From Impacts to Perceptions: Exploring the Maya Train's Effect on Groundwater Systems and Communities in Quintana Roo, Mexico

Master Thesis

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ABSTRACT

The Maya Train project in Quintana Roo has raised significant concerns and differing viewpoints among the local community regarding its environmental and social impacts, particularly on the potential disruption to groundwater systems. Previous research has focused on highlighting the environmental impacts, especially those occurring on the surface. Therefore, this study aims to shed light on changes in groundwater systems, their social impacts, and the factors shaping the community's perception of these impacts. To achieve this, a comprehensive document review was conducted along with 10 semi-structured interviews with residents of varying demographic characteristics. The analysis revealed 19 groundwater-related impacts and 37 social challenges. Additionally, a difference was observed between the academically oriented findings and the community's risk perceptions, revealing a lack of awareness among the sample regarding the biophysical impacts and their resulting social challenges. Ultimately, the findings demonstrated the importance of factors related to social and cultural identity in shaping participants' perceptions. Variables such as group membership, beliefs and values, trust, sense of fairness, academic and empirical knowledge, and economic status were identified as the most influential.

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LIST OF ABBREVIATIONS

CONAGUA	National Water Commission
PEMEX	Mexican Petroleum
SEDENA	Secretariat of National Defense
EIM	Environmental Impact Manifestation
SEMARNAT	Secretariat of Environment and Natural Resources
EIA	Environmental Impact Assessment
INAH	National Institute of Anthropology and History
SIA	Social Impact Assessment
FONATUR	Fondo Nacional de Fomento al Turismo

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1 INTRODUCTION

This thesis focuses on the disruption of groundwater systems and the consequent social impacts of implementing the Maya Train in Quintana Roo, Mexico. This introduction contextualizes the domain and lenses of the research, which will be elaborated upon in the following chapters. It begins with a general overview of groundwater in a global context, followed by a detailed description of the karstic system and aquifer in Quintana Roo. It then provides an in-depth explanation of the Maya Train, which is complemented by a visual representation of the system that guides the research approach. Finally, the problem statement, research objectives, and research questions are presented.

Groundwater is a core component across various domains worldwide. First, it serves as the main water source for agriculture in many countries, thereby ensuring food security. It is necessary to provide essential services, given that a consistent supply of high-quality groundwater can alleviate poverty, foster equitable growth, and support communities in climate adaptation, by protecting them from severe climate events. Additionally, groundwater supports diverse ecosystems by providing the water needed for these to carry out their biological processes (Rodella et al., 2023). To illustrate the reliance on groundwater intake, Figure 1 compares its use for drinking water with other sources in non-high-income countries.

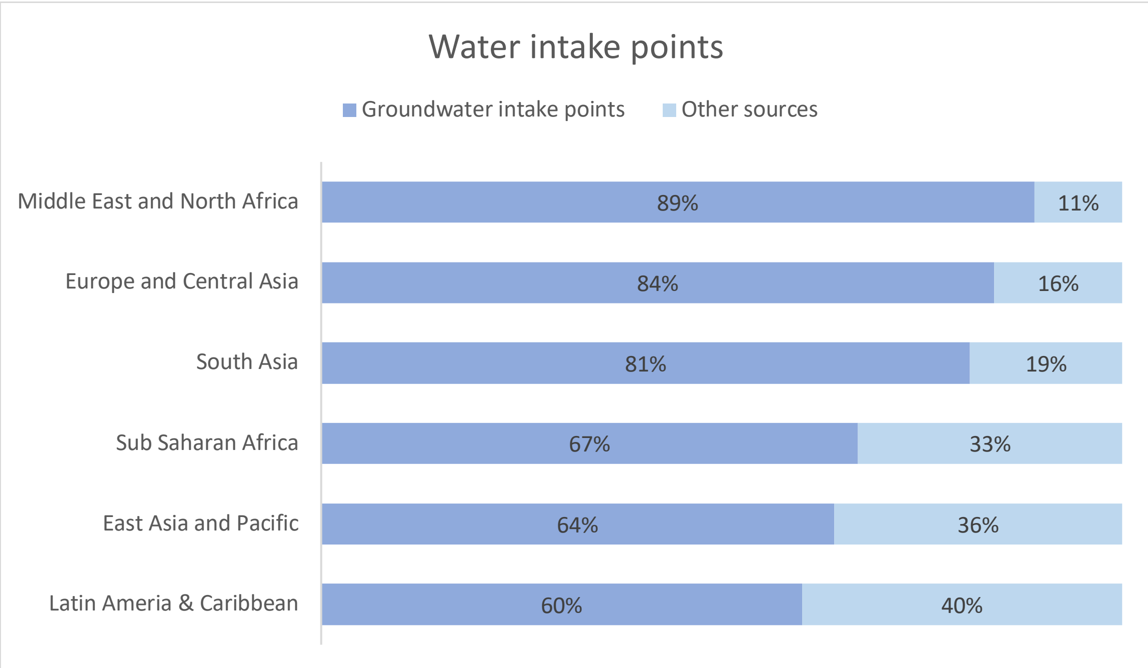

Figure 1. Water intake points in non-high-income countries per region
Adapted from (Rodella et al., 2023)

Note: The calculation considers non-high income countries as classified by the World Bank's income classification as of July 1st, 2022 (World Bank, 2022) .

