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Climate-induced flooding and coastal transportation vulnerability: Implications for urban resilience in Izmir, Türkiye

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Abstract

Climate-related sea-level rise and storm surges are progressively impacting coastal cities and their transportation infrastructure, placing increasing strain on mobility in these areas. Since major transportation routes are often located in low-lying coastal areas, assessing their susceptibility to flood-related hazards has become a critical aspect of urban resilience and climate adaptation planning. This research examines the relationship between sea level variability and traffic performance under flood-prone conditions through a case study of a coastal transportation corridor in Izmir, Türkiye. The analytical framework integrates long-term relative sea level observations (1999–2024) with high-frequency traffic volume data collected during rainfall and flood-prone periods in 2023. Long-term sea level variability and seasonal patterns were examined using time-series analysis, while the empirical relationship between sea level variability and traffic flow was analysed using regression and correlation analyses. In addition, exploratory future scenarios were developed to illustrate potential exposure pathways under continued sea level rise. The findings indicate that higher sea level values are associated with modest but statistically significant reductions in traffic volumes along coastal routes. The strength of these associations varies spatially and temporally, with stronger relationships observed at specific locations and during peak traffic periods. The analysis further highlights the vulnerability of coastal transport corridors to flood-induced disruptions and illustrates how corridor-scale analyses can identify localized vulnerabilities that may be masked at broader regional scales. By linking observed traffic responses to sea level variability under flood-prone conditions, the study contributes empirical evidence to the growing literature on climate-resilient transportation systems. These insights provide valuable insights for assessing transportation vulnerability and resilience in urban growth, infrastructure management, and climate adaptation interventions in coastal cities.

Keywords: climate-induced flooding, coastal transportation, sea level variability, transportation vulnerability, urban resilience

1. Introduction and Literature Review

Climate change has enhanced both the long-term risks of sea level rise and the short-term flood hazards to which coastal urban systems are exposed. Because it underpins mobility, economic activity, and emergency response, transportation infrastructure is especially at risk. Coastal areas are highly exposed because their mobility corridors and critical infrastructure are densely clustered in low-elevation zones vulnerable to tidal and storm surges, and high-intensity precipitation events (Hallegatte et al., 2019; Nawarat et al., 2026). When floods force the closure of roads and rail lines for repair, they trigger a series of transport service disruptions that can restrict accessibility, aggravate congestion, and produce cascading socio-economic effects; hence the resilience of transportation systems is considered a crucial element for climate adaptation (Koetse & Rietveld, 2009; Jaroszweski et al., 2010). Recent empirical analyses also suggest that flood-induced road infrastructure disruptions can significantly increase travel times and result in major economic losses through delays and inefficiencies in the road network (Saiz & Wang, 2022; Shan et al., 2025).

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A large number of studies have investigated the impact of weather and climate hazards on transport systems. Evidence-based research has shown that precipitation and severe weather conditions exert a substantial effect on traffic volume, road safety, and network operations (Brodsky & Hakkert, 1988; Changnon, 1996; Al Hassan & Barker, 1999). Recent studies indicate that precipitation, extreme weather events, and other weather-related phenomena continue to strongly impact flow, safety and transport efficiency often resulting in disruptions and or impairment of traffic performance and increased operation and maintenance costs (Touloumidis et al., 2025; Liu et al., 2026). Along with these usual weather effects, numerous studies have focused on the impacts of heavy rainfall and urban flooding. The studies demonstrate that flooding can significantly reduce road capacity, disrupt traffic flow and degrade network performance, particularly in densely populated urban areas (Chang et al., 2010; Cools et al., 2010; Mitsakis et al., 2014; Diakakis et al., 2020). Moreover, due to network interdependencies, such disruptions often propagate far beyond directly flooded zones, cascading into system-wide delays and reduced accessibility across broader transportation networks (Jenelius et al., 2006; Coles et al., 2017; Kasmalkar et al., 2020).

In addition to short-term flood impacts, extensive literature links sea level rise to long-term transportation vulnerabilities. Rising sea-levels can also change land-use patterns, impair roadway performance, and exacerbate congestion risks along coastal routes (Papakonstantinou et al., 2020). Regional-scale studies further argue that substantial populations, along with large stretches of transportation infrastructure, could increasingly face the risk of sea level rise, highlighting the urgency of anticipatory adaptation planning (Hauer et al., 2016; Pregnolato et al., 2016; Jacobs et al., 2018). Many of these analyses rely on sophisticated modeling techniques such as hydrodynamic flood models and resilience measures at the level of networks (Pregnolato et al., 2016; Arrighi et al., 2019; Boeing & Ha, 2024).

Despite these advances, important gaps remain in the literature. Much of the existing research focuses either on large-scale flood risk assessments or on model-based analyses of transportation systems. While these studies provide valuable insights, relatively little attention has been paid to corridor-scale empirical assessments that directly examine the relationship between observed sea level variability and transportation performance under flood-prone conditions. This limitation is particularly critical for coastal cities, which can be overlooked by regional evaluations of vulnerabilities. Understanding these place-specific dynamics is essential for embedding resilience into transportation planning and climate adaptation measures.

Izmir provides a particularly relevant case for examining these questions. As one of the major coastal cities of Türkiye, it has extensive transportation infrastructure along the coast. Numerous, critical transportation corridors are exposed to tidal flooding, storm surges, and intense precipitation, posing potential threats to transportation, accessibility, and infrastructure functionality. These characteristics make Izmir an appropriate setting for investigating the interactions between flood-related hazards and coastal transportation systems within a broader urban resilience context.

