Institution: Anglia Ruskin University

Unit of Assessment: 13 – Architecture, Built Environment and Planning

Title of case study: Raised awareness of water systems resilience in the UK, Brazil and India

Period when the underpinning research was undertaken: August 2015 to December 2020

Details of staff conducting the underpinning research from the submitting unit:

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Period(s) employed by submitting HEI:
August 2015 to date
June 2016 to December 2018
December 2018 to date

Period when the claimed impact occurred: August 2015 to December 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

ARU research on water quality, Sustainable Urban Drainage Systems (SuDS) and interdependency management of critical infrastructure has resulted in:

- raised awareness of water systems resilience issues amongst end-user stakeholders in the UK, Brazil and India;
- improved water management strategies resulting in the identification of flood hot-spots and raised awareness of sustainable water management mitigation options and resilience planning in São Carlos, Brazil;
- delivery of continuing professional development training in the design of resilient water infrastructure in Brazil and the UK; and
- the evidence base to support the business case for improved resilience to climate change of shared critical infrastructure assets.

2. Underpinning research (indicative maximum 500 words)

Three complimentary research projects investigating water systems resilience and SuDS in the UK, Brazil and India have generated greater understanding of the impacts of climate change on water system quality and critical infrastructure resilience and resulted in the development of resilience-informed visualisation and evaluation tools suitable for use by end-users.

Water Quality Resilience and Artificial Neural Networks (WQRGIS/WQR-ANN) funded by the Royal Academy of Engineering/Newton Funding (References 1 and 6)

This research partnership between ARU (lead) and Imperial College London in the UK, and the University of Campinas, University of São Paulo and São Paulo State's Environment Agency (CETESB) in Brazil, used a case study methodology to develop a resilience-based evaluation framework that enabled prediction of the resilience of surface water resources of the São Paulo region in Brazil. The research derived resilience thresholds to identify and map the spatial

vulnerability of water system development projects to climate change and developed an Artificial Neural Network (ANN) predictive model/tool to identify vulnerable areas in need of water system adaptation strategies. Although the ANN-based predictive model was validated against the São Paulo region in Brazil, the underlying research demonstrated that the theoretical principles developed through this project could be replicated by other water resources decision-makers to predict the resilience of their system, identify areas of risk, and support prioritisation of resilience-informed investment in adaptation decisions.

Resilience-Informed Urban Management with the Incorporation of Sustainable Urban Draining Systems in Brazil and India (RESoURce@Brandia) funded by Research England (References 2, 3, and 7)

The success of WQRGIS/WQR-ANN led to a research partnership between ARU, the Madras Institute of Technology (India) and the Department of Hydraulics and Sanitation at the University of São Paulo (Brazil) to develop a novel multi-criteria resilience-based optimisation model to support SuDS design and planning for developing countries. The optimisation model integrated 'high resilience, low cost, high quality of life' strategies into a decision-making framework to guide effective resilience-informed urban planning. This multi-criteria decision-making framework was gamified as an interactive tool (SPRSim) that provides a virtual assessment of the impact that different SuDS solutions have on urban resilience. The SPRSim tool allows decision-makers to evaluate a range of different SuDS solutions against their financial, environmental and social costs; increasing the decision-makers awareness of the impact that (peri)urban developments have on urban resilience using different SuDS options.

RV-DSS: An industry-friendly resilience-based interdependency assessment tool - North Argyll case study funded by NERC (Reference 4 and 5)

This research partnership between ARU, Transport Scotland, Scottish Water, Scottish and Southern Energy, and Atkins developed an 'industry-friendly' dynamic Resilience and Vulnerability Decision Support System (RV-DSS) tool to measure critical infrastructure (water, transport and energy) network resilience and vulnerability to hazard events. The RV-DSS was developed through an empirical case study of the interdependencies within and between critical infrastructure networks in North Argyll, Scotland UK. The RV-DSS tool provided a cost-benefit analysis of network vulnerability and resilience in response to hazard events, enabling asset owners to make evidence-based resilience and vulnerability adaptation (intervention) investment decisions.

