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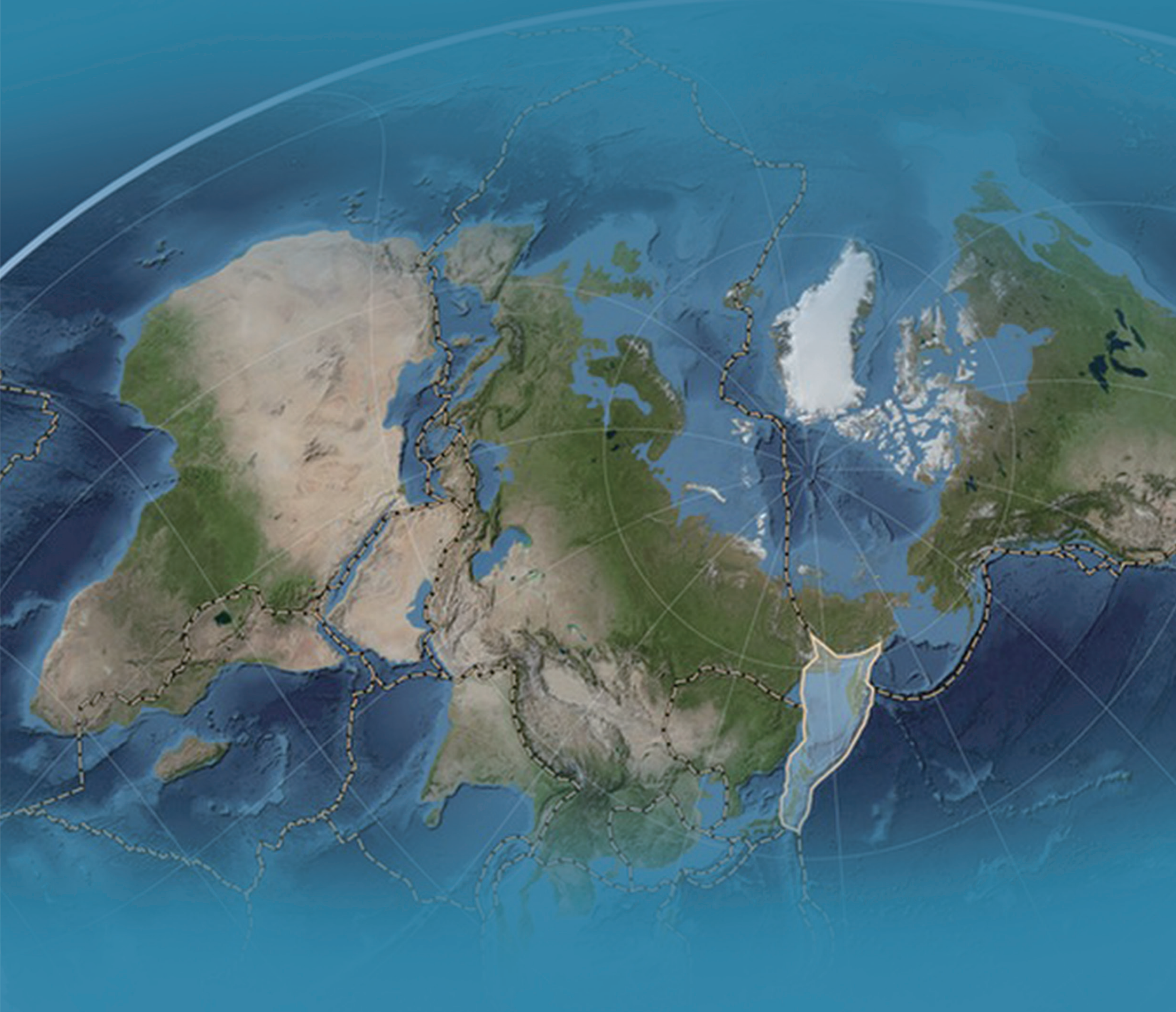

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ARTICLE

Locating Global System for Mobile Communication (GSM) Base Stations Using Geographic Information System (GIS)

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ABSTRACT

The global system for mobile communication (GSM) is planned to meet the needs of the whole subscribers. The number of subscribers increased as the population increased due to the acceptance of GSM services by the subscribers. Thus, there should be a way to monitor base stations that will meet the increasing demand of subscribers in any area as a population surge will lead to more subscriptions. This will allow GSM network operators to serve their subscribers better and ease network congestion. This work presents a review of mobile evolution from the first generation to the fifth generation. A review of global positioning system (GPS) technology and its applications to geographic information systems (GIS) was done. The coordinates of these base stations were taken using a GPS device. These base station coordinates were then exported to QGIS for the design of the map. Thereafter, the output map was then integrated into the website. The discussions on the results followed and some useful suggestions given will go a long way to help the operators of GSM in Nigeria and in general. If the propositions given are adhered to, it will go a long way to help the operators reduce congestion on their network and thereby increase the satisfaction of the subscribers.

Keywords: Global system for mobile communication (GSM); Global positioning system (GPS); Geographic information system (GIS); Subscriber; MAP; Images

1. Introduction

Global system for mobile communication (GSM) wants to achieve communication anywhere, at any time, thus the increase in popularity and acceptance. As a result, different advancements in GSM are now available for a variety of applications. A base station acts as a gateway for, a wireless network in

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wireless communications, signals from a single or multiple mobile cellphones of a region. The base station routes the call to a close by, mobile terminals telecommunications connection in a wireless mobile system. The global system for mobile communication (GSM) was created with the intention of enabling communication everywhere and at any time, which allows calls between and within networks [1].

A cellular network, sometimes called a mobile network, is a type of communication network with a wireless link between end nodes [2]. Each cell in the network has at least one fixed-position transceiver, and the network is divided into three or more cell sites. These base stations offer network coverage to the cells thus allowing the content types of voice, data, and others to be transmitted. To avoid interference so as to provide quality guaranteed cell service, it employs a separate range of frequencies from its neighbours.

Meanwhile, a geographic information system (GIS) creates, maintains, examines, and maps many types of data. A geographic information system (GIS) and spatial data are effective means for preserving and visualizing georeferenced data, that is related to a specific location. Due to this reason, GISs have become indispensable in a wide range of sectors, such as mapping applications for land management, planning for urban development, facility construction and maintenance, as well as, operations optimization [3]. Thus, establishes the foundation for mapping and analysis, which are used in science and almost every industry. As a result, Spatial analysis and visualization-based location-based services are centred on location intelligence applications and geographic information systems (GIS). This study will allow the integration of MTN base stations to the GIS map in other to let the subscribers easily locate their cell sites and observe the activities going around them.

The specific objective of this work is to create a geographic information system (GIS) map for locating MTN base stations using Akure North and South Local Government areas of Nigeria as a case study. This study would enable a location-based service that would aid in the location of MTN base stations in the Akure Metropolitan Area so as to determine areas that are covered, or not thereby, giving operations a known area to work on and explaining their cell sites to unsatisfied subscribers. This work includes a Google Earth interface that allows service providers to track population and land use growth. In order to improve the effectiveness of this work, a database was built and linked to the GIS, thus aiding the operators in stormy capturing the GPS positions of the base stations. This will help the operators know when to expand the network's coverage area.

Section two of this work discusses the global system for mobile telecommunication (GSM), the geographic information system (GIS) and the global positioning system (GPS). Section three discusses the related literature; while a detailed architecture of the work is presented in section four. Sections five and six showed the implementation of the web-based used for the GIS map and the conclusion of the research.

2. Global system for mobile communication

Global system for mobile communications (GSM) is a mobile communication that is mobile stations transmitted using radio waves for calls wirelessly over a large area, to fixed landlines, or via the internet [4]. The cell phone is recognized as a mobile system with hardware, software, and a SIM card that actually allows the mobile phone number in this networked system. The cellular phone has undergone various developmental stages and advanced since it was first introduced as a mobile communication concept using two-way radio technology. Cellular phones were incredibly heavy, much like heavy when it was first introduced and this characterizes the first generation of GSM. Mobile communication has developed from a voice-only called first generation to one that can support other services, such as short messaging services and internet access.

The communications in the first generation (1G) were voice-only on mobile telephony and used analogue technology for its operation. In the second generation (2G), analogue technology was replaced by digital communication, which marginally enhanced wireless communication technologies. The basic demand for voice was met in the first generation, while the second generation brought high capacity and a wide coverage area. Data communication systems, that is, accessibility to the Internet on the phone, were the primary emphasis of the third-generation (3G) technology. The fourth generation (4G) gave access to a variety of communication technologies. 4G provides an answer to the quest for a combination of both voice and data on Internet Protocol (IP). 4G is IP-based communication that gives a true mobile broadband. The fifth generation (5G) technology has incredible data possibilities within the present mobile operating system, including the ability to connect unlimited call volumes and infinite data broadcasts [5]. The fifth generation of communication systems has low latency and fast speed when compared to the former generation [6].

2.1 Global positioning system (GPS)

The global positioning system is a satellite-based navigation system made up of a network of 24 satellites in six different orbital trajectories that are orbiting at a distance of 11,000 nautical miles in space [7]. The space segment, the control segment, and the user segment make up the three main segments of the global positioning system. The constellation of satellites that are currently in orbit, including working, backup, and inoperable units, makes up the space segment.

The users who have bought any of the several commercially available receivers are the only ones who make up the user segment. The control segment, the upkeep and proper operation of the satellites fall under the purview of (CS). Station keeping, or keeping satellites in their intended orbits, as well as keeping an eye on the health of their individual subsystems are included. The constellation of satellites in the space section is where users take their range readings. The user segment is made up of the user receiving equipment. A GPS receiver is a piece of hardware that receives L-band signals from satellites and processes them to calculate the user's position, velocity, and time (PVT).

The United States government has extended the capabilities of GPS to provide more benefits to the general public as a result of the widespread applications of GPS technology over the past decade. Three new signals have been added to the GPS: (i) a new L5 frequency in the ARNS band with a signal structure intended to improve aviation applications; (ii) Coarse Acquisition (C/A) code to L2C carrier (L2 civil signal); and (iii) a new military (M) code on L1 and L2 frequency for the DoD. Even in challenging circumstances, where C/A code tracking on L1 would be impossible, the enhanced GPS has the capacity to trace the signal.

2.2 Geographic information system (GIS)

A geographic information system (GIS) is a computer program that gathers, stores, validates, integrates, manipulates, analyzes, and presents information about locations on the surface of the Earth [8]. A geographical information system is used to manage many types of maps. These could be viewed as a number of distinct layers handling various types of maps. These may be seen as a number of levels, each layer containing information on a specific class of features. Each feature has a connection to both a record in an attribute database and a place on the map's graphical representation. Some of the software used for GIS are ArcGIS, QGIS, ArcMap among others. The software might vary quite a bit from one another for the reason of how each piece of software represents and manipulates geographic data, as well as the relational importance that each action is known [8].

2.3 GPS and GIS integration

Obtaining, storing, manipulating, analyzing, and displaying geographically referenced data are all possible with the use of a geographic information system (GIS) tool [1]. Data that are recognized by their geographic location are referred to as spatially referenced data like streets, light posts, and fire hydrants through geographic or spatial data can be acquired GPS, satellite imagery, and already-made maps are just a few examples of the sources. A GIS stores the information as a set of layers in the GIS database once it has been gathered. The information can then be analyzed using the GIS to help in decision-making [1].

The GIS field data is correctly and efficiently collected using GPS. GPS collects this information digitally, either in real-time or non-real-time. There are now several GPS/GIS systems in the market that offer centimeter-to-meter precision [9]. For each feature, most of these systems allow users to input user-defined attributes. There is also a built-in navigation feature for moving field assets. Some manufacturers of GPS receivers employ pen computer-based systems that enable data to be modified and displayed as it is gathered. Integrated GPS/GIS systems have applications in many fields, such as fleet management, forestry, agriculture, and utilities management [9].

3. Review of related literature

Kuboye et al. [1] presented the GSM base station monitoring using a geographic information system. They provided a location-based service that will help in the location of MTN base stations in the area so as to know which areas are still lacking. They designed a web-based geographic information system for locating MTN base stations in an area. Zu et al. [10] presented the development of a monitoring and management system for non-heritage tourist attractions based on mobile GIS and multisensory technology. They discussed the need to create a system for monitoring and managing tourist attractions that is rational and based on science. On the basis of mobile GIS and multisensory technologies, they explicitly discussed the creation of a monitoring and management system for scenic areas of intangible cultural assets.

Kim et al. [11] studied malaria vulnerability map mobile system development using GIS-based decision-making techniques. Making improvements to the usage of GIS data and multiplatform compatibility would help overcome the limitations of the earlier malaria risk analysis tools. Using GIS data, they created a mobile web-based malaria vulnerability map system. Baral [12] presented applications of GIS in community-based forest management in Australia (and Nepal). The paper explored the potential and constraints for the application of GIS technology in community-based forest management in Australia and Nepal. In the meantime, he studied GIS applications in forestry and community-based forestry across the globe. The paper found out what the stakeholders think about the need for GIS in CBFM in the Wombat State Forest (WSF), then prepared and showed a variety of GIS-related practical applications requested by community organizations in the WSF, and assessed reactions and issues. It also displays the GIS applications' advantages and disadvantages for community forestry as well as compares and contrasts Australian GIS application findings with Nepal's community forestry (CF).

Zhang [13] presented a classroom teaching evaluation and instruction system based on a GIS mobile terminal. The author desires to raise the standard of instruction in the elementary, secondary, and tertiary institutions as well as the universities throughout the nation. The work recognizes the importance of proper teaching evaluation and guidance given the current levels of education and instruction. Using GIS mobile terminals, its teaching assessment system was created that may enhance teacher-student contact and teaching diagnosis and aid further improve teaching. Chen et al. [14] provided a GIS-based method for predicting the field strength of mobile communication networks. They intend to assist network operators in making the greatest investments possible to increase the network's capacity and quality. The goal is to use a GIS to analyze the field strength coverage, visualize the projected signal strength, and predict the coverage of the city's cellular network. Maciej et al. [15] presented a research work on mobile GIS applications for environmental field surveys. They contributed to raising awareness of such mobile device options. Such software could improve data quality, accuracy, and workflow, which can aid in achieving study outcomes. They showed the usefulness and accessibility of mobile apps as a tool for doing field research.

Hariani and Astor [16] presented a research topic depending on distance, duration, congestion, and land usage, in determining the fastest route for fire engines in Cirebon City. They want to help identify several alternative routes that can be determined for the fire station trucks to the location of the fire and calculate the travel time on each alternative routine in Cirebon City. Then determined the best alternative routes for the fire trucks from the fire station to the fire in Cirebon City. Das et al. [17] presented a research project on the road network analysis of Guwahati city using GIS. In order to prevent problems like traffic congestion delays, increased vehicle operating costs, and road accidents in Guwahati City, they emphasized the necessity for and limitations on traffic movement. They analyzed a digitalized road network of the concerned city and found the shortest route between two places. Yang et al. [18] presented a research evaluation of hotel locations being done using a combination of web GIS and machine learning techniques. They were aware of the requirements for an accurate, unbiased, and objective evaluation of hotel locations. By developing an automated web GIS tool, they offer a novel method for assessing possible hotel property sites.

Ahmed et al. [19] engaged in GIS-Network Analysis for the Greater Cairo Area's Road Networks. They discovered that it is challenging to locate a specified destination, particularly using forest fire experts, opinions and GIS remote sensory in emergency circumstances in Cairo. Amiri et al. [20] worked in order to effectively suppress and control fires, prompt fire detection and early notification to fire stations are essential. The goal of the project was to create a method using a geographical information system (GIS) to decide where to place fire lookout towers based on the recommendations of forest fire specialists. Aouadj et al. [21] presented a contribution of GIS and remote sensing for the risk mapping of soil water erosion at Saida province (Western Algeria) in order to establish a strategy for employing remote sensing, the digital terrain model (DTM), and geographic information systems to map regions at risk of water erosion, they are worked on the contribution of GIS and remote sensing for risk mapping of soil water erosion at Saida Province (West of Algeria).

4. Model architecture

The architecture to build a geographic information system (GIS) based system for locating GSM base stations is seen in **Figure 1**. It has several phases namely the data acquisition, data preparation, data conversion, digitalization, and website interface (result).

4.1 Data collection

Data collection for this work was done primarily by using GPS. It was collected through the sighting of base stations of MTN Nigeria in the North and South local governments of Akure, Ondo state, with the use of a global positioning system (GPS). Akure is the state capital city of Ondo state in the Southwest geopolitical zone of Nigeria. MTN Nigeria is

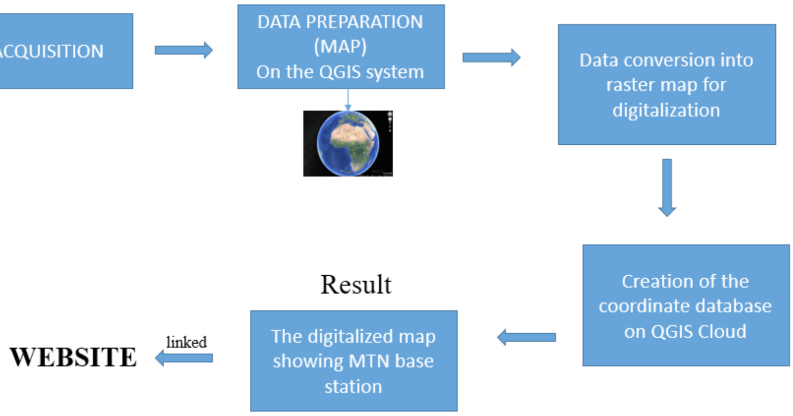

Figure 1. System architecture.

one of the GSM operators in Nigeria that has wide coverage over nearly all the geo-political zones in Nigeria. The data to the base station were recorded showing the location of each base station with their longitude and latitude using the global positioning system (GPS) device.

4.2 Data preparation

In the data preparation stage, the data which includes the site name of each base station location with the longitude and latitude were saved and converted to a CSV. file on an Excel spreadsheet. The file was saved and uploaded to Google Earth. It is a virtual globe, map, and geographic information system that depicts the earth by superimposing pictures from satellite imagery, aerial photographs, and a 3D GIS globe. As shown in **Figure 2**, users can view things like cities and homes by gazing perpendicularly down at the screen or at an oblique angle thanks to Google Earth's presentation of satellite photos of different resolutions of the Earth's surface.

4.3 Georeferencing images

Georeferencing refers to defining something's presence in space [22]. That is, identifying its position using coordinate systems or map projections. It is employed to describe the relationship between coordinate systems and raster or vector images. Four specific control points on the image with a red, orange, purple and yellow dot can be seen. Each of the site locations is in yellow arrow point as shown in **Figure 4**. The coordinates (longitude and latitude) of the MTN base stations were recorded at each location. Then, QGIS 3.10 is used for georeferencing. The coordinates are then inputted so that the images can be georeferenced. Geospatial data are viewed, edited, printed, and analyzed using QGIS, QGIS is a cross-platform desktop geographic information system (GIS) tool that is free and open-source. Users can generate, edit, and export graphical maps as well as analyse and alter geographical data using geographic information system (GIS) software like QGIS. QGIS supports raster, vector, and mesh layers. Vector data characteristics come in point, line,

Figure 2. The site locations are shown on the Google Earth.

and polygonal varieties. The application supports a range of raster image formats, the manipulation of geospatial data to acquire high-quality insight, and the ability to geo-reference images [23]. The location of the cell sites is indicated as shown using the location of the base station on the georeferencing points in **Figure 3**. It is clearly seen that some occupied areas have not been adequately covered by GSM operators. The places are shown as very distant base stations from one another. Some areas do not yet have base stations therefore to cell site covered the place.

In such places, the subscribers will be experiencing an ephaptic signal connection. Thus, the importance of this type of work is to let the operators know where to erect their base station so as to subscribers which will lead to optimum gain for their operators.

4.4 Creating a digitized map

Upon the capturing and georeferencing of the images, with the aid of an analysis tool in QGIS 3.10 the images will be connected. Images are preserved during the capture process in a manner that causes them to overlap. This overlap facilitates the seamless integration of all accessible photos into a single, complete image. Thereafter the border between Akure North and South local government was cut out and then converted to shape files as shown in **Figure 4**.

The coordinates of the base stations were collected, saved and inputted on an Excel spreadsheet. They were saved as CSV files and then they were exported to QGIS so they can be inputted in the attribute table. The event theme was then added using these coordinates. When this is done and the coordinates are activated, they immediately take their location on the map as shown in **Figure 5**.

As observed in **Figure 5**, the location of the already existing base station is clearly seen and the unoccupied area is also shown. As a result, the operators can now explore the yet to occupied areas for the possible erection of base stations so as to let

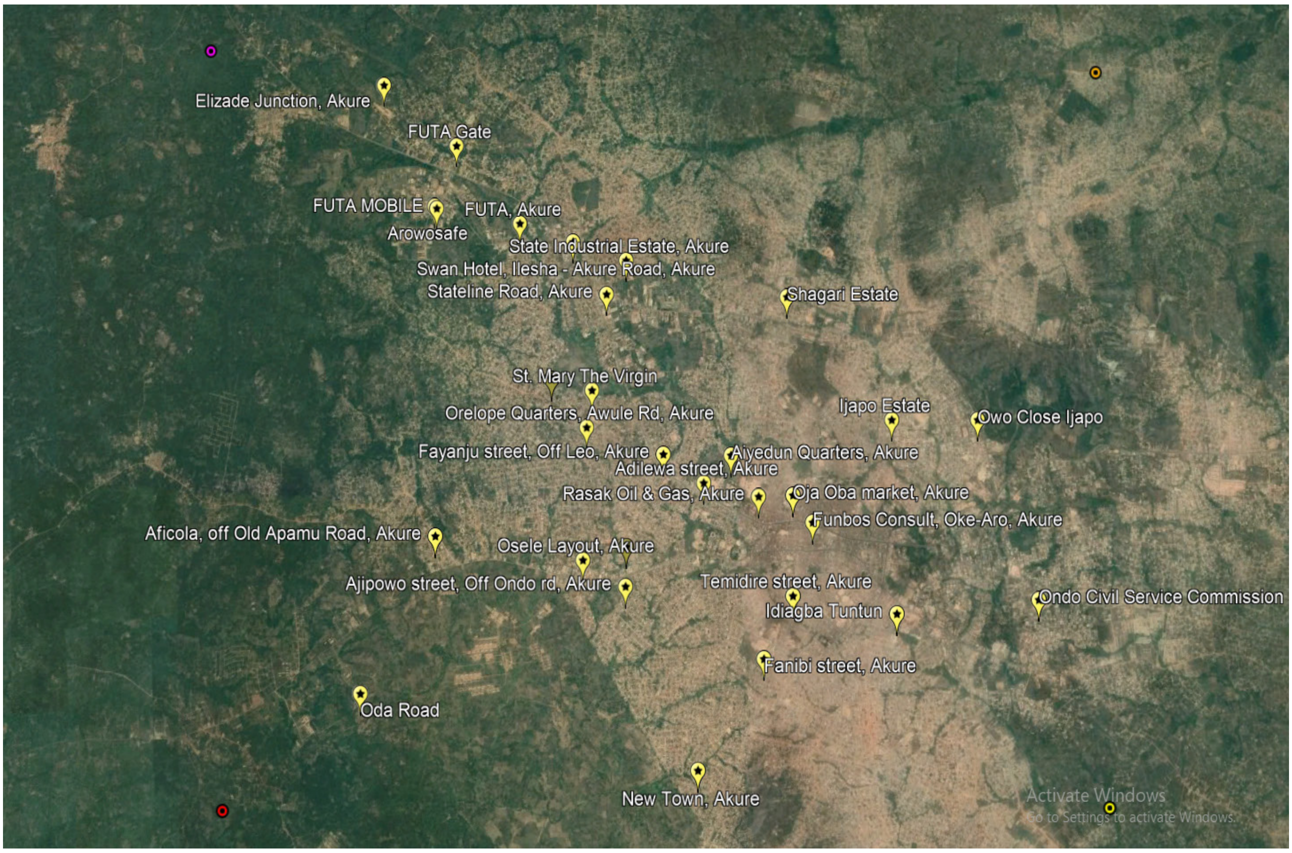

Figure 3. Geo-reference points and the site locations are shown on QGIS display.

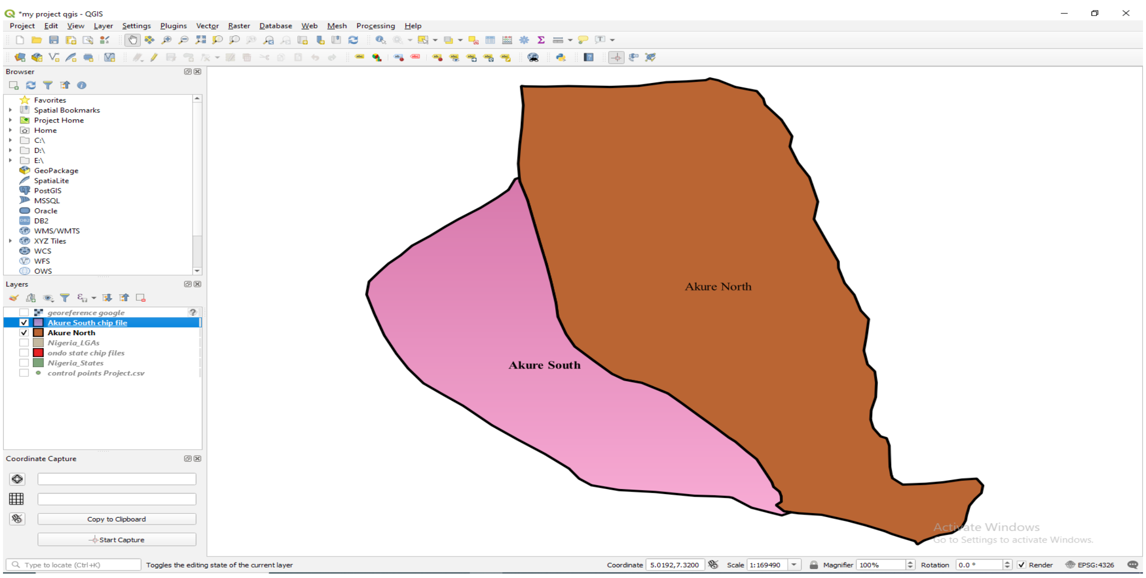

Figure 4. A digitalized map of Akure South & Akure North.

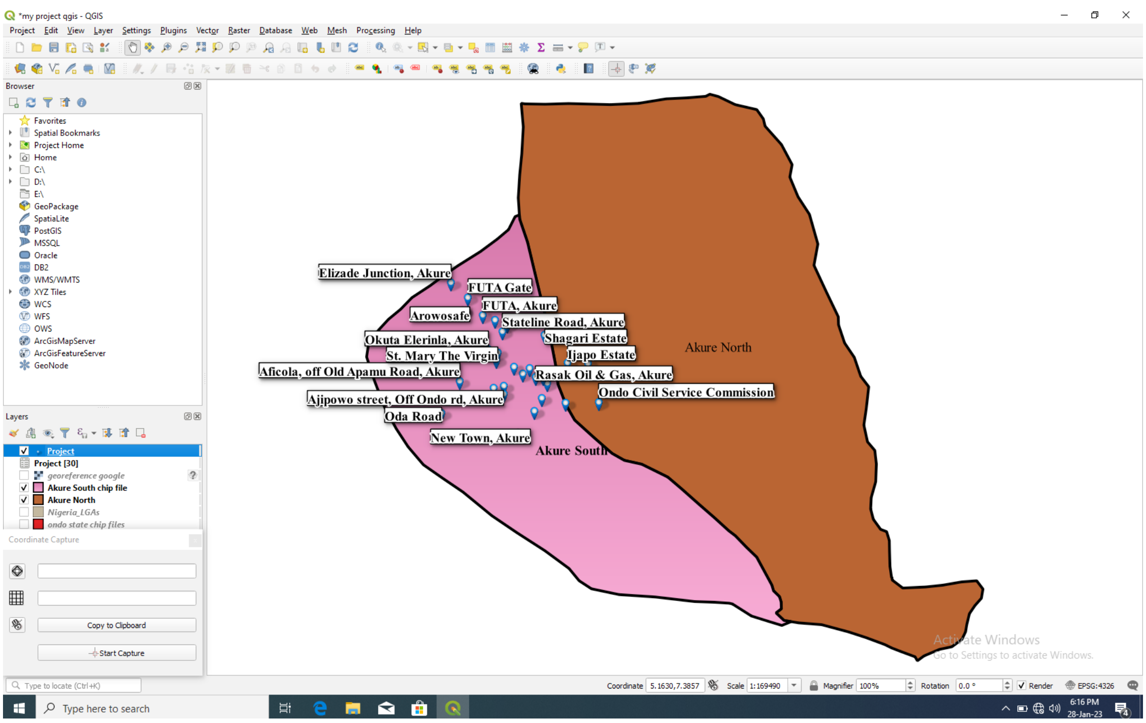

Figure 5. A digitalized map of Akure showing the base stations.

their signals cover the affected areas, thereby giving a level of satisfaction to subscribers who might have been experiencing epileptic communication signals of their GSM mobile stations. Thus, it will directly attract more subscribers and lead to increasing revenue for operators and satisfaction of the subscribers.