Local climate risk assessment is considered a key element of urban climate planning, specifically addressing the exposure of critical infrastructure, such as transport systems, to local climate risks. Municipal vulnerability assessments and risk analyses - such as those which may be conducted within the context of the Sustainable Energy and Climate Action Plan (SECAP) - need to explicitly address climate hazards (e.g. sea-level rise, flooding, etc.), as well as their impacts on urban infrastructure and mobility systems (Davide et al., 2025). Although the SECAP guidelines provide a general methodological framework rather than city-specific analyses, their focus on local risk assessment is consistent with the climate adaptation priorities in Izmir, where coastal districts, infrastructure and seaports are susceptible to sea level variability and coastal flooding. Transportation strategy development also highlights the sensitivity of coastal transport systems and the need to incorporate adaptation to climate change in transportation planning activities in the Izmir Sustainable Urban Transportation Plan (SKUP) (Izmir Metropolitan Municipality, 2025).

Supplementary environmental planning systems have also recognized transportation infrastructure as a critical climate risk-vulnerable sector; e.g., the Izmir Green City Action Plan (GCAP) highlights the requirement for integrated resilience approaches that connect infrastructure planning, environmental management and sustainable mobility (Izmir Metropolitan Municipality, 2020). The city's recent climate-neutrality plans also emphasize the need to consider sea level rise in long-term city and infrastructure planning (Izmir Metropolitan Municipality, 2021). Moreover, global coastal risk screening tools suggest that large swathes of Izmir's coastal urban areas could be at risk of flooding in the future even in moderate sea level rise scenarios (Climate Central, 2021).

The scholarly literature dedicated specifically on Izmir primarily addresses the risk of sea level rise particularly from the standpoints of planning and policy. Studies on city climate plans indicate differences in the capacity to adapt to risks and to assess them among cities on the Turkish coast (Iavarone & Kaya, 2021). Studies on urban design and spatial planning have highlighted the importance of water-sensitive urban morphology, blue–green infrastructure, and sustainable stormwater management to improve climate resilience and mitigate flood risks in coastal areas (Barbosa et al., 2012; Akdeniz, 2022; Özeren Alkan & Hepcan, 2023). Various other reviews of the literatures have also focused on the flood hazard mapping with GIS applications (Ozkan & Tarhan,2016), adaptation measures for coastal areas under threat through sea level rise and flooding (Ercanlı & Savaşır, 2022a), vulnerability of ecosystems to climate change (Arslan, 2023), and historical major flood events in Izmir (Karataş, 2024; Mutluer & Işık, 2025). Further planning research also focuses on mainstreaming the climate adaptation aspects in the urban transformation policies and governance arrangements (Allarané et al., 2024). However, despite the growing emphasis on resilience-oriented planning and climate adaptation, empirical evidence linking observed environmental variability to transportation system performance remains limited. As a result, the transportation aspect of urban resilience remains underrepresented in local climate adaptation assessments. However, there are still few empirical studies that directly examine the relationship between observed sea level variability and transportation performance.

In addition, the thematic analysis of the literature related to coastal transport planning revealed gaps, including a lack of empirical studies at the scale of a corridor, limited focus on contexts where data is scarce, and poor linkage between concepts of climate adaption and measured transport performance (Lennon et al., 2014; Mushtaq et al., 2024). Recent reviews highlight that the majority of transportation studies in flood have a strong dependence on modeling techniques and data availability, while empirical studies founded on observational data of real events remain limited in number (Boeing & Ha, 2024; Dharmarathne et al., 2024; Chen & Lo, 2026). Consequently, transportation planning in many coastal cities continues to rely on generalized risk assessments rather than on site-specific empirical data.

Within this context, the present study examines the vulnerability of a coastal transportation corridor in Izmir by investigating the relationship between sea level variability and transportation performance under flood-prone conditions. Long-term sea level data were combined with traffic flow data gathered during rainfall and flood-prone periods to provide an empirical analysis of the sensitivity of coastal transportation systems to environmental perturbations. The study is thus expected to add value to resilience-focused transportation planning by assessing localized transportation vulnerabilities associated with sea level variability and illustrating how such analyses can inform corridor-based climate adaptation strategies in coastal urban areas.

1.1. Contribution and Limitations

This paper contributes to the growing literature on climate resilience and transportation by examining the relationship between sea level variability and transportation performance under flood-prone conditions in a Mediterranean coastal city. The study provides empirical evidence of the relationship between sea level variability and transportation performance under flood-prone conditions at the corridor scale, an area that remains relatively underexplored within climate adaptation and resilience research.

The scale of the study at the corridor level allows for a direct evaluation of the relationship between observed sea level variability and disruptions to traffic flow during rainfall and flood-prone periods. Focusing on a single coastal transport corridor in Izmir, the study reveals local effects that may be masked in analyses at the network level or by the model-based research alone. This high-resolution view reveals how low-lying coastal highways respond to periods of elevated sea levels and identifies critical points of exposure in urban transportation grids.

The study proposes a corridor-scale empirical assessment framework for examining relationships between sea level variability and transportation performance under flood-prone conditions. Rather than replacing advanced climate or transportation models, the framework complements existing planning approaches by identifying localized vulnerabilities and potential exposure pathways under future sea level rise conditions. Its application demonstrates how empirical observations can support resilience-oriented transportation planning and climate adaptation in coastal urban environments.