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3. References to the research (indicative maximum of six references)

Published outputs

1. Hasan, M.M., Lwin, K., Imani, M., Shabut, A., Bittencourt, L.F. and Hossain, M.A. (2019) "Dynamic multi-objective optimisation using deep reinforcement learning: benchmark, algorithm and an application to identify vulnerable zones based on water quality", *Engineering Applications of Artificial Intelligence*, 86, 107-135, DOI: 10.1016/j.engappai.2019.08.014. Submitted in REF2.

2. Costa, C.W., Lorandi, R., Lollo, J. A., Imani, M., Dupas, F.A., (2018). "Surface runoff and accelerated erosion in a peri-urban wellhead area in south-eastern Brazil", *Environmental Earth Sciences*, 77:160. DOI:10.1007/s12665-018-7366-x. Submitted in REF2.

3. McClymont, K., Gasparini Fernandes Cunha, D., Maidment, C., Ashagre, B., Floriano Vasconcelos, A., Macedo, M.B. Nóbrega dos Santos, M.F., Nóbrega Gomes Júnior, M., Mendiondo, E.M., Paceli Barbassa, A., Rajendran, L., and Imani, M. (2020). "Towards urban resilience through sustainable drainage systems: a multi-objective optimisation problem". *Journal of Environmental Management*. DOI: 10.1016/j.jenvman.2020.111173

4. Imani, M, Hajializadeh, D. (2019). A resilience assessment framework for critical infrastructure networks' interdependencies. Journal of Water Science and Technology, wst2019367. DOI: 10.2166/wst.2019.367.

Grant funding

5. RVDSS (November 2017 – April 2018): was a £62,800 UK NERC funded project (NE/R008973/1)

6. WQR_{GIS}/WQR-ANN (December 2016 – August 2017): was a £20,000 UK Royal Academy of Engineering/Newton Fund (Funder project: FoE SF1617\1\42)

7. RESoURce@Brandia (August 2018 – July 2019): was a £40,081 Research England funded project (Funder Ref: 10508)

4. Details of the impact (indicative maximum 750 words)

Research by ARU has enabled raised awareness (amongst policy makers and end-users) of water system and critical infrastructure resilience to climate change in the UK, Brazil and India. The research has developed new visualisation and analytical tools that have allowed key stakeholders including agency directors, council leaders, urban planners and asset owners develop a greater understanding of how to effectively plan, maintain and manage vital water infrastructure, ensuring water quality compliance, and integrating resilience and vulnerability into their decision-making. The research has also led to a new tool for better managing the interdependencies between critical infrastructure systems, including water systems, subject to extreme weather events.

Enhancing Knowledge of Water Quality Management and SuDS in Brazil and India

The exploitation of ARU research, in the form of seminars, workshops, lectures, focus groups, tools, articles and models has shaped the knowledge and understanding on water quality and resilience management amongst key decision-makers (including engineers, public health professionals and policymakers) in the state of São Paulo and São Carlos region in Brazil, a state which is home to 44 million people, of whom 11 million live in the São Paulo Municipality

itself. Four training seminars; the first held in São Carlos, Brazil on 4 December 2018, the second held at ARU on 10 June 2019, the third held at the state environment agency, CETESB, in Brazil on 14 February 2020, and the fourth held at in São Carlos, Brazil on 18 February 2020, shared the practical tools developed in the WQRGIS/WQR-ANN and RESoURce@Brandia projects with representatives from Brazil and India. Formal feedback from those attending these seminars indicated a significant increase in their knowledge and understanding of water quality and urban resilience issues and of the practical measures they needed to incorporate water systems resilience into their day-to-day business practices (source 1, 2, 3 and 4). Following the 2019 training seminar in the UK, ARU was invited to run a similar training seminar for a wider range of stakeholders in Brazil and India.

Following the second training seminar held in Brazil, the São Paulo's Civil Defence Department arranged a series of site visits to validate the effectiveness of ARU's tools to identify the "hot spots" of flooding risk. Following the successful validation, São Paulo's Civil Defence Department initiated a review of the role that the SPRSim tool could play in supporting their SuDS and flood management decision-making (source 4). Unfortunately progress on the integration of the SPRSim tool into working practices has been temporarily paused due to the impact of Covid-19.