5. Web implementation

The digitalized map of Akure North and South local government that depicts the locations of the base stations was then integrated into a website so that it could be accessed online. The GIS Map page shows the digital maps of Akure North and South local governments indicating where the MTN base stations are located. On clicking the page, it displays the base station location; by clicking on a location it displays the site name, latitude and longitude respectively as shown in **Figure 6**.

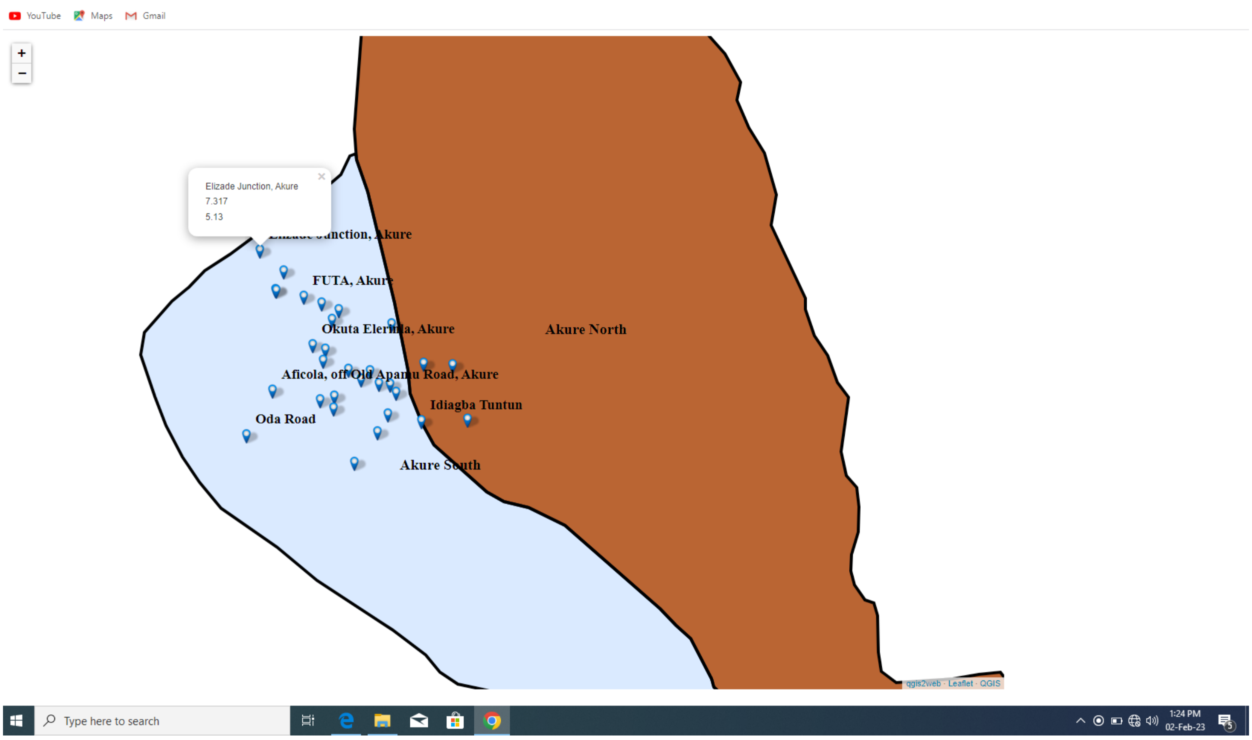

Figure 6. Web-based GIS map showing the base stations.

6. Conclusions

The work shows where the base station is needed to bring optimum satisfaction to the subscribers which will directly impact positively on the optimum profits returns of the operators. If these identified areas do not have enough or adequate base stations, the subscribers experience low or no signals. Thus, operators will be assisted in improving their services if implementation of this work is done. Operators should offer a map that shows the number and locations of their base stations in order to monitor the population growth so as to know when to install new base stations to better serve their users and prevent signal failure and other issues. This work has demonstrated the ability of GSM operators to locate and keep an eye on their base stations.

Author Contributions

Bamidele Moses Kuboye was the one who generated the concept note, supervised the design and implementation and the preparation of the publication.

Victor Gbenga Abiodun was involved in the design, and implementation of the work.

Conflict of Interest

There is no conflict of interest.

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ARTICLE

Regional Tourism Resilience under Crisis Impacts: The Cases of Yangtze River Delta and Pearl River Delta

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ABSTRACT

Since the beginning of the 21st century, various crisis events have occurred frequently, inflicting substantial impacts on the tourism sector, which has garnered considerable scholarly and policy attention. Nevertheless, limited research has systematically explored tourism resilience at the urban scale, and there is a paucity of studies comparing regional differences in tourism resilience under distinct crisis scenarios and their underlying causes. Thus, this study focuses on the Yangtze River Delta and the Pearl River Delta, employing Martin's regional economic resilience measurement method. It assesses the tourism resilience of the two regions under the impact of the 2008 financial crisis and the COVID-19 pandemic, subsequently visualizing the data results using ArcGIS software. The study also endeavors to unveil potential causes for disparities in urban tourism resilience. The main conclusions are as follows: Firstly, regions with higher economic development exhibit relatively weaker tourism resilience during economic crises, yet demonstrate comparatively stronger resilience during public crises. Secondly, distinct differentiations exist both between and within the Yangtze River Delta and the Pearl River Delta, primarily stemming from variations such as geographical positioning, tourism resource endowments, and industrial and economic structures, both regionally and within individual cities. Thirdly, the determination of regional tourism resilience is intricate and cannot be restricted to a single dimension; multidimensional indicators better encapsulate the essence of regional tourism resilience.

Keywords: Tourism resilience; Financial crisis; COVID-19; Impact of crisis events; Spatial differences

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1. Introduction

In recent years, the urban tourism sector in China has undergone substantial growth owing to the expanding demand for tourism in conjunction with the advancement of socio-economic progress. Nevertheless, the tourism industry operates as an intricately interlinked sector, characterized by notable inter-industry associations and a pronounced reliance on interconnected factors. This complex structure renders it highly susceptible to the influence of extraneous influences and unanticipated crises. As a consequence, the tourism sector often exhibits heightened vulnerability, rendering it susceptible to external shocks, such as the SARS epidemic in 2003, the global financial crisis in 2008, and the worldwide COVID-19 pandemic in 2019. The resultant economic repercussions stemming from these crises underscored the fragility inherent in the tourism industry. This fragility, in turn, had emerged as a pivotal determinant influencing the sustainable and qualitative progression of the sector. Therefore, addressing these challenges warrants profound consideration and engagement from all strata of society.

There has been an increased scholarly interest in the investigations of tourism resilience. Most of the extant research on tourism resilience predominantly has focused on the destination level, often confined to assessing the suitability for ongoing tourism activities. However, there remains a significant lacuna in the resilience of the tourism industry at the urban scale, further compounded by the absence of comparative analyses concerning regional variations. Consequently, in the context of specific external perturbations, what distinctions and variations might emerge in tourism resilience across diverse regional economic entities? How does the resilience and recuperation trajectory of the tourism sector diverge from that of other industries in the face of uncertain extrinsic economic and public health shocks? Moreover, what discernible features characterize the tourism resilience among urban entities within regional economies? Is there a tendency towards convergence in trends between urban and regional economic entities? As industries undergo transformative upgrades and the imperative of sustainable tourism development gains prominence, addressing these questions assumes paramount importance.

Therefore, this study selects the Yangtze River Delta and the Pearl River Delta as research subjects, scrutinizing their respective tourism resilience and disparities in the face of financial crises and the impacts of the COVID-19 pandemic. The rationale behind this choice stems from the contemporaneous phenomenon where China's regional spatial arrangement is undergoing transformative cycles characterized by the recalibration of resources and the dynamic interplay between nascent and established forces, thereby synergistically driving fluctuations in urban ascendancy and decline. Consequently, the exploration into the resilience of the tourism sector within China's preeminent urban agglomerations holds the inherent capacity to engender pioneering insights into adept responses to multifaceted crises and challenges. Moreover, the Yangtze River Delta and the Pearl River Delta are two pivotal regional economic entities and urban clusters in China, with their tourism industries holding significant nationwide prominence, rendering them representative samples.

This paper employs a multifaceted approach that considers various dimensions including crisis types and industrial disparities, with the aim of bridging the existing research gap in comparative analyses of tourism resilience among regional economic entities and unveiling differentials and underlying rationales inherent to the tourism development within different urban clusters. By doing so, this research contributes to the formulation of strategic measures and recommendations conducive to fostering sustainable advancement within the tourism industry.

2. Literature review

2.1 Resilience in tourism

The term "resilience" originated from the Latin word "resilience" and initially found application within physics, engineering, and allied disciplines. It denoted the capacity of a material to restore its initial configuration and functionality after deformation induced by an external force. Subsequently, the ecological domain incorporated the terminology "resilience", introduced by Holling [1] to characterize a system's adeptness in adapting to and recuperating from disturbances. Further advancing this discourse, Price [2] discerned that the ecosystem's resilience dynamically evolves alongside the ecosystem's progression, manifesting varying attributes across distinct developmental stages. Consequently, grounded in the conceptual framework of panarchy, the perspective of evolutionary resilience emerged, connoting the process through which systems exhibit adaptive resistance to shocks over time. The term "evolutionary resilience" signified this perspective. Remarkably illustrative of the system's capacity to withstand perturbations, this notion transcended the domain of ecology and extends its utility to diverse fields such as psychology, economics, and urban planning [3,4].

Prior to the conceptualization of tourism resilience, Butler [5] introduced the pioneering "Tourism Life Cycle" (TALC) model, which posited that the developmental trajectory of a tourism destination generally encompasses six sequential phases—exploration, involvement, development, consolidation, stagnation, and decline (or rejuvenation). This evolving progression may engender deterioration in environmental integrity and a diminished visitor experience. Within this framework, recovery and resurgence emerge as pivotal junctures that account for both environmental and economic dynamics. Resilience, in turn, elucidates the cyclicality and intricate nature of the tourism life cycle [6]. Foreign scholars exhibited varied interpretations of tourism resilience, albeit converging on its core focus, namely the resilience of tourism destinations or the tourism sector in the aftermath of disruptive events [7].

2.2 The origin and development of tourism resilience

Since the mid-1990s, foreign scholars have emphasized the vulnerability of tourism and gradually introduced resilience into the tourism field. Sharpley [8] noted that the vulnerability of tourism to socioeconomic and environmental shocks (fast events) and stressors (slow events) has been widely recognized. Faulkner [9] believed that due to the complexity of the tourism system and its inherent fragility, external threats such as natural disasters or social, political and economic crises tend to have a great impact on tourism activities. Based on clarifying the vulnerability of tourism, scholars have further emphasized the importance of tourism resilience for tourism development. Tyrrell and Johnston [10] saw tourism resilience as part of a broader tourism sustainability issue. Espiner et al. [11] also linked tourism resilience to sustainable development, arguing that sustainable destinations are those with high resilience and stating that resilience can be seen as a "buffer" or "lubricant" to achieve sustainable development mechanisms, emphasizing the importance of resilience in sustainable development. Watson et al. [12] noted that in regions where major employment and income come from the tourism industry, the resilience of the tourism industry represents the economic resilience of the region. These topics are related to the concept of resilience that has been discussed in the tourism literature, which points to the resilience of the tourism industry itself. While attention has been paid to the importance of tourism resilience for sustainable regional development, the literature has neglected tourism resilience in areas where tourism development is weak.

Existing tourism-focused resilience research typically conceptualizes resilience theoretically [13] or assesses resilience based on the qualitative experiences and perceptions of individual or collective stakeholders [14]. There were also studies that used quantitative data to measure tourism resilience, but most of them focused more on the supply side of tourism based on the economic characteristics of resilience, which may overlook the fact that tourism resilience itself is one of the influencing factors of economic resilience [15,16]. In a typical quantitative data study, Song et al. [17] employed deductive theoretical models, or computable general equilibrium models, as the primary method for estimating the "macroeconomic" impacts of tourism and hospitality. Models of this type were based on Keynesian and Walrasian models and described the circular flow of the economy. Tourism is an export sector, and tourists bring revenue to the tourism economy, which is circulated through the economy through a multiplier effect. It is instructive that the measurement of tourism resilience may have to take into account more dimensions, encompassing the production side and the consumption side.

In addition, the role of tourism resilience is currently being explored by a number of scholars. Morakabati [18] confirmed that the recovery of tourism is more resilient than that of the overall economy. Sharma et al. [19] concluded that tourism has rebounded rapidly after disasters and epidemics such as Ebola, Middle East Respiratory Syndrome (MERS) and Severe Acute Respiratory Syndrome (SARS). Wang et al. [20] argued that if tourism becomes a pillar industry, the vulnerability of tourism means economic vulnerability. Watson and Deller [12] discovered that under the influence of the COVID-19 pandemic and after vaccines and medicines are popularized, tourism regions that rely more on local tourists have a greater contribution to economic resilience. Gaki and Koufodontis [21] examined the economic resilience of the Greek tourism industry from a quantitative perspective under the impact of the financial crisis and the COVID-19 pandemic, focusing on tourism employment data. By calculating the resistance index and recovery index, the special economic resilience of Greece was reflected in the fact that the mainland region, including the large cities, was not necessarily the most resilient region for the tourism economy; on the contrary, the regional resilience that relied on tourism development seemed to be stronger than other regions. Synthesizing the literature above, it can be seen that while tourism resilience has a role to play in helping regional economies recover, this role may hold under certain conditions, such as a certain type of crisis, or a region that has reached a certain level of economic development. There is a certain ambiguity, and the specific role of tourism resilience may be further explored by comparing different types of crises and different regions.

Therefore, with the help of multi-dimensional quantitative data, this study hopes to discover the performance of tourism resilience in the YRD and PRD, taking the financial crisis of 2008 and COVID-19 as examples, with a view to defining the specific conditions under which tourism resilience plays a specific role, and providing new perspectives for measuring tourism resilience.

3. Methodology

3.1 Regional general situation

The Yangtze River Delta and the Pearl River Delta constitute two prominent urban agglomerations in China, characterized by their elevated levels of economic development and flourishing tourism industries (**Figures 1-3**). As shown in **Figure 1**, situated in the southern region of China, the Pearl River Delta is adjacent to Hong Kong and Macau, boasting advanced manufacturing and modern service bases with global influence. This region encompasses a total of nine cities: Shenzhen, Guangzhou, Zhuhai, Foshan, Dongguan, Zhongshan, Zhaoqing, Jiangmen, and Huizhou. Conversely, the Yangtze River Delta is positioned along the eastern coastal area of China and has evolved into the country's foremost financial industry cluster and technological innovation hub (**Figure 2**). It comprises 27 cities, including Shanghai, and cities from Jiangsu Province (Nanjing, Wuxi, Changzhou, Suzhou, Nantong, Yangzhou, Zhenjiang, Yancheng, and Taizhou), Zhejiang Province (Hangzhou, Ningbo, Wenzhou, Huzhou, Jiaxing, Shaoxing, Jinhua, Zhoushan, and Taizhou), as well as Anhui Province (Hefei, Wuhu, Ma'anshan, Tongling, Anqing, Chuzhou, Chizhou, and Xuancheng).

The distinct geographical positioning and economic development models of these two regions, alongside the intricate and diverse economic structures of cities within each region, underline their inherent differences (**Figure 3**). These variations contribute to the potential divergence in their responses to shocks, rendering them highly comparable entities when considering their respective contexts. Furthermore, the population density and economic density of these two regions are much higher than the national average level, which means that the issue of the region's economic and tourism resilience is particularly important in the current unstable situation.

3.2 Methods

In terms of methodology, this study draws on Martin's method of measuring regional economic resilience [22] , which has gained some consensus. This method not only examines the relative resilience of each study region or city in response to shocks when they occur but also measures the divergence in the economic performance of each study region or city when shocks do not occur at ordinary times. The calculation formula is derived as follows.

$$\Delta Y_i = Y_i^t - Y_i^{t-k} \quad (1)$$

$$\Delta \mathbf{E} = \left(\frac{\mathbf{Y}_r^t - \mathbf{Y}_r^{t-k}}{\mathbf{Y}_r^{t-k}}\right) \mathbf{Y}_i^{t-k} \quad (2)$$

Equation (1): ΔY_i is the actual economic performance of the research object *i* (city or economic region), Y_i^t, Y_i^{t-k} are the quantity index of the research object i at the period of *t*, *t* – *k*;

Equation (2): $\Delta \mathbf{E}$ based on the overall economic performance of the region where the research object is located, predicted economic performance of the research object *i*, Y_i^t, Y_i^{t-k} are the quantity index of the region (economic region or whole country) where the research object is located at the period of *t*, *t* – *k*.

$$Resis_i^t = (\Delta Y_i - \Delta E) / |\Delta E| \quad (3)$$

Equation (3): $Resis_i^t$ is the relative economic resilience of the research object *i* at *t* time; for the convenience of operation, Equations (1)-(3) can be combined and simplified as follows:

$$Resis_i^t = \frac{(Y_i^t - Y_i^{t-k})/Y_i^{t-k} - (Y_r^t - Y_r^{t-k})/Y_r^{t-k}}{|(Y_r^t - Y_r^{t-k})/Y_r^{t-k}|} \quad (4)$$

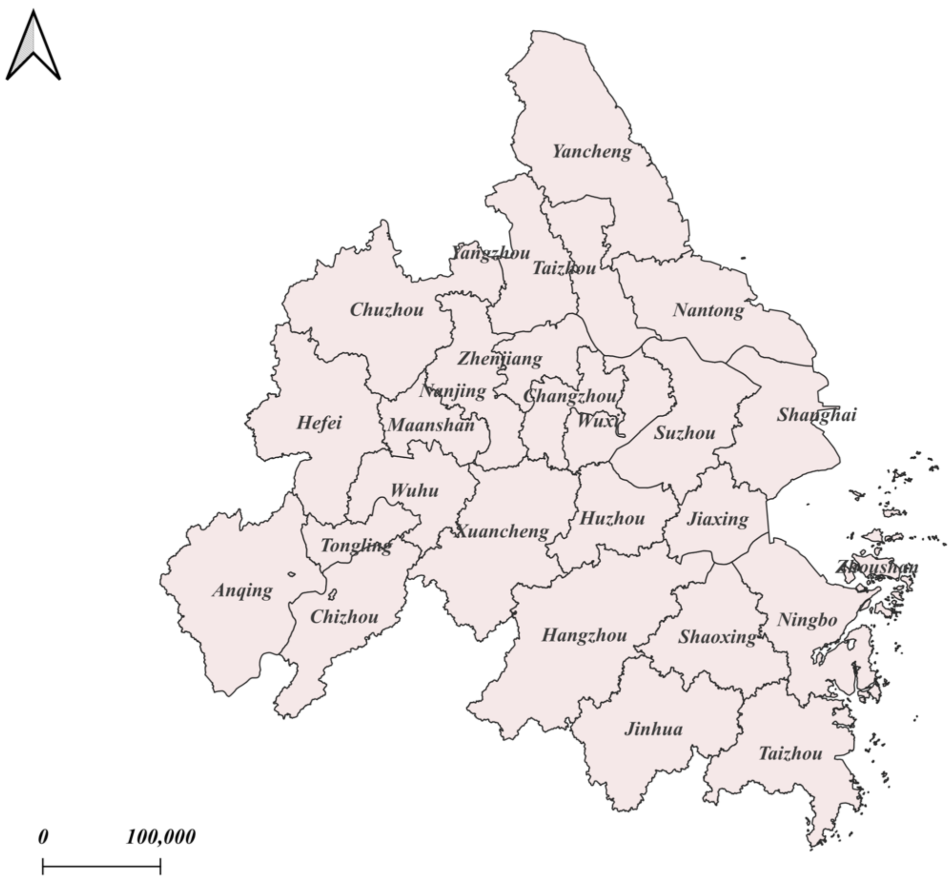

Figure 1. Map of cities in the Yangtze River Delta.

Figure 2. Map of cities in the Pearl River Delta.

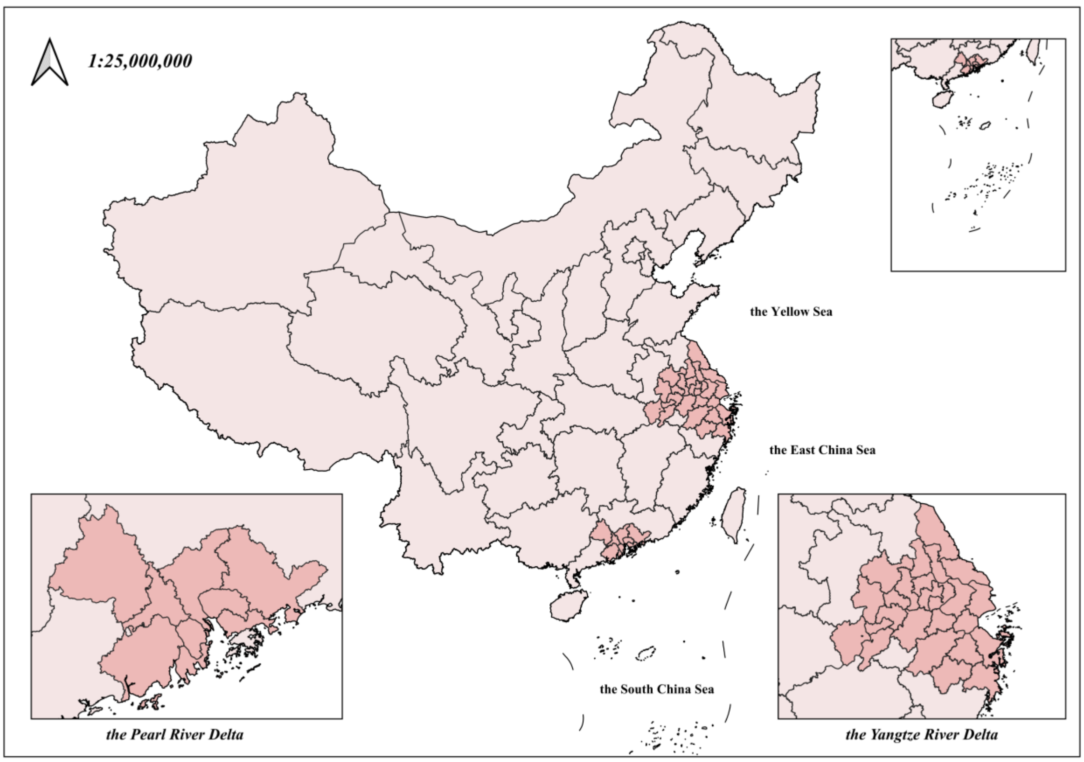

Figure 3. The macro-location of the Yangtze River Delta and Pearl River Delta.

To facilitate comparative analysis among all study subjects, the results can be centralized:

$$\mathbf{R}_i = \left(\boldsymbol{Resis}_i^t - \sum_i^n \frac{\boldsymbol{Resis}_i^t}{\boldsymbol{n}}\right)(-\mathbf{1})^{\boldsymbol{p}} \quad (5)$$

Equation (5): n is the total number of research objects; $(-1)^p$ is the correction coefficient, when the selected economic indicators are ordinary indicators (such as GDP, industrial value added, etc.) p = 0, when the selected indicators are negative indicators (such as the unemployed population, the number of closed enterprises, etc.) p = 1; so far, $\mathbf{R}_i$ can be directly used to compare the relative economic resilience of the degree of economic resilience of each research object, when $\mathbf{R}_i > 0$, the economic performance of the research object *i* exceeds the average level of the economic performance of the region, and the larger the value means that the economic resilience of the research object performs better in the region; when $\mathbf{R}_i < 0$, the economic performance of the research object *i* is lower than the average level of the economic performance of the region, and the smaller the value means that the economic resilience of the research object performs worse in the region. By bringing the collected data into Equations (4) and (5), the economic performance of each city or component of the Pearl River Delta and Yangtze River Delta can be compared. When a shock occurs, the resilience of each city in response to the shock can be compared.

3.3 Data sources

The data in this paper primarily originate from sources including the "Guangdong Statistical Yearbook" (1999-2019), statistical yearbooks from various cities within the study regions, and databases of the National Bureau of Statistics, spanning the timeframe from 1999 to 2021. To provide a preliminary understanding of the overall resilience comparison between the Pearl River Delta and the Yangtze River Delta at a macro level, this study initially selected the value added of industries including hotel and catering services, manufacturing, wholesale and retail trade, transportation, storage and communications, as well as agriculture, forestry and fishing. The overall regional resilience was then computed based on these indicators.

Besides, tourism, being a service industry, displays an inherent unity of production and consumption. This signifies that while tourism providers generate or offer products and services, tourists simultaneously engage in the purchase of these tourism products and services, thus completing a full production-consumption cycle. Consequently, when assessing the resilience of a region's tourism sector, it becomes imperative to incorporate indicators from both production and consumption aspects. This approach ensures a comprehensive and precise capture and depiction of the regional tourism industry's resilience. Specifically, the value-added of the hotel and catering services sector is employed to represent the production-oriented aspect of tourism resilience. Meanwhile, tourist numbers and tourism revenue are used to signify the consumption-oriented aspect of tourism resilience. Subsequently, the relative resilience of the tourism industry within the Yangtze River Delta and the Pearl River Delta has been quantitatively computed, followed by the utilization of ArcGIS software for visualization purposes.

4. Research findings

4.1 Regional resilience in general

As illustrated in **Figures 4 and 5**, the vertical comparison of the growth rates of various sectors in the Yangtze River Delta and the Pearl River Delta shows that from 1999 to 2021, the economic development of both regions as a whole exhibited an upward trend with an average annual growth rate maintained at around 10%. This result indicates that the equivalent overall economic scale and similar development dynamics of the two regions, rendering their comparability in nature.

In terms of specific years, the economic growth rates of the two regions both in 2009 and 2020 experienced a significant decline, even turning negative, which was inextricably linked to the global financial crisis in 2008 and the outbreak of COVID-19 in

2019. This suggests that both crises had significant negative impacts on the economic development of the two regions. In contrast, the economies of these two regions recovered in 2010 and 2021, both of which were resilient enough to withstand the crisis in a relatively short period of one year. It implies that the selected time periods for this study have a socially realistic basis, which are 2009-2010 and 2019-2020.

It is worth noting that the growth rate of hotels and catering services, which partly represent tourism, differed between the two regions under the two crises. During the financial crisis, the tourism industry in the Pearl River Delta was hit harder than that in the Yangtze River Delta. Under the influence of COVID-19, the tourism industry in both regions suffered a very significant impact compared with other sectors. The following section analyses the resilience of the tourism industry in the two regions during the two crises.

4.2 Comparison of the tourism resilience at the production level in the two regions

During financial crisis

During the financial crisis, notable disparities in tourism resilience between the Pearl River Delta (PRD) and the Yangtze River Delta (YRD) regions became evident (**Figure 6**). Compared to the YRD, the PRD suffered more pronounced shocks and presented weaker tourism resilience. More than half of the cities in the PRD have negative tourism resilience values, with two cities exhibiting resilience values below –1.5, lower than the corresponding figures in the YRD. Furthermore, the inter-city variance in tourism resilience within the PRD was significantly pronounced, characterized by a broader range of values (close to 2 for the highest and approximately –2.4 for the lowest), in contrast to the YRD (with resilience values ranging from 1.2 to –1.6).