In addition to methodological contributions, these results also inform discussions on policy and planning by grounding adaptation concerns in empirical observations of traffic behavior. The combination of traffic performance measures with an analysis of exposure to flooding provides a linkage between climate risk analyses and transportation planning that can offer decision-relevant insights to enhance the resilience of coastal mobility systems.

Despite these contributions, several limitations should be acknowledged. The analysis is based on a relatively short period of overlap between sea-level observations and traffic counts. Traffic data are only available for selected flood-prone periods within a year, whereas long-term sea level records are available. Moreover, the two datasets have different temporal resolutions: sea level data are represented by monthly averages, while traffic volumes are recorded hourly. This temporal misalignment prevents exact synchronization between the two datasets and therefore limits the interpretation of the resulting statistical relationships. Therefore, the statistical relationships identified in the study should be interpreted as exploratory associations rather than casual effects. Studies in the future that include longer durations of both concurrent traffic and sea level observations, as well as other potential explanatory variables (such as rainfall intensity, traffic demand, road conditions, and traffic incidents), may make it possible to conduct more robust multivariate analyses and provide stronger evidence for causation.

The methodological framework consistently relies on a few basic statistical tools such as regression and correlation analysis. While these techniques suit exploratory analyses given data limitations, they do not capture the complexity of climate–transport system interactions. More sophisticated methods reflecting hydrodynamic flood modeling on the one hand and network-level analysis or climate model–based projections on the other could shed light on prospective transportation effects.

The future scenarios are based on a trend-continuation assumption rather than on downscaled global or regional climate model outputs and should therefore be interpreted as a what-if sensitivity analysis rather than as a predictive model. They are used to examine how potential rises in sea level might change the spatial exposure of low-lying coastal transportation segments, not to estimate particular future traffic volumes. Therefore, the scenarios can be considered as representative exposure pathways for potential future sea level conditions.

This research is concerned mainly with road traffic on one coastal route. Effects on public transit, active modes and wider socio-economic aspects are not explicitly monetised. Addressing these issues would require further data and methodological tools, marking them as the main challenges in forthcoming research.

2. Methodology

An empirical approach was adopted to investigate the connection between sea level variability and transportation performance under flood-prone conditions in a coastal city. The approach integrates long-term sea level observations with traffic volume data to examine how sea level variability is associated with transportation performance along a coastal corridor during rainfall and flood-prone periods. Rather than aiming for exact predictive forecasting or strict causal attribution, the purpose of the analysis is to identify empirical regularities, spatial sensitivities, and possible risk transference mechanisms related to flood- associated hazards. By concentrating on observed interactions of environmental variables with traffic performance, the framework delivers a corridor-scale view that can be used for transportation resilience quantification and climate risk management in coastal urban areas. The overall methodological process is illustrated in Figure 1.

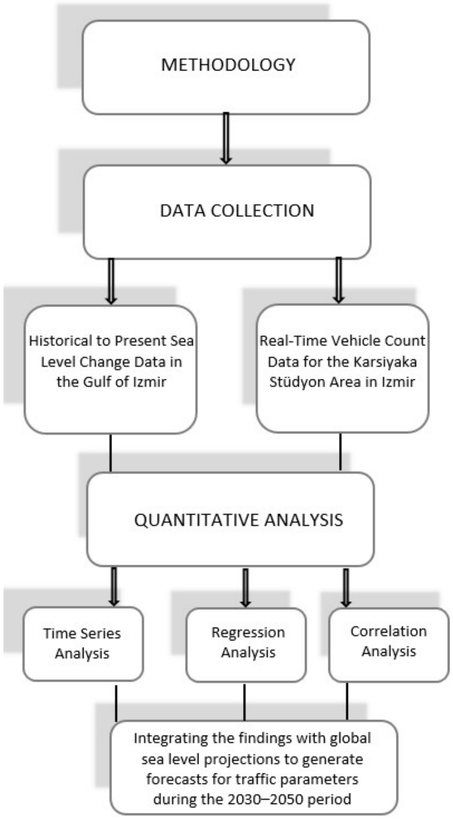

Figure 1 Methodological framework of the study

2.1. Research Design and Study Context

A case study approach was used to investigate the correlation between sea level variability and transportation performance under flood-prone conditions in a coastal city. The methodological approach combines observational sea level and traffic data to evaluate the susceptibility of a coastal transportation corridor to flood-induced disturbances. Rather than constructing predictive climate–transport simulation models, the methodological framework seeks to identify empirical relations and site-specific vulnerability patterns that can be used to inform transportation resilience assessment and climate adaptation planning.

