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Compounding focusing events as windows of opportunity for flood management policy transitions in Singapore

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ABSTRACT

Urban floods are the result of natural and man-made events, with their economic, social, and environmental impacts reflecting policy and political decisions taken at different times in the history of cities. In this paper, we discuss flood events in Singapore over 2010 and 2011 specifically in the Orchard Road area, one of the traditionally most important retail and touristic areas in the city-state, as the compounding focusing events that opened a window of opportunity for national flood management policy transitions. Using qualitative case study analysis and topic modelling, we evaluate the multi-pronged plans and measures taken by the government to strengthen Singapore's flood resilience, and the lessons learned that were born out of these events. We conclude the Orchard Road floods served as a focusing event that directed and raised the attention to the limitations of flood management in Singapore and reaffirmed the importance of adaptive management in policy making.

1. Introduction

Floods reflect the convergence of climatic, demographic, socioeconomic, and political factors. As riparian urban development intensifies, floodplains are increasingly disconnected from river channels (Gober and Wheater, 2015) despite the potential risks this represents. While the issue of flooding has often taken on a political dimension over the years, it may not always be defined immediately as a political problem at the point of occurrence (Prater and Lindell, 2000). Rather, it may only be moved from the backseat into the realm of public discussion and political attention through sudden events that cause significant impacts in communities. Such events could create 'policy windows', brief periods when the *status quo* is disrupted to the extent that policy change becomes more likely. In our case study, responses involved major changes in public policies that have ensured their relevance within a longer term framework. Specifically, we use the 2010 and 2011 floods in Singapore in a traditionally retail and touristic area, Orchard Road, as exemplars of events that opened a policy window and expanded its agenda — in this case, in terms of flood management. This window allowed policymakers to examine, revise, and even reinvigorate Singapore's approach to urban flood resilience with a greater sense of purpose in the longer term. We argue that the resulting policy changes were not gradual or incremental; rather, they happened in a highly compressed period of time. We also perform a detailed analysis, and provide in-depth evidence, of how the transition occurred in practice. With our analysis, we aim to contribute to the literature on best practices to improve the mitigation capability and capacity of public agencies in managing flood events in other highly urbanised areas.

2. Focusing events and policy change

A 'focusing event' is a rare, harmful and sudden event that becomes known to the community and policymakers (Birkland, 1997). Such events often highlight policy failure and open policy windows – momentary periods of time when the policy *status quo* is disrupted and the likelihood of instituting policy change is higher (Kingdon and Stano, 1984). While the mitigation of, adaptation to and responses to natural disasters often taken on a political dimension, they may not always be defined immediately as a political problem at the point of occurrence (Prater and Lindell, 2000). Rather, a pre-existing perception of the problem often exists (Kingdon and Stano, 1984; Farley et al., 2007). However, this may only be moved from the backseat into the realm of

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public discussion and political attention through a focusing event. This process can be understood by a consideration of the Multiple Streams Approach (MSA) which theorises that potential changes in the policy agenda are frequently placed on the radar only when the policy stream, politics stream and problem stream converge (Kingdon, 1995; Birkland, 1997). Kingdon and Stano (1984) explain that this happens when public opinion is embraced by the political stream, potential solutions to a problem are embedded within the policy stream and the characteristics of a problem are highlighted in the problem stream through a focusing event.

To date, numerous studies have examined the role of disasters, both natural and man-made, in enacting policy change. For example, Meijerink (2005) used the case of flood policy changes in the Netherlands from 1945 to 2003 to investigate how policy shifts, while influenced by flood events, were catalysed by citizens' environmental awareness and provided the enabling condition to be brought to the fore by the newly elected national government. Johnson et al. (2005) and Birkland (2006) assert that policy responses to floods are not the result of changes in the values or beliefs of policymakers. Rather, they often increase attention to various policy solutions that were discussed and considered prior to the disasters. For example, Hurricane Katrina that made landfall along the southeastern coast of the United States in late August 2005 brought to the fore gaps in policies designed to deal with disasters, inequitable resource allocation and cast a spotlight on politicians' ability to demonstrate their understanding of the problem and push forth accompanying policy solutions (Farley et al., 2007). Although research had already warned of the relationship between climate change and the resultant impacts on hurricane intensity, it took the tragedy, its impacts on the community, and widespread public unhappiness and discussion to bring natural disasters to the foreground of political discourse.

While floods in Singapore have always garnered a great degree of attention, they were most effective as focusing events that opened up policy windows in the case of the 2010 and 2011 floods. Several conditions created the enabling environment for the policy windows to bring flood management to the forefront of the policy agenda. In the wake of the flood events, the problem stream emerged with the finding of the limitations of existing drainage infrastructure and provided a glimpse into how the hazardous nature of such events may become more frequent in the face of climate change. The policy stream pointed to the problematic approach towards floods along Orchard Road – largely of a reactive nature in the form of built infrastructure that might not have kept pace with the rapid urbanisation of the area and changes in rainfall patterns over the years while the governing regime or political stream influences the policies to be discussed and the attention paid to them in parliamentary debates.

The rest of our paper proceeds as follows. We first describe our mixed methods approach which combines qualitative case study analysis and topic modelling, a quantitative machine learning approach. We then present the evolution of flood management in Singapore, including flood events, drainage management and institutional responses as backgrounds for the study. This is followed by a review of the development of Orchard Road and its flood events, highlighting the 2010 and 2011 floods as case studies. These accounts are supplemented by policy discussions as reflected in the parliamentary debates; the impacts of the floods; and how to prepare for and mitigate them. We then explore the incremental changes in flood policy and management in Singapore. Using the concept of focusing events and their role in opening policy windows, we argue that floods can catalyse policy change within a long-term framework. We conclude by summarising the main findings and identifying avenues for future research. Potential limitations of the study, inherent to qualitative case study analysis in the sense that they are case-specific and findings cannot be generalised, are also presented in the conclusion section.

