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The effects of flooding on railway infrastructure: A literature review

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Abstract

Flooding of railway infrastructure can lead to significant adverse complications, including infrastructural damage and large-scale disruptions. These can lead to increased economic costs and decreased reliability. Due to climate change, flooding is expected to increase in severity and frequency globally. This paper presents the findings of a systematic literature review surrounding the effects of flooding on railway infrastructure. 24 relevant papers found via the Scopus database were reviewed. We find that studies focus on quantifying the effects of past and or future flooding events on railway infrastructure, while fewer studies mention adaptation strategies to mitigate the impacts. To understand and predict the future impacts of flooding on railway infrastructure and develop appropriate adaptation strategies, it is important to first quantify and understand past events.

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Keywords: systematic literature review; railways; flooding; resilience to extreme weather events

1. Introduction

Railway infrastructure is vulnerable to extreme weather events which lead to infrastructure failures and disruptions. Such events increase economic costs and decrease the reliability of railways as means of transporting goods and people. Flooding is one type of these extreme events, which can lead to infrastructure failures such as damage to railway slopes, embankments, electrical equipment, and railway tracks, as well as bridge failure due to scour (the removal of sediment at bridge foundations due to the rapid movement of water (Dikanski et al., 2017)). This in turn can lead to large-scale disruptions across railway networks (Correia et al., 2020). The damage of railway infrastructure

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due to flooding can result in several months of repair work and rerouting of trains, which is more prevalent in railway networks compared to road networks due to the complexity and less flexibility (Doll et al., 2014).

Climate change projections indicate that railways will become more vulnerable to flooding in the future. Bubeck et al. (2019) estimates that in the EU, the annual damage to railways is approximately €581 million per year. Flooding in Europe is expected to increase due to increased temperatures and rainfall events, especially during the winter months, and since railway infrastructure has a relatively long-life span, it is important to ensure its resiliency to flooding events throughout its entire life span (Doll et al., 2014). It is thus important to establish an understanding of the current research surrounding these issues, to increase the resiliency of railways to flooding, and to develop appropriate adaptation strategies.

Flooding has been studied in multiple sectors such as transportation and building construction, with various studies revolving around vulnerability impacts, policy making, and spatial flood mapping. However, the research surrounding railway transportation specifically has generally received less attention. In this paper we systematically reviewed literature to understand the current state of knowledge on the relationship between flooding and railway infrastructure, thus leading to the following research questions:

1. What is the main focus in previous research on flooding related to railways?
2. How are future adaptation strategies addressed in research on the effect of flooding on railways?

2. Methods

A systematic literature review surrounding the effects of flooding on railway infrastructure was conducted during March 2022. The first step included mapping the field (Denyer & Pilbeam, 2013), a process used to define the scope of the study. Next, the Scopus database was used to systematically identify relevant literature, which was then assessed using a set of inclusion and exclusion criteria. Finally, titles, abstracts, and full-text articles were screened, narrowing down literature during each step (Figure 1).

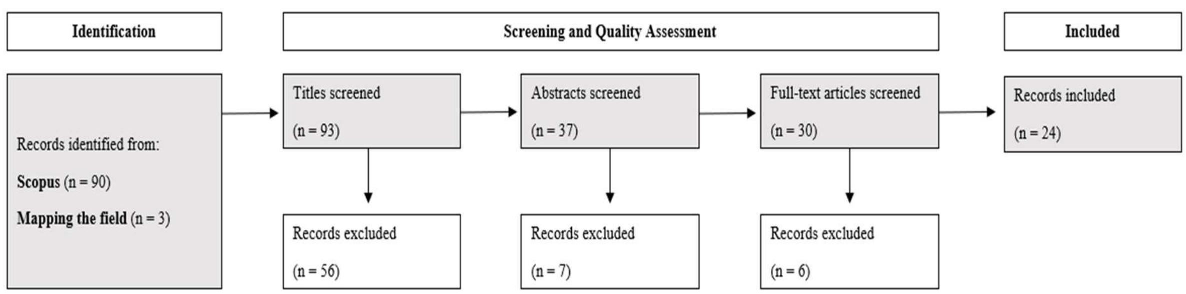

Figure 1. Process for identifying relevant papers. Adapted from: (Page et al., 2021)

Keywords chosen for a search string included *rail** and *train* and were combined with disruption and flooding related keywords *delay*, *disruption*, *cancel**, and *flood*. Publications were limited to English with no restrictions on publication year, and to peer-reviewed journal articles, reviews, and conference papers. The main criteria for inclusion were that the study included railways and some aspect of flooding impact, assessment, or prevention. Studies were excluded when the full-text version was not accessible, the focus of the study was not on railways, or when other natural hazards such as hurricanes or earthquakes were the in focus rather than flooding. A total of 24 studies were included in this study.