The second training seminar planned for India on 24 March 2020, in which stakeholders from practice and regulatory bodies were to receive training in water system resilience and the use of the SPRSim game, was also delayed due to Covid-19, but recent correspondence from the Indian Institute of Technology Madras Chennai has clearly indicated their desire to progress with the training workshop and round table discussions between ARU researchers and Indian stakeholders as soon as Covid-19 restrictions allow (source 2).

Finally, in addition to enhancing water quality resilience and SuDS knowledge amongst existing practitioner stakeholders (source 1), ARU's Brazilian partners (UFSCar and São Paulo University) have also used our research to raise awareness amongst the next generation of Brazilian architects, engineers and urban planners by including the learning on water quality resilience they gained from the training seminars into their postgraduate course Águas Urbanas: Interdisciplinary studies for resilience and sustainability (source 5). The delivery of this course was supported by researchers from ARU.

Raised awareness and support for the business case for improved infrastructure resilience to climate change in the UK

In addition to enhancing knowledge of water quality management and SuDS in Brazil and India, ARU research has also raised awareness and supported improved management practices of infrastructure resilience (source 6, 7 and 8) and SuDS (source 9) amongst UK practitioners.

The results from the RV-DSS project have raised awareness amongst practitioners (see quotes in source 6) of the need to consider the interdependencies between infrastructure systems when developing management solutions to ensure their resilience in the light of climate change, and in particular the impact of extreme weather events (source 7, 8). The RV-DSS tool has been shared with all the project's critical infrastructure partners, and the wider findings of the project with the wider construction industry through the Construction Industry Research and Information Association, and through an impact seminar held at the Institution of Civil Engineers (source 6) attended by approximately 35-40 delegates.

The results from the RESoURce@Brandia project have been used by Peterborough City Council to inform their risk management strategies and achieve improvements in the sustainability of Peterborough's drainage system (source 9). The ANN-based model developed in (WQR_{GIS}/WQR-ANN) project was also shared with practicing engineers through an Institution of Civil Engineers CPD workshop (source 10) attended by approximately 30 delegates.

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Taken together, the WQRGIS/WQR-ANN, RESoURce@Brandia and RV-DSS projects represent a body of research on water system quality and infrastructure resilience that has had an impact not only on those directly involved with the projects, but also on the wider practitioner communities in Brazil, India and the UK. Further, had it not been for Covid-19 curtailing planned exploitation activities, the impact from these projects would have been even greater.

5. Sources to corroborate the impact (indicative maximum of 10 references)

1. Letter from São Paulo State's Environment Agency (CETESB) WQ Sector Director confirming that the 'Water Quality Resilience Model' (produced in WQR_{GIS} project) has raised awareness of water quality and SuDS and has enhanced their water quality monitoring and management.
2. Letter from Indian Institute of Technology Madras confirming the contribution of the RESoURce@Brandia workshop in raising awareness of SuDS and resilience and setting up a workshop in India to further share the awareness with other stakeholders once Covid-19 restrictions allow.
3. News article from *The Source* magazine describing the collaborative SuDS workshop held between Brazil, India and the UK.
4. Letter from São Paulo civil defence department outlining the use of the SPRSim tool.
5. USP newspaper article detailing the transfer of water quality resilience knowledge from ARU to the next generation of architects, engineers and urban planners in Brazil.
6. Case study newsletter report from NERC and CIRIA describing the impact from the RV-DSS project, including statements by Transport Scotland and Scottish Water about how it raised awareness amongst critical infrastructure asset managers. Case study newsletter report also confirms the RV-DSS tools made available to all the projects commercial partners and describes the workshop held at the ICE.
7. Letter from Transport Scotland confirming the usefulness of the RV-DSS technology as part of a toolbox for better managing Scotland's critical transport infrastructure in response to climate change.
8. News article from *Construction News* raising awareness amongst practising construction professionals of the need to consider infrastructure interdependency when evaluating potential solutions to climate change.
9. Letter from Associate Director, STIRLINGMAYNARD consulting engineers, confirming that Peterborough City Council had used the results of the RESoURce@Brandia to inform their risk management strategies and drainage design.
10. Notice from the Institution of Civil Engineers of a CPD seminar to raise awareness of practising civil engineers of the ANN and water quality resilience model developed in the WQRGIS/WQR-ANN project.