3. Methodology

3.1. Qualitative case study analysis

The first method focuses on the 'how' and 'why' questions pertaining to a contemporary phenomenon in a real-world context (Yin, 2017). As a longitudinal approach, it elicits rich details to understand, in this instance, the policy evolution in Singapore's flood management, specifically the milestones and key activities describing the policy shifts and interventions.

Documents reviewed included academic papers, books, policy documents, and the annual reports of PUB (Public Utilities Board, National Water Agency of Singapore) from 1963 to 2020. At appropriate junctures, we supplemented our document review with news reports that provided additional contextual information to the milestones and key activities, such as the public outcry because of the use of the term "ponding" to characterise the Orchard Road floods.

The narratives were particularly relevant in understanding the historical importance of floods in Singapore, and the government's continuous efforts to reduce flood prone areas by first constructing drainage and flood alleviation schemes as well as water development projects, and subsequently, considering also non-structural measures to strengthen flood resilience and folding flood management into the ambit of climate change. This narrative development came about as a result of the understanding by policymakers of the risks related to climate change.

3.2. Structural topic modelling (STM)

Ideally, as it has been done in the qualitative case study analysis part of the study, researchers would also examine and manually annotate all the Hansards (Official Reports on Parliamentary Debates) published by the Singapore Parliament, to understand the political attention accorded to the impacts of floods and associated policy responses. However, since more than 30,000 documents have been published since 1963 when Singapore gained self-government, we used automated content analysis to detect themes within this corpus. Web scraping techniques were applied to retrieve Hansard documents from 1963 to February 2020. Next, NVivo software was used to identify 568 paragraphs in 123 Hansard documents with content related to floods. The resulting dataset contains 54,034 words, with a mean of 95.13 words per paragraph. We then used topic modelling to identify the themes within this dataset.

For the estimation process and to describe and interpret the topics, we used structural topic modelling (STM) (Roberts et al., 2014a, 2014b, 2016). This approach allows the use of covariates such as document source and date in the topic modelling algorithm. In comparison to other probabilistic topic models such as Latent Dirichlet Allocation (LDA), this approach provides improved estimation of the topics and introduces valuable information into the inference procedure (Roberts et al., 2016).

3.2.1. Diagnostic testing

We estimated a series of STM models by varying the number of topics in a series of diagnostic tests, including calculating the held-out likelihood (Wallach et al., 2009) and performing a residual analysis (Taddy, 2012) to assess goodness of fit (Roberts et al., 2014a, 2014b). The small set of models that performed well in the diagnostic tests were further compared using scores of semantic coherence and exclusivity. We estimated the STM models in a series of declining intervals to narrow down the range of appropriate models and to reduce the computation time for the diagnostic tests. Further tests revealed that a model building upon 21 topics gave us the best fit. All substantive findings were verified for small variations in the number of estimated topics and found to be robust. We also elaborated on the tests and sensitivity analysis, including the complete results from the diagnostic tests and estimated topics. These analyses can be found in the online Supplementary Material.

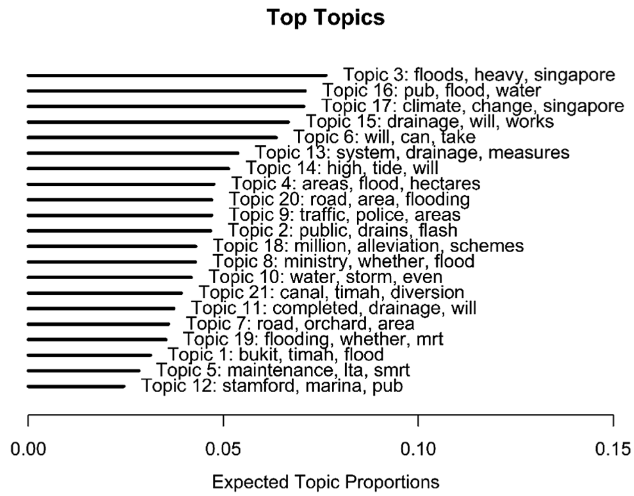


Fig. 1. Expected values for topic proportions. The figure displays the top three FREX (Frequency and Exclusivity, words that are both frequent and exclusive to the topic), which indicate the proportion of the dataset that belongs to each topic.

The results of 21 topic STM model are shown in Fig. 1. The topics are collections of words that are ranked according to their prevalence (documents contain topics with varying probabilities). For example, Topic 3, the most prevalent topic in Fig. 1, is dominated by words such as "heavy", "rainfall'', "floods", and "people" and can be labelled as "heavy rain & affected people". This indicates that the topic primarily represents discussion of heavy rainfall as one of the main causes of the floods and the groups of people affected by it in Singapore.

The key inferential task of STM is defining the semantic content of each topic using the distribution of words in each topic and expected topic proportion, which indicates the expected proportion of the corpus that belongs to each topic. When an expected topic proportion value is negative, no proportion of the documents refers to the individual topic in question.

Once the topics have been identified using STM, the topic proportions can be plotted to examine how flood discourse in the Hansard documents has evolved over time. The negative expected topic proportion values showed in the figures with the results, have been highlighted to mark the years when a particular topic was not discussed in the Hansard documents.

3.3. *Iterations between the qualitative case analysis (method 1) and the structural topic modelling (method 2)*

The value of a mixed method approach was how the two methods could offer feedback to each other, thus strengthening the insights and conclusions from the analysis. A longitudinal qualitative case analytic approach (method 1) builds the chronology of events and the "plot" which arranges the events in a loose causal order (Miles and Huberman, 1994). The narratives assembled sensitised and guided us to perform deep reading of the topics generated from STM (method 2), which involved interpreting and making sense of the results extracted in topic modelling to define topic labels (Nelson, 2020). In turn, the topics identified through STM were also used to further verify and refine the chain of events that led to policy changes in Singapore's urban flood management. This interactive and iterative process served as the devil's advocate, forcing us to seek clarification or offer alternative explanations, thus reducing the likelihood that our analyses might conclude prematurely.