3. Results

In this section, a review of the impacts of flooding on railway infrastructure is presented. The studies utilized in this review are divided into the past impacts of flooding, future impacts of flooding, and future adaptation strategies (Figure 2). Regarding past impacts of flooding, these studies mainly use specific case studies to understand the past and present impacts of flooding on railway infrastructure before taking into consideration the future impacts (Fabella & Szymczak, 2021). Studies that predict future impacts on railway infrastructure often combine estimates of past effects with projections of future climate change to predict the future impacts. Some studies also discuss future adaptation or mitigation strategies. Double counting occurred when multiple different approaches were used in the article.

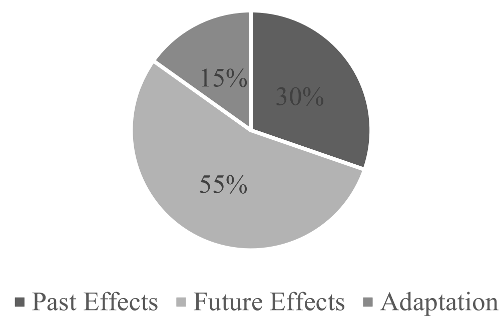

Figure 2. Distribution of studies

Most of the studies were conducted in Europe, with a strong emphasis on the UK (Dikanski et al., 2017; Ilalokhoin et al., 2021; Lamb et al., 2016; Lamb et al., 2019; Pant et al., 2016; Pregnolato & Dawson, 2018) and Alpine countries (Doll et al., 2014; Fabella & Szymczak, 2021; Kellermann et al., 2015; Kellermann et al., 2016).

3.1. Effects of past flooding on railway infrastructure

Flooding has a negative impact on the reliability of railways due to damage of infrastructure which in turn leads to increased disruptions on the railway network. Fabella and Szymczak (2021) analyzed the vulnerability of German railways to four different natural hazards: floods, mass movements, slope fires, and tree falls. They found that flooding has the highest impact on disruptions and can reduce the daily train traffic by up to 19%. Similarly, Changnon (1999) estimates that the flash flood that occurred during July 17-18 in 1996 in Chicago, USA resulted in over 300 freight trains having to be rerouted during the event which led to a loss in $48 million due to train delays, rerouting, and direct damage to the infrastructure. Bubeck et al. (2019) estimates that the annual damage of railway infrastructure due to flooding in the EU is around €581 million per year under present risk scenarios.

Commonly used methods to quantify the impacts of flooding on railway infrastructure include vulnerability and risk analyses (Petrova, 2020). Often frameworks and models are also developed to quantify the resilience (Gonzva et al., 2017) or vulnerability of railway infrastructure. Resilience has many different definitions dependent on the study, however in this case we define it as the ability of a railway system to recover from disruptive events within acceptable costs and time after being disrupted. Kellermann et al. (2015) developed the RAilway Infrastructure Loss (RAIL) model to quantify expected damage of railway infrastructure to flooding and subsequent repair costs by using photo documentation of infrastructural damage to a railway line in Austria after the 2006 March river flooding. The RAIL model was used in later research to predict damage and resulting repair costs under various climate change scenarios (Bubeck et al., 2019) and flood scenarios (Kellermann et al., 2016).

These studies highlight that flood damage is expensive and has a negative impact on railway reliability. There is a strong emphasis on studies with a smaller spatial scale, which is important due to regional differences in geography (Binti Sa'adin et al., 2016a), and quality of maintenance and infrastructure (Doll et al., 2014). For effective risk management and future adaptation planning it is important to gain a good understanding of the past impacts of flooding on railway infrastructure. The importance of characterizing flood events based on catchment size helps aid the characterization of high and low flooding intensity (such as Cheetham et al., 2016a and Kellermann et al., 2016) and studies that focus on temporal and spatial patterns of rainfall induced hazards (such as Liu et al., 2018) can help infrastructure managers and planners prioritize adaptation strategies, identity flood risk hot spots, and plan for the best areas to build future railway infrastructure.

3.2. Effects of future flooding on railway infrastructure

The majority of the literature reviewed here estimates the future impacts of flooding on railway infrastructure by using historical data, climate change projection data, or a combination. This indicates that past impacts can help guide the development of methodologies that predict the future effects.

Climate change projections indicate that flood events in Europe will most likely increase due to increased amounts of rainfall and higher temperatures in the winter months. For instance, Ilalokhoin et al. (2021) developed a multi-track model to predict delays due to windstorms and flood events, with the aim to guide and inform future decision making and scenario planning. Gonzva et al. (2016) assessed the resilience of guided transport systems to flood hazards by presenting a qualitative and systematic methodology in order to predict future resilience to flooding.

Bubeck et al. (2019) utilized seven climate projections, simulations of daily stream flow with the Lisflood model, and RAIL model data to project annual flood damage increases due to climate change for 29 EU member states. They estimate that damages will increase by 255%, 281%, and 310% under a 1.5 °C, 2 °C, and 3 °C climate warning scenario respectively, and identify the countries of Austria, Belgium, Slovakia, and Slovenia as the most at risk to flood due to climate change.