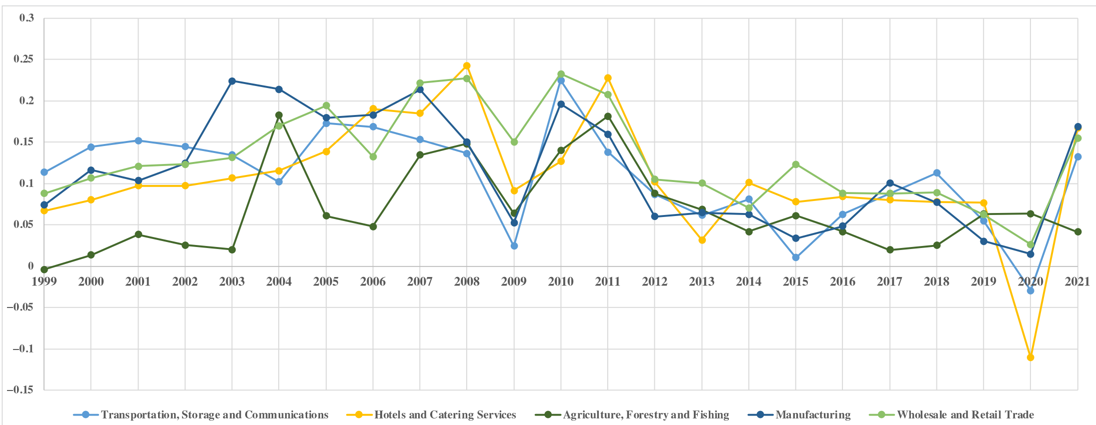

Figure 4. YRD's sector growth rates in 1999-2021.

Figure 5. PRD's sector growth rates in 1999-2021.

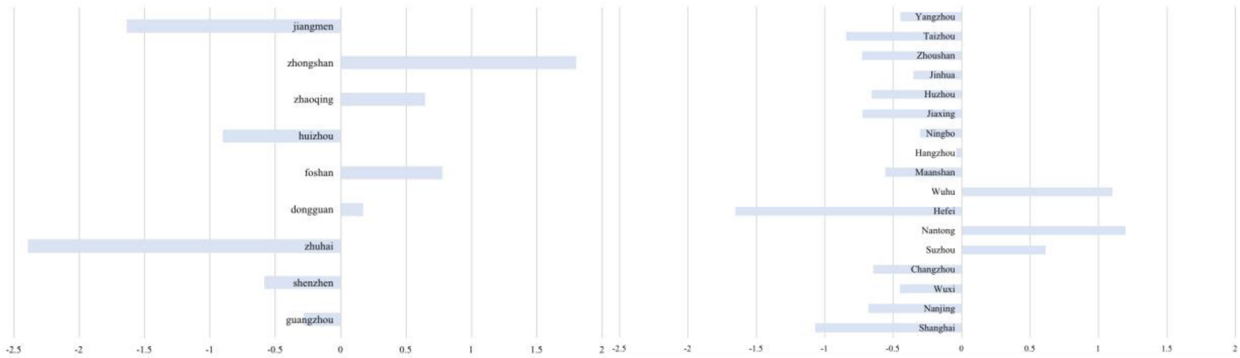

Figure 6. PRD and YRD's tourism resilience at the production level during the financial crisis.

This divergence is attributed to the PRD's outward-oriented economy, deeply embedded in the global production network. As such, the PRD's economic development is intricately linked to global economic activities, rendering it more susceptible to fluctuations in the global macroeconomic landscape. Thus, during the financial crisis, the pronounced impact of the crisis on the global economy, coupled with the PRD's integral role within the global production network, resulted in a forceful blow to the PRD's economy. Persistent crisis conditions led to severe regional economic contraction, elevated unemployment rates, reduced household income, and consequently, diminished tourism consumption revenue, directly impacting the tourism industry. However, due to the PRD's complex and diverse economic structure, significant disparities in geographical positioning, endowment of tourism resources, industrial economic structures, and modes of economic development among its cities, distinct responses to the financial crisis ensued, resulting in conspicuous inter-city variance in tourism resilience.

In contrast, the tourism resilience of the YRD demonstrated relatively higher stability, characterized by lower degrees of inter-city tourism resilience differentiation. Compared to the PRD, a broader spectrum of cities within the YRD manifests weaker tourism resilience and a more pervasive negative impact. This outcome could be attributed to the YRD's richer and more diversified endowment of tourism resources, along with a higher level of maturity in urban tourism development. Consequently, in the face of the financial crisis, the YRD cities collectively experienced a broader shock. Yet, due to the YRD's economic structure not being predominantly outward-oriented, its reliance on global economic development is lower, resulting in a limited scope and depth of the impact from external economic shocks, thus leading to comparatively stable tourism resilience.

Moreover, it is imperative to acknowledge certain commonalities in tourism resilience between the two regions during the financial crisis, such as weaker tourism resilience observed in the super first-tier cities and cities with tourism as a foundational industry, as well as stronger tourism resilience demonstrated in manufacturing cities with a robust industrial base.

Overall, within the context of the financial crisis, substantial differentials in tourism resilience become evident between the YRD and the PRD regions.

During COVID-19

During the COVID-19 pandemic, the overall resilience of tourism between YRD and PRD regions displays a notable similarity, with marginal disparities (**Figure 7**). Cities within both regions experienced distinct disruptions in their tourism sectors, evidenced by a predominant manifestation of negative resilience values.

Delving into the specifics, the observed resilience in urban tourism across the YRD and the PRD leads to the following results:

In both regions, the tourism resilience of metropolitan areas and cities that rely heavily on tourism as a foundation industry has declined. Notably, prominent cities such as Shanghai in the YRD and

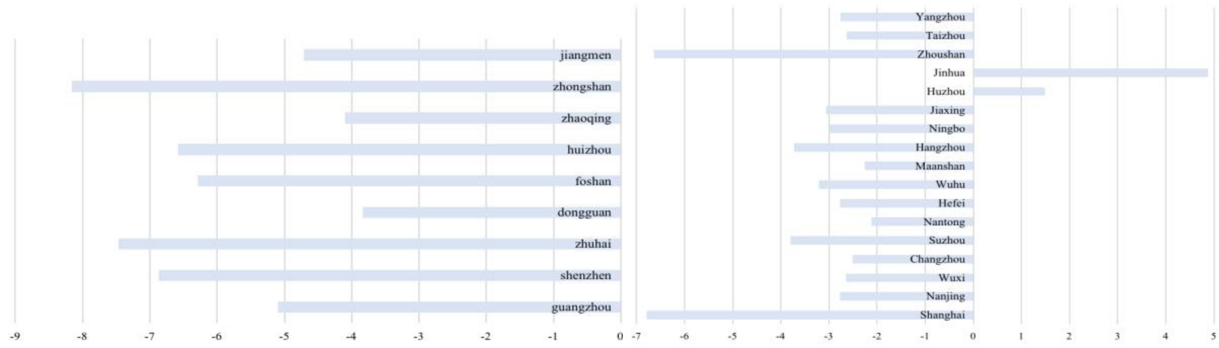

Figure 7. PRD and YRD's tourism resilience at the production level during COVID-19.

Shenzhen in the PRD confronted elevated risks of disease outbreaks due to their substantial populations and substantial passenger flows. Furthermore, these cities possessed a robust tertiary sector, resulting in considerable repercussions on the tourism industry due to the impeded conduct of business-related travel, conferences, and related activities. Consequently, tourism resilience tended to be relatively feeble in the unchanged scenario. Similarly, cities like Zhoushan in the YRD and Zhuhai in the PRD, where tourism constitutes a pivotal economic pillar, faced a stark reduction in tourist numbers during the pandemic. These cities grappled with pronounced negative impacts, as the pandemic's effects lingered within a condensed timeframe, consequently leading to subpar tourism resilience.

Satellite cities of major metropolises demonstrated relatively high tourism resilience. Cities in proximity to major urban centers, such as Jinhua and Huzhou in the YRD, and Huizhou and Jiangmen in the PRD, exhibited commendable tourism resilience. This trend was chiefly attributed to pandemic-induced constraints on long-distance population movements, which stimulated demand for tourism in the vicinity of larger urban hubs.

Internally within both regions, disparities in tourism resilience among some cities, which are the traditional industrial centers or emerging manufacturing hubs, remained indistinct, characterized by a generally weak state of resilience. The pandemic's impact on the tourism sector did not manifest conspicuous differences across these two city typologies.

In summary, the COVID-19 pandemic underscored an overarching deficiency in tourism resilience across the YRD and the PRD. The two regions exhibited analogous patterns, with minimal differentiation in tourism resilience among the cities within each respective region.

4.3 Comparison of tourism resilience at the consumption level in the two regions

During financial crisis

As depicted in **Figure 8**, the research findings are in concordance with previously employed production-oriented indicators of resilience, indicating a consistent outcome. Regardless of whether measured by tourist visitation or tourism revenue, the resilience of the Pearl River Delta's tourism sector appeared notably inferior in comparison to that of the Yangtze River Delta. On one hand, the financial crisis had a more extensive impact on the Pearl River Delta. In terms of tourist visitation, represented by the number of tourists, nearly half of the cities within the Pearl River Delta exhibited negative R-values. This disparity becomes even more pronounced when considering the indicator of tourism revenue, as only one city, Jiangmen, displayed a positive R-value. In contrast, within the Yangtze River Delta, the scope of cities with negative R-values for both tourist numbers and tourism revenue indicators was significantly lower compared to the Pearl River Delta, indicating a relatively stronger tourism resilience in the Yangtze River Delta.

On the other hand, the Pearl River Delta exhibited a more pronounced fluctuation in its R-values, with a distinct and significantly negative profile of tourism resilience. In terms of tourist numbers, Zhuhai and Shenzhen within the Pearl River Delta exhibited notably low R-values of approximately –0.7 and –0.62, respectively, while the highest R-value observed in Jiangmen was only approximately 1.05. Within the cities of the Yangtze River Delta, however, the lowest R-value was approximately –0.26, while the highest reached around 0.78, thus depicting a comparatively narrower range of fluctuations. Furthermore, when considering the indicator of tourism revenue, the lowest R-value among the cities within the Pearl River Delta was approximately –0.66, whereas the corresponding figure for the Yangtze River Delta was about –0.42, providing further emphasis on the lower resilience observed in the Pearl River Delta.

Nevertheless, it is noteworthy that both regions exhibited disparities in their internal structures. In the case of the Pearl River Delta, the eastern regions generally displayed weaker relative tourism resilience at the consumption level compared to the western regions, irrespective of whether assessed by tourist numbers or tourism revenue. In the Yangtze River Delta, on the other hand, the northern regions demonstrated relatively lower tourism resilience in terms of tourist numbers, whereas in terms of tourism revenue, the southern regions manifested generally weaker relative resilience.

During COVID-19

As depicted in **Figure 9**, in stark contrast to the resilience measurements at the production level, the impact of the COVID-19 pandemic yielded distinct regional differentiations in tourism resilience within the Yangtze River Delta and the Pearl River Delta at the consumption level. Moreover, these outcomes stood in complete opposition to the results observed during the financial crisis.

During the COVID-19 pandemic, the western regions of the Pearl River Delta consistently displayed lower levels of relative tourism resilience at the consumption level compared to the eastern regions. This phenomenon was entirely divergent from the findings during the financial crisis, wherein the eastern regions of the Pearl River Delta exhibited comparatively inferior relative resilience. Turning to the

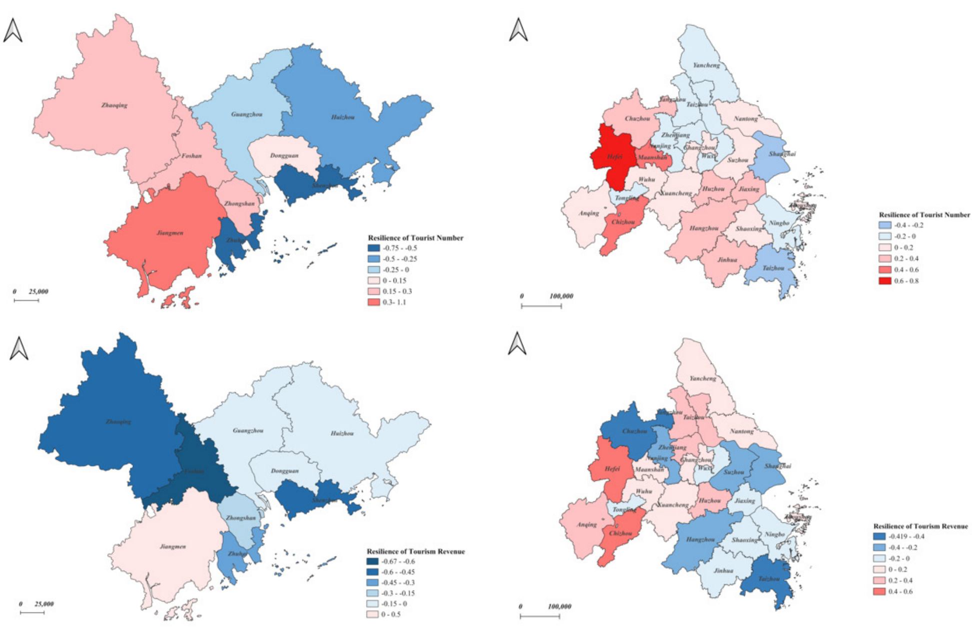

Figure 8. PRD and YRD's tourism resilience at the consumption level during the financial crisis.

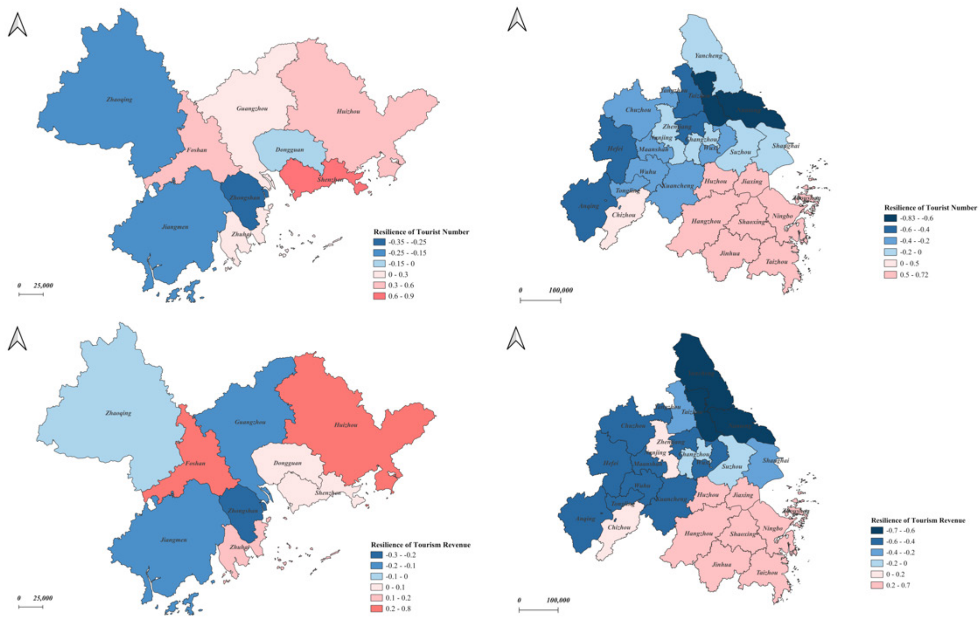

Figure 9. PRD and YRD's tourism resilience at the consumption level during COVID-19.

Yangtze River Delta, regardless of whether measured by tourist numbers or tourism revenue, the relative resilience within the northern regions of the Yangtze River Delta significantly lagged behind that of the southern regions, again in complete contrast to the performance during the financial crisis.

This study discerns a consistent pattern amidst notable variations in responses to distinct crises within the two regions. Specifically, in economically advanced locales, their tourism resilience tends to exhibit weaker performance during financial crises while displaying stronger performance during public crises. The eastern region of the Pearl River Delta is more economically advanced than its western counterpart, encompassing cities such as Guangzhou, Shenzhen, and Dongguan. Among these, Guangzhou serves not only as the provincial capital of Guangdong province, but also as a pivotal commercial, trade and industrial hub in South China, boasting advanced sectors in automobile production and electronic manufacturing industries. Shenzhen holds the status of a mega-city and international metropolis in China, featuring a well-developed sector of electronic information and communication equipment manufacturing. Similarly, Dongguan possesses a solid manufacturing foundation and has nurtured clusters of electronic industries. As for the Yangtze River Delta, its southern region covers a range of provincial capitals, first-tier megacities, and emerging cities such as Shanghai, Nanjing, Hangzhou, Suzhou, and Changzhou. These areas are characterized by their robust industrial foundation and notable levels of economic development. It is observed that both the eastern region of the Pearl River Delta and the southern region of the Yangtze River Delta exhibited weaker relative tourism resilience during financial crises, whereas they demonstrated notable resilience during the COVID-19 pandemic.

This distinction can be attributed to the varying scopes of the impact that different crises have on industries, as well as the differentiation in residents' income and demand levels among regions of different economic levels. In the case of economic crises, the repercussions often span across various industries and tend to result in pronounced market fluctuations, thereby detrimentally affecting the real economy. This process is often accompanied by a surge in business closures, leading to an escalation in unemployment rates and a reduction in residents' income and purchasing power. This directly contributes to a rapid contraction in consumption within the leisure and tourism sector. Therefore, during economic crises, economically advanced regions tend to exhibit poorer relative tourism resilience. Conversely, during public crises, the extent of damage to the real economy is generally lower than that seen during economic crises. Economically advanced regions still maintain robust economic capabilities, with generally higher social incomes and greater consumer capacity compared to less developed regions. Even under pandemic control measures and transportation restrictions, residents in these advanced regions still have a demand for leisure travel and the purchasing power to support it. Thus, in comparison to less developed urban areas, the tourism industries in these advanced regions exhibit greater resilience in the face of public crises, attributed to their stronger capacity to withstand and adapt to such circumstances.

5. Conclusions and discussion

This study undertakes an evaluation and comparative analysis of the tourism resilience performance of the Pearl River Delta and the Yangtze River Delta under different crises. It derives the following three main conclusions.

Firstly, regions with higher levels of economic development tend to exhibit relatively weaker tourism resilience in the face of economic crises, while showcasing relatively stronger resilience during public crises. This pattern is evident in both the eastern region of the Pearl River Delta and the southern region of the Yangtze River Delta, both of which are characterized by their greater economic development. During the financial crisis period, these regions manifested a notable fragility in terms of relative tourism resilience. However, during the COVID-19 pandemic, their tourism resilience demonstrated a more robust performance. This observation is intrinsically linked to variations in the scope of impact that different crises have on industries, as well as differences in the income levels and leisure demands of residents in regions with varying economic statuses.

Secondly, in a broad sense, there are discernible disparities, both inter-regionally and intra-regionally, within the Yangtze River Delta and the Pearl River Delta. The overall tourism resilience of the Yangtze River Delta surpassed that of the Pearl River Delta, and this characteristic was more pronounced during the financial crisis period. Moreover, at the intra-regional urban scale, during the financial crisis, the western region of the Pearl River Delta's tourism resilience outperformed its eastern counterpart, while within the Yangtze River Delta, the tourism resilience of the northern region slightly exceeded that of the southern region. However, during the COVID-19 pandemic, the tourism resilience of the eastern coastal area of the Pearl River Delta surpassed that of the western coastal area, while within the Yangtze River Delta, the tourism resilience of the southern region notably outperformed that of the northern region. These variations predominantly stem from variations in geographical positioning, tourism resource endowments, industrial and economic structures, as well as economic development paths, both regionally and within individual cities.

Thirdly, when assessing the resilience of regional tourism industries, a singular dimension is insufficient for measurement; instead, a multi-dimensional perspective should be employed to more comprehensively capture the essence of tourism resilience. As an industry where production and consumption occur concurrently, the tourism industry necessitates an evaluation that encompasses both production and consumption dimensions to adequately gauge its resilience. This study reveals that when utilizing indicators from these dual dimensions to measure regional tourism resilience, there is a relatively consistent outcome during financial crises. However, there is substantial divergence in results during the COVID-19 pandemic: In comparison to the production-oriented indicators, employing consumption-oriented indicators to measure regional tourism resilience yields more pronounced regional differentiations. Consequently, the adoption of multi-dimensional indicators is imperative for characterizing and dissecting regional tourism resilience accurately, enabling a precise understanding of the process and impact of crisis shocks.

The comparative analysis of the tourism resilience between the Yangtze River Delta and the Pearl River

Delta in this study is based on grasping the absolute resilience of the two regions, and then analyzing intraregional disparities. This approach helps to better grasp the development characteristics of the region and provides a potential perspective for addressing the challenge of comparing relative resilience. In practice, this study adopts a multi-dimensional method to elucidate the essence of regional tourism resilience under various crises, thereby offering valuable insights for local governments when formulating relevant tourism policies. For example, in the event of a crisis, it is necessary to judge whether the crisis has affected the foundational aspects of the tourism industry and to pay close attention to employment and consumption support within the tourism industry. Overall, the method adopted in this study allows for a nuanced understanding of how and to what extent different types of crises affect the tourism sector, which plays a positive role in advancing the research on regional tourism resilience.

This study believes that future research should focus on further enhancing resilience, delving deeper into the comprehensive characterization of the evolution of regional tourism resilience, and providing further elucidation on the causal relationship between multi-dimensional indicators and the disparities in the impact of multiple external factors on regional tourism resilience.

Author Contributions

Yi Liu: Conceptualization, Methodology, Case analysis, Resources, Investigation, Writing—Original Draft, Writing—Review & Editing, Funding acquisition.

Liaofan Chen: Methodology, Case analysis, Investigation, Data Curation, Writing—Original Draft, Writing—Review & Editing.

Fangfei Han: Case analysis, Investigation, Writing—Original Draft, Writing—Review & Editing, Visualization.

Tong Zhang: Case analysis, Data Curation, Writing—Review & Editing, Visualization.

Conflict of Interest

There is no conflict of interest.

Data Availability Statement

The data generated during and/or analyzed during this study "Regional Tourism Resilience Under Crisis Impacts: the cases of Yangtze River Delta and Pearl River Delta" are available from the corresponding author on reasonable request.

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REVIEW

Climate Justice Dimensions: Approaching Loss and Damage and Adaptation towards a Just City

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ABSTRACT

The escalating occurrence of severe climatic events over the past decade, with a projection for further intensification due to the climate emergency, underscores the critical role of urban and regional planning in climate action towards just cities. Municipalities and regions are both significant contributors to CO_2 emissions and are vulnerable to the adverse impacts of climate change. This paper contends that urban and regional planning must undergo a paradigm shift to address this challenge. Climate justice, encompassing dimensions of inequality and environmental equity, is a pivotal dialogue in these contexts. Through a comprehensive review, this study contributes to the evolving landscape of climate justice planning and policy, offering insights that could resonate across the Global South and beyond. As an illustrative case, the authors delve into Brazil's climate challenges, discussing adaptation planning and post-disaster response, and emphasizing the need for localized and community-driven initiatives. This article delves into the interplay between Loss and Damage, adaptation, and just cities, with a focus on the Global South. The authors scrutinize the emerging discourse on Loss and Damage, its associations with climate impacts, and the quest for a just and equitable approach. The work advances the understanding of the distinction between adaptation and Loss and Damage actions, highlighting the significance of a dedicated fund for addressing Loss and Damage in vulnerable countries.

Keywords: Climate justice; Loss and Damage; Global South; Just adaptation; Brazil

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1. Introduction

The incidence of severe climatic events (droughts, floods, hurricanes, and rains) has increased in the past decade, and the tendency is to increase with the worsening of the climate emergency [1]. The statement that municipalities have been considered an essential territory for action for global climate problems is not new, either because they are essential vectors of CO_2 emissions or because they will suffer from its harmful effects, forcing them to adapt. It may also be due to the need for more legally binding and robust agreements and the role of national governments [2].

Thinking or rethinking the role of urban and regional planning in the face of this challenge seems imperative [2-5]. Both in reports by the Intergovernmental Panel on Climate Change [6] and in the article "*Six research priorities for cities and climate change*" [7], cities and their urban planning appear as fundamental to thinking about a future with just sustainability. Nevertheless, there are still many "gaps", barriers, and challenges, especially in the most urbanized part of the planet, Latin America [8], and in Africa and Asia regions that are projected to become the most urbanized in the coming decades [9,10].

Climate change scenarios indicate that by 2050, three billion people are expected to live in slums and precarious settlements, exposed to the effects of climate change [7]. How will these cities be produced and planned? As early as 2010, urban planner Ray Quay presented proposals and tools for adapting to climate change, which he coined Anticipatory Governance [11]. Quay explained that the process for a response could be simplified into four distinct phases:

1) Anticipate a wide range of possible futures.
2) Develop multiple strategies.
3) Monitor changing conditions over time.
4) Act as anticipated and evaluate your progress.

However, these tools usually work—if they work—differently across all parts of the planet. In the context of the Global South, for example, dialogue regarding notions such as inequality, environmental justice, and climate justice is most imperative [12]. Otherwise, there is a risk of producing the type of planning that engenders poverty and inequality in these regions [13].

A growing collection of literature has illuminated this issue. However, few empirical studies focus on the territory of the Global South with researchers from the Global South, and even fewer, quantitatively, in Latin America. Barton [2] has worked on Chile's theme, making a significant contribution based on the peculiarities of South America. The work led by Shi L. et al. [14] is another critical example of the need to approach the debate on inequality concerning planning for adaptation to climate change. Adaptation projects or green infrastructure should not reinforce inequalities [15]; however, it is necessary to attack adaptation and inequalities simultaneously [16].

Talking about climate justice is also talking about its dimensions, scale, and social voices. This paper addresses this issue, approaching Loss and Damage and adaptation towards a just city. It aims to contribute to an ongoing critical discussion on climate justice planning and policy, avoiding the risk of it becoming one more panacea or reinforcing local and planetary privileges.

The article is divided as follows: The first part seeks to contextualize the need to more carefully approach the differences between action or reaction when we address climate change adaptation policies, programs, and plans. Understanding the context is fundamental for establishing a dialogue at the science-policy interface, which we propose to do in this work by observing these particularities towards just cities. In the second section, we describe the materials and methods of our analysis. In the third section, we present a review of Loss and Damage, aiming to understand the overview of the publications and the links with action and reaction to climate change events. In the final part of this article, we present the results and discuss the importance of these findings given the applied policy dialogue perspective. For the discussion, we use Brazil as an illustrative case study, an essential representative of the Global South and South America, and which has been suffering the uneven impacts of climate change in its continental territory.

2. Climate change adaptation policies, programs and plans: Action or reaction?

What does working with urban and regional planning related to climate change mean? Planning is already an anticipatory practice. The planning field and its practice deal with medium- or long-term schedules, which should contain uncertain ingredients for future development paths. The increasing importance of plans, in that sense, must contain indications for monitoring and periodic review, which is crucial to adapt to extreme eventuality.

So, recognizing this is critical. Recognizing this should alert us to how radical and far away from business-as-usual planning it needs to be. It is, therefore, about working within a scenario of uncertainty [11]. Climatic variability includes even more unpredictability in planning since it demands the need to work with the best available scientific data, often where a knowledge gap exists in several locations—even more in Global South countries [12].

For example, the natural resources interdependence of water supply needs to be addressed on a macro and cross-scale. It involves stakeholders and an extrapolation of the traditional frontiers and business as usual, the usual guide practices of planning and management [12]. Water scarcity events can be demonstrated in diverse cities and regions worldwide and have shown evidence of the distance between the territory of production of the ecosystem service and consumption [17].

Planning becomes essential in this context as it can also contribute as an intersection for an inter, multidisciplinary, and transdisciplinary articulation of responses and reflections to the challenges that arise. For this, a climate justice dialogue is crucial, a term originating in the Global North and solidifying in Latin America more recently [18].

