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3D visualisation tool for improving the resilience to urban and coastal flooding in Torbay, UK

Albert S. Chen*[a], Mehdi Khoury[a], Lydia Vamvakeridou-Lyroudia[a], Dave Stewart[b], Mike Wood[b], Dragan A. Savic[b], Slobodan Djordjevic[a]

[a]*Centre for Water Systems, University of Exeter, UK*
[b]*Torbay Council, UK*

Abstract

Torbay, located in South West England, UK, is one of the Case Studies on the EU-funded project EU-CIRCLE, which is aimed at enhancing resilience of Critical Infrastructures (CI) to natural hazards. The region includes three urban centres (Torquay, Paignton and Brixham) and hosts more than 3 million tourists every year that contribute over £450 million to local economy. However, flooding, including coastal, fluvial and pluvial, has been a major threat to the area with more than 15 major incidents occurring since 1999. Rising sea levels, combined with increasing rainfall intensity, linked to climate change, are expected to exacerbate the problem. Better adaptation strategies are needed to safeguard CIs and services while improving resilience to climate hazards. EU-CIRCLE partners are engaged in a review of the existing capacity of flood defenses and the drainage systems in Torbay. To enhance the risk communication with the stakeholders, we adopted a high performance flood model to analyse the flood risk to Cis under a wide range of scenarios. The results are integrated into an innovative 3D visualization tool, showing the progress over time of any flood scenario in the region, via a fully interactive interface allowing stakeholders to better understand flood impacts to CIs.

Keywords: climate change; flood impact; resilience; critical infrastructure; urban flooding

* Corresponding author. Tel.: +44-1392-724075.
E-mail address: a.s.chen@exeter.ac.uk

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1. Flood impact in Torbay

Torbay is located in South Devon (UK) and covers an area of approximately 62 km^2 as a popular tourist destination in the UK. The area, which includes three towns, Torquay, Paignton and Brixham, with more than 130,000 residents, has suffered from flooding over many years from a number of different sources, including surface water runoff, highway flooding, sewer flooding, main river and ordinary watercourse flooding during intense rainfall events [1]. In addition, the coastal areas of Torbay suffer from flooding due to the overtopping of sea defences during high tides that coincide with easterly winds [1]. It should be noted that the surface water, highway, sewer, main river and watercourse flooding is exacerbated in the low-lying areas around the coast during high tidal cycles when the capacity of the surface water outfalls discharging to coastal waters is impeded. In addition to flooded properties, during all of these flood events numerous roads flood to some extent, with some of the roads having to be closed to traffic until the flood water has subsided. These closures result in long traffic diversions and delays, as well as disruptions to the railway transport system.

During the last major flooding event, which occurred on 24th October 1999, over 200 properties across all three towns were affected by flooding [2]. Approximately 50% of these properties were commercial properties including shops, restaurants, hotels, bars and a cinema. In addition to the property flooding both the major roads linking Torquay to Paignton and Brixham were closed for a significant period making travel within the Bay extremely difficult and affecting emergency response.

Obviously, climate change can affect local flood risk in several ways. Impacts will depend on local conditions and vulnerability. Wetter winters and more of this rain falling in wet spells will increase river and watercourse flooding. More intense rainfall causes more surface run-off, increasing localised flooding and erosion [3,4]. In turn, this will increase pressure on drains, sewers and water quality. Sea level rise, as a result of climate change, is expected to increase local flood risk both in coastal regions due to increased risk of overtopping of the sea wall, combined with inland flooding from main rivers and watercourses due to the interaction with drains, sewers and smaller watercourses [5]. As sea level is predicted to rise by over 1m in Torbay over the next 100 years the frequency and impact of overtopping of the sea defences will increase resulting in more infrastructure and properties being affected by flooding [6].