4. Evolution of flood management in Singapore

Singapore is a highly urbanised city-state located near the equator. It has a tropical climate, with abundant rainfall, high and uniform temperatures, and high humidity throughout the year (Meteorological Service Singapore (MSS), n.d.). The combination of small drainage basins, low-lying land (90% is within 15 m above sea level and 30% less than 5 m above sea level), and its location in the tropics render the city-state naturally flood-prone (National Climate Change Secretariat (NCCS), 2021a, 2021b). This has been exacerbated due to climate change. According to the National Climate Change Strategy, annual total rainfall has risen at an average rate of 101 mm per decade between 1980 and 2016; annual mean temperature has increased at an average rate of 0.25 °C per decade between 1948 and 2016; and sea level rise in the Straits of Singapore has risen at the rate of 1.2 mm to 1.7 mm per year between 1975 and 2009 (NCCS, 2021a, 2021b).

Floods' disruptions and destruction in Singapore have been documented for decades (PUB, 2015; Tortajada et al., 2013). Prior to the implementation of flood control measures, sudden downpours tended to cause floods in low-lying areas, especially during high tides. Looking at the overall deliberations in the Hansards using STM, it was clear that related events were discussed in the Parliament over the years. These can be found in Fig. 2, specifically in Fig. 2a and 2b, which show the expected topic proportions of the topics "Heavy Rain" and "High Tide", respectively within the Hansards. Looking at the figures, we see that the values for "Heavy Rain" peaked in 1970, and "High Tide" peaked in 1973. It is interesting that both terms reached similar peaks again after 2010 after the Orchard Road floods.

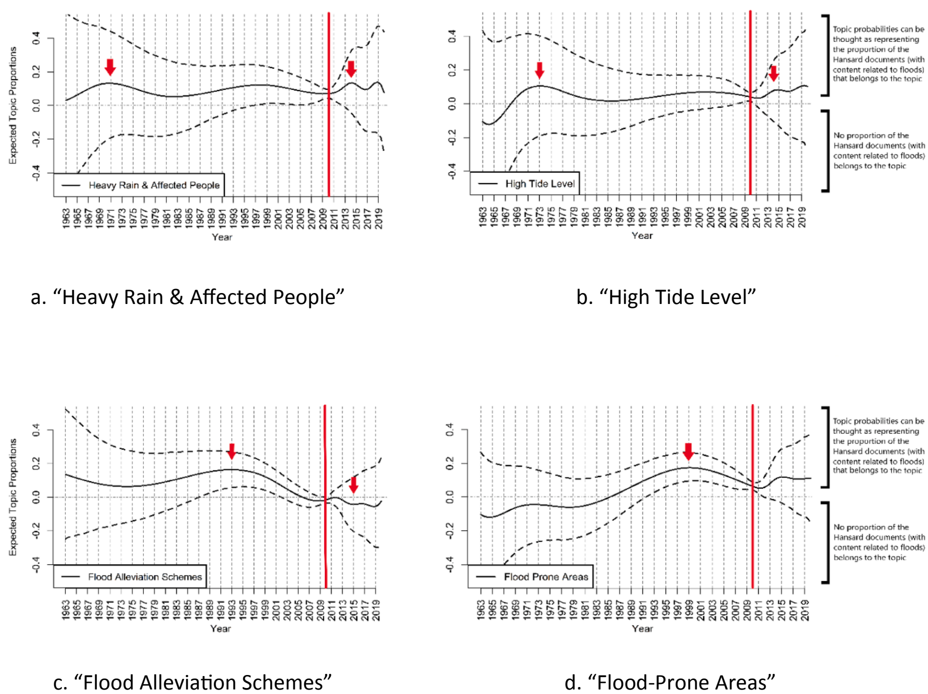
One can also affirm that flood events have shaped policy discussions in the Parliament. Concerns have shifted with time from trying to understand the reasons for the flood events (Parliament of Singapore, 1967, 1969, 1974) to longer-term flood management and the development of flood alleviation schemes (Parliament of Singapore, 1966, 1968). Since the 1970s, flood protection has incorporated structural and non-structural measures, such as the construction and widening of drains and diversion canals, as well as construction of reservoirs in the first case; and flood control guidelines that have included raising the height of low-lying areas and making construction sites do not release silty water into the drains mandatory, in the second one (PUB, 2003).

Among the main flood alleviation schemes is the Bukit Timah Flood Alleviation Scheme. Completed in 1985, it paved the way for other equally important schemes. During that time, in a parliamentary discussion, the minister for environment proposed to accelerate the construction of drainage infrastructure. Two years later, the government earmarked about S$700 million for flood alleviation schemes over the next five years. The new schemes were meant to alleviate flooding in the existing flood-prone areas, and to construct drainage infrastructure for new towns (Parliament of Singapore, 1986, 1987, 1990). A corresponding peak in the expected topic proportion values for the topic on "Flood Alleviation Schemes" in late 1980s can be seen in Fig. 2c, indicating that it was a topic frequently discussed in the Parliament.

Another main infrastructure constructed for flood alleviation (in addition to water supply and recreation) is the Marina Barrage (PUB, 2010). Located in central Singapore, its construction started in 2005 and was completed in 2008. It has the capacity to pump water out of the reservoir and into the sea, up to 40 m^3/second when high tides coincide with heavy rains (PUB, 2003).

An innovative flood management initiative that has been implemented is the Active, Beautiful, Clean (ABC) Waters Programme. Launched in 2006, the objective of the PUB programme is to transform drainage infrastructure (e.g., waterways and waterbodies) into a more natural stage, integrating it with the built environment and bring people closer to water (PUB, n.d., a).

Some of the most relevant non-structural measures have been institutional and regulatory in nature. A major institutional milestone was the merger between PUB and Sewage and Drainage Department of the



a. “Heavy Rain & Affected People”

b. “High Tide Level”

c. “Flood Alleviation Schemes”

d. “Flood-Prone Areas”

Fig. 2. Topic probabilities estimated with STM for four topics as a function of time from 1963 to 2020. Highlighted Red Line: Orchard Road Flood 2010. Arrows indicate key years when expected topic proportion values peaked. Fig. 2 (a-d) are meant to illuminate the historical context of flooding in Singapore leading to the 2010–2011 floods. Dashed lines indicate 95% confidence intervals reflecting the regression uncertainty and measurement uncertainty that comes from the STM model; the y axis indicates how much the topic was discussed in the Hansard documents (parliamentary debates). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

then-Ministry of Environment in 2001. This enabled an integrated management of water by a single agency, including flood alleviation and management (PUB, 2001). Regarding regulations, the Code of Practice on Surface Water Drainage specifies the minimum engineering requirements for surface water drainage for new developments that should be considered at the planning, design, and implementation stages of development proposals (PUB, 2018c). This Code is essential to minimise the impacts of numerous new developments in Singapore in the surface water drainage and avoid that its capacity is exceeded.