Porter, Rickards, Moloney, and Anguelovski, I. [19] organized a Planning Theory & Practice section entitled "Climate Justice in a Climate Changed World". It is a must-read, mainly the contribution by Isabelle Anguelovski and David N. Pellow, "Towards an Emancipatory Urban Climate Justice Through Adaptation?". However, voices/authors are absent from the Global South, mainly from South American countries, which has been recurring and can be explained by several reasons, including, amongst others, the priority and necessity of the inequality agenda [20].

Therefore, urban and regional planning needs to adjust its practice to local demands in the face of climate change. The best way to do this is not only from a formal participatory planning process; it is necessary to go beyond that including radical and insurgent approaches [21,22]. It ensures the necessary territory for community actors to propose actions, breaking the business-as-usual paradigms of current planning and management practices. Being direct: It is not a question of including the bottom-up discussion. Notwithstanding, it is from there that it must be done.

In this case, what may seem local will actually be evidence of the well-known and widespread term *glocal* [23].

According to IPCC AR 6 [6]:

> *"Adaptation planning and implementation have progressed across all sectors and regions, with documented benefits and varying effectiveness. Despite progress, adaptation gaps exist, and will continue to grow at current rates of implementation. Hard and soft limits to adaptation have been reached in some ecosystems and regions. Maladaptation is happening in some sectors and regions. Current global financial flows for adaptation are insufficient for, and constrain implementation of, adaptation options, especially in developing countries" (IPCC, 2023, p.6).*

From what we can see, there was still an enormous gap initially. Moreover, there is an uneven distribution of those gaps: the global south countries. Second: maladaptation or what has been reported as fake solutions, or green makeup, that, instead of solving a problem, reinforce green privileges and enrich corporations. Third, financial flow for adaptation is insufficient, despite the increase of profits of fossil fuels, among other sectors—these have names from a climate justice perspective: climate debts and climate colonialism.

However, some adaptation actions seem more like immediate response actions than medium and long-term planning, and that is based on climate change forecasts. Wouldn't these measures be what is conventionally called *Loss and Damage*? Loss and Damage mean different things to different groups, and there is no agreed-upon definition of Loss and Damage within the UN Framework Convention on Climate Change (UNFCCC). However, Loss and Damage can generally be understood as the negative impacts of climate change that occur despite, or in the absence of, mitigation and adaptation.

Loss and Damage are increasingly discussed in the global agenda for tackling climate change. Although the genesis of an agreement to finance a fund for Loss and Damage took place in 2013, with the Warsaw International Mechanism and later in 2015, with the Paris Agreement Article 7, it was at COP26, in Glasgow, Scotland, that pressure from civil society led to a boost on the topic [24]. At COP27, which took place at the end of 2022 in Sharm el-Sheikh, Egypt, the decision to establish a Loss and Damage fund was ratified to compensate low- and middle-income countries that are already suffering from the negative impacts of climate change [25].

Despite the progress made in the decision taken at COP27 [24,25], there is a risk that the discussion on Loss and Damage becomes a merely symbolic issue about the urgencies and dangers of global society. Having a political understanding of the losses and damages related to climate change that the fund's compensations would cover and the governance mechanisms that would be applied to address justice in its different dimensions can reduce this risk [24].

Differentiating between adaptation and Loss and Damage actions seems imperative. Both to clarify their differences and the dispute over resources, the type of projects, programs, policies, and plans. This paper seeks to advance and contribute in this direction. To do so, it presents this discussion and, in addition, observes, through reviews, what has been published about Loss and Damage. The topic will undoubtedly grow in the coming years [24-26] and research will incorporate Loss and Damage more strongly. That justifies the importance of this study even more as we mark the frame we are making and, on the other hand, follow an emerging agenda designed for the coming years.

Brazil, our illustrative case here, has experienced several severe climate impacts. Only in the last few years, tragic events, such as those that occurred in Pernambuco and the south of Bahia, in the northeast region, the floods in Acre and Amazonas in the north, the fires and floods in the center-west, severe droughts in the south and southeast, as well as floods. Despite having a national adaptation plan, from 2016, actions and differentiations on post-tragedy response and adaptation planning need to be clarified.

3. Material and methods

For this work, research was mobilized on the relationship between the area of climate change and planning, as well as on Loss and Damage and adaptation. The objective is not to present a systematic review of the literature, which would require specific techniques and protocols, but an initial mapping of the works—what has been produced and understood by the academy—on the themes in order to fertilize the discussion in the light of the lens of climate justice. In this sense, as an illustrative element for discussion, a country from the Global South, in South America, Brazil, is used not as a case study but as an element that enables reflection and replicability in other countries in the region.

The steps taken on the bibliographic searches carried out are shown below. For the literature review process, mixed research methods were used in multiple databases since databases with a predominance of publications in the English language tend to suppress and make invisible the extensive academic production of countries in the global south, mainly in South America, in which many of the publications are produced in Latin American papers, or books and journals that are not indexed in databases such as Scopus or Web of Science. To this end, a search was added to the Scopus and Web of Science databases of Scielo and Redalyc—open-access databases with publications from the region.

Scielo (Scientific Electronic Library Online) is a Brazilian open-access database, operating since 1997. It is the result of a partnership between FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo) and BIREME (Centro Latino-Americano e do Caribe de Informação em Ciências da Saúde) with the aim of increase the visibility of Brazilian scientific production and develop a methodology for electronic publication in Brazil, Latin America, and Caribe. Redalyc is an open-access indexing system supported by the Autonomous University of the State of Mexico. Founded in 2003, its main goal is to give visibility and increase the quality of Latin American Social Sciences and Humanities journals.

For each database, a methodological path was carried out. The search was conducted in a specific time frame (31/10/2022 to 07/11/2022), considering the 27th Conference of the Parties—COP27 as a turning point in the discussion about Loss and Damage, by consolidating the need for a fund. Therefore, the focus was on articles published before COP27, understanding the prior concept construction. The timeframe with the end of COP 27 is due to the assumption—as a hypothesis—that from COP 27, the number of research and publications on Loss and Damage increased in volume, changing the current profile of what has been published [27].

3.1 Scielo

The first search on the Scielo database was the descriptor "Loss and Damage" until November 2022—the eve of COP27. The second search with the terms (Loss and Damage) AND (Climate) in order to try to refine the search for articles dealing with Loss and Damage in the context of climate change, excluding articles in the area of AgroSciences and health. **Figure 1** indicates the search carried out on the Scielo data.

3.2 Redalyc

The first search in the Redalyc database with the descriptor 'Loss and Damage'. The second search with the terms 'Loss and Damage' AND 'Climate' is to refine the search for articles dealing with 'Loss and Damage' in the context of climate change, excluding articles in AgroSciences and health. The third search was with the terms 'Loss and Damage' AND 'Climate' AND 'Brazil'. The fourth search included 'Loss and Damage' AND 'Climate' AND 'Global South'. The fifth search was with the term "Loss and Damage AND Climate AND Global South AND Paris Agreement". The sixth and final search with the terms 'Loss and Damage' AND 'Climate' AND 'Global South' AND 'Paris Agreement' AND 'Brazil'. **Figure 2** indicates the search carried out on the Redalyc database.

3.3 Web Of Science (WoS)

The descriptors were all written in the English

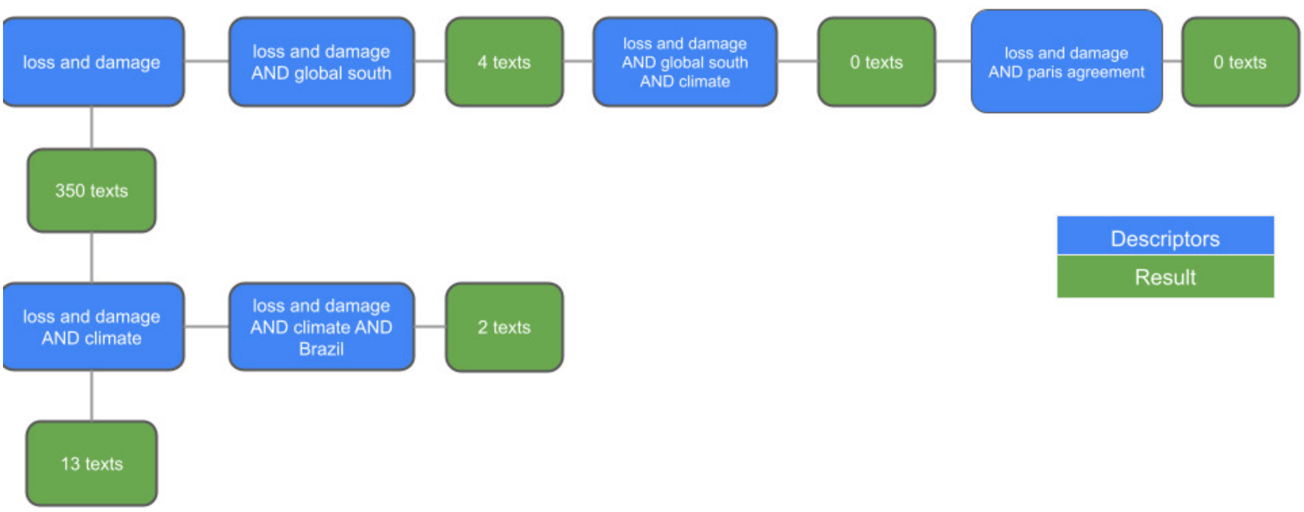


Figure 1. Scielo.

Figure 2. Redalyc.

language, and the first Web of Science (WoS) search was 'Loss and Damage'. At the WoS database, articles, book chapters, notes, editorial material, and news items, among others, are included. The second search was with the descriptor 'Loss and Damage' AND 'Climate'. Exclusion filters were applied, excluding the study areas: Sport Sciences, Reproductive Biology, Radiology Nuclear Medicine Medical Imaging, Optics, Computer Science Theory Methods, Pharmacology Pharmacy, Engineering Aerospace, Biochemistry Molecular Biology, Astronomy Astrophysics, Computer Science Information Systems, Physiology.

The third search with 'Loss and Damage' AND 'Climate' AND 'Global South'. The final and fourth search with 'Loss and Damage' AND 'Climate' AND 'Global South' AND 'Paris Agreement'. **Figure 3** indicates the search carried out on the Web Of Science (WOS) database. **Figure 4** indicates the search carried out on the Web Of Science (WOS) database with the exact search.

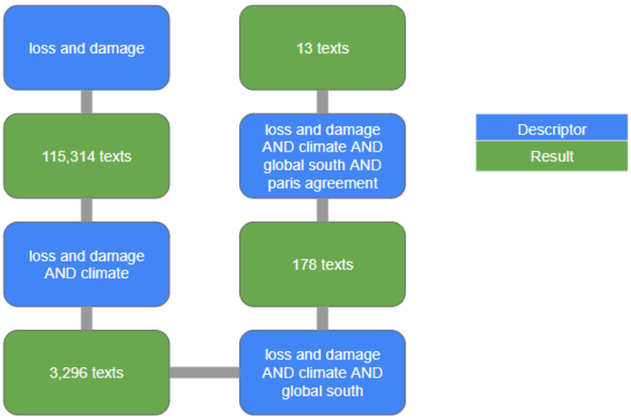


Figure 3. WoS 1.

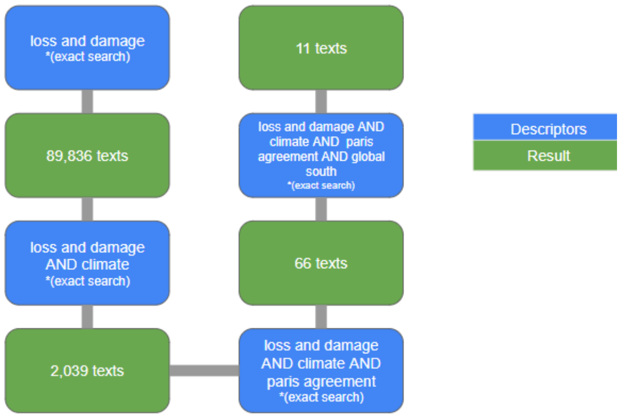


Figure 4. WoS 2.

3.4 Scopus

The first search used "exact term" in Scopus data, identified by the square brackets {loss and damage}, noting that the descriptors were all written in the English language. Exclusion filters were used to exclude areas unrelated to the issue: Medicine, Biochemistry, Genetics and Molecular Biology, Physics and Astronomy, Neuroscience, Pharmacology, Toxicology and Pharmaceutics, Immunology and Microbiology, Veterinary, and Dentistry.

The second search was {loss and damage} AND {climate} while the third search was {loss and damage} AND {climate} AND {global south}. Finally, the fourth search was {loss and damage} AND {climate} AND {global south} AND {Paris agreement}. **Figure 5** indicates the search carried out on the Scopus database.

4. Results

The topic below presents the results of searches in the various databases. **Table 1** below confirms the discrepancy between the bases. What would be even greater if we had included the Portuguese or Spanish searches. Although the theme already has a considerable number of published works—as indicated by the data in the WoS base—when the filter for the Global South, the most vulnerable region on the planet, the drop is considerable. It is even more significant if we include the descriptor Brazil, a country used here to illustrate a territory of the Global South concretely.

4.1 Scielo

From the first Search on Scielo with the descriptor "Loss and Damage" until November 2022—the eve of COP27—a total of 350 articles were returned, most from the medical (46%), biological (13%), rural production (29%), and related areas. In the second search with the terms (Loss and Damage) AND (Climate) 13 articles returned, highlighting:

- Arévalo, G, Jorge, G. (2020). Challenges of Compensation and Reparation for Loss and Damage Related to the Adverse Effects of Climate Change.

For (Loss and Damage) AND (Climate) AND (Brazil). Only two articles returned, which do not deal directly with the topic; they only permeate the discussion of Loss and Damage when dealing with the effects of climate change, but the subject is not part of the primary purpose of the article:

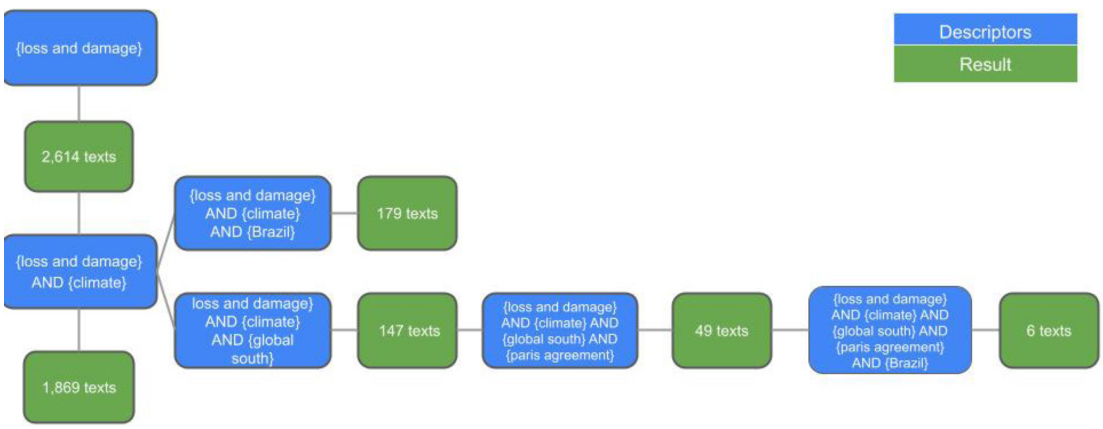


Figure 5. Scopus.

Table 1. Learnings from the database search: WoS, Scopus, Scielo and Redalyc.

Descriptors	WoS*	Scopus*	Scielo	Redalyc	Total
Loss and Damage	89.836	2.614	350	149	92.949
Loss and Damage AND Climate	2.039	1.869	13	52	3.973
Loss and Damage AND Climate AND Global South	118	147	0	28	293
Loss and Damage AND Climate AND Paris Agreement AND Global South	11	49	0	6	66
Loss and Damage AND Climate AND Brazil	67	179	2	16	264
Loss and Damage" AND "Climate" AND "Paris Agreement" AND "Global South" AND Brazil	0	6	0	1	7

*using the "exact search" features.

- Alvalá, R.C.S., Cunha, A.P.M.A., Brito, S.S.B., et al. (2019). Drought monitoring in the Brazilian Semiarid region.
- Regina da Cal Seixas, et al. (2014). Perception of fishermen and shellfish producers on global environmental changes in the Northern Coast of São Paulo State, Brazil.

In the search 'Loss and Damage' AND 'Global South'. Only four articles returned, with little relation to the topic; two of the articles deal only with the issue of Loss and Damage related to health conditions and diseases. The other two articles have a slightly closer relationship. Although they deal specifically with the subject of public health, they bring a correlation between Loss and Damage in the public health sector and floods; both articles were written by the same authors (Minervino and Duarte):

- Millar, A., Joubert, K., Naude, A. (2020). Prevalence of hearing loss and tinnitus in a group of adults with Human Immunodeficiency Virus. S Afr J Commun Disord.
- Hassan-Moosa, R., et al. (2017). Cytomegalovirus retinitis and HIV: Case reviews from KwaZulu-Natal Province.
- Minervino, A.C., Duarte, E.C. (2016). Loss and Damage affecting the public health sector and society resulting from flooding and flash floods in Brazil between 2010 and 2014—based on data from national and global information systems. Cien Saude Colet.
- Minervino, AC, Duarte, E.C. (2018). Material damage caused to public health and society due to inundations and flash floods in Brazil, 2010-2014.

Finally, the search for 'Loss and Damage' AND 'Global South' AND 'Climate' did not return the mention of any article; the same happened for the last search on 'Loss and Damage' AND 'Paris Agreement' did not mention any article.

4.2 Redalyc

The first search in the Redalyc database with the descriptor 'Loss and Damage' returned 149 articles (**Figure 6**), most of them in the large areas of AgroSciences and health. From the second search with the terms 'Loss and Damage' AND 'Climate', try to refine the search for articles dealing with 'Loss and Damage' in the context of climate change, excluding articles in AgroSciences and health. Fifty-two articles returned, most still in AgroSciences, but now followed by administration, accounting, and earth sciences.

- Loss and Damage affecting the public health sector and society resulting from flooding and flash floods in Brazil between 2010 and 2014—based on data from national and global information systems.
- The UN Framework Convention on Climate Change and the Paris Agreement: Challenges of the Conference of the Parties Prolegómenos. Derechos y Valores, 2019.
- Lara, E., Lázaro, T., Michel, S. (2014). Cambio climático: Un negocio de alto riesgo?

The third search with the terms 'Loss and Damage' AND 'Climate' AND 'Brazil'. Sixteen articles returned. The articles originate from the following countries (**Figure 7**):

- Brazil (12), Mexico (2), Portugal (1) and Bolivarian Republic of Venezuela (1).
- Loss and Damage affecting the public health sector and society resulting from flooding and flash floods in Brazil between 2010 and 2014—based on data from national and global information systems.
- Global justice and environmental governance: An analysis of the Paris Agreement. Revista Brasileira de Política Internacional. 2017, 60(1).

The fourth search with the terms 'Loss and Damage' AND 'Climate' AND 'Global South'. Returned twenty-eight articles. The articles originate from the following countries (**Figure 8**):

- Brazil (9), Mexico (5), Colombia (5), Portugal (2), España (2), Costa Rica (2), Puerto Rico (1), Argentina (1), Bolivarian Republic of Venezuela (1).

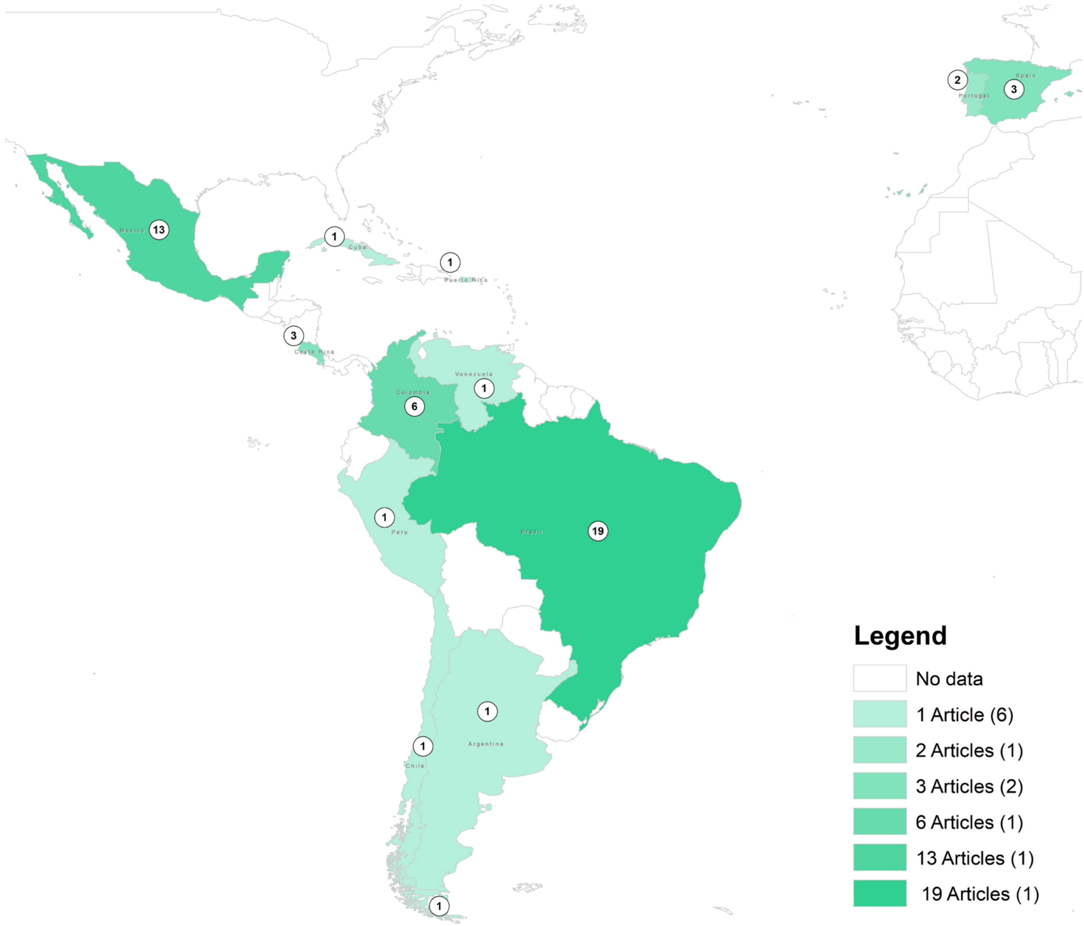


Figure 6. Cartography of Redalyc search.

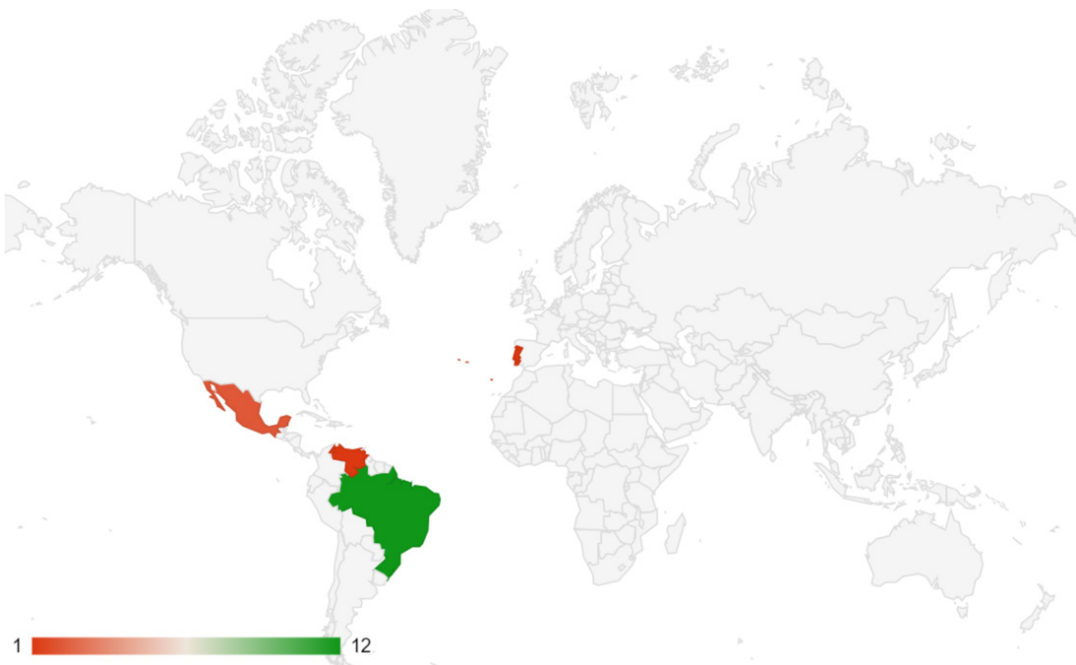


Figure 7. Redalyc global distribution of the results 1.

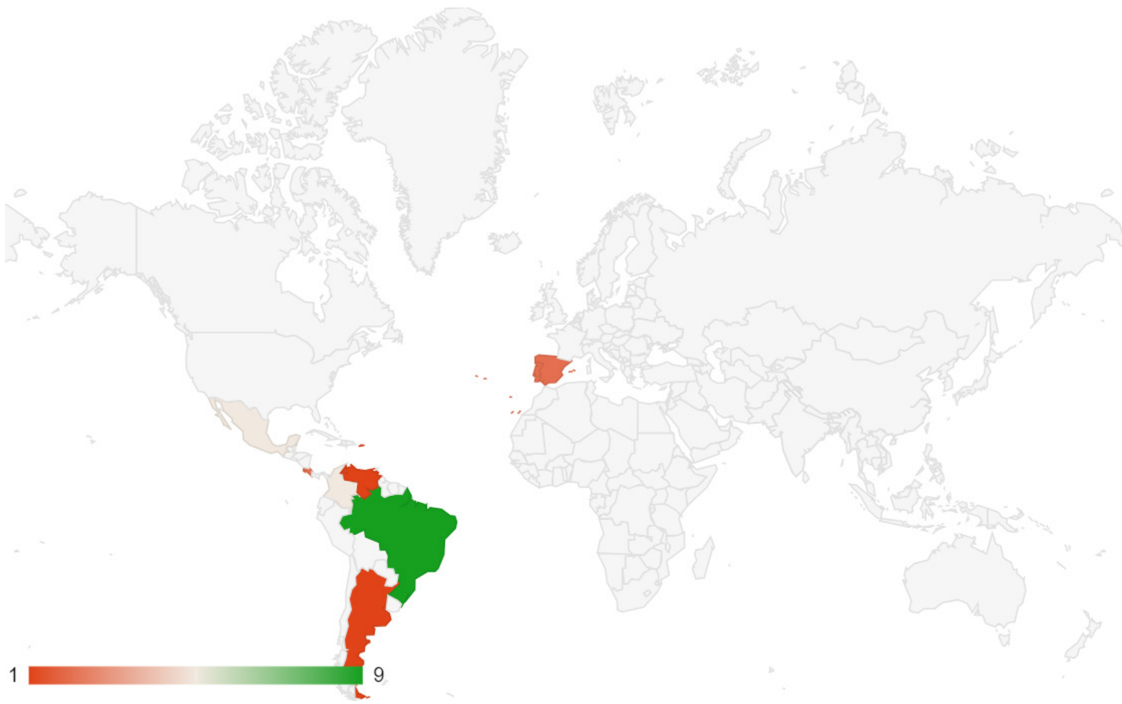


Figure 8. Redalyc global distribution of the results 2.

- Loss and Damage affecting the public health sector and society resulting from flooding and flash floods in Brazil between 2010 and 2014—based on data from national and global information systems.
- The un Framework Convention on Climate Change and the Paris Agreement: Challenges of the Conference of the Parties Prolegómenos. Derechos y Valores, 2019.
- Lara, E., Lázaro, T., Michel, S., et al. (2014). Cambio climático: Un negocio de alto riesgo?

The fifth search with the term "Loss and Damage AND Climate AND Global South AND Paris Agreement". Six articles returned. The articles originate from the following countries:

- Portugal (2), México (2), Costa Rica (1), Brazil (1).
- International climate framework in the making: The role of the basic countries in the negotiations towards the Paris agreement. (2016).

The sixth search with the terms 'Loss and Damage' AND 'Climate' AND 'Global South' AND 'Paris Agreement' AND 'Brazil'.