Despite its critical importance, groundwater faces significant challenges related to both its quantity and quality. First, overexploitation can lead to seasonal and long-term depletion, increasing the unpredictability of water availability and causing water stress, potentially displacing vulnerable populations and fostering competition between urban and rural communities. Additionally, reduced groundwater volume translates to higher extraction costs and diminished economic welfare (Rodella et al., 2023).

Furthermore, deteriorating groundwater quality presents another major challenge, influenced by natural factors such as rainfall and recharge patterns, as well as anthropogenic activities. Unlike surface water, groundwater processes occur over different temporal scales, with flows ranging from days to centuries. This complexity makes the identification of contaminants and their sources more difficult, hindering effective remediation efforts (Rodella et al., 2023). Therefore, addressing these challenges is crucial for ensuring water security in the face of evolving environmental and human pressures.

1.1 QUINTANA ROO AND MAYA TRAIN

1.1.1 Groundwater System

Groundwater plays a critical role in Mexico's water supply, accounting for approximately 38.7% of the national water use (Souza et al., 2023). Notably, Mexico's unique geological features, particularly prevalent in the regions of Chiapas and the Yucatan Peninsula, influence groundwater dynamics. Covering about 25% of the country's surface area, karst geology characterized by the presence of soluble carbonate rocks primarily consisting of limestone, shapes the landscape with formations such as sinkholes, springs, and caves (Souza et al., 2023; United States Geological Survey, 2021). Figure 2 shows the distribution of Mexico's karst geology.

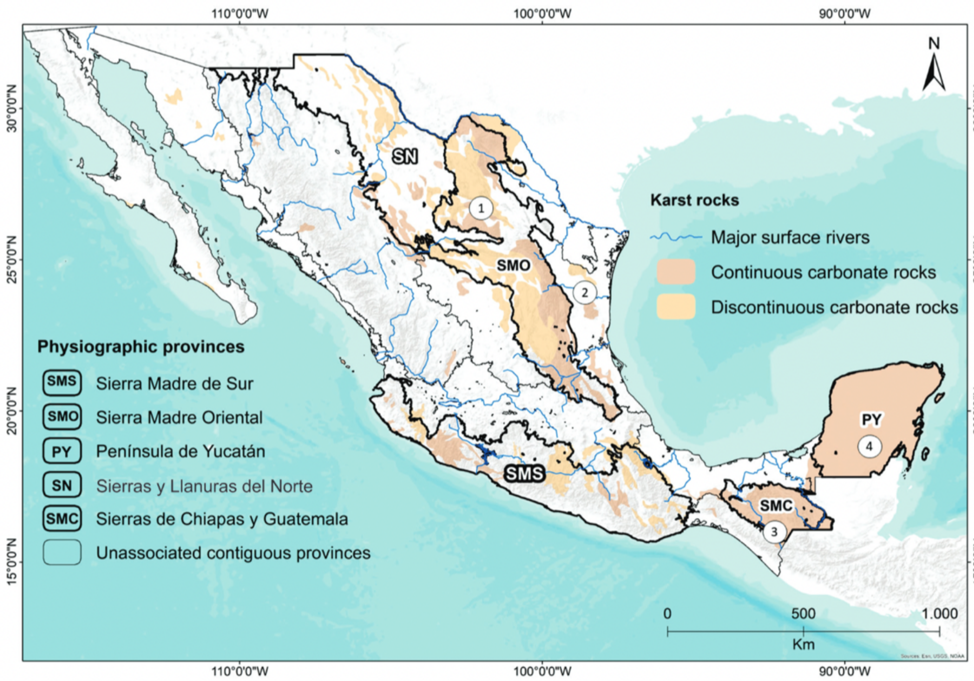

Figure 2. Karst surface of Mexico
(Bautista, 2023)

Quintana Roo state is part of the Yucatan Peninsula Platform, which extends over 165,000 km2 across Southeastern Mexico (Ballou et al., 2022). Within this region, the high solubility of limestone, along with the permeability of soils, contributes to a significant volume of groundwater compared to surface water bodies (Bautista, 2023). These geological formations act as natural filters, extracting salt from seawater and forming a large aquifer that serves as the sole source of drinking water for the region. (Estrada Medina et al., 2019; NASA Earth Observatory, 2021). However, as the sea level drops, the flooded caves exchange water for air, a phenomenon that can lead to the collapse of sections of the ceiling, creating access points to the cave network from the surface (Moroy-Ríos, 2019).