All the above improvements have resulted in a greater sense of security. Even then, floods and flood management have been a constant concern for the parliamentarians. In Fig. 2d, for example, the expected topic proportion values for the topic on “Flood Prone Areas” reached peak levels in late 1990s and early 2000s (Parliament of Singapore, 2001). Several years later, in 2004, discussions in Parliament continued to demonstrate concerns that areas above high tide level were still

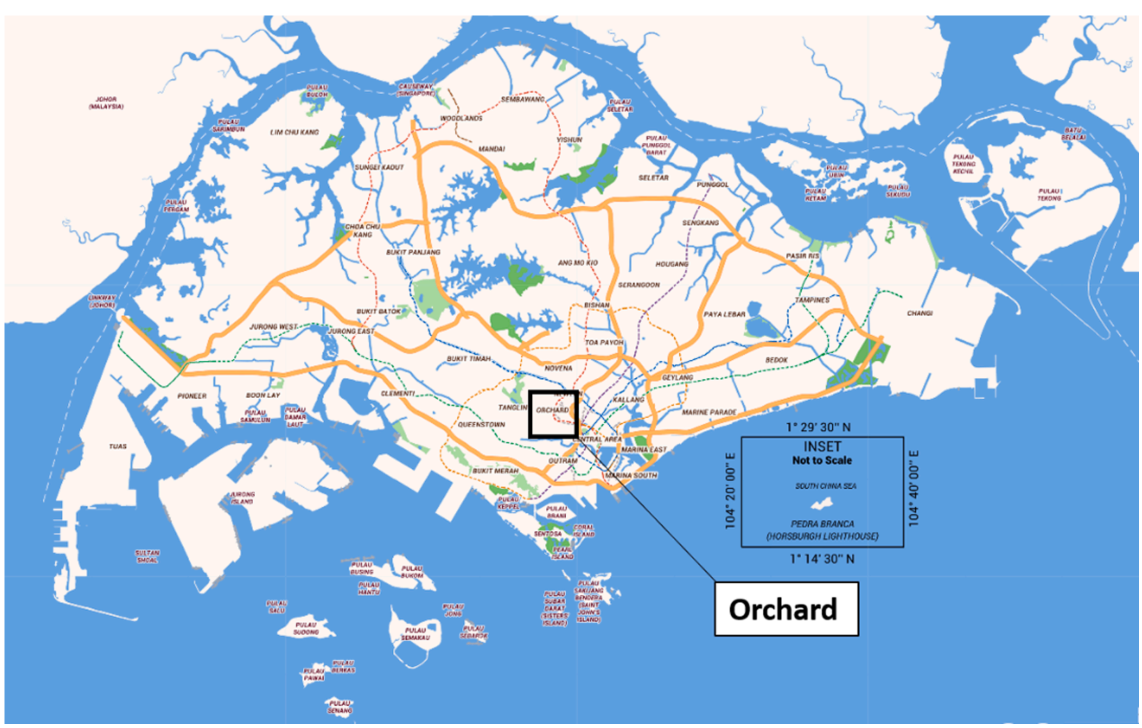


Fig. 3. Map of Singapore and location of Orchard. Source: Onemap.sg.

getting flooded during heavy rains (Parliament of Singapore, 2004).

The structural and non-structural measures mentioned had been generally effective in coping with the strains of increasing economic and population growth, urbanisation, and industrial development (CLC, 2012). In recent times, however, flood risks have increased due to more intense rains, surface runoff exceeding the capacity of stormwater drains, and topographical changes from land use modifications, among others (Chow et al., 2016; PUB, n.d., b).

4.1. Urbanisation and flood risks: The case of Orchard Road

Orchard Road is located in central Singapore (Fig. 3). Traditionally one of the most important retail and touristic places in the city-state, the highly urbanised area has undergone multiple intensive rejuvenation and redevelopment initiatives. These have included the S$1 billion Tourism Product Development Plan in the 1980s, the 'Tourism 21: Vision of a Tourism Capital' plan in 1997 (Lee et al., 2020), and, most recently, the 'Bring Back the Orchard' Plan (URA, 2020).

The Orchard Road area sits in a depression in low-lying land, making it highly vulnerable to flooding. During the 1980s, enormous effort was invested in alleviating and reducing flood events in the area. Modifications to the built environment included the deepening and widening of the Stamford Canal (the main stormwater drain of the catchment) to cover a catchment area of 619 ha, at a cost of S$56 million; the construction of a 1.2 km canal; and the conversion of an open drain along Orchard Road to a closed drain (Loh and Pante, 2015). One could argue that with the successful implementation of protection measures, the lower frequency of floods could have blurred Singaporeans' 'collective memory' – the 'inherited knowledge' of flood hazards (Viglione et al., 2014; Gober and Wheater, 2015). People's memory of flood risk is shaped by more complex processes than the length of time since the last flood event. As high-water marks, warning signs, and other visual reminders of flood risk fade from view, the 'memory landscape' of floods also fades, fostering underestimation of future flood risk (Ludy and Kondolf, 2012; Gober and Wheater, 2015; McEwen et al., 2017). For example, in the late 1990s, the Drainage Department remarked that the floods in Orchard Road were 'a thing of the past' (Loh and Pante, 2015: 45). Even parliamentary discussions touted that "flooding is no longer a serious problem in Singapore. It is now less frequent and less extensive" (Parliament of Singapore, 1992).