2. EU-CIRCLE framework

The EU H2020 funded project EU-CIRCLE (A pan-European framework for strengthening critical infrastructure resilience) aims to develop a holistic framework for identifying the risks of multi – climate hazards to heterogeneous interconnected and interdependent critical infrastructures (CIs). Figure 1 shows the EU-CIRCLE Risk and Resilience framework, which considers the services provided by CIs to society as a flow of goods / commodities pertinent to each type, while respecting the unique characteristics of each sector. Additionally, the framework is highly flexible to include more elements such as resilience capacities, once they are interpreted into modelling components, and allowing for the orchestration of different analytic components. The EU-CIRCLE approach also makes possible to propose metrics for different types of impacts, both directly associated with the CI (damages, performance levels, economic, losses of lives, environmental, etc.) and indirect impacts to the society, the environment and other sectors of the economy. A number of indicators are defined, which are fully aligned to the EU and International policies, and significant work is made to expand them into the operational metrics for CI resilience. Therefore, better adaptation strategies and their effectiveness for improving resilience of vulnerable social and economic support systems to climate change impacts can be evaluated and implemented to future proof the existing CIs.

For any given flood scenarios, the spatio-temporal evolution of flood hazards is fed into the algorithm shown in Figure 2 for evaluating the flood impact to CIs within the EU-CIRCLE framework. Firstly, the primary CI assets that have direct contact with flood are pinpointed by overlapping the flood maps with the CI locations. The disruption of their service areas are determined by considering the flood depth and the duration, the protection level, and the backup facilities/resources of these assets. The secondary CI assets that depend on the services of the compromised primary CI assets in those affected areas are therefore selected and the same analysis procedure will be repeated until no further affected assets are found. With all the flooded and affected assets identified, the flood impact to the CIs and the timeline can be calculated, and then summarised for overall assessment and visualised for demonstration.