According to data compiled by the Quintana Roo Speleological Survey (2022) the state contains at least 105 flooded caves discovered and mapped through various exploration projects, diving expeditions, and institutional efforts. Moreover, the Ox Bel Ha and Sac Aktun Systems are the two longest in the region. The latter is recognized as the world's largest underwater cave system, spanning over 376 kilometers with a maximum depth of 120 meters and encompassing an estimated 228 cenotes (National Geographic, 2018; Quintana Roo Speleological Survey, 2022).

Furthermore, the hydrological flow in these areas is entirely underground, connecting through intricate networks of underground rivers (Estrada Medina et al., 2019). Groundwater within the Aquifer "Cerros and Valles," as it is referred to in national hydrological studies, located beneath the region of Quintana Roo, has varying flow speeds. According to the latest report from the National Water Commission (CONAGUA), hydrologic conductivity ranges from 0.02 to 16038 meters per day (equivalent to 2.31 x 10^-7 to 1.86 x 10^-1 m/s). This variability in values is attributed to differences in cavity sizes resulting from the porosity of limestone. Notably, in the initial meters of depth, permeability tends to be very low, leading to low extraction flow rates. As reported by the Public Registry of Water Rights (REPDA), a total extraction volume of 29.1 hm^3 per year was recorded by the end of 2022. Of the total volume, 68% was designated for agricultural use, 27.5% for diverse purposes, and only 4.5% for urban public consumption (CONAGUA, 2023). These particular characteristics of Quintana Roo’s karstic system offer unique opportunities for comprehending groundwater dynamics and its implications (National Geographic, 2018).

1.1.2 Maya Train

Among the major tourism-driven projects in Quintana Roo, the Maya Train stands out as a flagship initiative of the national government, initiated in 2018 with a planned route spanning 1460 km through the jungle (BBC News, 2018). This train will connect five states of Southeastern Mexico, often considered "underdeveloped" compared to the northern regions of the country, with Quintana Roo being one of them (González-Días, 2023). Initially, the train will be used solely for passenger transportation. However, once all routes are completed, the project’s profitability will come from additional freight services. Petróleos Mexicanos (PEMEX), the state-owned company responsible for national hydrocarbon production and commercialization, will be the main client, accounting for approximately 80% of the train's cargo. (Gobierno de México, n.d.-b; Tolentino Morales, 2023). The type of materials PEMEX plans to transport include fuel, cement, and vehicles (Tolentino Morales, 2023).According to official reports, the train aims to foster sustainable development by connecting remote communities and urban centers (Gobierno de México, n.d.-a). This connection is intended to enhance socioeconomic development and improve people’s quality of life, by attracting tourism, increasing job opportunities, and protecting cultural heritage and the environment through new models of responsible development. Its primary objective is to achieve the development of Southeastern Mexico based on territorial planning, conservation, inclusive economic models, social welfare, and the protection of the historical heritage and identity of the region’s communities (Gobierno de México, n.d.-c). Moreover, the project aims to attract new investors and developers to the region, enhancing infrastructure to sustain tourism trends and boost the local economy. The Secretariat of National Defense (SEDENA) already has plans to build six Tren Maya hotels along the entire route, with one located in Quintana Roo, which is expected to trigger the construction of additional private properties (Carrillo, 2023).

Initially, the proposal suggested the restoration and utilization of old railway tracks dating back to the late twentieth century for the new route, a plan executed in most instances. However, in the case of Quintana Roo, there were no pre-existing railway tracks, demanding the construction and preparation of the terrain from scratch. The initial plan designated the segments crossing through Quintana Roo as "Tramo 5” and “Tramo 6”, intended to run parallel to the state's sole existing highway (González-Días, 2023). However, after a few months of construction, the hotel sector exerted pressure, claiming that a train running through urban areas would negatively impact tourism income in the region (Cruz, 2023). As a result, it was determined that this approach was no longer feasible, leading to a reevaluation of the route to cross through nearly untouched jungle terrain (González-Días, 2023). Figure 3a illustrates the entire route of the Maya Train, and the sections that comprise it, and it highlights Tramo 5 and Tramo 6 in orange and light green color, respectively, which traverse Quintana Roo. Moreover, as shown in Figure 3b, this new route crosses through primary sinkhole areas, locally known as cenotes.