4.2. The 2010 and 2011 Orchard Road floods

Despite the many improvements in flood-alleviation infrastructure, the events of 2010 and 2011 reminded both the community and the policymakers that the geographical profile of the Orchard Road area still rendered it vulnerable to flooding.

In June 2010, intense rainfall of about 100 mm in two hours generated surface runoff that surpassed the drainage capacity of the Stamford Canal. This situation was aggravated by the blockage of the canal by debris that was flushed into and trapped in the culvert across Orchard Road, resulting in water overflowing onto Orchard Road in the form of a flash flood up to 300 mm deep. The flood severely disrupted traffic and inundated the basements of several buildings. The 868 insurance claims from business interruptions, property and motor vehicle damage amounted to approximately S$23 million (PUB, 2012a).

On 16 June 2011, heavy rain again fell over the central parts of Singapore, including Orchard Road. With 65 mm of rain falling in about half an hour, Stamford Canal overflow covered the road to a depth of 100–300 mm. Like the year before, the flood stalled cars and flooded the basement level of buildings (PUB, 2012a). Several months later, on 23 December 2011, 152.8 mm of rain fell, with more than half of it falling within 30 min, causing another flash flood (Chan et al., 2018). Although a S$200,000 barrier system had been installed about a year before, there were buildings that were affected again (Eco-Business, 2010; AsiaOne, 2011). These events showed how a trend of more frequent and intense rainfall events in highly urbanised areas, can overwhelm drainage infrastructure not designed for extreme rainfall (Chow, 2018; PUB, 2012a).

The increased sense of safety among the population living and working in the area, as well as the policymakers, may have resulted in more adverse effects due to the flash floods because of an increase in exposure and vulnerability. This sense of safety is known as the 'safe development paradox' or 'levee effect' (Burby, 2006). In trying to reduce flood risk by enacting proactive strategies on flood protection, the government could have created a false sense of security and indirectly reduced incentives for people and businesses in the affected area to put in place additional autonomous mitigation measures, thereby exacerbating risk by situating assets in a flood-prone area (Haer et al., 2020). As the mitigation measures were only designed to protect against rainfall events of a certain magnitude and scale, the hazardous nature of the area surfaced during the 2010 and 2011 events when these were exceeded.

5. The 2010–2011 floods as focusing events: A policy window opens

According to the 'multiple streams' approach, potential changes in policy appear on the radar when the policy stream, the politics stream, and the problem stream converge (Kingdon and Stano, 1984). This happens when public opinion is embraced by the political stream, potential solutions to a problem are embedded in the policy stream, and the characteristics of a problem are highlighted in the problem stream through a focusing event. A focusing event refers to large, sudden, rare, and harmful event that occurred in a specific locale or community of interest that is known to both the public and policymakers (Birkland, 1998). The 2010 and 2011 floods can be considered as examples of focusing events that opened a policy window: they were sudden, taking place within hours of the onset of a rainfall event, and showed that the thinking that floods of that magnitude, while understood to be rare in Singapore, were still possible and could lead to significant destruction. Because these events represent "sudden shocks to polity systems that rapidly increase attention to a suddenly revealed problem" (Birkland, 2016), they allow communities (e.g., the public, subject matter experts, and politically disadvantaged groups) to champion their messages and push for policy change (Birkland, 1998). Recent research on rarity of floods as aggregate focusing events (compounded disasters such as repetitive floods) has also shown to trigger policy change (O'Donovan, 2017). In fact, given the right conditions, such as the extent of 'shock' triggered by the focusing events, policymakers might even over-react for a limited period of time to insulate themselves from political repercussions (e.g., election loss) (Maor et al., 2017).

The occurrence of three flash floods along Orchard Road within 18 months galvanised social and political attention. Thus, opportunities for the authorities to push flood risk management onto the policy agenda came through the political stream. This could be seen when the then Ministry of Environment and Water Resources (MEWR, renamed the Ministry of Sustainability and the Environment in July 2020) appointed an Expert Panel on Drainage Design and Flood Protection Measures to review the events. The panel also assessed the flood protection and risk management measures that were slated for implementation in Singapore over the next decade (PUB, 2012a, 2012c).

A key difference between the damage brought about by the floods in earlier decades and the 2010 and 2011 ones lies in the intangible damages caused by the latter. The expert panel's report highlighted that Singapore's reputation as a safe, "well-organised and well-engineered city" could have been marred (PUB, 2012a). Most Singaporeans learned about the floods through the mass media than first-hand experience. Unlike the more traditional media (such as television, radio, and newspapers) through which information on floods was disseminated in earlier decades, information conveyed on social media tends to be less credible, as its accuracy is not validated before it is disseminated (Ismail et al., 2019). Therefore, people's response via social media could also have amplified the perception of risk from floods (Kasperson, 1992; Pidgeon et al., 2003). Although flooding events have been a preoccupation of the city-state since the 1960s and 1970s, the response of Singaporean society to the 2010 and 2011 events made the now Ministry of Sustainability and the Environment and PUB to concentrate on longer-term flood risk management. In response to the policy window created by the Orchard Road floods, various efforts were taken to increase resilience to future events, and new benchmarks were set. The main strategies and formal responses were as follows:

1. Carrying out event-based learning to elucidate the causes of the 2010 and 2011 floods and the compounding factors that led to their impacts.
2. Harnessing the potential of digital, green, and built infrastructure, implementing comprehensive solutions, and building new capabilities.
3. Improving public understanding of flood events.

These are discussed in the next sub-sections.

5.1. Event-based learning

Until 2010, floods were discussed in general terms, with only specific events being emphasised by policymakers. However, the floods of 2010 and 2011 were so severe that they became a self-contained discussion topic in the Hansards with its own policy implications. This can be seen In Fig. 4a, where the expected topic proportion values for the topic on "Orchard Road Floods" turned positive only after 2010 and continued to rise all the way to 2019.