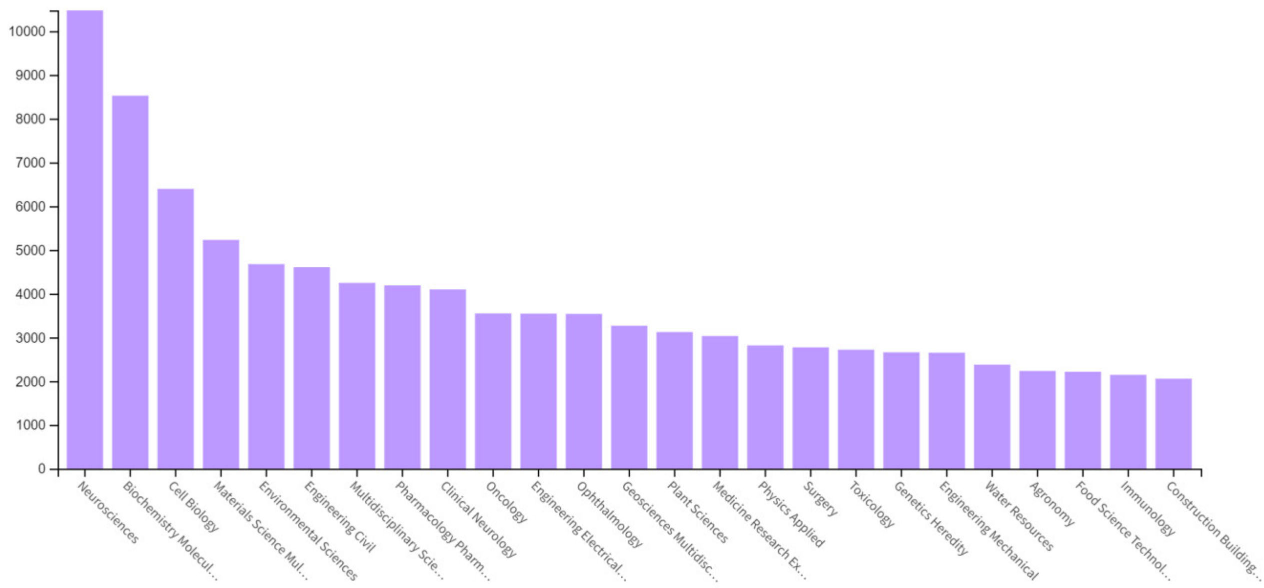
Returned only one article.

Brazil (1)

- Bueno, M.D.P., Pascual, G. (2016). International climate framework in the making: The role of the basic countries in the negotiations towards the Paris agreement.

4.3 Web Of Science (WoS)

The first Web of Science search used the descriptor "Loss and Damage", which returned 115,314 studies. WoS includes articles, book chapters, notes, editorial material, and news items. WoS already shows in graphs (**Graphic 1**) which area most studies are in, and the first ten areas were: Neurosciences, Biochemistry Molecular Biology, Cell Biology, Materials, Multidisciplinary Science, Environmental Sciences, Civil Engineering, Multidisciplinary Sciences, Pharmacology Pharmacy, Clinical Neurology, Oncology. WoS's filters were applied using the same descriptor, including areas of environment and social sciences. Forty-nine inclusion filters were applied, and it returned 24,477 texts.



Graphic 1. WoS most studies on Loss and Damage.

Of the "most cited first" and the first ten articles, six were still in medicine. The 6th was in the environmental area, about invasive species in the USA. The 7th text was closer to the theme, as it was about the destruction caused by cyclones in the last 30 years. The 8th article focuses on the loss of crops to pests. Finally, the 10th text researches the loss of plantations to drought (water stress).

The second search with the descriptor 'Loss and Damage' AND 'Climate' returned 3,296 articles. Exclusion filters were applied, excluding the study areas: Sport Sciences, Reproductive Biology, Radiology Nuclear Medicine Medical Imaging, Optics, Computer Science Theory Methods, Pharmacology Pharmacy, Engineering Aerospace, Biochemistry Molecular Biology, Astronomy Astrophysics, Computer Science Information Systems, Physiology. Environmental Sciences is the area with the highest scientific production using the two descriptors 'Loss and Damage' + 'Climate'.

The third search with 'Loss and Damage' AND 'Climate' AND 'Global South' returned 178 articles. Sorting them by "most cited first" analyzing the titles and abstracts of the first 5, which only contained the terms 'Loss and Damage', and sometimes not together, just as separate words, and therefore, outside the topic. Note: Even the articles focusing on climate change did not have 'Loss and Damage' as a clear concept mentioned in the abstracts.

The final and fourth search with 'Loss and Damage' AND 'Climate' AND 'Global South' AND 'Paris Agreement' returned thirteen articles (**Figure 9**).

Eight of the thirteen articles had 'Loss and Damage' directly cited in the abstract. From the summaries of the thirteen, seeking to identify if they discussed a little about 'Loss and Damage' or if they only quoted, five articles were found:

- Mechler, R., Singh, C., Ebi, K. et al. (2020). Loss and Damage and limits to adaptation: recent IPCC insights and implications for climate science and policy.
- Mayer, Benoit. (2017). Migration in the UNFCCC Workstream on 'Loss and Damage': An Assessment of Alternative Framings and Conceivable Responses.
- Winkler, H. (2020). Putting equity into practice in the global stocktake under the Paris Agreement.
- Jacobs, M. (2022). Reflections on COP26: International Diplomacy, Global Justice and the Greening of Capitalism.
- Puig, D. (2022). Loss and Damage in the global stocktake.

Using the WoS "exact search" feature with the

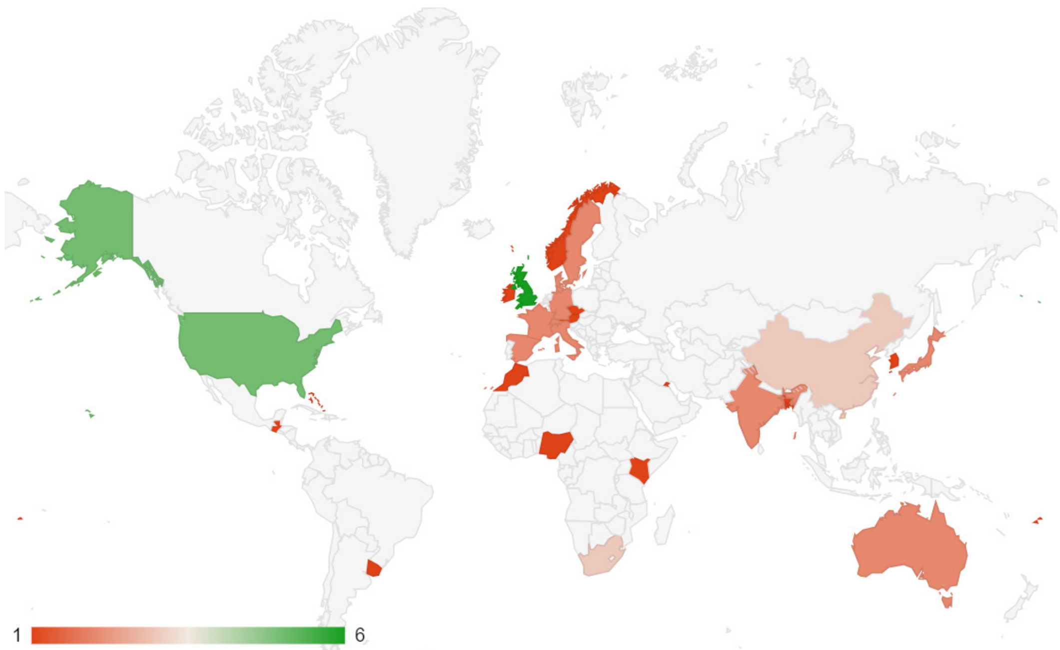


Figure 9. WoS global distribution of the results.

'Loss and Damage' descriptor, the search returned 89,836 articles. Even so, classified by "most relevant first", articles related to the environmental dimension appear. With the ratings "recently added", "newest", "oldest", "most cited", "least cited", and "use: all the time", the top ten are not related to the environment in general but to medicine. The second exact search, 'Loss and Damage' AND 'Climate', returned 2,039 articles. On the other hand, the third exact search, 'Loss and Damage' AND 'Climate' AND 'Paris Agreement', returned 66 articles. In this search, the titles and abstracts of the first ten articles discuss the concept of 'Loss and Damage', and the 7th article discusses 'Climate Justice'.

Fourth exact search "Loss and Damage" AND "Climate" AND "Paris Agreement" AND "Global South" returned 11 texts. Analyzing the abstracts of the eleven, all discuss Loss and Damage directly related to climate change, except for the two highlighted in orange below. Origin of the thirteen articles:

- Winkler, H. (2020). Putting equity into practice in the global stocktake under the Paris Agreement.
- Puig, D. (2022). Loss and Damage in the global stocktake.
- Mayer, Benoit, (2017). Migration in the UNFCCC Workstream on 'Loss and Damage': An Assessment of Alternative Framings and Conceivable Responses.
- Mechler, R., Singh, C., Ebi, K. et al. (2020). Loss and Damage and limits to adaptation: recent IPCC insights and implications for climate science and policy.
- Mead, S., Wewerinke-Singh, M. (2021). Recent Developments in International Climate Change Law.
- Skeie, R. B. et al. (2017). Perspective has a strong effect on the calculation of historical contributions to global warming.
- Jacobs, M. (2022). Reflections on COP26: International Diplomacy, Global Justice and the Greening of Capitalism.
- Pretis, F., Schwarz, M., Tang, K., et al. (2018). Uncertain impacts on economic growth when stabilizing global temperatures at 1.5 °C or 2 °C warming.
- Yumashev, D., Hope, C., Schaefer, K., et al. (2019). Climate policy implications of nonlinear decline of Arctic land permafrost and other cryosphere elements.
- Klinsky, S, Winkler, H. (2018). Correction to 'Building equity in: strategies for integrating

equity into modelling for a 1.5 °C world'.

- Angulo, E., Hoffmann, B.D., Ballesteros-Mejia, L. et al. (2022). Economic costs of invasive alien ants worldwide.

Of the eleven, only one focuses on the Global South:

- Mead, S. Wewerinke-Singh, M. (2021). Recent Developments in International Climate Change Law.

4.4 Scopus

The first search used "exact term" in the Scopus database, which is identified by the square brackets {loss and damage} and returned 2,614 texts. The two major areas of the articles are Environmental Sciences (1,292) and Social Sciences (1,124), followed by Earth and Planetary Sciences (663). Adding the application of filters to exclude areas: Medicine, Biochemistry, Genetics and Molecular Biology, Physics and Astronomy, Neuroscience, Pharmacology, Toxicology and Pharmaceutics, Immunology and Microbiology, Veterinary, and Dentistry 2,262 texts returned.

The second search {loss and damage} AND {climate} returned 1,869 texts. In comparison, the third search {loss and damage} AND {climate} AND {global south} returned 147 texts within the areas: of Social Sciences (115), Environmental Science (76), Earth and Planetary Sciences (30), and others.

On regions/countries of the studies, results bring a predominance of papers from the Global North, United States, and United Kingdon among the firsts: United States (48), United Kingdom (30), Canada (21), Germany (20), Australia (18), Netherlands (12), South Africa (11), and others (**Figure 10**). Brazil appears with only one publication: Simpson, N.P., Clarke, J., Orr, S.A., et al. (2022). Decolonizing climate change-heritage research. Nature Climate Change. 12(3), 210-213. https://doi.org/10.1038/s41558-022-01279-8

Fourth search {loss and damage} AND {climate} AND {global south} AND {Paris agreement} returned 49 texts along areas such as Social Sciences (40), Environmental Sciences (31), and Earth and Planetary Sciences (8). With these filters, the regions/countries are the US (16), Canada (7), UK (7), Netherlands (5), and others below 5 (**Figure 11**). Brazil does not appear.

Adding a new filter {loss and damage} AND {climate} AND {Brazil}, the search returns 179 texts along the areas: Environmental sciences (102), Social sciences (86, Earth and Planetary Sciences (51), then all areas under 15 articles. Articles generally address extreme events, such as droughts and heavy

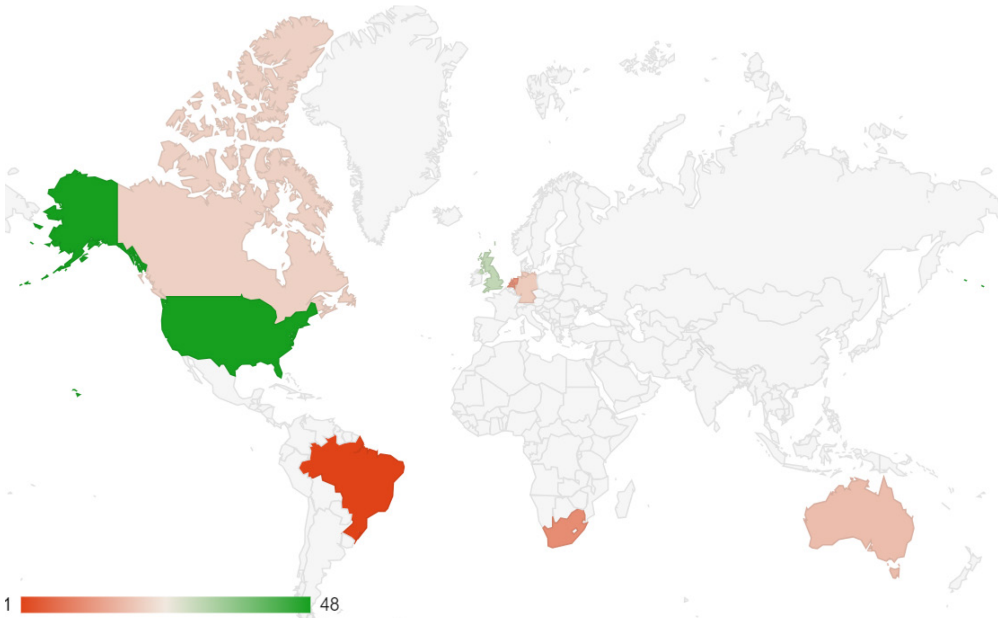


Figure 10. Scopus global distribution of the results 1.

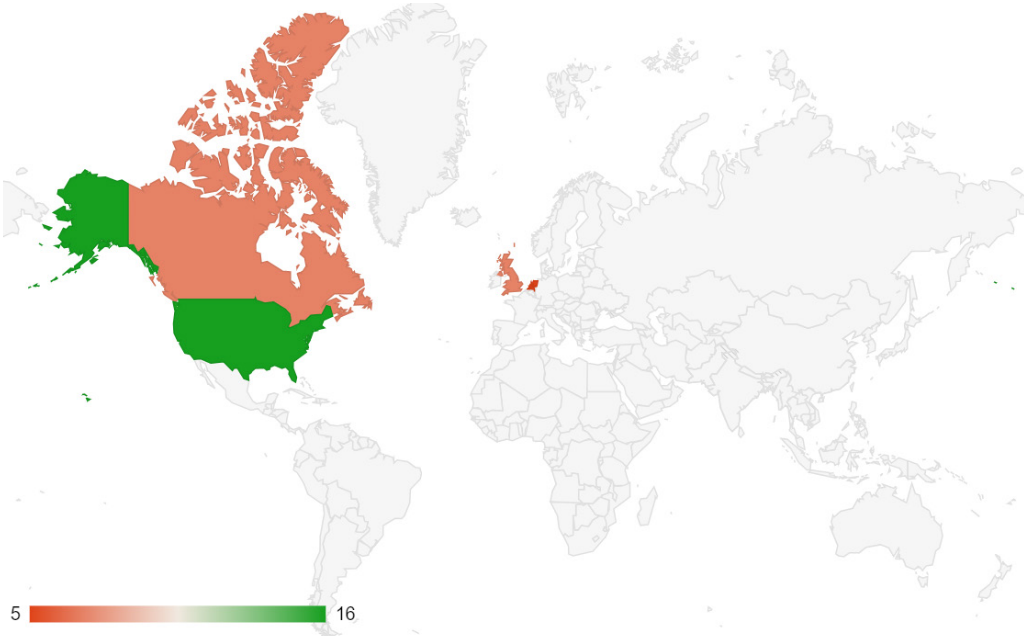


Figure 11. Scopus global distribution of the results 2.

rains. Regions/countries: Interestingly, even with the descriptor {Brazil}, the countries that produced the most in this search were the United States (45), United Kingdom (35), Germany (31), Brazil (24), Canada (21), the others, under 17 articles (**Figure 12**).

Finally, a new search with all keywords {loss and damage} AND {climate} AND {global south} AND {Paris agreement} AND {Brazil} returned six texts. The areas were: Social sciences (5), Environmental sciences (3), Regions/Countries (**Figure 13**): India (2), China (1), Italy and Spain (1), USA (1), Undefined (1).

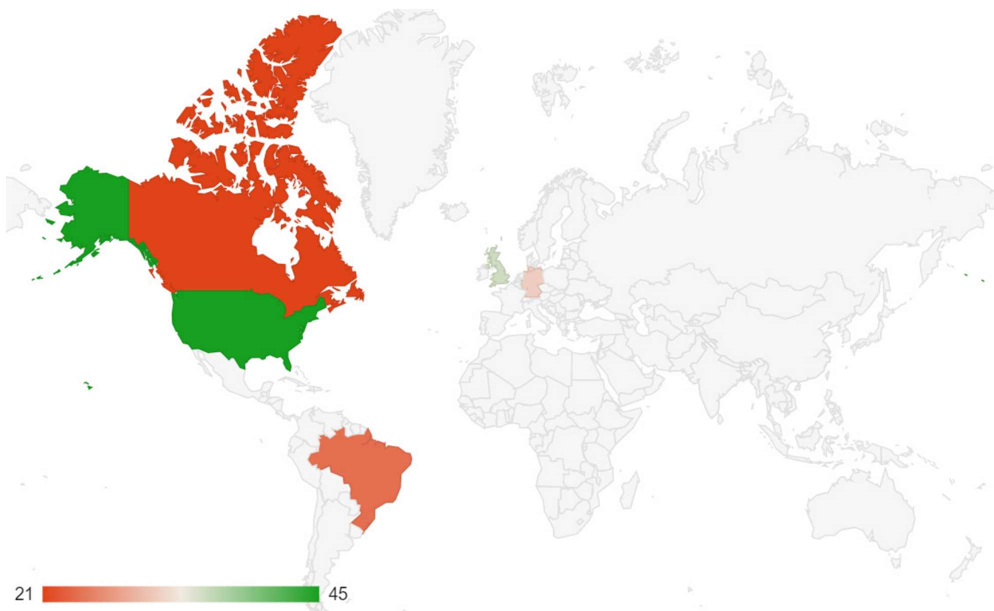


Figure 12. Scopus global distribution of the results 3.

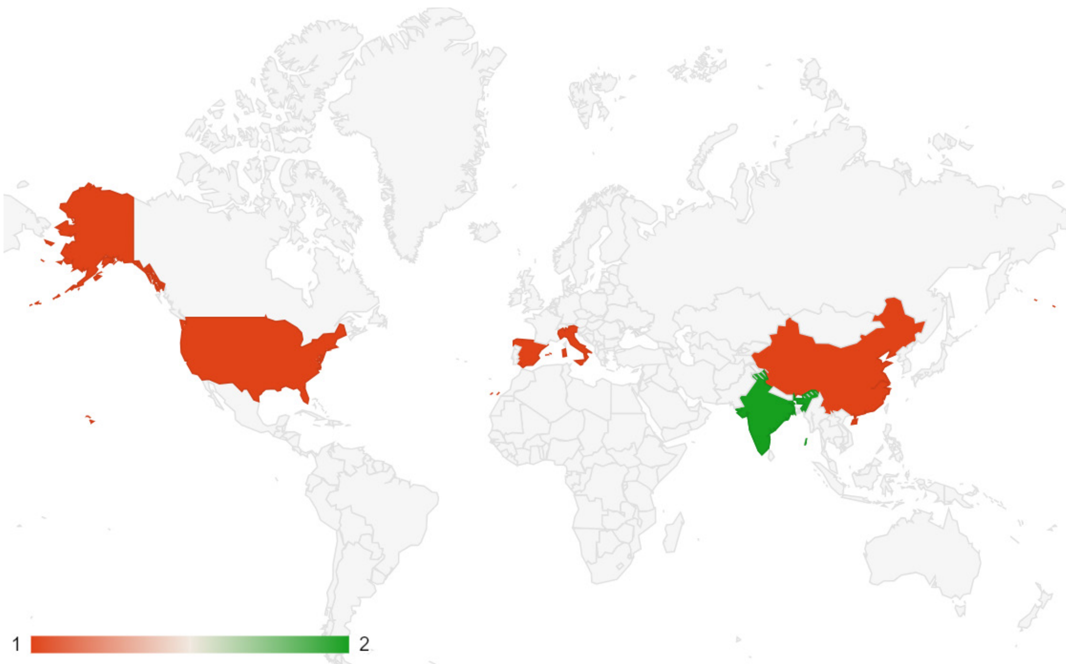


Figure 13. Scopus global distribution of the results 4.

5. Discussion

Despite the progress of establishing a Loss and Damage fund at COP27, it is essential to emphasize that the debate on Loss and Damage goes beyond the economic aspects involved. Through an interdisciplinary analysis, Balzter et al. (2023) show that it is necessary to consider the complexity involved in managing the fund, considering the difficulty in monitoring and implementing the fund in a just way. In addition, it is vital to take into account the frequent inadequacy of plans for climate adaptation, which are often done top-down when they should be co-constructed with local communities, an essential aspect for the Loss and Damage associated with climate change to be at the core the cultural specificities of the communities.

Dialoguing with the above statements, Adger [24] states that "The Loss and Damage issue is a further manifestation of the requirement for solidarity and recognition of the multi-dimensional injustices of climate change" and that:

"Loss and Damage brings the issues of climate justice into sharp relief: climate change is not simply about technologies, carbon markets, and alternative imagined futures, but about the lived experience of climate change consequences for life and livelihoods" (Adger, 2023, p. 147).

Therefore, it is necessary to advance in the concrete implementation of a fund for Loss and Damage without losing sight of the fact that climate change is a phenomenon permeated with injustices and that the construction of responses must have as a central focus the communities that are the target of these injustices, as this reduces. There is the risk of an ineffective fund that is incapable of adapting and reproduces injustices. This brings us back to the initial issue in this paper of the importance of differentiating policies, plans, and programs aimed at Loss and Damage from those specific to adaptation. Differentiating this seems essential even from the point of view of financial distribution and hierarchy in public management, the payment of climate debts between rich and historically more polluting countries on an international scale, and the specific strengthening of climate capabilities and constituencies in the territories.

Results indicate that despite recent severe events in the Global South, such as floods in Pakistan, droughts in India, hurricanes in Mozambique, or droughts, fires, and floods in Brazil, Loss and Damage remains a theme predominantly focused on or produced from the Global North. Within the Global South, Brazil stands out among the countries mentioned. According to research carried out on the WoS database of 118 works found in the Global South on Loss and Damage, more than half (67) include the country. It is also possible to learn from the research that there is a considerable discrepancy in the research bases, which can bring problems and biased results in future review research.

It is still too early to understand the nuclei, fields, and subfields of study on the topic of Loss and Damage from the results generated. However, as shown in the figures below (**Figures 14 and 15**), the theme of climate change is the nucleator; others, such as pollution, the ocean, and the Paris Agreement, are emerging among the themes addressed in the research.

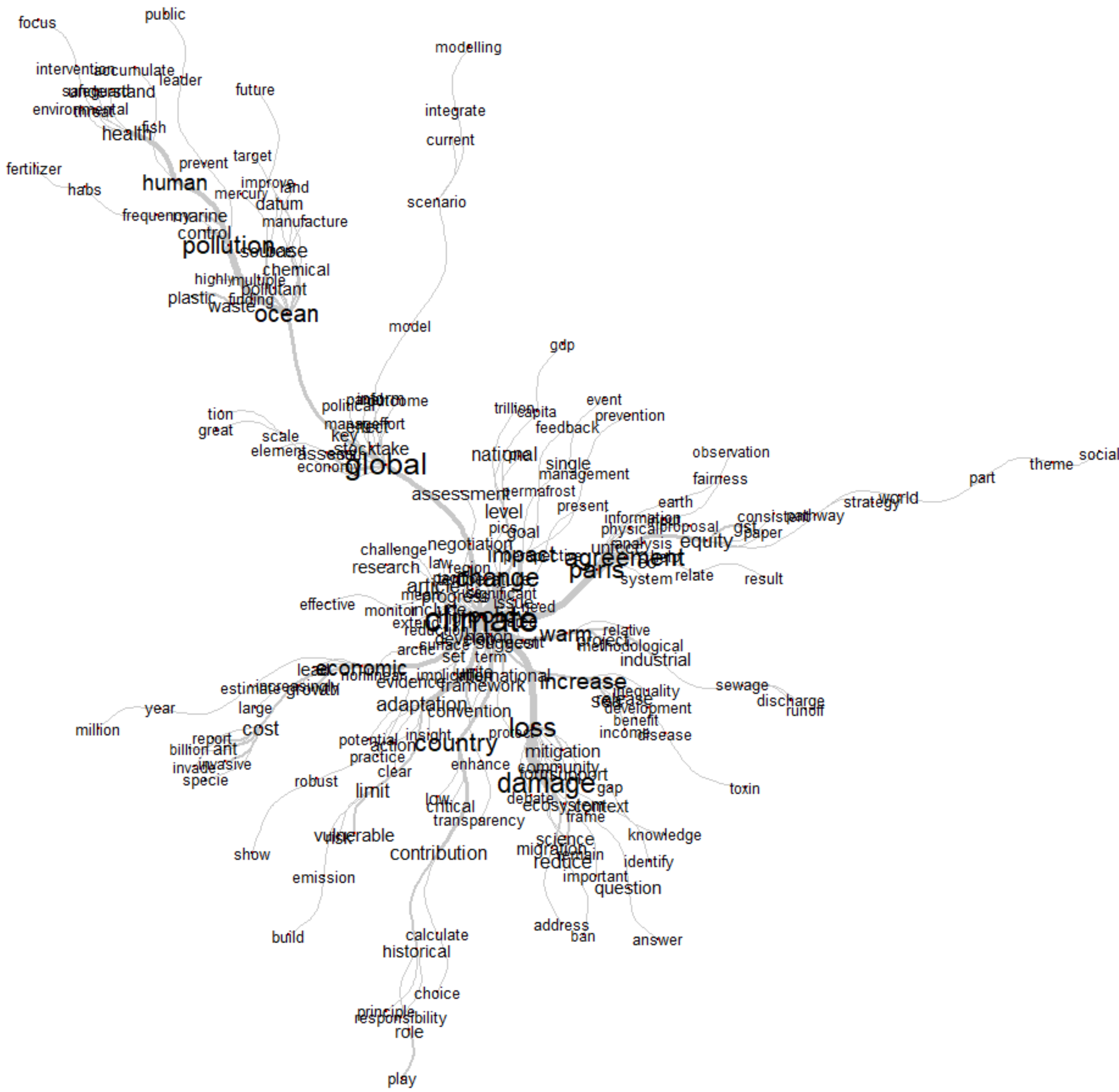


Figure 14. Issues addressed by Loss and Damage papers.

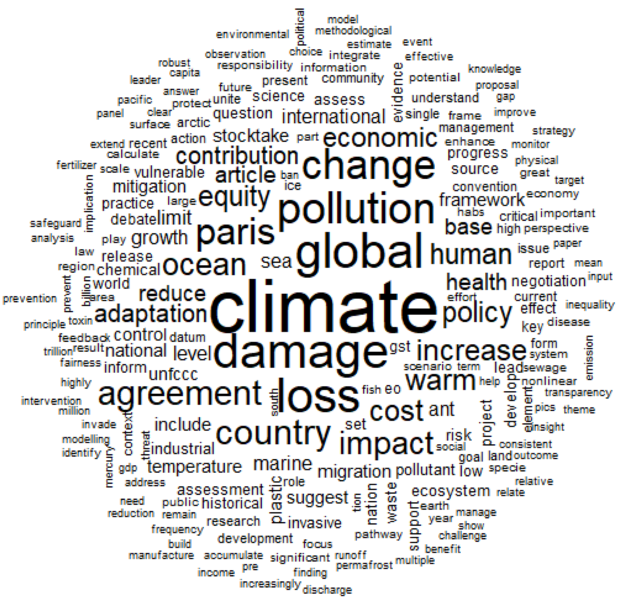


Figure 15. Word clown with main cited terms among the articles.