Figure 3a. Mayan Train route

(González-Días, 2023)

Figure 3b. Maya Train route over areas with cenotes system

(González-Días, 2023)

As of five years since its initiation, most segments have been inaugurated between December 2023 and February 2024. However, portions of the Tramo 5 remain under construction, primarily due to the soil-related obstacles encountered, numerous criticisms, and legal drawbacks (Mungía, 2024). According to initial governmental reports, the train will safeguard the natural ecosystem by establishing natural protected areas, improving biological corridors, and restoring and conserving soil and water. These are to reverse the deterioration process resulting from prior unplanned utilization of the area and its natural resources (Gobierno de México, n.d.-c). However, despite its sustainability motivation, the construction of this segment commenced without an Environmental Impact Manifestation (EIM), which led to the filing of several legal appeals, resulting in the temporary suspension of construction works (BBC News Mundo, 2022; González-Días, 2023). In Mexico, an EIM is a mandatory technical document that must be prepared and submitted to the Secretariat of Environment and Natural Resources (SEMARNAT) by any person or company planning to carry out a project. This document evaluates the potential environmental changes the project may cause and outlines how they will be mitigated (Procuraduria Federal de Proteccion al Ambiente, 2019). The EIM is essential for the competent authority to conduct an Environmental Impact Assessment (EIA) analyzing the project and determining whether it will be approved, approved with modifications and conditions, or rejected.

Subsequently, once the EIM was presented and approved by SEMARNAT, the decision was made to alter the planned route of the train. Therefore, the environmental evaluation conducted in that document pertained to the original project rather than the new route (González-Días, 2023). Despite this, the train continued under construction. However, in May 2022, the updated EIM was finally presented and reapproved by SEMARNAT. Nevertheless, according to the Center for Biological Diversity, the process was overly subjective, as it minimized significant environmental factors like the preservation of the jungle and the karst ecosystem. Specifically, they assert that regarding the southern segment of Tramo 5, inadequate attention was given to impacts that could be considered critical, such as habitat fragmentation, disturbance of underground rivers, as well as harm to protected species (Center for Biological Diversity, 2022). Despite being described as "the work of greatest environmental care" by Andrés Manuel López Obrador, President of Mexico, the actions that followed the construction of Tramo 5 triggered a wave of criticism, leading to community protests and the emergence of regional collectives such as Sélvame del Tren, Selva Maya, Cenotes Urbanos, SOS Cenotes, among others. (AMLO, 2023; Mungía, 2024). Comprising local residents, these groups have played a crucial role in exposing mismanagement and associated water risks during the train's construction phase.

In prior instances of regional suspensions, the project proceeded with construction due to the classification of all presidential flagship projects as "national security" initiatives, exempting them from such suspensions (BBC News Mundo, 2022). However, in February 2024, a federal court in Mérida, Yucatán, mandated the interruption of works on the remaining segment of Tramo 5. This suspension will persist until the government provides evidence of having conducted comprehensive geological and hydrogeological studies to assess potential impacts on the soil and subsurface (Varillas, 2024a). However, as of the last update in March, the construction work continued despite this suspension (Varillas, 2024b). Therefore, in June another definitive suspension was issued by the same court (Vazquez, 2024)

1.2 PROBLEM STATEMENT

According to information disseminated by local organizations and collectives comprising engineers, water experts, divers, freedivers, and civilians, among others, the construction of the Maya Train has altered the natural environment, for instance by logging thousands of trees for railway preparation. Moreover, an increase in the number of jaguars being run over has been noted as they become trapped between the train and the highway (Cruz, 2023). Moreover, it creates a barrier that separates wildlife populations, impacting the continuity between protected natural areas like Sian Ka'an and Yum Balam (Consultores en Gestión Política y Planificación Ambiental, 2022). Additionally, the train crosses above flooded and semi-flooded caves that contain historical artifacts and some of the oldest human remains in North America (El Universal, 2022; Stevenson, 2022).

Despite the National Institute of Anthropology and History (INAH) stating that soil mapping studies would be conducted to prevent any damage to caves from the support structures of the train's elevated section, environmentalists have reported three primary activities of concern during the construction phase that pose threats to water ecosystems (AP News, 2024). These activities include the drilling of surface rocks, the injection of concrete into caves, and the installation of metal piles up to 25 meters deep, which have already begun to rust (Varillas, 2024a). Such activities can result in the collapse of semi-flooded caves as the bedrock becomes progressively thinner, while also presenting the risk of contaminating high-quality subsurface water with external pollutants (Chiomante, 2024).

Given the interconnected nature of the system, any damage or contamination to a cenote or cave poses a significant risk to the entire ecosystem (SOS Cenotes, n.d.). Groundwater deterioration threatens, for instance, the endemic biodiversity that depends on it (BBC News Mundo, 2022). It would also directly impact the lifestyle and well-being of the local community, as the aquifer is the sole source of potable water in Quintana Roo (Estrada Medina et al., 2019). Additionally, concerns have arisen regarding the operation of the train promoting a development model that attracts more tourists to the area. While this increase in tourism may create jobs in the short term, it is likely to have negative long-term consequences such as increased water demand and improper disposal of contaminated water or wastewater. This is particularly relevant considering that some cenotes in Quintana Roo have registered record-high contamination levels in 2023 and according to water authorities, it can be attributed to inadequately discarded wastewater (Baratti, 2023).