An effective public bureaucracy created an enabling environment for an in-house investigation team to be brought together. PUB convened an Inter-Agency Review Committee, gathering key public development agencies to evaluate drainage design standards and the capacity of major drains and canals. This exercise provided a valuable forum for the exchange of perspectives, identifying both problems and avenues for improvement. To ensure that the recommendations were judicious, an independent review was also conducted by an external panel. The panel brought together local and overseas experts across disciplines, including hydraulic engineering, climate change, hydrology, and flood management, to review PUB's drainage planning assumptions and parameters, identify innovative and practical solutions, and develop ways to improve people understanding of floods (PUB, 2012a).

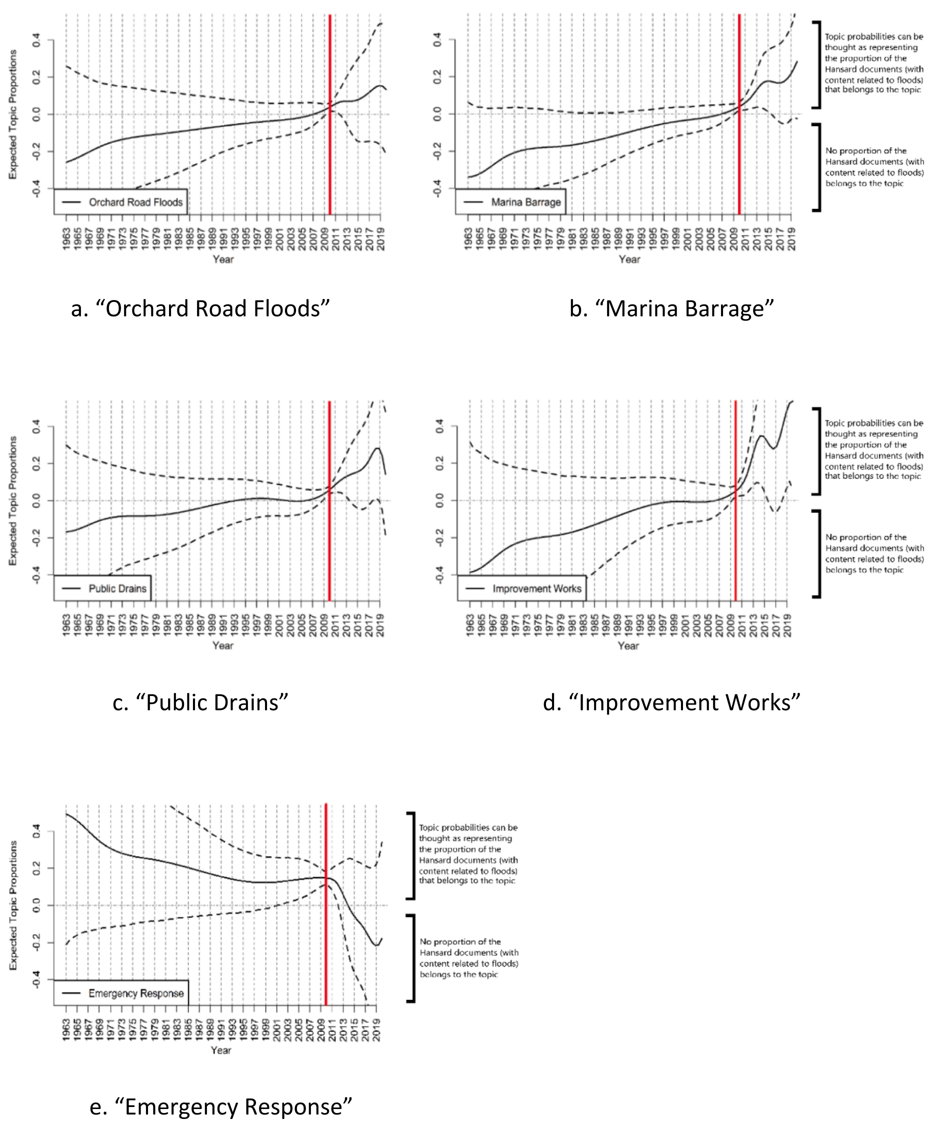


Fig. 4. Topic probabilities estimated with STM for five topics as a function of time from 1963 to 2020. Highlighted Red Line: Orchard Road Flood 2010. The figures are used in understanding the policy discussion change after 2010–2011 floods. Dashed lines indicate 95% confidence intervals reflecting regression and measurement uncertainty that comes from the STM model; the y axis indicates how much the topic was discussed in the Hansard documents (parliamentary debates). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Before the 2010 and 2011 floods, the design return period in Singapore for outlet drains and secondary drainage facilities was 5–10 years; for major rivers, 50–100 years; and for developments, 50 years. In December 2011, drainage design standards were revised with the potential to carry up to 45% higher rainfall intensity (Parliament of Singapore, 2018; PUB, 2012a). The design return periods for drain capacity were also revised (PUB, 2012a).

PUB also showed that policy change is far from a linear process by making a commitment to review its drainage master plan every three years, and to make the first one available to the public by the end of 2013 (PUB, 2012b), which the agency did. This exemplifies the iterative nature of policy learning, which can be understood as using experiences and new information to better actualise or reformulate policies (Hall, 1993; Dovers and Hezri, 2010).

5.2. Harnessing the potential of built, green and digital infrastructure

In the wake of the 2010 and 2011 floods, PUB announced plans for 20 drainage improvement projects (at a total cost of S$750 million) to improve flood protection. Direct infrastructural developments included the Stamford Diversion Canal and Stamford Detention Tank that became operational in 2018. The 2 km canal diverts stormwater from the upstream of Stamford Catchment into the Singapore River and eventually into the Marina Reservoir. The Stamford Detention Tank can temporarily store up to 38,000 m^3 of excess stormwater from the drains upstream of the Stamford Canal. After heavy rains subside, water is pumped back into the drains for subsequent discharge (PUB, 2012a; PUB, 2019). The infrastructure cost S$227 million, including more than two million man-hours across four years of construction, to protect Orchard Road from future rainfall events of the same intensity as the ones in 2010 and 2011 (Straits Times, 28 September 2018).