6. Conclusions

The present work contributes to reducing the knowledge gap that exists on Loss and Damage—related to climate change—academic production. The article contributes to understanding the challenges and opportunities presented by climate change adaptation and planning, focusing on the Global South. It seeks to address inequality, environmental justice, and climate justice while discussing the potential impacts of Loss and Damage. The illustrative case of Brazil sheds light on these topics and offers insights that could be applicable to other countries in similar contexts.

Urban and regional planning in the face of climate change must incorporate dialogue with what Quay [11] proposes as anticipatory governance and uncertainty, shifting business as usual planning system for a new one. Conversely, especially in the Global South, the problem must be tackled with two complementary fronts: adaptation to the climate and social inequalities. In this sense, the debate on justice (climate justice and climate colonialism) and inequality need to be contained in the planning, not only including the communities in the planning process but also creating arenas in which they can propose and plan their demands, equipping them with the available scenarios and technologies that expose the risks and their vulnerabilities. It is also essential to ensure that the global-local (glocal) understanding distinguishes the cross-scale dimensions of ecosystem services that will be impacted and must be confronted locally from a regional perspective, especially in megacities or city regions.

This will be fundamental to advance both the climate change adaptation agenda and the Loss and Damage policies that should emerge in the coming years. Differentiating, training, planning, and managing these issues are challenges that planners and managers must recognize in the face of the climate emergency and the data presented by the scientific community and by communities and traditional and ancestral knowledge.

Author Contributions

Conceptualization, P.H.C.T.; Data curation, P.H.C.T, B.D.D, I.C.C; Formal analysis, P.H.C.T., G. P. A; Investigation, P.H.C.T, G.P.A, B.D.D, I.C.C, M.T. A.F.; Methodology, P.H.C.T; Supervision, P.H.C.T; Validation, P.H.C.T, G.P.A, M.T. A.F. Writing—original draft, P.H.C.T, G.P.A; Writing—review & editing, P.H.C.T. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

There is no conflict of interest.

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ARTICLE

The Problems and Measures for Small Tourism Town Development in China: A Case Study of Wan Town

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ABSTRACT

With the rapid development of tourism and urbanization in China, small tourism towns gradually grow toward prosperity. This paper takes Wan Town as an example to analyze the problem and countermeasures concerning the development of small tourism towns in China. There are a series of issues in the process of development of Wan Town, which includes uncoordinated architectural style, inaccurate market positioning, repeated cultural themes, and vulnerable linkage of the industrial chain. Based on the factor analysis, these development issues were classified into three categories: confusing architectural style, repetitive cultural theme, and weak linkage of industrial chain. To achieve the goal of sustainable development of small tourism towns, some countermeasures must be taken which include promoting the development of small tourism towns with the new rural revitalization, strengthening services improvement in small tourism towns, gathering industrial elements related to the tourism industry, and increasing tourism cultural connotation.

Keywords: Tourism; Small tourism towns; Tourism planning; Wan Town

1. Introduction

With the vigorous development of tourism and driven by urbanization, a large number of small tourist towns with distinctive characteristics and beautiful environments have emerged in China. However, academics have different focuses on the definition of small tourism towns. Meng (2002) believes that small towns that can attract foreign tourists are called small tourism towns [1]. Tomoko (2009) believe that most people perceive both positive and negative impacts of tourism [2]. Tourism-based small towns

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promote the development of regional economic, and social progress through tourism resource integration, tourism service support, and tourism facilities improvement. At the same time, compared with general small towns, small tourism towns have certain inherent characteristics, such as population mobility due to the function of tourist reception, the orientation of tourism service function, and the development model relevant to the tourism industry. In particular, small tourism towns pay more attention to the creation of cultural landscapes [3].

With the gradual development of tourism, from the end of the 20th century to the beginning of the 21st century, small tourism towns have gradually become a mainstream small town development form as an effective way to promote urbanization [4]. At the national level, to protect and make use of the characteristic landscape resources of villages and towns, promote the development of the new socialist countryside, and coordinate the development of urban and rural areas, China has vigorously carried out the national famous towns (villages) with characteristic landscapes for tourism, which has tremendously promoted the standardized development of small tourism town.

In the context of new urbanization, small tourist towns have become one of the important types of characteristic small towns in China [5]. However, in the process of tourism development, the production-living-ecology space in the small tourist towns of southern Jiangsu presents a problem of imbalance [6]. Since the concept of "characteristic town" in Zhejiang Province was presented in 2014, other cities in China have also borrowed and transformed according to their own actual situation, dividing them into different cities and small towns, so that tourism of "characteristic town" can develop rapidly [7]. This paper takes Anhui Province Wan Town as an example analysed the problems existing in the development of Wan Town, and puts forward a series of countermeasures for the similar domestic small tourism towns.

2. Methodology and brief description of the Wan Town

2.1 Study methodology

According to the research targets of this paper, the method of the case study was used to analyze the problems of measures in Wan Town. In the study, firstly, we conducted field visits to Wan Town, collected related information and documents on architectural style, commercial operation, cultural theme, industrial chain, etc., and then organized interviews among managers, operators and tourists in Wan Town, they were asked to fill in a questionnaire on relevant issues to systematically understand the different views of stakeholders to the problems and measures of Wan Town in the process of development, and finally a systematic summary and generalisation was carried out to form the main conclusions of the study.

2.2 Case study area

Wan Town is located in Qianshan City, Anhui Province, 3 kilometers away from the main scenic spot of Tianzhu Mountain, which is a national 5A level scenic spot in Anhui Province, China (**Figure 1**). Backing by the mountain and facing the water, closely depending on the famous Three Ancestors' Zen Temple in Anhui Province and other attractions, Wan Town is a high-quality tourism comprehensive services center that integrates the functions of traveling, shopping, catering, lodging, holiday, entertainment and recreation. Wan Town was designed and developed with the main idea of reproducing the culture of Anhui, and it consists of an ancient theatre, an ancient Anhui food street, tourist goods shopping street, a star hotel, an Anhui culture park, an entertainment center and other business buildings. The first phase of the project covers a total area of about 7 hm^2, with a total development area of about 60,000 m^2.

The reasons why choosing Wan Town as a case in this article are attributed to the significance of developing the small tourism towns in Qianshan City.

Firstly, studying Wan Town can help us fully explore the historical lineage between Qianshan City and the outside world by building some characteristic tourism projects such as "Anhui Cultural Park", "Ancient Theatre", and "Wan Mountains Cuisine Street", etc. The second one is to make Wan Town turn into a comprehensive high-quality tourism service center in Anhui Province, and to improve the taste and grade of tourism services in Tianzhu Mountain Circle. Thirdly, in terms of the architectural design, the overall planning of the ancient town pattern and the buildings with the characteristics of Anhui culture in Wan Town was used to create a small tourist town with a strong cultural heritage. From the perspective of development mode and power mechanism, Wan Town was formed and developed under the joint action of tourism real estate, small town development and scenic area expansion, which belongs to the comprehensive model of small tourism towns.

Figure 1. Location of Wan Town in Qianshan City.

3. Typological patterns of small tourism towns

Small tourism towns are an important type of small town. In the process of China's accelerated urbanization and moving towards the post-industrialization era, small tourism towns have shown vigorous development momentum and great development potential because they can correspond to the changing needs of the market [8]. Small tourism towns in developed countries are generally the most beautiful places in the whole country, Residential function is a unique characteristic of the Disneyization of cultural tourism towns in China [9]. Generally speaking, small tourism towns are small towns that have richer natural and humanistic tourism resources, which can provide corresponding sightseeing, leisure, business services, and some other tourism economic activities. According to the division of tourism resources, small tourism towns are divided into the following types: natural resources-based small tourism towns, humanities and landscape resources-based small tourism towns, mixed resources-based small tourism towns, and special service-based small tourism towns [10]. In terms of the formation mechanism of small tourism towns, there are four main types of small tourism towns, namely, ancient cultural towns, new type towns, tourism real estate towns, and scenic spot expansion towns.

3.1 Ancient cultural towns

Ancient cultural towns relying on good resource conditions become an important part of China's village tourism, especially in the Chinese Jiangnan-water-towns. Ancient villages in southern Anhui Province, Shanxi compound, and other representatives of the world's cultural heritages were typically renowned tourism resources. The art and cultural value of a tourist town is the whole of mankind's common spiritual wealth. Ancient cultural towns not only have always been a hot spot for tourism, but have also gradually become an important form of tourism as China's small tourism towns, the strong demand of the tourism market is the main driving force for the development of this type of small tourism town.

3.2 New type towns

The rapid development of tourism often brings certain pressure to the reception of tourism towns, when the old tourist towns can not meet the demand for tourism services. The center of the tourist city generally needs to build new towns to ease the pressure of reception during the peak season. This kind of movement can absorb more rural population into the small towns to work and live. Through the planning of tourism projects and the development of tourism service facilities, the new areas of small towns are built to become new tourism functional areas, promoting the development of the original small towns while the new areas of the towns become tourism attractions, increasing the reception capacity of the tourist towns, enhancing its cultural charms, and forming brand-new tourist small towns.

3.3 Tourism property towns

Tourism real estate is a rapidly developing mode of real estate, relying on the influence of well-known scenic spots, and Tianzhu Mountain. Tourism property towns have become the most promising type of real estate. Tourism property towns have obvious market-oriented characteristics, such as holiday centers, health bases, shopping blocks, cultural communities, etc. This type of tourism real estate project can be aggregated into small tourism towns after development to a certain scale. The market price of tourism real estate is generally higher than other local commercial property, its premium comes from the popularity of the surrounding scenic spots and the excellent environment. Furthermore, the natural and humanistic attractions of the tourism real estate can create an intangible added value.

3.4 Scenic spot expansion towns

In recent years, in order to limit the spatial capacity of historical cultural towns, preserving the heritage of historic towns has become an urgent task. Many historical cultural towns and scenic spots have implemented the scenic area expansion plan, this kind of initiative led to the boost of a large number of scenic spot expansion towns. For example, as early as 1958, Lijiang in Yunnan Province, China had established the "protection of the ancient city, another new city" scheme. "Mountain upstream, under the mountain to live" strategy comes from the Huangshan Mountain Scenic Area in Anhui province. China has greatly spawned the development of small tourist towns such as Tangkou Town, and Phoenix Ancient City in Hunan province. China carried out the initiative of building a new tourist town to protect the cultural relics and monuments of the ancient town as a whole. Scenic spot expansion towns and historical cultural towns complement each other in the field of tourism reception function so the formation of scenic spot expansion towns can improve the configuration of the entire scenic area, and promote the sustainable development of regional tourism.

4. Problems in the development of small tourism towns

China's small tourism town development has just started, Wan Town, as a typical small tourism town in Anhui province, is also at the exploratory stage regarding how to coordinate the relationship between regional tourist attractions and small town development, there are a series of problems and deficiencies in the process of development.

Based on the interviews and research with government managers, operators and tourists, this paper conducts a factor analysis to the problems of Wan Town in the process of development, and the empirical study found that the key problems existing in the small tourism town include three types, one is the "F1 confusing architectural style", the second is "F2 repetitive cultural theme", and the third is "F3 Weak linkage of industrial chain" between the tourism industry and other industries. The eigenvalues of the three types of common factors are 3.546, 2.561, and 4.201, and the variance contribution rate is 34.31%, 33.37%, and 31.28% respectively. The reliabilities of the male factors are all between 0.77 and 0.88, with good internal consistency within the common factors, high sample reliability, and good reliability of the indicator data (**Table 1**).

4.1 Confusing architectural style

Generally speaking, the architectural style of a tourist town needs to be consistent in order to form a good image for tourists; otherwise, chaotic architecture tends to lead to a decline in the quality of the tourist experience. Wan Town has a comprehensive tourism functions system and can carry out tourism reception, tourism catering, tourism entertainment and other functions thanks to its completed tourism indus-

Table 1. Factor analysis of stakeholders' perceptions of the problems of Wan Town.

Factors	Factor variable	Loading	Mean	Reliability	Eigenvalue	Variance contribution rate (%)
F1 Confusing architectural style	Lack of uniformity in architectural style	0.783	4.21	0.88	3.546	34.31
	Anhui style of architecture is not distinctive	0.694	4.13			
	Architectural iconic elements are not attractive enough	0.682	4.25			
	Architectural style not in harmony with surrounding environment	0.575	3.76			
F2 Repetitive cultural theme	The Tourism catering cultural theme is repetitive	0.874	3.79	0.79	2.561	33.37
	The tourism shopping cultural theme is repetitive	0.793	3.76			
	The tourism entertainment cultural theme is repetitive	0.773	3.65			
	The tourism hospitality cultural theme is repetitive	0.706	3.46			
F3 Weak linkage of industrial chain	Linkage between cultural industries and tourism is weak	0.758	3.72	0.77	4.201	31.28
	Linkage between entertainment industries and tourism is weak	0.745	3.85			
	Linkage between modern service industry and tourism is weak	0.712	4.10			
	Linkage between other pillar industries and tourism is weak	0.689	3.77			

try chain. The main building of Wan Town consists of ancient Anhui food street, ancient theatre, tourist commodities street, star hotel, leisure and entertainment center, etc. The core tourist area adopts the whole Chinese classical architectural style, which is elegant, dignified, and without losing the modern atmosphere, particularly, the Anhui style is the main tone, and the "black tile, white wall, big roof" is the characteristic of these buildings. Adjacent to the new town area are the original residential houses and shops along the street, most of which are self-built two-storey buildings with different styles and scattered distribution. The shops distributed along the road are mainly of Huizhou style, with distinctive features of "pink walls, green tiles, and horse-head walls". On the whole, the entire town of modern architectural style and Anhui style mixed, not very coordinated, and the visual effect seems out of place (**Figure 2**).

Figure 2. Confusing architectural style in Wan Town.

4.2 Repetitive cultural theme

A cultural theme is the soul of a small tourism town, novel tourism theme can increase the attractiveness of a tourism town and popularity. Wan Town tries to promote the "Anhui culture" revival and adapt to the role of the Tianzhu Mountain Scenic Area service center. However, the cultural theme of Wan Town is seriously homogenised with the surrounding scenic spots and tourist facilities, and has not formed its own distinctive features (**Figure 3**). Tianzhu Mountain Scenic Area has successfully become a world Geopark and the national 5A scenic spot, Qianshan City, Wan Gong Square, Wan cultural style park and other tourist attractions are making Wan culture as their cultural theme. Therefore, Wan Town also needs to be characterised by the theme of

Anhui culture, drawing on and absorbing elements of Hui culture to create a representative tourism node, so that Wan Town can improve tourist satisfaction and crack the difficulty of the similarity of tourism cultural themes.

Figure 3. Repetitive cultural theme in Wan Town.

4.3 Weak linkage of industrial chain

Small tourism towns development has different dynamic mechanisms, local advantageous industries can directly support the development of small tourism towns. As a comprehensive industry, the development of tourism towns requires the support of agriculture, handicrafts and tertiary industries, and the formation of a complete industrial chain is crucial to the sustainable development of small tourism towns. However, at present, the industrial chain of Wan Town has a relatively low degree of association, and it is difficult to build a complete industrial supply chain, so it is necessary to strengthen the allocation capacity of industrial factors. Qianshan City, where Wan Town is located, is a famous tourist destination in China, where natural sightseeing and cultural experience tourism are both developed, and leisure and holiday tourism is under rapid development. As the most important tourist town in Qianshan City, Wan Town has gradually become the main business centre of catering, entertainment, and accommodation since it was put into the market in 2010. But other projects have not yet played the expected roles, 35% of the tourist commercial street is in an inactive state, and the current tourism industry chain is relatively short. In particular, the low linkage between tourism and other industries has seriously affected the sustainable development of Wan Town (**Figure 4**).

Figure 4. Weak linkage of industrial chain in Wan Town.

5. Measures for the development of small tourism towns

5.1 Integration with the development of new rural areas

The development of a new socialist village is a major historical task in the process of China's modernization. Many regions across China are exploring various ways of building new socialist countryside through the model of small tourism towns relying on their resource advantages. The tourism industry utilizes the "tourism to promote agriculture" scheme to participate in the development of new socialist villages actively at the same time. Many vigorously small tourism towns played a comprehensive role in the overall coordinated economic and social development. New rural development is one of the important driving forces for the development of small tourism towns, not only can expand the tourism market effectively but also can help to implement the national "three rural" policy to obtain government preferential subsidies and support. Integrating the resources of tourism towns and neighbouring areas to form a pattern of complementary advantages is conducive to extending the industry chain of small tourism towns and enhancing its core competitiveness.

5.2 Docking the spatial pattern of town expansion

Under the background of rapid urbanization, spatial expansion of major towns becomes inevitable. Docking the regional town planning scheme, integrating the development of tourism towns with town expansion, optimizing the functional structure and spatial layout of tourism towns through building new small tourism towns, tourism service centers, tourism real estate and other forms, while increasing the attractiveness of the tourism towns themselves. Wan Town is spatially located in Qianshan City, the 105 National Highway is closely linked to the two tourist towns, in the new round of town planning in Qianshan City, Wan Town will undertake the spillover of Qianshan City's tourism function. After about 10 years of development, Wan Town will definitely become a regional tourism service centre, which will greatly improve the tourism product system of Qianshan City and optimize the structure of regional tourism services.

5.3 Strengthening the supporting service function of tourism

The small tourist town is an important support way and guarantees for the development of tourism resources. A fully functional small tourist town is not only the gathering and dispersing place for tourists and the concentration of tourism facilities, but also the organizational center of regional tourism resources development [11]. Wan Town had planned to develop a series of tourism-supporting projects including hotels, leisure and entertainment centers, cultural display halls, tourism shopping malls, and these functional facilities need to be further strengthened. As the hometown of Huangmei Opera, relying on the cultural advantages of Qianshan City, Wan Town has great potential to build Anhui Huangmei Opera tourism, culture, and entertainment center by using the facilities of the ancient opera house. At the same time, it can combine intangible cultural heritage resources such as Qianshan black pottery and Shu Mat making to increase the functions of tourism commodity design and production as well. By supporting all elements of tourism services, Wan Town will be built into a service center that can meet the needs of tourists and local residents for leisure, experience, shopping, entertainment, etc. Through special planning and high-quality development, it will be formed into a small tourism town with a comprehensive supporting capacity.

5.4 Promote the gathering of relevant industrial factors

The development of small tourism towns needs industrial support, following the principle of "adapting to the market, relating to local conditions, highlighting characteristics and giving full play to advantages", strengthening, optimizing, and revitalizing the relevant industries, building characteristic industrial chains, constructing an economic system with comparative advantages, and promoting the interaction between the small tourism towns and the cultivation of industries is the best path to promote the sustainable development of the small tourism towns. Wan Town strengthens the government's guidance and service function, actively attracts investments, has played the fundamental role of the market in resource allocation and formed a diversified and multi-channel investment pattern. When talents, capital, transport and other industrial elements gather in the small tourism town, the development of the small tourism town will usher in a historic opportunity.

5.5 Digging deep into the regional cultural connotation

The main feature of small tourism towns different from general small towns is that they have distinctive tourism images. Small tourism towns gathered excellent characteristic cultural landmarks and landscape facilities. For example, the ancient villages in southern Anhui, a world cultural heritage site, are renowned in the world for "the depth of cultural connotation, the image of exquisite, creating decorative" [12]. Cultural experience is one of the important driving forces for the development of small tourism towns, on the contrary, the lack of local characteristics of small tourism towns, is bound to be "one side of a thousand towns", and it is difficult to form a tourist attraction. Wan Town in architectural style, spatial layout, urban design, overall image and other aspects of the distinctive characteristics of the Anhui culture. In a word, small tourist towns are the result of the interaction between urbanization and tourism in the new period [12,13]. Driven by the development of cultural towns, the development of new towns, the protection of scenic area resources and the development of tourism real estate and other forces [14]. The small tourism town has developed rapidly, and has gradually become an important carrier of village tourism. However, China's tourism town development is in its infancy stage with unique development motivation and type mode. Digging deeper into the cultural connotation of the region and enhancing the cultural attraction of tourist towns is important for the long-term development of tourism towns.

6. Discussion and conclusions

With the rapid development of urbanisation and the tourism industry, many developing countries are vigorously pursuing the development strategy of small tourism towns. The strategy of building small tourism towns will have a comprehensive long-term effect on the coordinated economic and social development of the region. On the one hand, putting forward to small tourism town strategy can enhance the attractiveness of tourism destinations and optimize the investment structure of the tourism real estate market. On the other hand, due to the unscientific planning and design, many shortcomings have emerged one after another in the development course of many tourism small towns, which need to be realized through the strategies of industrial linkage, thematic unity, and stylistic coordination to achieve the sustainable development of small tourism towns in developing countries.

In recent years, with the rapid development of China's urbanization, a large number of small tourist towns have been developed around many tourist scenic spots, and these small tourism towns have improved the tourism service functions of reception, shopping, entertainment during the peak season, and played an irreplaceable role in the overall development of regional tourism. At the same time, some small tourist towns have some problems because of irrational planning schemes and ineffective management measures, such as architectural style inconsistency, homogenization of tourism and cultural themes, and weak industry chain association. Facing these problems and challenges, local tourism management authorities need to take some strong measures, including integration with the development of new rural areas, docking the spatial pattern of town expansion, strengthening the supporting service function of tourism, promoting relevant industrial factors, digging deeply into the regional cultural connotation etc. The case study of Wan Town can bring about some inspiration for the development of small tourism towns in developing countries, which is the main research significance of this paper.

Conflict of Interest

There is no conflict of interest.

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ARTICLE

Strategic Planning for Equitable RWIS Implementation: A Comprehensive Study Incorporating a Multi-variable Semivariogram Model

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ABSTRACT

This paper extends the previously developed method of optimizing Road Weather Information Systems (RWIS) station placement by unveiling a sophisticated multi-variable semivariogram model that concurrently considers multiple vital road weather variables. Previous research primarily centered on single-variable analysis focusing on road surface temperature (RST). The study bridges this oversight by introducing a framework that integrates multiple critical weather variables into the RWIS location allocation framework. This novel approach ensures balanced and equitable RWIS distribution across zones and aligns the network with areas both prone to traffic accidents and areas of high uncertainty. To demonstrate the effectiveness of this refinement, the authors applied the framework to Maine's existing RWIS network, conducted a gap analysis through varying planning scenarios and generated optimal solutions using a heuristic optimization algorithm. The analysis identified areas that would benefit most from additional RWIS stations and guided optimal resource utilization across different road types and priority locations. A sensitivity analysis was also performed to evaluate the effect of different weightings for weather and traffic factors on the selection of optimal locations. The location solutions generated have been adopted by MaineDOT for future implementations, attesting to the model's practicality and signifying an important advancement for more effective management of road weather conditions.

Keywords: RWIS; Location optimization; Multi-variable semivariogram; Heuristics; Spatial simulated annealing (SSA); Collision rate (CR)

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1. Introduction and background

Road Weather Information System (RWIS) is one of the most crucial highway Intelligent Transportation Systems (ITS) for gathering, analyzing, and distributing road weather and surface condition information. The information derived from RWIS plays a vital role in enabling maintenance authorities to make informed operational decisions prior to, during, and after severe weather events to ensure improved traffic safety, mobility, and operational efficiency, particularly in regions facing adverse weather conditions. By offering real-time road weather and condition updates, RWIS data aid the general public in making informed choices regarding their travel routes and modes of transportation [1,2]. Recognizing the numerous benefits associated with RWIS stations, various transportation agencies in the United States, Canada, Europe and Asia, including the Maine Department of Transportation (Maine DOT), have made significant investments in establishing their own RWIS networks [3,4]. These networks aim to comprehensively cover their highway infrastructure and enhance their existing monitoring capabilities. Nevertheless, there are several drawbacks associated with RWIS. Apart from the significant expenses incurred during installation (US $100K per station) and maintenance (approximately US $10K yearly), RWIS systems only offer point measurements, necessitating additional processing to accurately depict the diverse and expansive road network conditions in Maine [5,6]. Consequently, to optimize the effectiveness of RWIS, it is imperative to strategically and systematically install new RWIS stations, ensuring their synchronization with the existing ones.

In the past few years, a number of studies have attempted to establish a systematic methodological framework for RWIS network planning. In 2005, the U.S. Federal Highway Administration (FHWA) made significant efforts by conducting interviews with multiple states' Department of Transportation (DOTs). The study's findings, which relied heavily on personal insights and expertise from field operators, indicated a recommended spacing of 30 to 50 km (20 to 30 miles) between RWIS stations [6]. Due to the fact that this recommendation was derived from subjective experiences, numerous researchers have sought to establish a more objective approach for quantifying the spatial coverage and determining the optimal placement of RWIS stations [7-12]. Kwon and Fu (2013) conducted a study using a Geographic Information System (GIS) to introduce a framework for evaluating the location of RWIS networks. Their approach incorporated various factors such as surface temperature variability (VST), mean surface temperature (MST), snow water equivalent (SWE), and topographical location attributes. The study's findings demonstrated the potential for developing a systematic methodology for RWIS installation by integrating multiple variables into the location allocation model [13]. Zhao et al. employed a methodology centered around cost-benefit analysis to identify the most advantageous sites for RWIS placement. Their objective was to achieve maximum spatial coverage while considering the variability of weather severity [11]. Jin et al. took a similar approach to maximize spatial coverage, but instead of a cost-benefit analysis, the optimization process involved using a metric called "safety concern index" derived from weather-related crash data [7]. Spatial analysis within GIS platform was also incorporated in several different fields of study, for example, Valjarević et al. (2021) examined the Morava city conurbation in Serbia, utilizing Kriging-based spatial analysis with a particular focus on the interaction between rural and urban areas, traffic connectivity, geographical positioning, and sustainability and profitability [14]. Moreover, Timalsina and Subedi explored the growing significance of open spaces in urban development planning in Nepal. This paper examines the evolution of open space integration in recent urban planning practices in Nepal, highlighting the growing emphasis on sectoral integration with open space development, particularly within Periodic Planning, Integrated Urban Development Planning (IUDP), and Smart City Planning, aiming to create resilient and sustainable cities [15]. However, in a recent study, RWIS network optimization was conducted using kriging-based method, aimed at enhancing monitoring capabilities and minimizing the average kriging variance of hazardous road surface conditions. This study was formulated as a Nonlinear Integer Programming (NIP) problem and showcased its applicability through a case study in the state of Minnesota, U.S. [16].

Although the previously mentioned studies have made valuable contributions to the development of RWIS location models, they focused solely on investigating the spatial characteristics of a single variable, specifically road surface temperature (RST). While RST is undoubtedly an essential measurement, it is important to consider many other weather variables measured by RWIS in the location optimization process.

The primary motivation of this research is to break new ground by concurrently incorporating the spatial characteristics of multiple weather variables. For the first time ever, we are developing an innovative multi-variable semivariogram model that specifically considers critical weather variables, including air temperature (AT), road surface temperature (RST), and dew point temperature (DPT). This novel approach is directed at optimizing RWIS placement by ensuring effective monitoring coverage of the region. Additionally, our method takes into account areas prone to traffic accidents for improved safety, and demonstrates the superiority of the proposed method in ensuring an equitable distribution across different maintenance zones.

In addition to the primary objective, this research encompasses two specific sub-objectives, which are outlined below:

- *Implementation of the developed model for the planning of the regional RWIS network:*
  The RWIS planning tool we developed will be utilized for the region-wide prioritization of potential RWIS sites. Furthermore, we will conduct a comprehensive statewide gap analysis to validate prioritized and potential sites by identifying all new optimal locations.
- *Conducting sensitivity analysis to offer flexibility to decision-makers:*
  Sensitivity analyses will be conducted to explore the effect different weight schemes have on the optimal location. These analyses will provide valuable insights into how variations in weather and traffic factors can influence the selection of additional RWIS locations. The analysis results will provide the flexibility to choose parameter weights based on the decision-maker's needs, considering both weather variables and safety implications related to traffic.