The case study focuses on the Yali Boulevard which is one of the main coastal transportation arterys in Karsiyaka district found in the city of Izmir, Türkiye. This corridor was chosen both for its importance to transportation and its documented exposure to coastal flood hazards. Following the general direction of the Aegean coastline, the corridor is a major artery between its clustered residential, commercial and recreational areas. Previous studies have identified the Karsiyaka coastline as one of the most vulnerable coastal zones in Izmir due to its low elevation, and exposure to sea level rise, storm surge, and extreme precipitation events (Özkan & Tarhan, 2016; Ercanlı &

Savaşır, 2022a; Ercanlı & Savaşır, 2022b; Climate Central, 2021). Because of its low-lying nature and proximity to the coast, the corridor is vulnerable to tidal flooding, storm surges, and heavy precipitation events. Moreover, the availability of continuous traffic monitoring data from multiple camera locations makes this corridor particularly well suited for studying the relationship between sea level variability and transportation performance. It therefore provides a suitable context for analyzing the effects of flood-induced hazards on transport performance in coastal urban areas. The study area also represents a general problem faced by many Mediterranean coastal cities, where critical mobility infrastructure is becoming increasingly exposed to climate-induced flood hazards and associated resilience challenges.

2.2. Data Sources and Preparation

The analyses draws on two primary datasets: long-term sea level observations and traffic volume data. Sourced from official monitoring networks, these datasets were integrated to analyze the relationship between sea level variability and transportation performance under flood-prone conditions. Tide data for Izmir Bay were obtained from the Turkish National Sea Level Monitoring System (TUDES), established by the General Command of Mapping. The time series extends from April 1999 to September 2024 and is the longest continuous sea level record ever obtained in the study region. Daily sea-level observations were combined to produce monthly averages in order to minimize the impact of short-term variations and to give an overview of possible long-term trends and seasonal variations. Although the time series principally represent relative sea level variability resulting from local tectonic and oceanographic processes, it is a solid empirical basis for analyzing coastal flood exposure in the coastal zone.

Traffic volume data were obtained from traffic-counting detectors and cameras managed by Izmir Transportation Center (IZUM). Data on traffic volumes were obtained for specific intervals between April and December 2023, covering periods with rainfall and other flood-prone. The data comprises hourly vehicle counts recorded by several camera locations along Yali Boulevard, enabling a high-frequency traffic flow analysis at the corridor-level under flood-prone conditions. For the purpose of interpretation, meteorological data (hourly line precipitation) was acquired from the Turkish State Meteorological Service (MGM) and synchronized in time to the sea level and traffic data. It should be noted that the sea level and traffic datasets have different temporal resolutions. Although traffic counts are available as hourly observations, sea level data were compiled as monthly averages for the purposes of this study. Therefore, accurate temporal synchronization on an hour-to-hour basis between the two datasets was not feasible. Hence, the monthly sea level values were used to represent wider environmental conditions during the corresponding traffic observation periods, rather than to represent sea level conditions at the exact time of individual traffic observations. This difference in the temporal resolution is a significant limitation of the analysis and has to be taken into account in the interpretation of the observed statistical associations.

2.3. Analytical Approach and Exploratory Scenarios

The analytical framework consists of three interrelated parts: (i) a time-series analysis to investigate long-term and seasonal fluctuations of sea level variability; (ii) regression and correlation studies to analyze empirical connections between sea level variability and traffic performance under flood-prone conditions; and (iii) an exploratory scenario analysis to illustrate potential future exposure under continued sea level rise.

The sea level data were analyzed using time-series analysis to evaluate trend persistence and seasonal behavior, and historical patterns were assessed through conventional stationarity tests to determine whether these patterns could be applied for exploratory scenario development. Regression and correlation analyses were subsequently conducted to investigate whether sea level variability is significantly correlated with traffic volume at specific locations and times of the day.

These analyses are not expected to be causal, but rather to capture signals in a complex urban traffic environment, driven by a variety of interplaying factors.

To consider potential future conditions, simplified scenarios for 2030 and 2050 were developed using observed local trends and regional sea level rise projections from the literature. These scenarios are presented as an exploratory sensitivity analysis rather than a predictive forecasting model. They are designed to investigate the effects on the spatial exposure of the low-lying parts of the coastal transportation corridor to plausible increments in sea level. Thus, the scenario analysis focuses on the spatial overlap between potential future sea level conditions and at-risk road segments, rather than extending the 2023 regression relationships to estimate future traffic volumes. These scenarios therefore demonstrate possible exposure pathways and should not be interpreted as forecasts of the magnitude or timing of future transportation impacts.

The overall methodological design is to allow for an empirical evaluation of transportation susceptibility to sea level variability under flood-prone conditions at the transportation corridor level. The method facilitates detection of regional exposure and potential system-level vulnerabilities in the coastal transportation system by using observational datasets and a relatively straightforward analytical procedure. The framework is designed to support early-stage assessments of risk and processes for considering options for adaptation, while acknowledging that more sophisticated modeling techniques may be needed for detailed engineering and long-term investment decisions.

3. Results

Empirical results demonstrate that both sea level variability and traffic responses under flood-prone conditions are characterized by specific spatial and temporal patterns. The results are organized to progress from the physical environment context (long-term sea level behavior) to the observed relationships with transportation performance and their spatial and temporal patterns. The final stage explores the robustness of these results to different statistical specifications and to simple foresight sensitivity cases.

3.1. Sea Level Variability and Long-Term Trends

Analysis of relative sea level data for Izmir Bay from 1999 to 2024 shows a slow increasing trend with obvious seasonal variations. The time series analysis demonstrated that the sea level variability remains within a relatively stable range during the period of time observation, which means that the observed relationships support the hypothesis that long-term behavior is stable and free of abrupt behaviors. As illustrated in Figure 2, higher sea level values in recent years reflect the long-term variation (the cumulative effect) in the coastal system.