Some studies are aimed at understanding future susceptibility of specific infrastructure assets or highlighting flood risk hot spots. Binti Sa'adin et al. (2016b) assessed the vulnerability of a new proposed Singapore-Malaysia high-speed railway and concluded that steep cuttings, ballast foundations, as well as tunnels are amongst the most vulnerable assets to flooding. They highlight the importance of performing vulnerability assessments during the planning stages of new infrastructure in order to increase resilience of railway infrastructure with quick recovery from flooding events. Flood susceptibility and frequency maps using GIS for instance are common methods for identifying regions at risk to flooding (used in Correia et al., 2020; Cheetham et al., 2016a; Hong et al., 2015; Hu et al., 2014; Liu et al., 2018; Murphy et al., 2016; Pant et al., 2016; Pregnolato & Dawson, 2018).

Bridges are valuable infrastructure assets, and bridge failures can drastically impact maintenance costs and network disruptions. Dikanski et al. (2017) developed a model to analyze the relationship between bridge scour and climate change for four different bridges in England and Wales and determined that current risk models used by Network Rail are insensitive to climate change. Lamb et al. (2016) and Lamb et al. (2019) use fragility curves and fragility curves combined with a passenger journey disruption model respectively to quantify the risk of future bridge failures due to climate change in Great Britain and found that the probability of bridge failure increases with the amount of extreme weather events.

Overall, these studies indicate the vulnerability of railway infrastructure to flooding is expected to increase with climate change. The literature analyzed is focused on identifying hotspots to flooding and quantifying the infrastructural damage. These all can help guide appropriate adaptation strategies to ensure long-term resilience.

3.3. Future Adaptation Strategies

Out of the 24 studies analyzed only five highlight adaptation, resilience, or mitigation strategies to future flooding events and climate change. Doll et al. (2014) considered adaptation strategies for two cases: winter conditions impact on road transportation in Baden-Württemberg, Germany, and the impacts of flooding on Alpine railways, specifically Switzerland, Austria, and Slovenia. In the case of Alpine railways, they concluded that an increase in preventive maintenance could be a beneficial and cost-effective method of adaptation to future flooding events. The authors also discuss the importance of establishing risk maps, reliable weather warning systems, and reviewing current infrastructure codes and adapting them to changes in climate. Gonzva et al. (2017) suggests protecting infrastructure components that initiate delay propagation to increase resilience of the system and robustness of capacity. Hong et al. (2015) identifies four mitigation strategies and concludes that maintaining the most vulnerable links and ensure non-disruptive services during flood events is the best strategy towards mitigating the effects of flooding on the 20 vulnerable railway links identified in the Chinese railway network. Cheetham et al. (2016b) suggest eight options for flood protection of a rail embankment in Tarascon-Arles, France, and conclude that the most effective ones are protection using vegetation and geosynthetics on the west side along with additional drainage on the east side; and suggest that low impact and low-cost solutions such as these can be highly effective.

Kellermann et al. (2016) discusses a more policy-based approach to adaptation referring to the risk management cycle and strategies used by the national railway operator in Austria, ÖBB; which focuses on synergies between structural and non-structural measures. Additionally, there is further emphasis on the importance of including the estimation of structural damage in existing flood damage models linked with potential flood risk hot spots in order to aid future risk management decision making.

4. Concluding Discussion

In this work, 24 studies are reviewed to gain an understanding of the current state of knowledge surrounding the impacts of flooding on railway infrastructure. Railway infrastructure is already vulnerable to flooding impacts resulting in large-scale disruptions and increased infrastructure maintenance costs. Climate change is expected to increase this vulnerability, making this a growing and important field of interest. We find studies that 1) focus on the past effects of flooding using specific case studies and historical data, 2) quantify the future effects of flooding on infrastructure, or a combination of both; while fewer studies 3) mention adaptation strategies to mitigate the impacts and increase resiliency. There is a strong emphasis on identifying areas at risk to flooding using spatial analyses such as susceptibility mapping. Low-lying areas such as plains, valleys, and coastal areas are generally the most vulnerable to flooding, and these areas are also typically where much of railway infrastructure lies. Attention to spatial scale is also important to consider in these types of studies due to global and regional differences in current and future climate, and quality of infrastructure and maintenance.

To understand, predict and prepare for the future impacts of flooding on railway infrastructure, it is important to quantify and understand past events. Most of the literature analyzed we have reviewed utilize historical events and data to quantify current vulnerabilities and resilience and use this as a base to predict the future impacts. Many of these studies have indicated that they are a base for future adaptation studies and resiliency planning highlighting the importance of adaptation in future research. Moving forward, more emphasis should be put on developing appropriate adaptation strategies that are suitable to the local geography and infrastructure. As railway infrastructure has a long-life span, so it is important to adapt current infrastructure and build new infrastructure with resiliency in mind.

Acknowledgements

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