Overall, our proposed multi-variable semivariogram model represents a pioneering step in RWIS location determination. By concurrently considering multiple weather factors and addressing traffic safety in accident-prone areas, we enable planners to tailor the RWIS network to specific needs. This innovation is therefore expected to enhance monitoring capabilities and more effective winter road maintenance decisions.

2. Methodology

2.1 Overview of research procedures

The first phase of this project is data collection, where information about the study area, stationary RWIS data, and traffic data are gathered. In the second step, the collected data is processed by removing missing and erroneous data as per our predefined guidelines [18]. Next, the processed data is merged into a GIS-based platform for further analysis. Moving on to stage three, a highly effective spatial sampling technique called geostatistical analysis is utilized to determine the spatial autocorrelation of the RWIS variables. This technique is designed to enhance the likelihood of capturing spatial variations while minimizing potential biases in the input data. Specifically, semivariogram analysis is conducted here to generate semivariogram clouds for the selected RWIS variables, which are then combined to generate a multi-variable semivariogram model. This multi-variable semivariogram model is then applied in the final stage to optimize the placement of RWIS locations by refining our previously developed location optimization framework. The overall research procedures for this study are summarized in **Figure 1**.

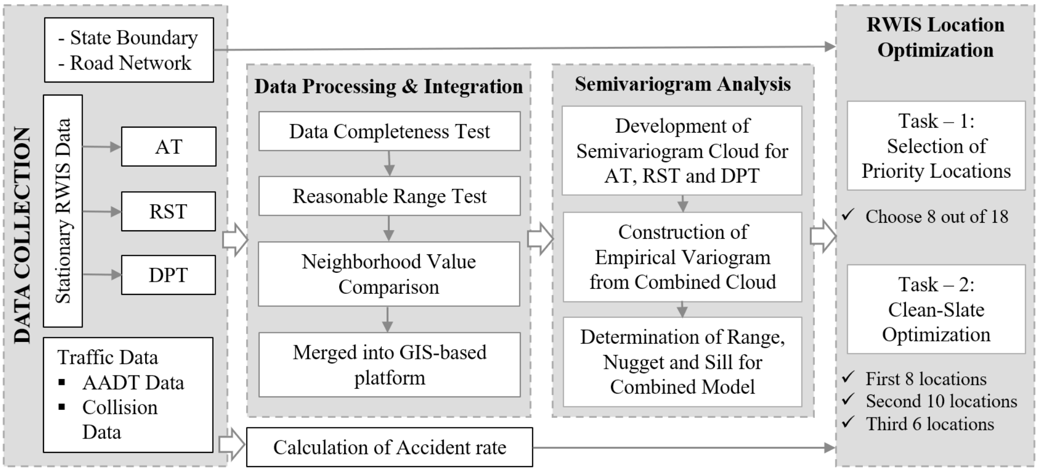

Figure 1. An overview of the research procedure.

2.2 Data collection, processing and integration

As depicted in **Figure 1**, the initial step of our framework involves the collection of the following seven variables: state boundary and road network information, stationary RWIS data (AT, RST, and DPT), and traffic data (AADT and collision). The RWIS measurements obtained from the database undergo several checks to ensure data quality [18]. The processed datasets are then consolidated into a unified GIS database to facilitate spatial analysis.

2.3 Geostatistical semivariogram modeling

In our previous work, we developed a systematic approach for RWIS network planning that utilizes kriging-based optimization to determine the optimal locations for RWIS stations. A key aspect of this framework is the integration of RWIS information for spatial inference [18,19]. To incorporate spatial inference, the geostatistical modeling approach known as semivariogram analysis is utilized to quantify the spatial autocorrelation of RWIS measurements.

A semivariogram is a graphical representation of spatial autocorrelation using a metric called semivariance. Semivariance is a statistical measure that assesses the similarity between two measurements based on their spatial separation distance [20]. It is computed by averaging the squared differences between measurements separated by a designated lag distance. A larger autocorrelation range indicates a higher level of spatial continuity in RWIS measurements, while a smaller range suggests lower continuity. Equation (1) represents the most commonly used method for estimating semivariance:

$$\gamma(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [z(x_i + h) - z(x_i)]^2 \tag{1}$$

In this equation, $\gamma(h)$ represents the semivariance. It is calculated by comparing two measurements, $z(x_i + h)$ and $z(x_i)$, taken at locations x_i and $(x_i + h)$ respectively, with a separation distance of h.

In this research, semivariogram modeling is incorporated to quantify the spatial structure of critical road weather and surface conditions variables. Numerous GIS software packages and programming languages are available for semivariogram modeling, such as ArcGIS, QGIS, R, Python etc. In this research, separate semivariogram clouds are developed primarily for each selected weather variable (i.e., AT, RST, and DPT) and subsequently combined to form a comprehensive semivariogram cloud. By binning the cloud points together, a multi-variable semivariogram model is constructed to capture the spatial autocorrelation of all crucial weather variables. The parameters obtained from the multi-variable semivariogram model serve as critical inputs for optimizing the location of RWIS stations, ensuring that the additional RWIS stations are strategically positioned based on the spatial autocorrelation of the key weather variables.

2.4 RWIS network optimization

In continuation of the geostatistical semivariogram modeling conducted in the previous step, this stage builds upon the previously developed RWIS location allocation framework by incorporating a multi-variable semivariogram model in the location optimization process. The objective is to determine optimal locations for RWIS stations while minimizing spatial inference errors or maximizing spatial coverage across the road network, as demonstrated in previous studies [16-18]. The spatial inference errors are indicative of the requirements for installing RWIS stations to enhance monitoring capabilities and improve the efficiency of winter road maintenance operations. By refining the location allocation model, this study takes into account the spatial impact of multiple road weather variables.

The optimization method employed in this study is Spatial Simulated Annealing (SSA), a popular heuristic algorithm widely recognized for its effectiveness in solving spatial optimization problems [17]. SSA has been extensively used and has a reputation for generating more reliable location solutions [21-24].

In addition to considering various weather variables, the modified network optimization model also incorporates traffic demand distribution by considering the collision and AADT data. The accident rate is calculated using Equation (2) as follows [25].

$$\text{Crash rate, CR} = (\text{number of accident} * 1000000) / (\text{AADT} * 365) \quad (2)$$

In this context, the term "number of accidents" represents the total count of accidents observed during the study period. AADT, on the other hand, represents the average daily traffic volume for a specific road or road section. It serves as a measure of the number of vehicles passing through that area on a daily basis. Consequently, the resulting value of CR obtained from Equation (2) provides an estimate of the frequency of accidents. It indicates the number of accidents that occur per million entering vehicles.

The methodology described above is exemplified through its application in the state of Maine, providing detailed information in the subsequent section.

3. Model Application—Maine, United States

3.1 Study area and RWIS network

This research is primarily based on the expansion plan of the Maine DOT for their RWIS network. Currently, the number of existing stations in Maine (ME) is limited, resulting in insufficient coverage of the road network. To address this, authorities intend to gradually expand the RWIS network by installing a yearly average of 8-10 additional stations, considering budgetary limitations. Given the high costs associated with installation and maintenance, it becomes crucial to determine the precise locations for the placement of these new RWIS stations; so that the additional stations will work collaboratively with existing stations to maximize the value of RWIS information. The outcomes of this research will provide RWIS planners with optimal location solutions for expanding the network, ultimately enhancing the overall monitoring coverage to the best extent possible. Located in the northeastern region of the United States, Maine is positioned as the easternmost state, sharing its border with Canada. Maine exhibits diverse geographical features, encompassing distinctive regions such as uplands, coastal lowlands, mountains, and piedmont areas. Severe winter conditions, including heavy snowfall and freezing temperatures, result in the formation of slippery road surfaces and reduced visibility, consequently rendering winter driving a demanding and challenging task [26,27].

There are, 10 RWIS stations in Maine, with the majority of them strategically positioned along the interstate highway. Due to the limited number of existing stations, RWIS data from a neighboring state, NH (New Hampshire), is also utilized in this analysis. Additionally, ASOS (Automated Surface Observing System) data from both states are also included after conducting data representativeness tests. In the process of assessing the representativeness of NH data for the state of ME, an analysis was conducted on the variation patterns of selected weather variables in both states. According to the assessment, it can be inferred that NH's RWIS and ASOS data are reliable for representing Maine's weather.

The study period selected for this analysis includes three consecutive winter seasons between 2019 and 2022. Within these three years, RWIS and ASOS data collected over a span of five winter months (November to March) are utilized in this analysis. The distribution of RWIS and ASOS stations for the study area is presented in **Figure 2**.

3.2 Data description

This study utilized a comprehensive dataset obtained from the Maine DOT and supplemented with data from adjacent NH to compensate for Maine's lack of RWIS data. The dataset includes state boundary information, road network data, stationary RWIS data, and traffic data. Furthermore, the study incorporated information regarding candidate RWIS sites, which serve as potential locations for future installations of RWIS stations.

RWIS Data

Stationary RWIS data for Maine was collected from Maine DOT (https://www.maine.gov/mdot/). RWIS data for NH and ASOS data for Maine and NH were downloaded from Iowa State University (http://mesonet.agron.iastate.edu/RWIS/) and WxDE website (Weather Data Environment: https://wxde.fhwa.dot.gov/). State-wide RWIS data in the form of Excel files were downloaded, containing measurements from multiple parameters including air and surface temperature, visibility, wind speed, and road surface conditions. Likewise, ASOS data encompasses similar weather variables, excluding RST. These measurements are collected at intervals of approximately 15 to 20 minutes. In total, 25 RWIS stations from NH, 10 RWIS stations from Maine, 33 ASOS stations in NH, and 18 ASOS stations in Maine were included in the analysis. A total of 10,800 hours of data was incorporated into the analysis.

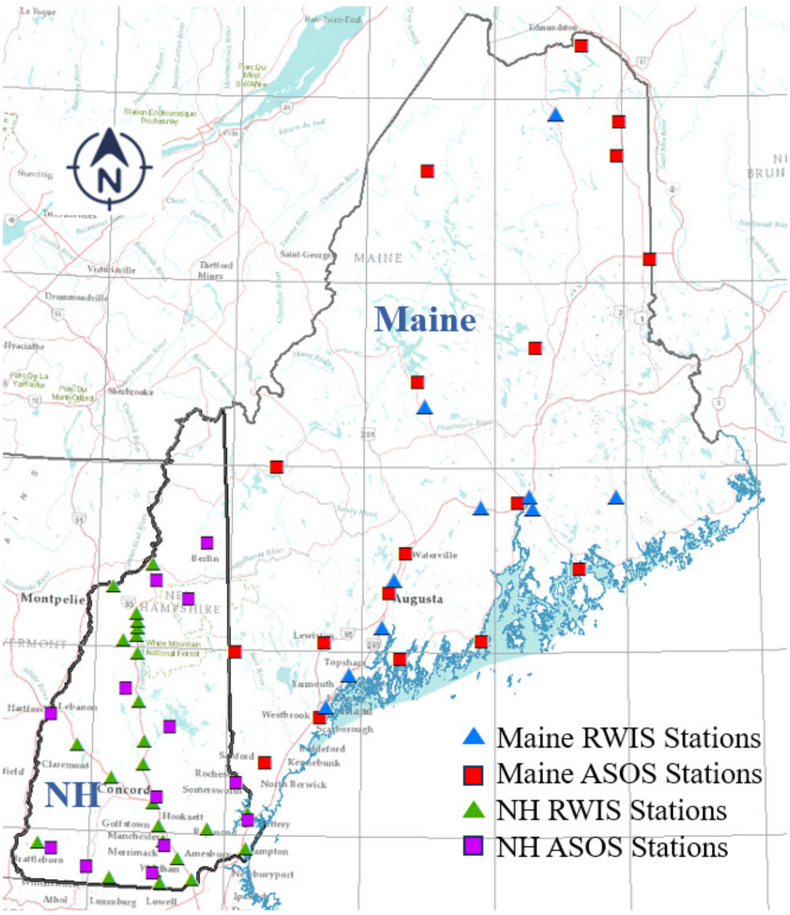

Figure 2. Distribution of RWIS and ASOS stations for Maine and NH.

The weather data underwent a predefined processing procedure to eliminate missing and erroneous data. These steps included a data completeness test, a reasonable range test, cross-checking RST data with AT and DPT data, and analyzing the pattern of weather data [18]. Using this procedure, a total of 60 sets of data were analyzed.

The descriptive statistics of the processed data are summarized in **Table 1**, providing insights into the minimum, average, maximum, and standard deviation values for the data collected from weather stations. Upon closer examination of **Table 1**, it can be observed that the AT exhibits a range of –34.0 ºC to 26.3 ºC throughout the study period, with an average value ranging from –1.2 ºC to –2.3 ºC. The RST varies between –25.9 ºC and 32.1 ºC, with an average value of 0.12 ºC. Furthermore, the DPT ranges from –41.9 ºC to 21.8 ºC, with average values of –6.0 ºC to –6.48 ºC. It is noteworthy that the standard deviation is slightly higher for DPT compared to AT and RST. These statistics provide a comprehensive overview of the temperature variations across the study period and highlight the relative variability among the different variables.

Traffic data

To calculate the accident/crash rate, AADT and collision data were collected for the same 5-year period as RWIS and ASOS data. Then, for the purpose of evaluating collisions during the winter season, only collisions occurring between November and March were considered. Furthermore, to identify collisions caused by adverse weather conditions, several factors were taken into account. These factors included: (i) the contributing factor of the accident, such as road surface conditions like wet, icy, snowy, slushy, etc., (ii) the surface condition during the accident, encompassing ice/frost, snow, slush, mud, dirt, and gravel, and (iii) the type of roadway, focusing on non-intersection collisions. By considering these factors, the study aimed to determine the collision rate (CR) associated with adverse weather conditions.

To create the CR distribution map, the study employed Equation (2) to calculate CR values for square polygons of different sizes generated from Maine's road network data. Smaller polygon sizes resulted in a significant number of polygons with zero CR values, leading to a random CR distribution map that made hotspot identification challenging. After an extensive search process to select the optimal polygon size, the CR map generated with 20 km by 20 km polygons was selected as the most suitable, providing a comprehensive representation of CR and better visualization of high-crash areas. The CR distribution map for Maine with 20 by 20 km square polygons is depicted in **Figure 3**.

3.3 Development of multi-variable semivariogram model

To assess the spatial structure of key road weather and surface condition variables, semivariogram modeling was integrated into this study. The gstat package in R [28,29] was utilized for this purpose. Initially, semivariogram clouds were generated for each weather variable, enabling an examination of the spatial autocorrelation among the recorded sample points. Each point within the cloud represents the variance between a pair of measurements [30,31]. Subsequently, the semivariogram clouds for the weather variables were combined to form a unified semivariogram cloud. By binning the cloud points together, an empirical semivariogram model was constructed that incorporated the spatial autocorrelation of all

Table 1. Descriptive statistics of weather station data for Maine and NH.

Station	**Maine ASOS**		**NH RWIS**			**NH ASOS**	
Weather variable	AT	DPT	AT	RST	DPT	AT	DPT
Minimum temperature	–30.61	–41.89	–29.50	–25.90	–33.00	–34.00	–40.00
Average temperature	–2.32	–6.46	–1.18	0.12	–6.48	–1.22	–5.97
Maximum temperature	24.39	19.00	26.30	32.10	21.80	25.00	21.00
Standard deviation	7.04	7.77	6.82	6.87	7.58	7.10	7.72

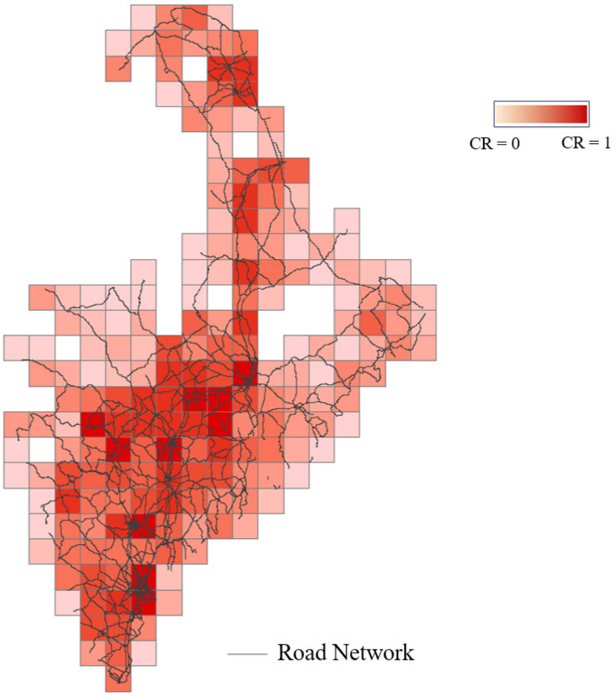

Figure 3. Crash rate (CR) distribution map for the State of Maine.

essential weather variables. **Figure 4** represents the multi-variable semivariogram model developed in this research. Here, the spatial range of autocorrelation was determined to be 145 kilometers, with a sill value of 3.55 and a nugget value of 0.01.

The use of a multi-variable semivariogram model was expected to yield a more accurate location solution by capturing the variability of multiple weather variables. To evaluate the validity of this hypothesis, single-variable semivariogram models were also employed in the location-allocation algorithm to compare against multi-variable-based solutions. This study utilized R statistical packages to generate separate semivariogram models for AT, RST, and DPT. These models were subsequently employed to determine location solutions for the state of Maine.

Recall that the location optimization process leverages the SSA (Spatial Simulated Annealing) algorithm. The primary objective was to maximize spatial coverage by minimizing estimation variance, represented by a value referred to as 'criterion'. The optimization process involves selecting locations that minimize the 'criterion' value. The resultant solution with the lowest 'criterion' value indicates maximized monitoring coverage. To demonstrate the superiority of the multi-variable model compared to single-variable models, optimization outputs from both approaches were compared.

Figure 5 illustrates the location solutions for eight stations (selected based on planning approaches) and optimization schedules for the three single and multi-variable cases. The optimization schedule displayed the 'criterion' value progression, indicating that the multi-variable model has a notably lower 'criterion' value compared to the single-variable models. This suggests that the multi-variable model offers enhanced monitoring coverage. The parame-

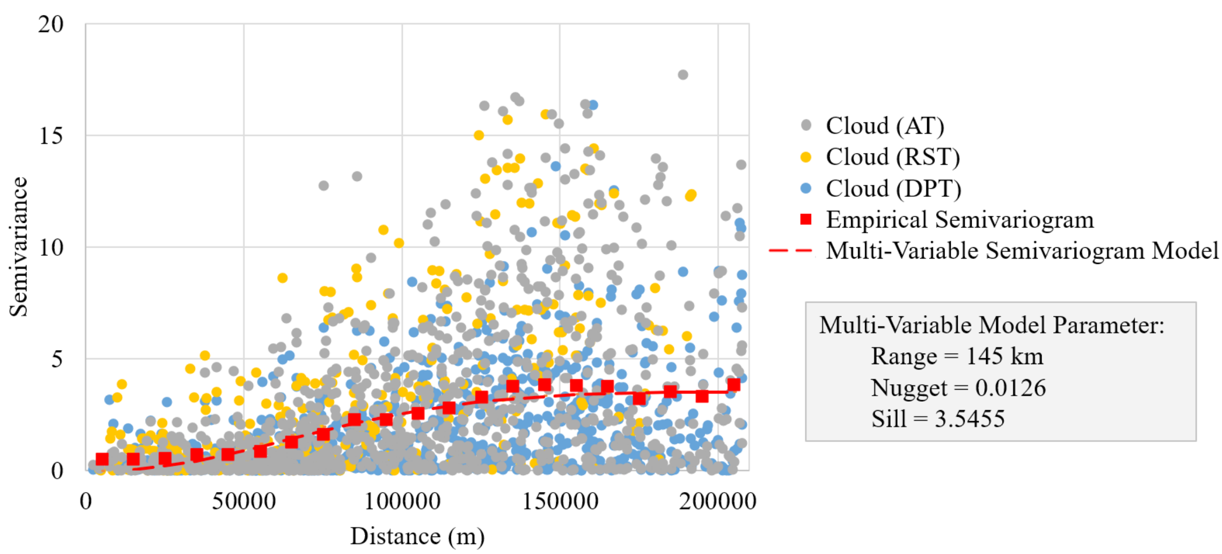

Figure 4. Multi-variable semivariogram model with model parameters.

ters of the multi-variable semivariogram model were then used as inputs in the location optimization process.

3.4 RWIS network expansion

Using the multi-variable semivariogram model developed in the previous step, the study proceeds to assess the effects of spatial demarcation on RWIS planning by constructing various design scenarios. In previous studies, we developed an innovative RWIS location modeling framework where the problem was formulated as an integer programming problem. The objective was to minimize spatial inference error, in other words, maximize spatial coverage across the road network. These spatial inference errors capture the necessity of installing RWIS stations to enhance monitoring capabilities, ultimately improving the effectiveness of winter road maintenance operations [16,18]. In this study, we refined the previously developed location optimization model by incorporating the influence of multiple critical weather variables as well as the distribution of traffic demand.

This study focused on two specific tasks for expanding the RWIS network. A detailed description of the specific tasks is given below.

Task 1: Selection of priority locations out of predetermined sites

A total of 18 potential RWIS locations in Maine have been identified by Maine's regional officers. Our first task was to select 8 priority locations from this pool of predetermined sites. The intent of this analysis was to prioritize RWIS locations based on the constraint that a limited number of RWIS installations can be installed per year. **Figure 6** illustrates the predetermined and existing RWIS stations. The state is divided into five maintenance zones by grey lines. According to **Figure 6**, there are two potential locations identified in zone-1 and zone-2, three locations in zone-3, four locations in zone-4, and seven locations in zone-5.

Both weather and traffic factors were considered to identify priority locations. The aim was to serve a wide range of road users while also effectively capturing weather variability. The weather criteria were incorporated by utilizing multi-variable semivariogram parameters, while the traffic parameters were considered by incorporating CR. In the optimization algorithm, equal weightage was assigned to both weather and traffic factors. This approach aimed to maximize the overall benefit by considering both weather conditions and traffic demands. This result-

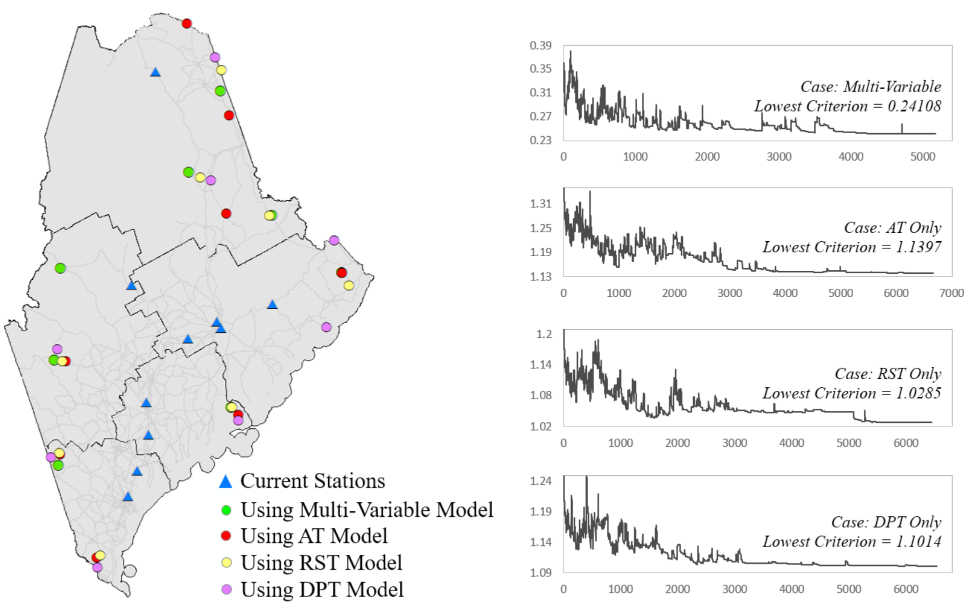

Figure 5. Comparison of single-variable and multi-variable models for network optimization.

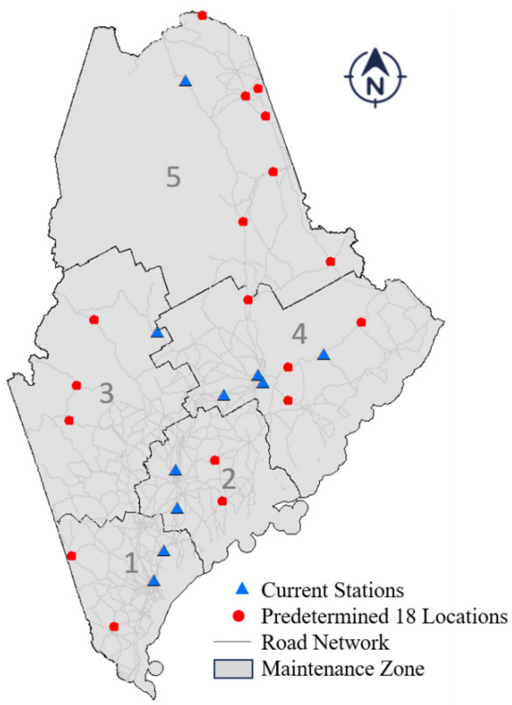

Figure 6. Distribution of current and predetermined locations.

ed in the generation of priority locations, represented by green circles in **Figure 7**.

Figure 7 presents the eight priority locations for RWIS installation, including maintenance zone, estimation error (EE) map, and CR distribution map. The priority locations are evenly distributed throughout the network. The EE map shows varying shades of red, indicating estimation error values computed using ordinary kriging. The kriging interpolation technique utilizes semivariogram parameters to estimate values at unsampled locations, while also providing an assessment of the uncertainty in the estimation, also known as estimation error. The presence of an RWIS station at a particular location results in a lower EE value. As the distance from the station increases, the estimation for unknown locations becomes associated with higher error. This indicates a greater requirement to install a new RWIS station in those areas to bridge the spatial gap and reduce estimation uncertainty. In the optimization process, additional RWIS stations are strategically positioned to minimize EE values and improve network effectiveness. The CR distribution map displays lower CR values in light-colored squares and higher CR values in dark-red squares. The new station locations strike a balance between weather variability and accident-prone areas, with strategic placement near high-traffic and hotspot locations.

Task 2: Clean-slate optimization

At this step, the candidate locations from Task 1 were expanded to encompass all non-interstate corridors in Maine. This extended study corridor includes interstate, freeway, expressway, major collector, principal arterial, and minor arterial roads. The purpose of this analysis was to objectively assess how to best utilize available resources by addressing gaps in

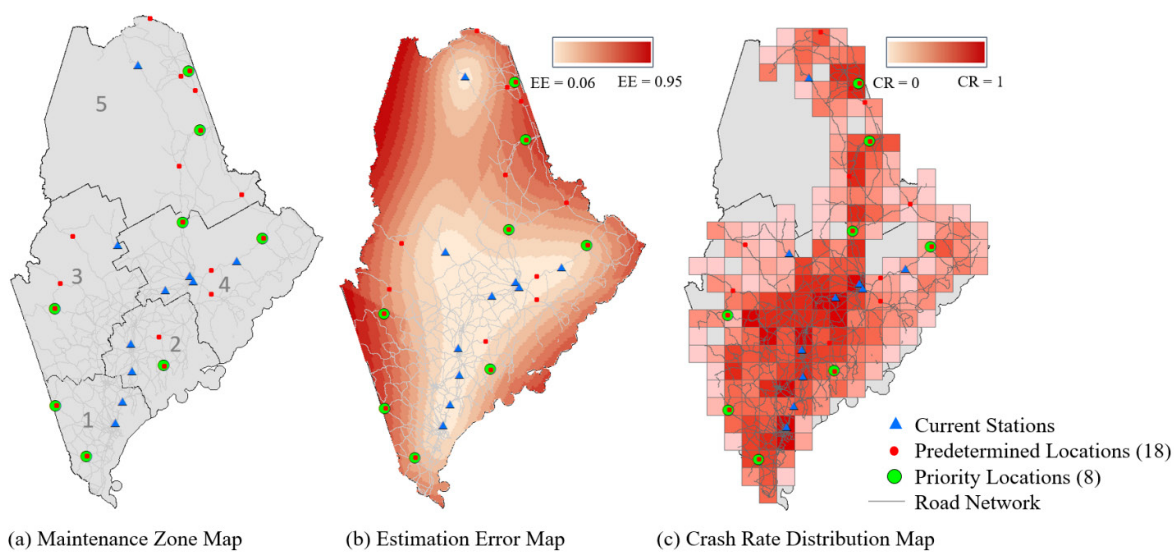

Figure 7. Visualization of priority locations.

the statewide data collection and road weather forecasting network. A constrained optimization process was conducted to determine the optimal locations for RWIS placement, referred to as clean-slate optimization. Three different scenarios were considered during the clean-slate optimization process.

i. Generate the first 8 optimal locations
Here, 8 optimal locations were generated through clean-slate optimization to compare with 8 priority locations that were identified in Task 1.

ii. Generate the second 10 optimal locations
To match the 18 predetermined candidate sites, 18 optimal locations were generated, including 10 new sites and 8 initial locations. The aim of this step was to create a direct alignment between the optimal locations and the predetermined candidate sites, ensuring a clear correspondence between the two sets.

iii. Generate the third 6 optimal locations
The RWIS network expansion plan of Maine DOT aims to install 8 new stations annually for three consecutive years. By the end of this expansion plan, a total of 24 stations will be installed. In this step, an additional 6 optimal stations were generated to reach a total of 24 additional sites (8 + 10 + 6). The outcomes of this step will provide the RWIS planners with a complete set of optimal locations for extending their network.