Apart from the long-term patterns, sea levels in Izmir Bay has strong seasonal oscillations. Mean sea levels are higher during late winter and spring, whereas it is relatively lower in summer. These seasonal cycles, depicted in Figure 3, are important in the context of flood-risk because they take place during the period of maximal activity in precipitation and storms. Although these patterns do not provide definitive forecasts of future sea levels, they provide an important context for assessing the long-term exposure of coastal transportation infrastructure and guiding resilience-oriented planning strategies.

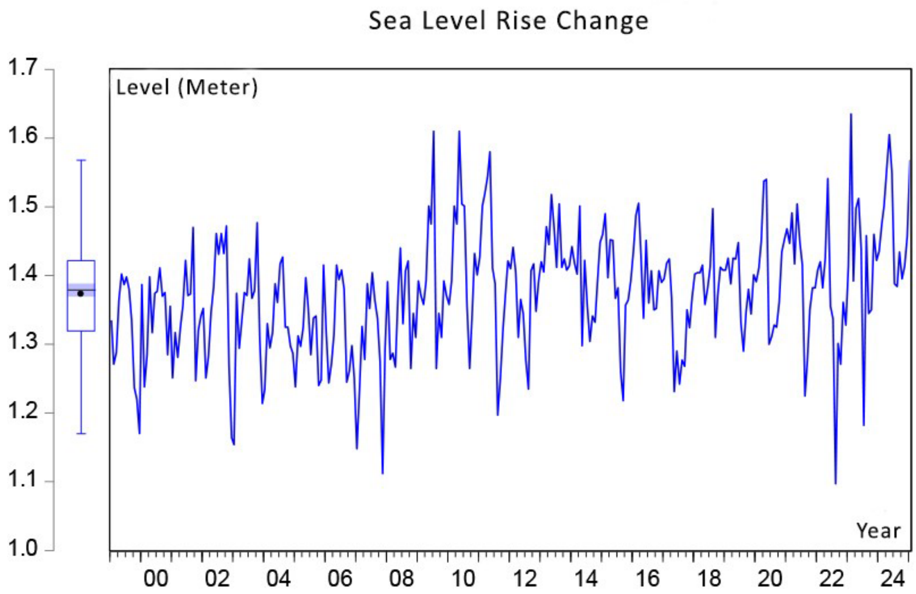

Figure 2 Long-term relative sea level variability in Izmir Bay (1999–2024)

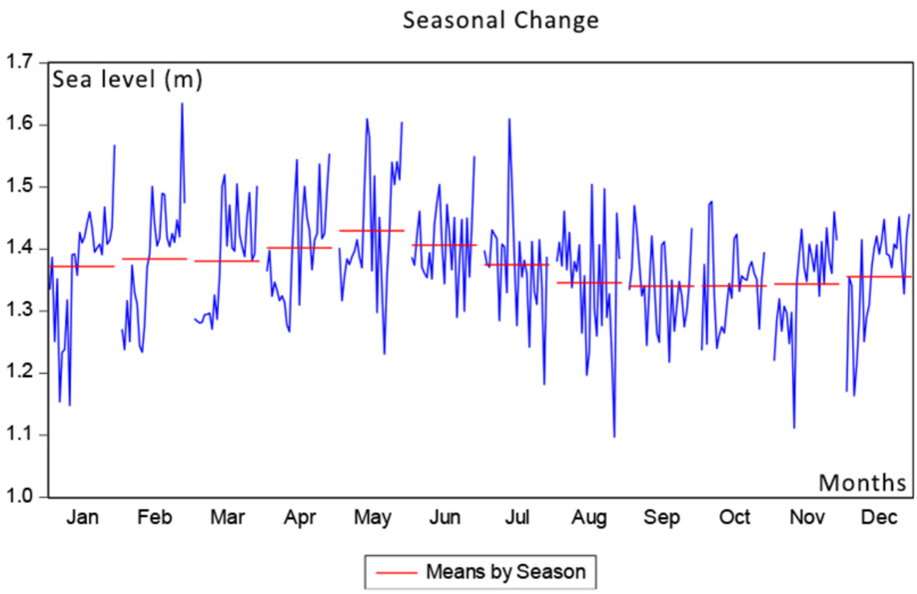

Figure 3 Seasonal variation in relative sea level values

3.2. Traffic Responses Under Flood-Prone Conditions

Traffic volume observations collected along Yali Boulevard during rainfall and flood-prone periods in 2023 indicate discernible changes in traffic volume during periods of elevated sea levels. At several camera locations, traffic volumes appear to decline during periods of elevated sea levels and heavy rainfall, notably along roadway segments adjacent to the coastline. The geographical layout of the study corridor and traffic cameras are depicted in Figure 4 to underlie the differences of traffic responses along the corridor.

