2014.07.025.
- [58] Gill, S.E.; Handley, J.F.; Ennos, A.R.; Pauleit, S. Adapting cities for climate change: The role of the green infrastructure. *Built Environ.* 2007, 33, 115–133, doi:10.2148/benv.33.1.115.
- [68] Tseng, Y.P.; Huang, Y.C.; Li, M.S.; Jiang, Y.Z. Selecting Key Resilience Indicators for Indigenous Community Using Fuzzy Delphi Method. *Sustainability* 2022, 14, 2018, doi:10.3390/su14042018.
- [73] de Moel, H.; van Alphen, J.; Aerts, J.C.J.H. Flood maps in Europe: Methods, availability and use. *Nat. Hazards Earth Syst. Sci.* 2009, 9, 289–301, doi:10.5194/nhess-9-289-2009.
- [74] Apel, H.; Aronica, G.T.; Kreibich, H.; Thielen, A.H. Flood risk analyses: How detailed do we need to be? *Nat. Hazards* 2009, 49, 79–98, doi:10.1007/s11069-008-9277-8.
- [75] Böcker, L.; Dijst, M.; Prillwitz, J. Impact of Everyday Weather on Individual Daily Travel Behaviours in Perspective: A Literature Review. *Transp. Rev.* 2013, 33, 71–91, doi:10.1080/01441647.2012.747114.
- [76] Saelens, B.E.; Handy, S.L. Built Environment Correlates of Walking. *Med. Sci. Sports Exerc.* 2008, 40, S550–S566, doi:10.1249/MSS.0b013e31817c67a4.
- [77] Zellner, M.L.; Massey, D. Modeling benefits and tradeoffs of green infrastructure: Evaluating and extending parsimonious models for neighborhood stormwater planning. *Heliyon* 2024, 10, e27007, doi:10.1016/j.heliyon.2024.e27007.
- [79] Fletcher, T.D.; Andrieu, H.; Hamel, P. Understanding, management and modelling of urban hydrology and its consequences for receiving waters: A state of the art. *Adv. Water Resour.* 2013, 51, 261–279, doi:10.1016/j.advwatres.2012.09.001.