Moreover, despite coverage by news outlets and local organizations regarding the environmental and water-related impacts of the Maya Train, construction activities persist with no apparent changes to mitigate these concerns. While significant attention is given to the issues occurring above ground, there is not enough focus on what happens beneath the surface. This lack of focus highlights a knowledge gap in understanding how the project's environmental effects on groundwater systems translate into broader social challenges. Addressing this gap is essential for better informing public and private sectors about the potential risks to livelihoods in both the short and long term.

1.3 RESEARCH OBJECTIVES

This research has two primary objectives. First, it aims to analyze the effects of the Maya Train's implementation on local groundwater systems and communities in Quintana Roo. This involves examining current and upcoming construction activities, as well as future consequences once the train becomes operational, and translating these effects into social challenges. This translation examines how biophysical changes lead to subsequent shifts in livelihoods, the economy, health, and security.

Secondly, the study seeks to conduct a comprehensive analysis of how the local community perceives potential social challenges and the factors that shape these perceptions. To accomplish this, the community's responses will be compared with the academic findings from the initial stage of the research. This comparison will highlight any implications or social changes that may have been overlooked in the literature but were identified through empirical observations.

This research will therefore shed light on the potential impacts of the Maya Train project to ensure that both the public and private sectors remain aware of these impacts. This awareness aims to motivate sustainable development that prioritizes the needs and interests of local communities and the environment over short-term economic gains.

1.4 SYSTEM REPRESENTATION

For an overall understanding of the case study, its elements, and its connections, this section presents a visual representation of the system (Figure 4). It was constructed using as a source the introductory and background information collected in the previous sections. The entire system is delineated within the borders of Quintana Roo, highlighting it as the primary area of study. The three primary concepts it aims to evaluate (groundwater, the Maya Train, and social challenges) are represented in green, while the remaining squares show the relationships among these concepts and their interconnected elements. Each square's color represents its respective category, and the arrow's color indicates the category it leads to. The different categories are described below in Table 1.

Table 1. System representation categories

(green)	Case study's primary elements
(pink)	Processes
(blue)	Biophysical elements
(violet)	Benefits
(yellow)	Constraints
(red)	Impacts

The diagram first develops groundwater as a resource, indicating within a blue square its benefits on a global scale as a crucial water supply. Outside the blue square, it illustrates how groundwater specifically relates to the case study. The mid-section of the diagram shows the constraints, processes, and impacts generated during the construction and operation phases of the Maya Train. The main concepts connecting groundwater and the train include the region's karst soil and the resulting soil-related issues for the train's development. Logging is positioned outside the construction area, as this study focuses exclusively on groundwater-related issues, excluding other environmental consequences that don't directly relate. Additionally, hydrological and geological studies are placed outside the construction square as they were not conducted before construction. These studies are now legally pivotal in determining the prolongation of the suspension.

Moreover, the bottom section of the diagram shows the impacts shared by both the construction and operation phases, such as social fragmentation due to varying perceptions of stakeholders, water quality deterioration, and habitat fragmentation. Finally, these impacts lead to consequential social challenges that this study aims to investigate, guiding the further development of more specific research questions.