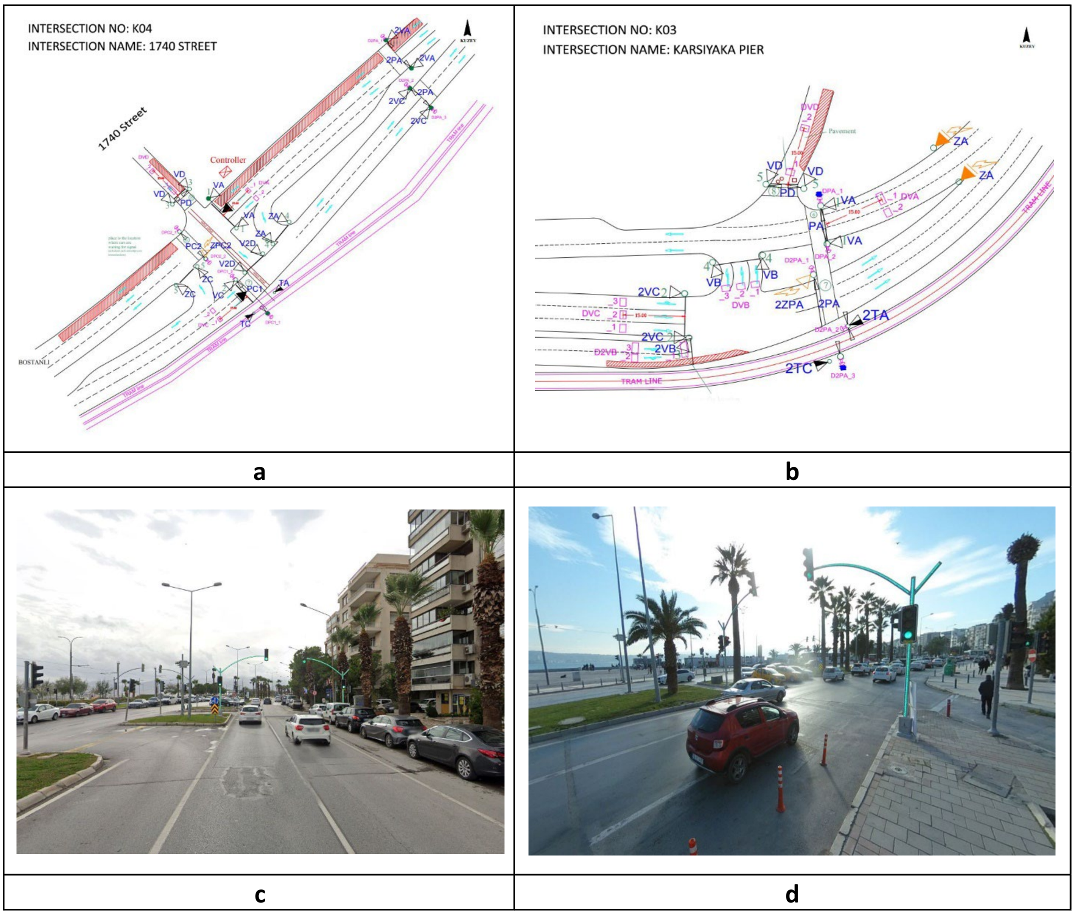

Figure 4 Study corridor and camera locations

Based on the spatial context described above, the analyses were conducted separately for each camera location to investigate empirical relationships between sea level variation and traffic volume along the study corridor. Findings suggest that these relationships are weak to moderate, with higher sea levels are typically associated with minor decreases in hourly vehicle counts at certain sites, while other site-specific responses are less definitive. Figure 5 provides a representative example of these relations, showing the general sign and order of magnitude of the observed relation without implying causality.

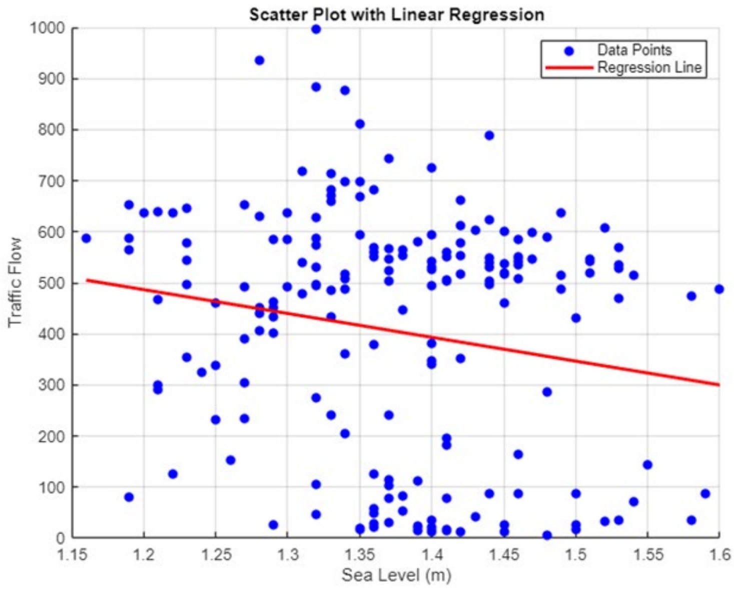

Figure 5 Representative regression result between sea level variability and traffic flow

The regression results should therefore be interpreted as descriptive associations, rather than causal effects. Multiple interacting processes, such as rain intensity, day-to-day travel demand variation, incidents on-route, and driver behavior, shape urban traffic dynamics. Hence, the representative regression result is presented to illustrate the direction and magnitude of the observed empirical relationship. Due to the complexity of urban traffic dynamics and the influence of multiple interacting factors, the figure should be interpreted as descriptive corroboration rather than evidence of a strong predictive or causal relationship between sea level variability and traffic flow.