During the process of determining optimal locations for the three mentioned scenarios, a series of sensitivity analyses were carried out to assess the impact of various weight distributions in kriging-based RWIS location optimization. This step yielded multiple location solutions depending on the weight assigned to weather (W) and traffic (T) factors. These location solutions offer flexibility to network planners and decision-makers, allowing them to choose installation sites based on their specific requirements. For each scenario, a total of 7 sets of weight distributions were considered as follows: Set-1: 0%W, 100%T; Set-2: 20%W, 80%T; Set-3: 40%W, 60%T; Set-4: 50%W, 50%T; Set-5: 60%W, 40%T; Set-6: 80%W, 20%T; and Set-7: 100%W, 0%T.

To generate each set of solutions for each scenario, on average three to five trials were conducted to find a conclusive outcome. In total, clean-slate optimizations were performed over one hundred times. To enhance computational efficiency, a portion of the optimizations in this study were executed using the advanced research computing system called the 'Digital Research Alliance of Canada' (https://alliancecan.ca/en) from the University of Alberta. This system utilized GPUs from the supercomputers "Cedar" and "Graham", each equipped with 12 to 32 GB HBM2 memory. The subsequent sections present comprehensive explanations of various clean-slate optimization scenarios and their outcomes.

Scenario i: Generate first 8 optimal locations

In order to determine the first eight optimal locations, multiple solutions were generated for seven sets of weight distributions, as mentioned earlier. For the sake of simplicity, we will focus on discussing the three most significant cases: (a) traffic only, (b) equal weightage for weather and traffic, and (c) weather only, as presented in **Figure 8**. For set-1, the selection of locations was based on the ranking of CR values. **Figure 8(a)** illustrates the distribution map of CR, highlighting eight square polygons with higher CR values. It is evident that most of these locations are in close proximity to the interstate and downtown area. **Figure 8(c)** displays the optimal locations along with the EE map (set-7). In this case, the objective was to fill the spatial gap in order to effectively capture weather phenomena. The resultant solution exhibits a uniform distribution of locations, effectively capturing the weather patterns. Lastly, for set-4, optimal locations were determined by considering dual criteria, as depicted in **Figure 8(b)**. Here, the selected locations aimed to strike a balance between capturing weather variability and addressing accident-prone areas. Consequently, we observe some stations located in proximity to hotspot areas, while the overall distribution also captures weather variability by placing stations in areas with higher EE (or areas with high uncertainty).

A comprehensive sensitivity analysis was conducted to assess the sensitivity associated with the optimal locations generated for the seven sets of weight distributions. This analysis aimed to capture how the optimal locations are influenced by different weightage assigned to the weather and traffic factors. To conduct the sensitivity analysis, the EE and CR values for all seven sets of solutions were extracted from the EE map and CR map, respectively, using ArcGIS. **Figure 9** displays the results of the sensitivity analysis. The analysis reveals that higher percentages of the weather factor prioritize locations with higher EE values, while higher percentages of the traffic factor prioritize accident-prone locations with higher CR values. These findings validate the effectiveness of the optimization process and offer insights into the influence of factor weightage on location selection.

Scenario ii: Generate the second 10 optimal locations

In the case of determining the second set of ten optimal locations, the initial eight optimal locations for the dual criteria were treated as existing stations, along with the current RWIS stations. Similar to scenario-i, solutions were generated for seven sets of weight distributions, and the three most significant cases are presented in **Figure 10**. **Figure 10(a)** highlights the top ten square polygons with higher CR values, while the weather-only criterion strategically places RWIS stations in locations with higher EE values to accurately capture weather phenomena. In

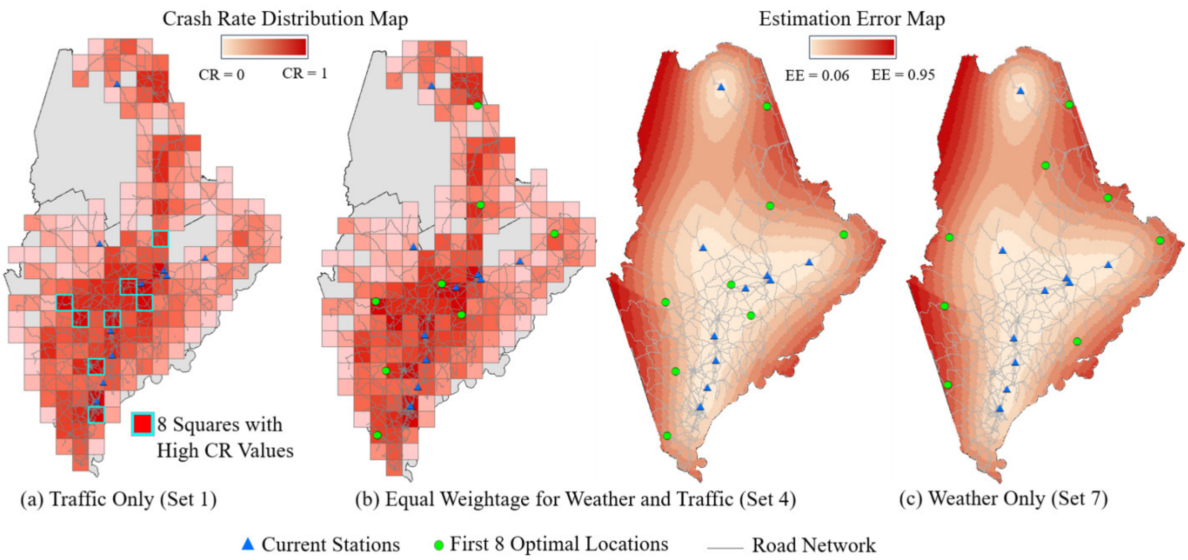

Figure 8. Distribution of first 8 optimal locations for (a) traffic only criterion, (b) dual criteria, and (c) weather only criterion.

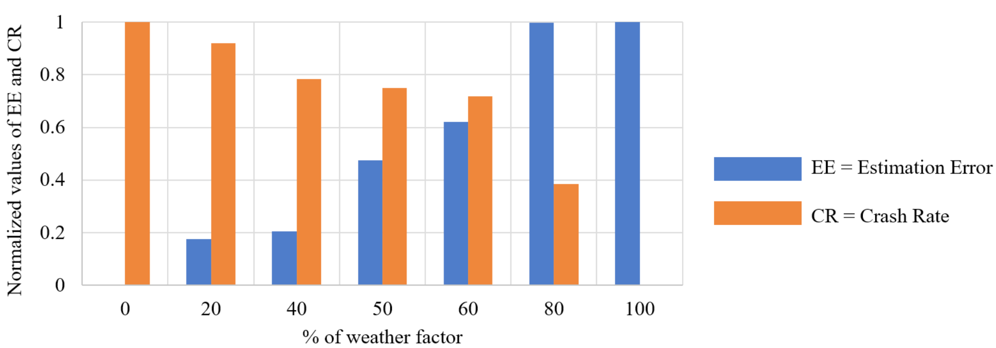

Figure 9. Sensitivity analysis result for first 8 locations: Normalized EE and CR values for 7 sets of optimal location.

the case of the dual scenario, the location solution achieves a balance between capturing weather variability and addressing hotspot areas.

Figure 11 presents the sensitivity analysis results for Scenario-ii, showing near identical pattern to the previous case, demonstrating the clear influence of factor weightage on optimal location selection.

Scenario iii: Generate the third 6 optimal locations

To determine the third set of optimal locations, the first eight and second ten optimal locations for the dual criteria were considered as existing stations, along with the current RWIS stations. Following the methodology employed in previous scenarios, solutions were generated for seven sets of weight distributions. The findings of the three most significant cases are presented in **Figure 12**. Here, in **Figure 12(a)**, the top six square polygons with higher CR values are emphasized, and the weather-only criterion strategically positions RWIS stations in locations with higher EE values to increase interpolation accuracy. The location solution in the dual scenario strikes a balance by effectively capturing weather variability while also addressing accident-prone areas.

Figure 13 displays the sensitivity analysis results for Scenario-iii, which is the same as the two previous cases. This highlights the significant dependency of the optimal locations on the weightage assigned to the weather and traffic factors.

Overall, the sensitivity analysis provides valuable insights into the impact of varying weightage on the selection of optimal locations. These findings under-

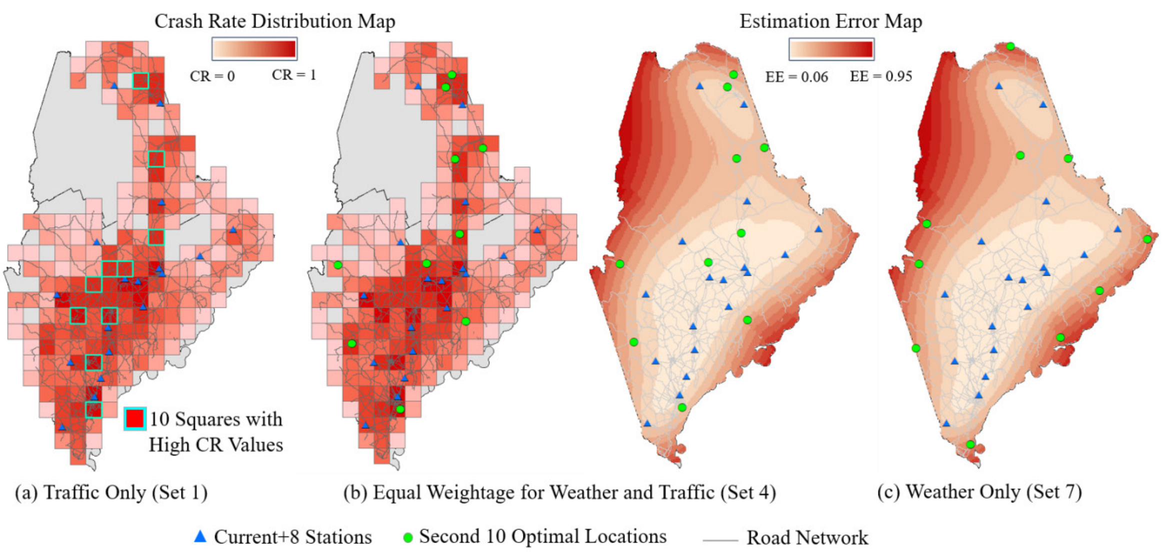

Figure 10. Distribution of the second 10 optimal locations for (a) traffic only criterion, (b) dual criteria, and (c) weather only criterion.

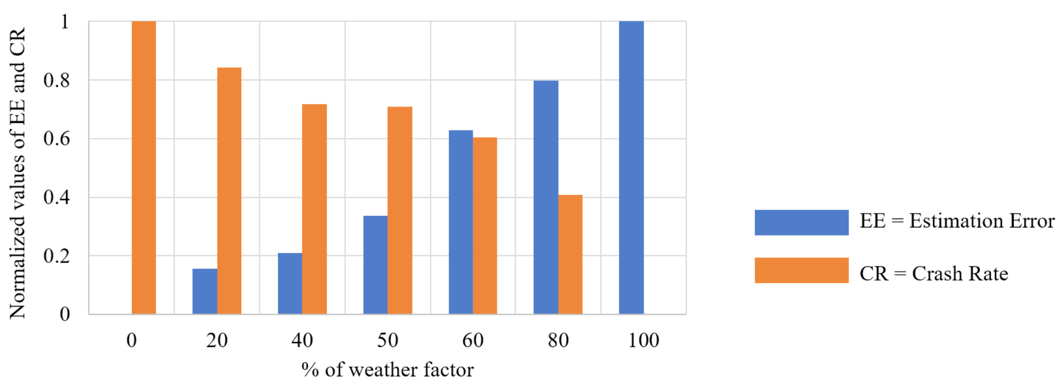

Figure 11. Sensitivity analysis result for the second 10 locations: Normalized EE and CR values for 7 sets of optimal locations.

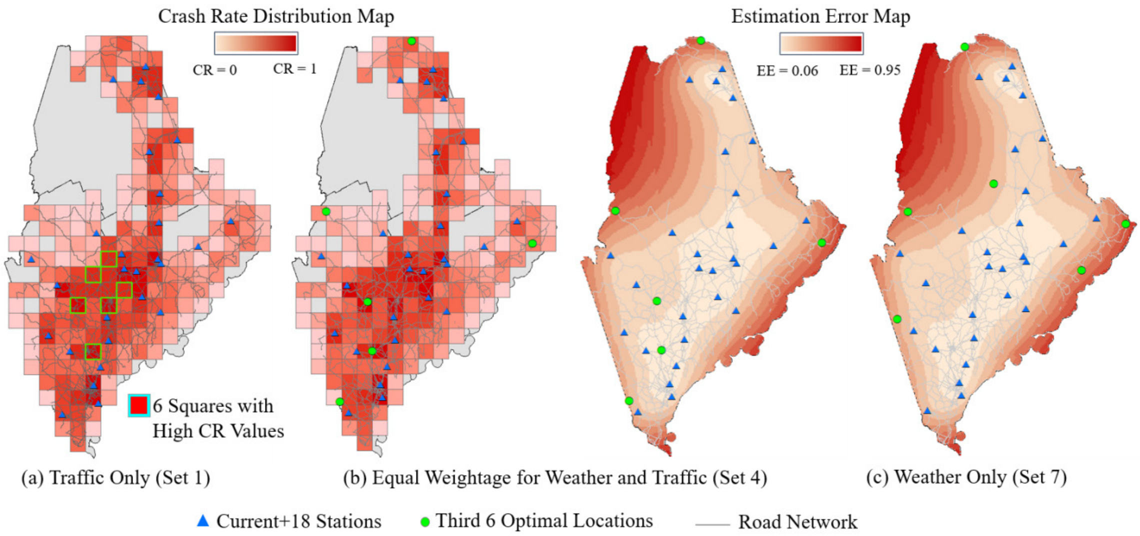

Figure 12. Distribution of the third 6 optimal locations for (a) traffic-only criterion, (b) dual criteria, and (c) weather-only criterion.

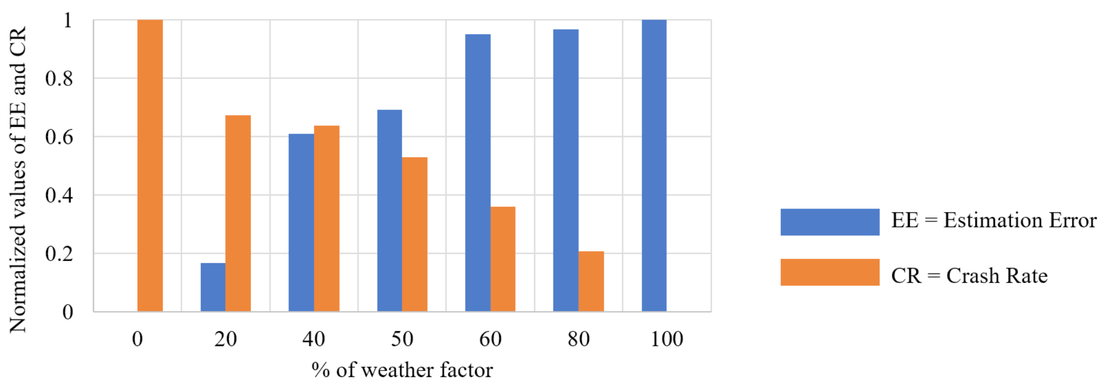

Figure 13. Sensitivity analysis result for third 6 locations: Normalized EE and CR values for 7 sets of optimal location.

score the importance of carefully considering and adjusting the weightage assigned to different factors when determining optimal RWIS locations.

3.5 RWIS density, equity and performance analysis

After identifying the optimal locations through clean-slate optimization, the study embarked on a comparative analysis with the 8 priority and 18 predetermined locations within Maine's five maintenance zones. Within this framework, the density of RWIS stations was determined based on the length of roads in each zone and the number of existing and new RWIS stations. The analysis was also aimed not just at validating the predetermined locations but also delved into an equity assessment to ensure that the RWIS stations are distributed fairly across the five distinct zones.

The results, presented in **Table 2**, indicate that the RWIS densities for both the priority and optimal locations remain consistent across eight stations. This consistency provides evidence supporting the validity of the selected priority locations. When comparing the 18 predetermined and 18 optimal locations, similar numbers of stations are observed in most regions, with minor differences between Zone 1 and 5. The evaluation of standard deviation values unveils that the predetermined case is characterized by a slightly higher variability (1.29), contrasting with the more streamlined standard deviation found in the optimal case (0.979). From an equity perspective, this numerical difference underscores a more refined alignment of the RWIS stations within the optimal

Table 2. RWIS density comparison between priority and predetermined locations with optimal locations.

Maintenance zone		**1**	**2**	**3**	**4**	**5**
Road length (1000 km)		2.245	1.725	1.623	2.049	1.63
8 priority locations	Number of priority and existing RWIS	4	3	2	6	3
	Density per 1000 km of road	1.782	1.739	1.232	2.928	1.84
First 8 optimal locations	Number of optimal and existing RWIS	4	3	2	6	3
	Density per 1000 km of road	1.782	1.739	1.232	2.928	1.84
18 predetermined locations	Number of predetermined and existing RWIS	4	4	4	8	8
	Density per 1000 km of road	1.782	2.319	2.465	3.904	4.908
First 8 + Second 10 optimal locations	Number of optimal and existing RWIS	5	4	4	8	7
	Density per 1000 km of road	2.227	2.319	2.465	3.904	4.294

solution, reflecting a concerted effort to evenly balance the distribution across different zones. Consequently, the optimal case not only illustrates the efficacy of the selected locations but also emphasizes a more harmonized and equitable distribution of RWIS stations across the maintenance zones.

The impact of incorporating additional RWIS stations into Maine's network was also evaluated by analyzing the 'objective function' values associated with each set of solutions during the optimization process. The findings, depicted in **Figure 14**, quantify the percentage improvement in monitoring coverage. The infusion of the first 8 and second 10 stations show substantial improvement, while the improve-

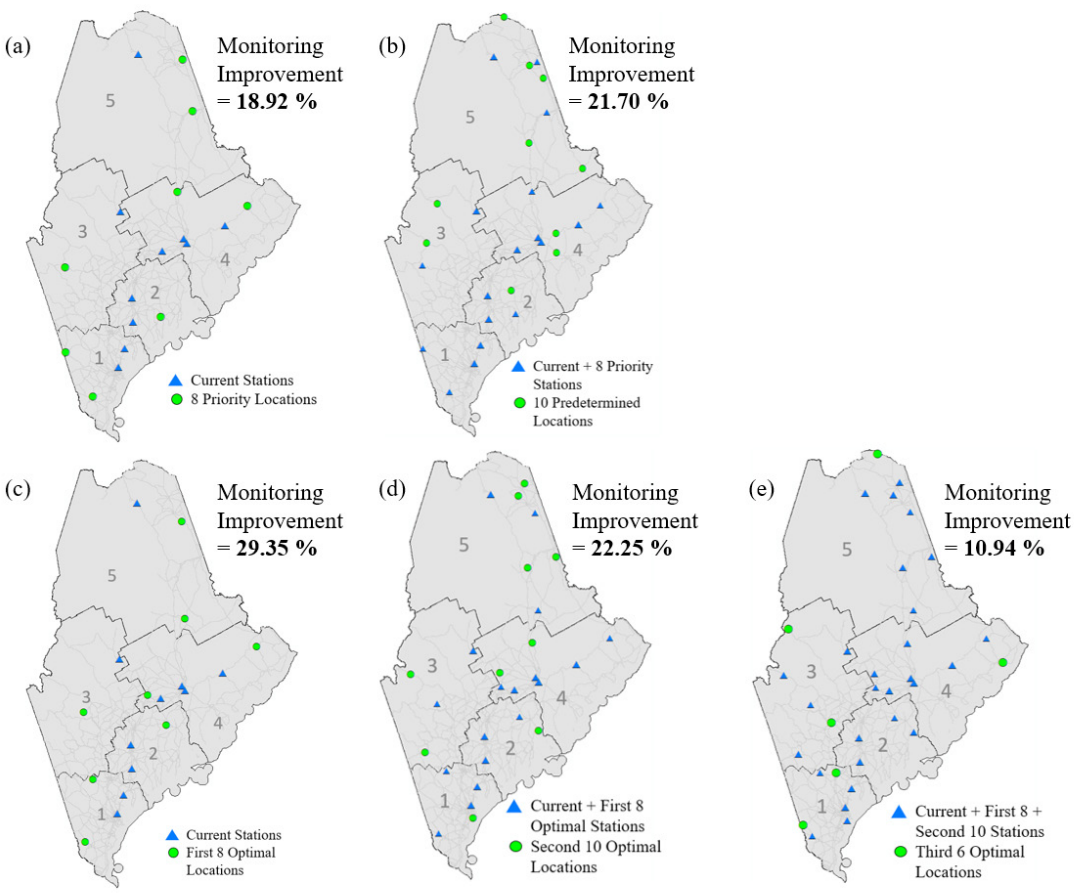

Figure 14. Enhanced network monitoring: The impact of additional RWIS stations.

ment for the third set of 6 stations is relatively lower, indicating that the network is nearing saturation. The monitoring improvement for optimal locations surpasses that of the proposed locations. This is because the entire road network of Maine was utilized as a study corridor for the optimal case, leading to more favorable outcomes. While the improvement for 8 priority locations is slightly lower than the optimal case, the second set of 10 locations demonstrates similar improvements. These findings confirm the effectiveness and validity of the predetermined locations proposed by Maine DOT in optimizing the RWIS network.

4. Conclusions and recommendations

This paper demonstrates the importance of incorporating the effect of multiple weather variables in optimizing the placement of RWIS. By refining the location-allocation algorithms and utilizing a multi-variable semivariogram model, we have developed a novel optimization framework for determining optimal solutions for RWIS network expansion, a valuable contribution to the field. The refined location allocation framework was applied in regional RWIS network planning for the state of Maine, where we carried out a comprehensive state-wide gap analysis to determine the most suitable locations. To further assess the selection of optimal locations, a sensitivity analysis was conducted to examine the effects of assigning different weightings to weather variability and traffic factors.

The key contribution of this research is listed below.

- This research has made significant strides in the optimization of RWIS station placement by introducing an innovative multi-variable semivariogram model that considers essential road weather variables. The comparative study between single and multi-variable semivariogram models demonstrates that employing the multi-variable approach leads to more precise location solutions by effectively capturing the variability of multiple weather variables, resulting in significantly improved monitoring coverage compared to single-variable models.
- Through the application of this refined framework to Maine's existing RWIS network, we model prioritized strategic locations for installing RWIS stations, ensuring equitable and balanced distribution across various zones, and statewide coverage. The location solutions generated are currently being adopted by MaineDOT for future implementations, demonstrating the practicality and robustness of our approach.
- A total of 24 locations were generated using the optimization model for the annual installation of RWIS stations, aligning with the requirements of Maine DOT. These generated locations serve as evidence of the validity and effectiveness of the proposed locations. Additionally, the sensitivity analysis allowed us to assess the impact of different weightings for weather and traffic factors on the selection of optimal station locations. This information empowers decision-makers to tailor the model according to specific monitoring requirements.
- Overall, the utilization of the multi-variable semivariogram model marks a crucial step forward in the optimization of RWIS station placement, providing a reliable and adaptable tool for decision-makers in the field of road weather management. As the model continues to be embraced and applied, it holds promise for contributing to safer, more efficient road systems in Maine and beyond.

Recommendations for further research are given below:

This research opens up several promising directions for future investigations, outlined below:

- *Development of an empirical optimal density model:*
  This extension aims to determine the optimal number of RWIS stations needed for sufficient monitoring coverage in Maine. Factors like geographical distribution, road network characteristics, and desired monitoring accuracy

will be considered.

- *Designing a bi-level sequential optimization model:*
  Another advancement involves creating a novel bi-level sequential optimization model to determine both locations and types of RWIS stations (regular and mini-RWIS). This comprehensive approach will enhance the efficiency and effectiveness of the RWIS network deployment.
- Lastly, incorporating a larger and more diverse sample size in this research could enhance the methodology's robustness and reliability.

In conclusion, this research serves as a fundamental guide and critical foundation for devising a long-term RWIS deployment strategy in the state of Maine. The outcomes of this study will greatly benefit winter travelers by enhancing safety, mobility, and environmental sustainability through an optimized RWIS network.

Author Contributions

The authors confirm their contribution to the paper as follows: study conception and design: S. Biswas, T. J. Kwon; data collection: S. Biswas; analysis, interpretation of results and draft manuscript preparation: S. Biswas, T. J. Kwon. All authors reviewed the results and approved the manuscript.

Conflict of Interest

The authors declare that they have no conflict of interest.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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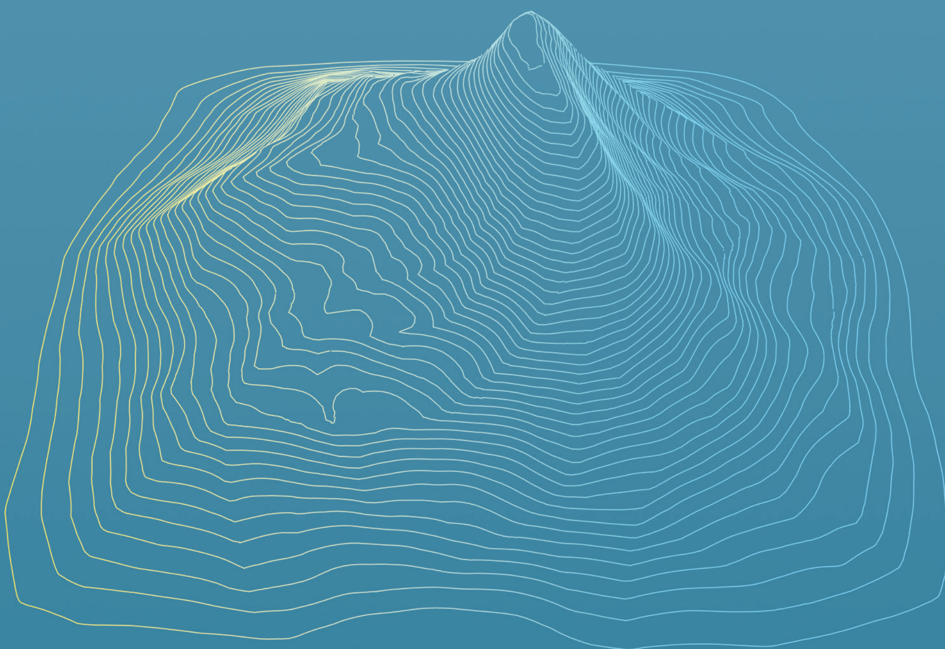

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