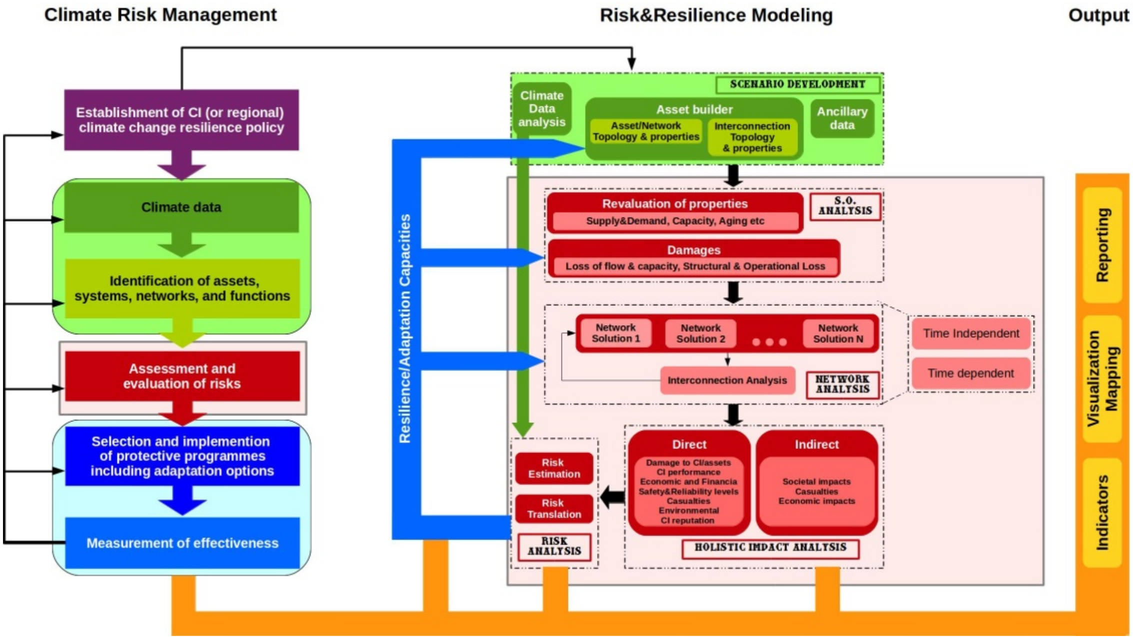

Fig. 1. EU-CIRCLE Risk and Resilience framework

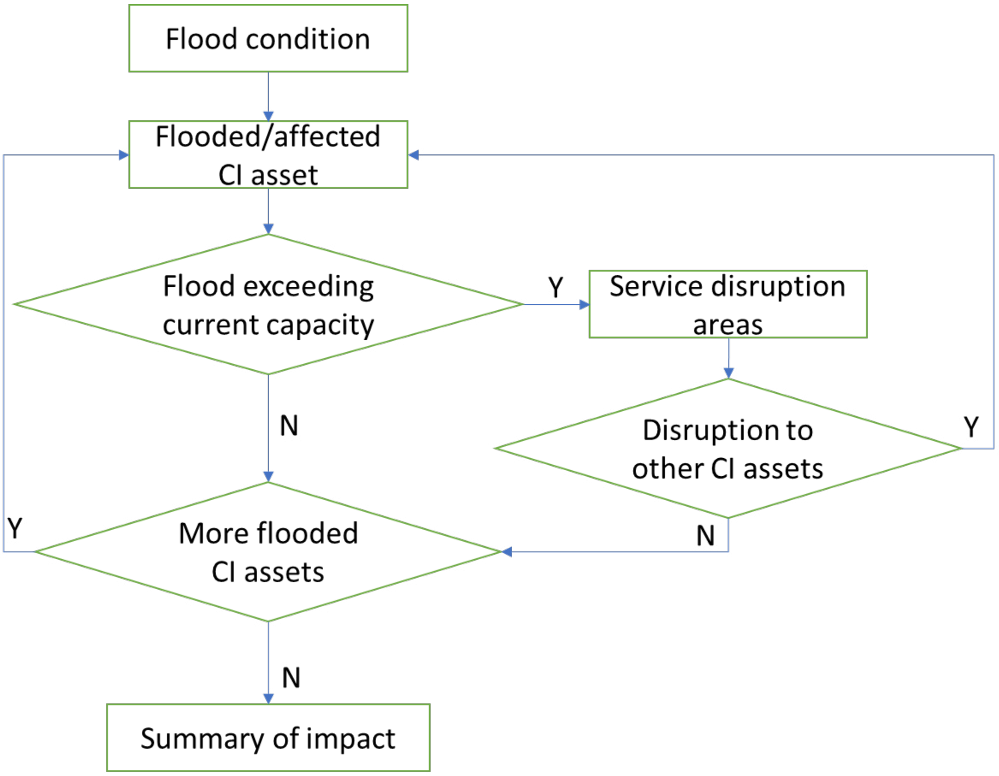

Fig. 2. Flowchart for assessing the cascading effect to CIs during flood hazard scenarios

3. Applications

3.1. Flood impact to CI

In order to enhance the CI resilience to climate change in Torbay, we adopted the EU-CIRCLE framework to evaluate possible flood scenarios, provided by Torbay Council, using the flood model CADDIES 2D [7] to identify vulnerable CIs and the consequences when their services are disrupted by flooding. The CADDIES 2D modelling framework [8] utilises the cellular automata (CA) method and the parallel computing technologies, which enable fast flood simulations on GPUs [9] for a wider range of weather conditions and interventions that would normally be not possible to be done via traditional hydraulic models. The CADDIES 2D model was applied to simulate the scenarios that were not included in existing flood analyses to identify the CIs that are susceptible to flood risk, with projections to examine the systems' ability to cope with future climate change scenarios. As a result, the full spectrum of future uncertainty associated with the system performance can be better addressed to provide a comprehensive flood risk assessment.

For each scenario, we investigated the propagation of flood hazards and its corresponding impacts to understand the cascading effect across the town and how this evolves with time [10,11]. The procedure was repeated for each timeframe of flood condition throughout each simulated event to deliver a comprehensive appraisal and recommendation for enhancing the town's CI resilience. This will be used to strengthen the adapting measures to protect the CIs and enhance the flood resilience in our case study. Since it is needed to repeatedly process abundant amount of information for the analysis, an automatic algorithm has been developed for this purpose. The algorithm also includes a 3D visualization function that enables the users more easily investigating the spatial relationships among flooding and different types of CIs.

3.2. Visualization for risk communication

In this paper, we are demonstrating the results in Torquay, one of the three main urban centres in Torbay. Figure 3 shows the 3D views of terrain, roads, buildings and CIs near the coach station in Torquay. The yellow blocks denote the locations of electricity sub stations, while the two orange blocks in the centre are the coach station and the blue block on the left is the hospital. The violet block on the bottom right is Torbay Council Town Hall.