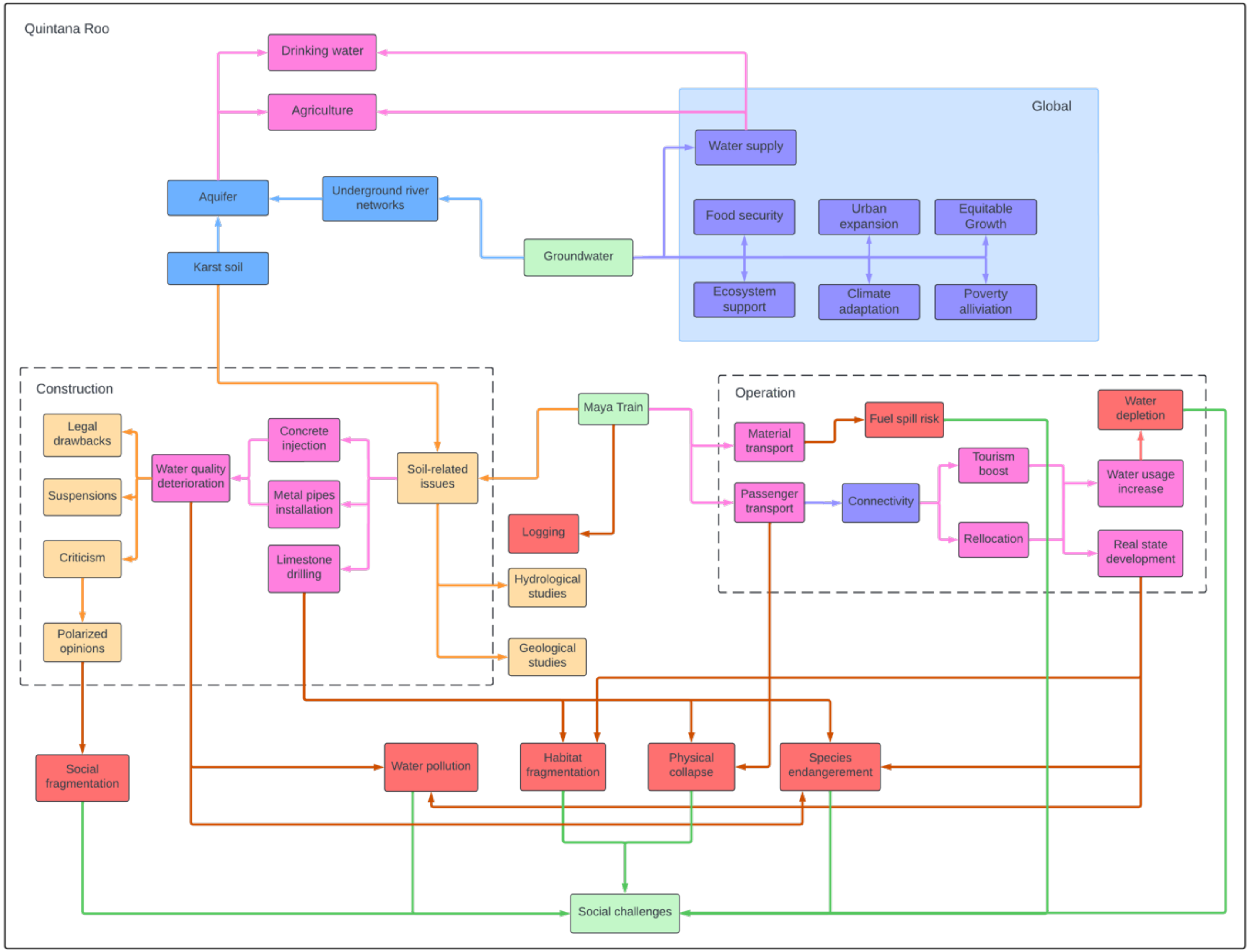

Figure 4. Schematical system representation

1.5 RESEARCH QUESTIONS

The main research question is formulated as follows:

How does the local community of Quintana Roo perceive the social challenges arising from the degradation of groundwater systems caused by the implementation of the Maya Train?

To answer the main research question the following sub-questions were formulated:

1) What are the biophysical impacts of groundwater system degradation in Quintana Roo resulting from the construction and operation of the Maya Train?
2) What social challenges are local communities in Quintana Roo likely to face due to groundwater system degradation caused by the Maya Train?
3) What is the local community's perception of the potential social challenges of groundwater system degradation associated with the Maya Train?
4) What factors shape the local community's perception of these impacts?

The first sub-question is explanatory as it aims to reveal the causal relationship between the construction and operational activities of the train and its biophysical impact on groundwater systems. In contrast, the second sub-question is evaluative, focusing on assessing the challenges that local communities may encounter due to these biophysical effects. The third sub-question is exploratory, delving into how the community perceives these social challenges. Similarly, the fourth sub-question is exploratory, as it examines the factors that shape these perceptions.

2 THEORETICAL FRAMEWORK

This chapter reviews four theoretical approaches identified in the literature, two of which were adapted to fit this research. Each section begins with a brief overview of the framework in question, followed by an explanation of why it was either chosen or discarded. Both frameworks selected guided the research design, data collection, and data analysis by indicating what to look for and which methods to use. Initially, the Social Impact Assessment (SIA) of Research Framework was used solely to categorize the results according to dimensions of impact. Subsequently, the Influences on Risk Perceptions Framework was employed as a tool to comprehend the factors influencing the perception of local community members. A more detailed explanation of how each framework was adapted to address the research questions is provided below.

2.1 ICONS FRAMEWORK

Jenkins et al. (2024) developed the Individual, Contextual, Cognitive, and Social (ICONS) Framework to analyze how individuals perceive and respond to risk, particularly in the context of consumer products. Despite its original focus, the framework is still relevant to this research as it synthesizes past literature to identify the factors that cause variations in how people perceive, tolerate, and communicate risks, drawing on various psychological disciplines. Notably, this framework includes the concept of risk tolerance, which addresses how individuals balance risks and benefits. It illustrates how cognitive appraisals, contextual elements, social factors, and individual differences are interconnected, influencing overall risk perception. Figure 5 presents a diagram of the ICONS Framework for risk perception.