In addition to spatial heterogeneity, traffic responses to high sea levels have clear temporal patterns. The correlation analysis suggests that the intensity and direction of the relationship between sea level variability and traffic flow are dependent on the time of day. As illustrated in Table 1, the negative correlations are stronger at specific morning and afternoon intervals, while there is a weak or no association during non-rush hours. These observations suggest that transportation vulnerability is not spatially uniform but varies according to corridor characteristics and temporal demand patterns. These temporal variations indicate that the observed relationships between sea level variability and traffic performance is not temporally uniform. During peak or transition periods, small reductions in effective road capacity can cause large drops in observed traffic volumes, while traffic during off-peak periods appears to be more resilient to changes associated with elevated sea levels. This time-varying susceptibility is especially of practical concern for traffic control and emergency response strategies in coastal cities.

Table 1 Correlation Between Monthly Average Sea Level Conditions and Traffic Volume

Hour				Traffic Volume
3:00	DVB_1	Sea Level (m)	Pearson Correlation	-0.871**
			Sig. (2-tailed)	0.002
4:00	DVB_1	Sea Level (m)	Pearson Correlation	-0.822**
			Sig. (2-tailed)	0.007
9:00	DVB_1	Sea Level (m)	Pearson Correlation	-0.804**
			Sig. (2-tailed)	0.009
10:00	DVB_1	Sea Level (m)	Pearson Correlation	-0.790*
			Sig. (2-tailed)	0.011
11:00	DVB_1	Sea Level (m)	Pearson Correlation	-0.692*
			Sig. (2-tailed)	0.039
16:00	DVB_1	Sea Level (m)	Pearson Correlation	-0.920**
			Sig. (2-tailed)	0.000
17:00	DVB_1	Sea Level (m)	Pearson Correlation	-0.672*
			Sig. (2-tailed)	0.047

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

3.3. Exploratory Future Sensitivity and Robustness of Findings

Using the observed patterns of long-term sea level variability and the empirically identified relationships between sea level variability and traffic flow, simplified future sensitivity scenarios were developed for the years 2030 and 2050 under a trend-continuation assumption. By applying the observed long-term sea level patterns and anticipated future increments, an exploratory sensitivity analysis was conducted for 2030 and 2050 under a trend-continuation scenario. Instead of predicting future traffic volumes, the analysis assesses how potential sea level rise scenarios could change the spatial exposure of low-lying sections of the coastal transportation corridor. As illustrated in Figure 6, low-lying parts of the Karsiyaka coastline appear particularly sensitive to incremental increases in sea level, indicating that future exposure may become spatially concentrated along specific coastal road segments. This spatial clustering identifies priority areas where adaptation measures could be especially relevant for sustaining transportation resilience.

These are examples of potential interactions between infrastructure and flood exposure for illustrative purposes and are not intended to provide estimates of magnitude or timing of impacts. Therefore, the spatial patterns in Figure 6 can serve a relative sensitivity to provide background with the empirical findings already presented above.

Figure 6 Illustrative flood exposure along the Karsiyaka coastline under a trend-continuation scenario (2030-2050)

To assess the sensitivity of the found relationships, further sensitivity analyses were conducted with other statistical methods and data partitions. The sign and relative size of the correlations between sea level variability and traffic flow were robust to using other correlation measures, excluding extreme values from the sample, and splitting samples between rainy and dry periods. In particular, the negative correlations between sea level variability and traffic-flow were stronger during rainy periods, which further supports the notion that the detected traffic drop-offs are related to flood-prone conditions, not just to inherent traffic variability.

The analyses indicate that sea level variability is associated with variations in transportation performance under flood-prone conditions and reveal localized patterns of vulnerability across space and time. Although the strength of the observed associations is moderate, their consistency across multiple analytical specifications suggests that flood-related disruptions represent a relevant consideration for resilience-oriented transportation planning and climate adaptation in coastal urban environments.

4. Discussion

The empirical evidence presented here demonstrates a relationship between sea level variability and transportation performance under flood-prone conditions within a coastal transportation corridor. The findings indicate that even moderate sea level variability under flood-prone conditions can be associated with changes in traffic flow and localized patterns of transportation vulnerability. These results add to an expanding literature on the vulnerability of urban mobility to climate-related hazards.

These findings are consistent with previous research on transportation disruption due to floods in other coastal cities. Research conducted on urban areas in San Francisco, Athens, and Portland shows that temporary flooding and modest sea level rise can bring about measurable deterioration in traffic flow, particularly on roads near the coast and in low-lying zones (Chang et al., 2010; Mitsakis et al., 2014; Kasmalkar et al., 2020). Contrary to numerous extant work that predominantly employs simulation methods, this paper showcases the insights from real world observations at the corridor level, with implications for resilience-based transport system planning. The analyses for Izmir reveal that the relationship between sea level variability and traffic performance varies both temporally and spatially. The findings also complement previous studies conducted in Izmir, which have primarily focused on flood hazard mapping (Özkan & Tarhan, 2016), coastal adaptation strategies (Ercanlı & Savaşır, 2022a), and ecosystem vulnerability under climate change (Arslan, 2023). These observations are consistent with prior planning-oriented evaluations of the Karsiyaka shore, highlighting the importance of integrated adaptation measures for managing such growing flood hazards in low-altitude coastal lands (Ercanlı & Savaşır, 2022b). While that study was centered on the analysis of adaptation options from planning level of detail, the current study draws on empirical data to examine the observed relationship between sea level variability and transportation performance under flood-prone conditions. However, in contrast to numerous model-based studies, where the vulnerability analysis is grounded on hydrodynamic modelling outcomes or on network-level performance measures, the present study demonstrates that similar patterns of vulnerability can be derived from sparse observational data. This indicates that patterns of transportation vulnerability associated with flood-prone conditions can be identified even through relatively simple corridor-scale empirical analyses. The present results are consistent with wider urban water management research arguing that the effects of flooding on urban infrastructure are not adequately mitigated by traditional drainage systems. Barbosa et al. (2012) argue that sustainable stormwater management is only attainable through integrated planning approaches that account for hydrological processes in the context of urban infrastructure and land use systems. The localized traffic disruptions identified in this study provide further empirical support for the argument that flood management and transportation planning should be coordinated as part of climate adaptation.