The flood models were calibrated and validated against available historical records. Through the CADDIES 2D simulations, the dynamic progress of flood propagation during an event was obtained and used for impact analysis. The CIs affected by the flood were pinpointed, following the flowchart in Figure 2, and then the area suffering the disruption of the service from those CIs are identified. The results are displayed using the 3D visualisation plugins qgis2threejs [12] and GEarthView [13] in QGIS [14], which allow end-users to interactively navigate the modelling results using a standard browser or the Google Earth without installing specific software. A user can easily explore the 3D space to investigate the flood impact to individual properties and their surroundings in detail. This provides an enhanced user experience and strengthens the understanding of spatial correlation between hazard, CIs and their service areas.

Figure 4 shows the area nearby the coach station is flooded, which are marked in dark orange, during a 1 in 100 year pluvial event. Flood depth on the north side of the station reaches 2m, and the extent covers the ground of the whole station that jeopardises the transportation service, as shown in Figure 5. The inundated electricity substations, three on the top left region and one near the central bottom part in the figure, are highlighted in red and assumed that they will not be able to provide energy to their surrounding areas due to the damage caused by flooding. In the study, apart from the locations of substations, we could not get the actual properties that each substation is serving in detail. Therefore, we assumed that each building, as well as the public facility such as traffic signal, street light, etc., receives the electricity from its nearest substation. The areas and buildings that suffer electricity disruption during the event were identified, coloured in brown and dark brown in Figure 4.

Roads are also classified, coloured in different shades of pink, according to the flood extent and depth, which indicate the downgrade of their service level. Brighter pink for the roads being heavily affected and lighter ones for those suffer less impacts. The hospital is slightly flooded on its north corner, which is on the back side of the building in the figure. Through the interactive option of the visualization tool, user can change the location, the altitude, the view angle, the scale, and the opacity of layers to inspect the analyzing results. Figure 6 shows the view from the northern side of the hospital, where the flooding can be seen more clearly, although the flood depth is less than 0.3m that might have limited influence for the hospital operation.

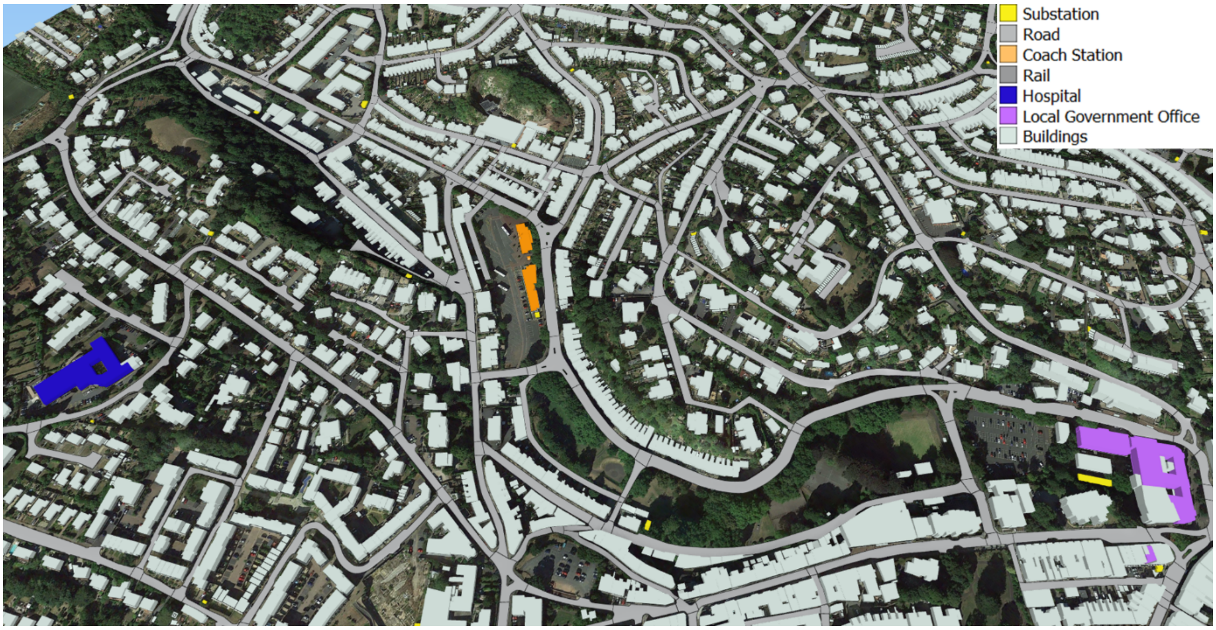

Fig. 3. 3D view of CIs, roads and buildings near the coach station in Torquay without flood situation