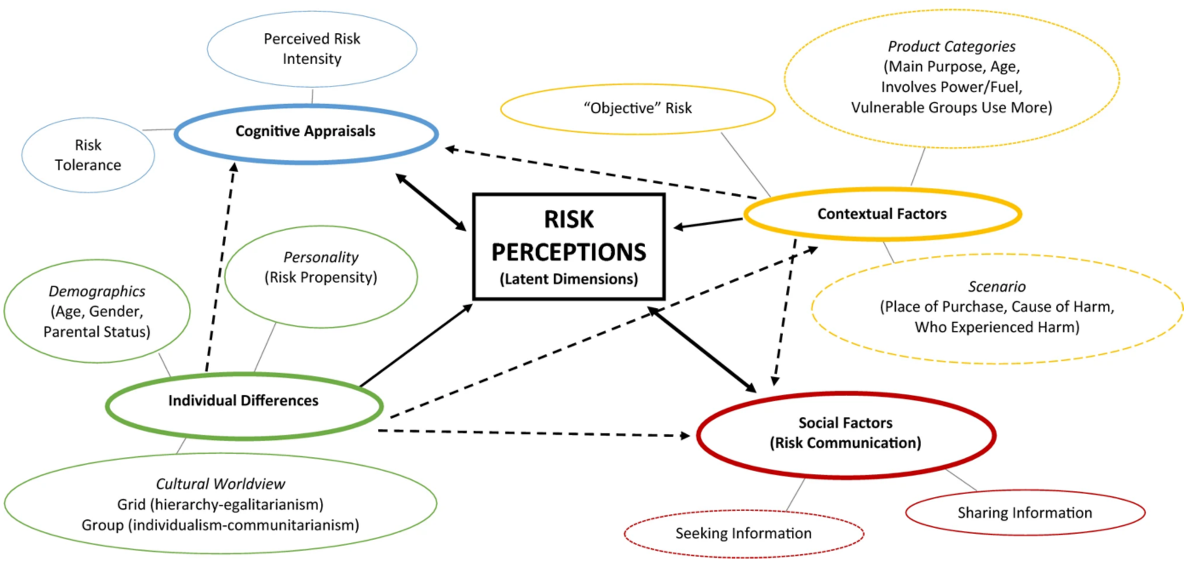

Figure 5. ICONS Framework
(Jenkins et al., 2024)

While it would be valuable to assess the trade-offs between risks and benefits to evaluate the community's risk tolerance, such an evaluation would likely overcomplicate the study. Given that the primary benefits of the Maya Train are economic and tourism-related, rather than connected to groundwater systems, focusing on social aspects not directly tied to biophysical changes would increase the study’s robustness, losing focus from its main objective, especially given the time and resource constraints. Additionally, since the ICONS Framework is more suited to consumer contexts rather than communities facing physical risks, it was ultimately considered unsuitable for guiding this study's data analysis.

2.2 SOCIAL AMPLIFICATION FRAMEWORK OF RISK AND ENVIRONMENTAL PRACTICE

The relationship between environmental risk perception and environmental behavior involves multiple factors. Gao et al. (2019) examine this connection in the Chinese context, proposing a model where environmental risk perception directly influences behavioral responses. In this model, environmental behavior is the outcome and dependent variable, shaped by elements such as environmental values, trust in governance, and access to information. The model considers different types of behavior, including radical behavior, concern behavior, and protective behavior. The study's findings indicate that three primary dimensions influence public risk perception: the characteristics of the risk itself (such as likelihood and severity), individual differences, and social psychological factors (including trust, values, and identity). Figure 6 provides an overview of the conceptual model illustrating how public environmental risk perception is translated into various behavioral responses.

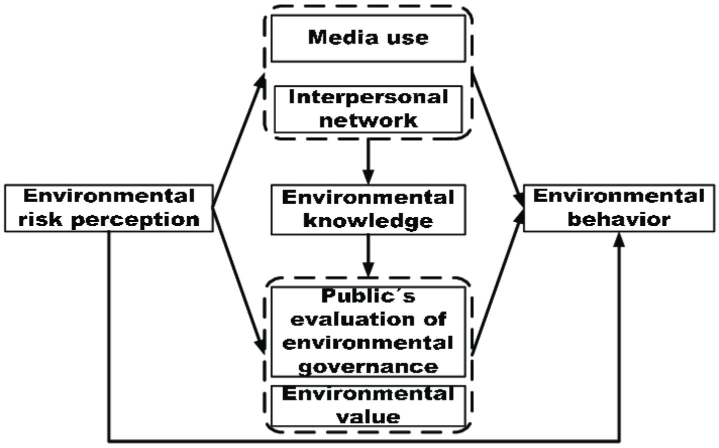

Figure 6. Social Amplification Framework of Risk and Environmental Practice
(Gao et al., 2019)

Although the framework offers valuable insights into how identity and personal factors influence risk perception, its primary focus is on evaluating how these perceptions affect environmental behavior. In contrast, the goal of this study is to understand the factors that shape people's perceptions, rather than what those perceptions influence. Therefore, the framework was only used to narrow down the shaping factors to those related to the identity of community members, and it was not employed to guide the data analysis.