For planning purposes, this underscores the need for corridor-based analyses to detect spatially dependent transportation vulnerabilities. Results also show that relatively small increases in observed sea level can degrade traffic performance during critical periods, indicating that coastal transportation planning should explicitly consider flood-sensitivity of low-lying routes. Monitoring of traffic-flow through flood-prone corridors can also be incorporated into or form part of standard monitoring precaution and short-term traffic control. In this context, the integration of real-time traffic data with elementary hydrological forecasting could offer a feasible basis for the coordination of traffic management under future climate scenarios. This method can be especially applicable to cities lacking in climate–transport modeling capabilities.

From an urban resilience perspective, the observed patterns suggest that transportation corridors should be considered critical components of climate adaptation strategies in coastal cities. Corridor-scale vulnerability assessments can support the identification of priority areas for intervention, including drainage improvements, nature-based solutions, protective infrastructure, and adaptive mobility management measures. These findings align with water-sensitive planning perspectives that promote the integrated management of stormwater, the use of blue–green infrastructure and nature-based solutions to mitigate flood risks and contribute to building urban resilience (Barbosa et al., 2012; Özeren Alkan & Hepcan, 2023). The empirical observations emphasize the value of incorporating corridor-scale risk assessments into strategic transportation planning processes (e.g., sustainable urban mobility plans) where climate adaptation actions can be addressed as part of the consideration of long-term infrastructure investments. Integrating such assessments into urban planning processes may help reduce future disruption risks and strengthen the resilience of coastal transportation networks. In the case of Izmir, these results contribute also to the integration of corridor-scale flood vulnerability in the Izmir Sustainable Urban Transport Plan (SKUP), where climate adaptation options for coastal transport corridors may be more clearly reflected in long-term transport investment and management decisions. Integrating flood-vulnerable coastal corridors into long-term transportation investment plans, traffic management systems, early warning systems and adaptive routing would enhance the transportation system's resilience to future sea level rise and related flood hazards.

The observed patterns suggest a number of other avenues for further research. The analytic framework can be expanded to account for some public transport systems, active modes of travel, and an accessibility measure, to capture a broader picture of disruptions to mobility related to flooding. More spatially and temporally extended traffic data sets may further allow for the use of more sophisticated statistical and simulation-based techniques, e.g., network-level resilience assessments and climate model–informed scenarios. Finally, a better integration of socio-economic and equity issues in flood–transport analyses could improve understanding of how climate-related disruptions may disproportionately affect particular population groups, allowing for more inclusive and context-sensitive strategies for adaptation.

5. Conclusion

This study examined the relationship between sea level variability and transportation performance under flood-prone conditions along a coastal corridor Izmir, Türkiye, with particular focus on the implications for transportation resilience and climate adaptation planning. By combining long-term sea level observations with traffic data collected during flood-prone periods, the present study provides empirical evidence on the relationship between observed environmental conditions and transportation performance.

Collectively, these results demonstrate the susceptibility of coastal transportation corridors to sea level variations and highlight the usefulness of corridor-scale analyses in uncovering spatially concentrated exposure within city-scale transportation systems. Relatively small increases in observed sea levels are also associated with variations in traffic performance during specific time intervals, indicating that transport planning in coastal cities would benefit from a formal consideration of flood sensitivity of routes in the low-lying areas. Meaningful vulnerability analyses can be conducted even with limited observational capabilities, providing a feasible analysis pathway for cities with limited access to advanced climate–transport modeling tools. These findings underscore the importance of incorporating transportation vulnerability assessments into broader urban resilience and climate adaptation frameworks.

From a planning and operational perspective, the observed relationships support the systematic consideration of flood-prone transportation corridors within resilience-oriented infrastructure management and urban adaptation strategies. Integrating real-time traffic observations with hydrological information may improve situational awareness during flood events and assist decision-makers in prioritizing adaptive interventions aimed at maintaining mobility and accessibility under changing climate conditions.

In prospective studies, the scope of analysis could be expanded to include public transport systems, active mobility infrastructures, and broader accessibility measures to foster a better understanding of climate-induced disruptions of mobility. Incorporating the socio-economic aspects and equity concerns in the evaluation of flood–transport interactions is thus expected to provide an even more robust basis for urban planners and policy-makers to develop inclusive adaptation options. Ultimately, the study demonstrates the importance of corridor-scale empirical evaluations for supporting urban resilience and climate adaptation in at-risk coastal cities.

CRediT Authorship Contribution Statement

Çağla Ercanlı: Data collection from relevant institutions, Data classification, Conducting analyses, and Manuscript writing. Ahmet Karakurt: Conducting analyses and Preparing figures.

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.

Data Availability

Data will be made available on request.

Ethics Committee Approval

Ethics committee permission is not required.

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Resume

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