Overall, from 2011 to 2020, the investment in flood mitigation measures was on the order of S$2 billion. Another S$190 million was expected to be invested in 2020 to improve flood resilience (MEWR, 2020). However, in line with Singapore government's long-standing policy, while limiting flood events is critical, resources and administrative attention need to be balanced with financial prudence. The government has been candid about the near impossibility of complete flood elimination. While heavy rain in a short period coupled with urbanisation can contribute to flooding, the infrastructure is not and will not be built for worst-case scenarios, as it is financially prohibitive and not space-effective in land-scarce Singapore.

In 2012, to maximise the ability of infrastructural measures to protect Singapore's urban areas, the expert panel recommended that PUB consider a broader range of drainage interventions. This would involve ensuring that there are no 'silos' in the various components of the drainage system. This is, drainage channels, green spaces, streetscapes and other built and green infrastructures would have to be integrated holistically. Specifically, the panel proposed going beyond the traditional 'pathway' approach (such as expanding drains and canals) to developing solutions at 'source' (e.g., local storage tanks, rain gardens and bioretention swales) to regulate stormwater runoff, and providing 'receptors' (e.g., flood barriers and raised platforms) to protect local infrastructure (PUB, 2012a, b). This comprehensive 'source-pathway-receptor' approach has been implemented by PUB: runoff pathways have been expanded, and previous work to naturalise previously concretised channels as part of the ABC programme, has been continued to include more green and blue spaces, in addition to rooftops when possible (PUB, 2018a). Finally, new developments are required to incorporate receptor solutions in their design to minimise flood risk (PUB, 2018b; Wang et al., 2018). This strategy has helped water engineers, planners and decision makers make more prudent decisions on land use changes and drainage requirements (Chan et al., 2018; PUB, 2013a,b). In addition, despite its land scarcity, Singapore has managed to set aside approximately 8 m^2/person of public open space that are meant to be impermeable to ensure that land surfaces are not unnecessarily made impermeable and stormwater can infiltrate, reducing runoff (Henderson, 2013).

Knowledge of and/or information about a flood does not necessarily translate to action with regard to public response or policy making. However, they provide policymakers with the elements needed to predict the outcomes of available policy alternatives to adaptively manage appropriate strategies. In line with the expert panel's recommendation, Singapore moved to a more risk-based approach to flooding events based on 'dynamic modelling and comprehensive monitoring' (PUB, 2012a: ii; PUB, 2012c). For example, to strengthen the real-time monitoring of site conditions during intense rainfall, about 210 water level sensors have been installed at various locations around Singapore (PUB, 2018b). Although the additional rain gauges, water level sensors and flow meters that were installed along the Stamford Canal following the 2010 floods did not lower the flood risk in the 2011 events, they did enable PUB to conduct a more thorough assessment of the events as they occurred (PUB, 2012a).

Effective inter-agency collaboration was also demonstrated through PUB's partnership with various agencies. This included working with the Singapore Land Transport Authority, which was already developing a national digital elevation map for whole-of-government applications, and the Institute for Infocomm Research to create a smarter flood detection system that uses image analytics technology to scan real-time footage from PUB's CCTVs and detect images of floodwaters (PUB, 2012b; Smart Nation and Digital Government Office, 2019; Today, 18 November 2015). In 2014, a network of 142 CCTV cameras was installed to monitor road conditions in real time, mostly in low-lying areas and at hotspots. The public can view CCTV images of 49 locations around the island and be updated on the latest flood situations via PUB's website and the MyWaters smartphone application (PUB, 2014a, 2014b). While it is argued that it is a myth that science can serve as a basis for effective policymaking (Baker, 2007), the measures taken by policymakers in Singapore in response to the floods demonstrate that while knowledge by itself, does not cause change, ideas that float around in a 'policy primeval soup' can accumulate and influence public policy (Penning-Rowsell et al., 2017: 10).

Social resilience has emerged as a particularly conspicuous policy narrative. As part of its comprehensive action plan to strengthen Singapore's flood resilience, PUB has committed itself to working with stakeholders to improve preparedness (Parliament of Singapore, 2012b). One way to increase public participation and thus preparedness is through the development of a free mobile text alert service for individuals who want to receive notifications of imminent heavy rain, flood risk, and water levels in specific major waterways (Chan et al., 2018). In August 2011, the National Environment Agency and PUB jointly launched the Integrated Heavy Rain and Water Level Alert Service. It facilitates more timely public updates on potential flash floods. The Drainage Operations Unit at PUB also alerts the public of flash flood locations through Facebook and Twitter and aids the affected premises. To better connect with the community, the MyWaters application also features a dedicated feedback channel so users can send their suggestions to PUB (PUB, 2012c).

These participatory approaches demonstrate that public participation is embedded in Singapore's flood management and governance frameworks. However, the modest attention given to them in comparison to the vast resources allocated to technical measures for flood protection suggests that more can be done to cultivate public participation as a best practice to enhance social resilience.

5.3. Improving public understanding of flood events

Far from being passive consumers of policy, citizens are actively involved in the development, adoption and adaptation of policy (Prater and Lindell, 2000). More than ever, public involvement in decision-making processes is indispensable for the effective application of flood risk management policies (Krasovskaia et al., 2001).

Singaporeans today have far higher expectations of the government than in the past (Straits Times, 4 May 2017). A reasonable criticism of PUB in the aftermath of the 2010 and 2011 floods was in terms of communication. In the aftermath of the floods on 23 December 2011, the flood event was called ponding, which resulted in a strong public reaction. On 9 January 2012, this was discussed by the then Minister of Environment and Water Resources in the Parliament, when he emphasised that the flood should not have been describe as 'ponding' but as a flood. During that session, the Minister also mentioned that the Stamford Canal capacity would have to be increased by 30% to reduce risk of floods along Orchard Road, as the flood events were part of a larger pattern of rainfall change over the pass decades (Parliament of Singapore, 2012a).