Fig. 4. 3D view of CIs, roads and buildings near the coach station in Torquay under 1 in 100 year return pluvial flood event

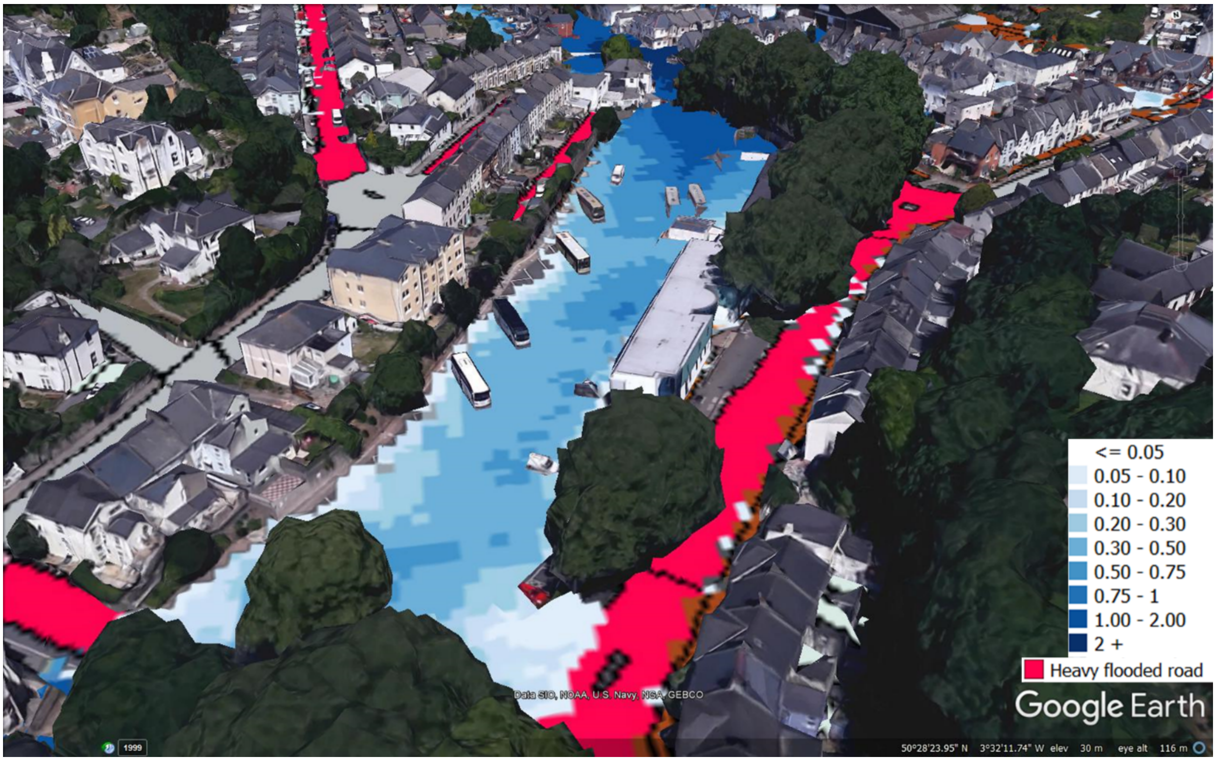

Fig. 5. Detailed flood situation at the coach station visualized in Google Earth

Fig. 6. Flooding on the north side of the hospital

4. Conclusions

Through the EU-CIRCLE framework and the cascading effect analysis flowchart adopted in this study, we developed an operational algorithm to identify the impact of flooding to the CIs and the consequence of the service disruption. We demonstrated the procedure with an event simulated by the CADDIES 2D model and results were visualised, using the qgis2threejs and GEarthView plugins in QGIS, via a web browser or the Google Earth View. The applications effectively avoided the software requirement for end-users to navigate the modelling domain in an interactive 3D space. With the tool, the flood risk managers can more effectively demonstrate the impact of flooding to the services of CIs to the stakeholders. This will improve the risk communication among participants such that better adaptation strategies can be developed, evaluated and visualised to support decision makings for strengthen the CIs resilience to flooding.

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