Another reasonable criticism is that PUB did not successfully convey to the public 'the scientific and economic philosophy underpinning its flood management practices' (Biswas, 2012). Failing to understand the concept of cumulative probability, citizens had considered the floods to be events that only happened 'once every 50 years' (Yong, 2013). It is likely that very few would be cognisant that this probability is defined by scientists and engineers based on historical records of rainfall and may thus be redefined based on future events that contribute to the historical record and tweak the averages. This misperception of risk could have been coupled with the false sense of security people had, given the effectiveness of drainage control and flood-prevention measures that have been put in place in Singapore over the years. Identified as one of the "nine fallacies" of floods, the notion that flooding is regular and predictable should thus be quashed, and greater effort must be made by policymakers to improve public education on this topic (Pielke, 1999:413). Specifically, more precise use of language must be adopted when communicating the causes of flood events and accurate description of their magnitude would reduce the confusion that can lead to anger towards and distrust of policymakers in the aftermath of such events.

Parliamentarians not directly involved with the then MEWR were concerned with Marina Barrage and whether it had played any role in the Orchard Road flooding. In Fig. 4b, it can be seen that the expected topic proportion values for the topic on "Marina Barrage" turned positive only after 2010 and continued to rise until 2020. The trend seen is similar to the one in Fig. 4a on Orchard road floods. In retrospect, the ministry could have better qualified its earlier statements that the barrage would contribute to flood-prone areas being 'reduced to less than 100 ha' and that the drainage programme would 'manage unprecedented flash floods'. This led population to believe that Singapore was safe from flash floods from then on (Singapore Budget, 2008).

The 2010 and 2011 floods also brought other topics of discussion in the Parliament such as the importance of maintenance and improvement of public drains (Parliament of Singapore, 2013). Discussions on improving the existing infrastructure also increased after 2010. Fig. 4c shows a sustained rise in the expected topic proportion values for the topic on "Public drains" after 2010 (Parliament of Singapore, 2009), while Fig. 4d shows a steep increase in the expected topic proportion values for the topic on "Improvement works" after 2010. This increasing trend continued until 2019.

In Fig. 4e, we can see that the expected topic proportion values for the topic on "Emergency response" drop down drastically after 2010. This reflects a shift in the parliamentary discussions from the immediate response provided by PUB to flood events towards setting up early warning systems to better prepare the public for the possibility of floods. After Orchard Road floods, PUB focused on devising a more holistic response strategy that included early warning systems and the 'Source-Pathway-Receptor' approach, in addition to existing emergency response protocols.

Earlier generations of Singaporeans were inadvertently socialised to keep the memory of floods out of sight through the integration of drainage control measures with the built environment. Similarly, the present generation may also be socialised to underestimate flood risks. Therefore, even though the shifts in mindset and organisational culture around flood risks in PUB are critical and commendable, there is a need to improve social awareness and expectations about flood risks and their management to increase acceptance of the inevitability of flood events and empower individuals to make fully informed decisions about the risks.

6. Conclusions

The Singapore Government, through the PUB, has demonstrated an iterative approach to policy making in addressing the recurring and dynamic problem of floods. The presence of flood management on the political agenda shortly after independence, and especially in the wake of the 2010 and 2011 floods, best exemplify this. Not all focusing events lead to major policy changes, but the Orchard Road floods catalysed changes in flood-risk management for three reasons. First, the floods were so much more severe than what many Singaporeans were accustomed so they could not be considered routine. Second, the short time that policy windows are typically opened for was taken advantage of to identify solutions. Finally, appropriate solutions were implemented. These were in turn the result of institutional strength and flexibility. As Singapore's National Water Agency, the PUB, led the charge in convening experts from both within and external to the organisation, this ensured that investigations could yield peer-reviewed lessons to inform recommendations and decision-making in flood management. Next, innovation was at the heart of improvements to augment the infrastructural capacity of the country's drainage system. Although Singapore has had a long history of continual upgrading and construction of drainage infrastructure, the 2010 and 2011 floods provided the impetus to construct large-scale infrastructure in the form of the Stamford Diversion Canal and Stamford Detention Tank without requiring extensive land surface in a land-scarce country. An effective framework to enable an adaptive approach to policy making is also key and is demonstrated through PUB's engagement of business owner's public participation to scrutinise the processes and outcomes of each strategy and enhance education in flood risk reduction.

It is also worth noting that as new developments and measures have been put in place in Singapore, the questions raised by MPs in parliamentary debates have also evolved. These questions have been key in providing a direction for future development. Still, the threat of climate change calls for more comprehensive contemplation of urban development and flood management policies, to balance development and its impacts on the environment under changing conditions. The Orchard Road floods resulted in adaptive policy learning and collaborative governance arrangements and demonstrated how the range of policy options for flood management can expand from traditional infrastructure options to include more robust non-structural measures. The challenge is to continually strive to consider multiple pathways for flood adaptation. The hope is that future policy advances arise as a result of flood management having a permanent place on the policy agenda in anticipation of climate change and rainfall scenarios rather than being pushed into the spotlight as a reaction to focusing events after they occur. Singapore has invested heavily in flood management. Future progress is contingent on the capacity of policymakers to ensure robust and continuous adaptive governance, and of the population to be more aware of the inevitable changes that will result from climate change.

Finally, while a case study approach offers robust internal validity, there will be questions surrounding its external validity, specifically the extent to which it is generalisable to other focusing events. Our study inadvertently suffers from this limitation that plaques in-depth case studies that focus on a concentrated series of events. Further research should be conducted to explore the applicability of our insights: focusing events, especially when its rarity is magnified, not only could lead to policy change in its immediate domain (i.e., flood management), but also in its global domain (i.e., climate change). Future studies should test and develop theories around this proposition, thus expanding the 'theoretic' and external validity of our explanations to un-studied parts of Singapore's experience in building climate change resilience, as well as other cases of focusing or extreme events.

CrediT authorship contribution statement

Cecilia Tortajada: Conceptualization, Investigation, Methodology, Writing - review & editing. **Rachel Koh:** Investigation, Writing - original draft, Writing - review & editing. **Ishaan Bindal:** Methodology, Software, Validation, Data curation, Writing - review & editing. **Wee-Kiat Lim:** Investigation, Methodology, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Competing interest statement

The authors have no competing interests to declare.

Appendix A. Supplementary data

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