2.3 SOCIAL IMPACT ASSESSMENT OF RESEARCH FRAMEWORK

Viana-Lora et al. (2023) introduce a framework to assess the societal impact of research in the tourism sector. The framework is structured to evaluate social impacts across three stages: ex-ante (prior to project development), in-itinere (during project implementation), and ex-post (post-implementation evaluation). Additionally, it aims to identify impact indicators or actions and categorize them into six thematic areas: Communication and promotion, Policy and regulation, Economic benefit, New technological resources, Environment, and Social Improvements. Furthermore, the framework proposes categorizing final impacts into four dimensions: applied, temporal, geographical, and sustainability. Figure 7 illustrates the Framework for assessing the social impact of research projects, including the possible stages and dimensions.

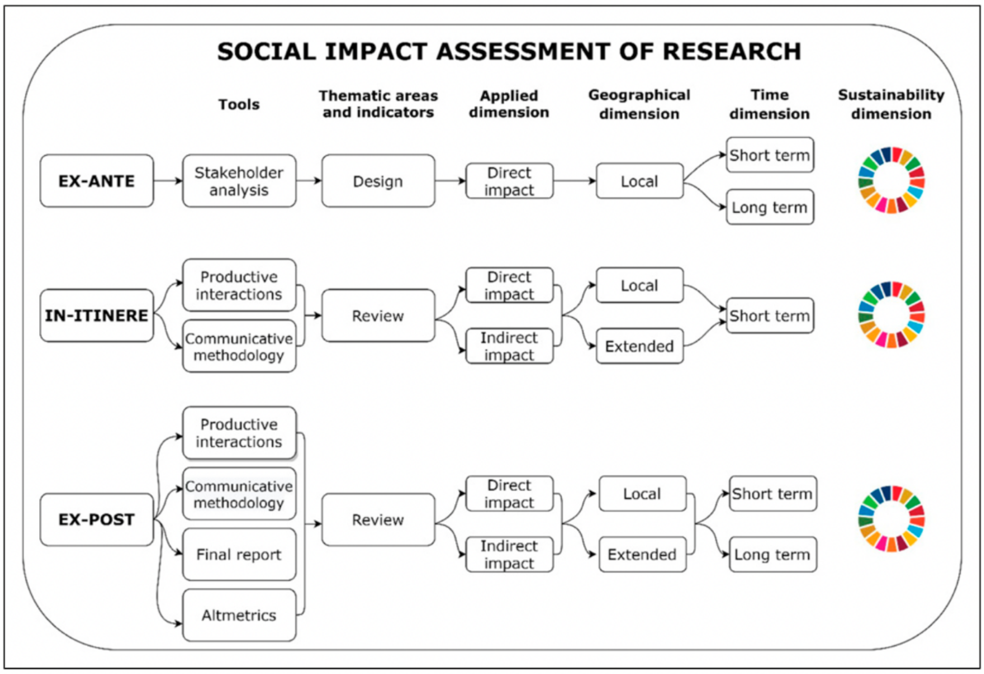

Figure 7. Framework for Social Impact Assessment of Research
(Viana-Lora et al., 2023)

While the framework does not directly evaluate the impacts of tourism but rather focuses on how research affects tourism by promoting sustainable practices, it is still relevant for this research as it classifies impacts into dimensions that help identify and categorize them. It helps determine whether impacts are direct or indirect to activities, whether they will affect only the regions of construction or the entire state, and whether they will be immediate or long-term. Therefore, for the analysis of data, this framework was adapted to categorize the final impacts encountered into applied, geographical, and temporal impact dimensions. This classification helps to clarify the nature and severity of the identified changes based on the document review. It also enables comparison with residents' perceptions, facilitating a discussion on whether there is greater awareness of immediate and localized impacts or if the nature of these impacts is not influential.

2.4 INFLUENCES ON RISK PERCEPTIONS FRAMEWORK

Dobbie and Brown (2014) constructed a framework for assessing risk perception within the water management sector, drawing from both conceptual and empirical studies. The framework outlines two primary components: the risk object and the object at risk. The risk object refers to the factor potentially causing the risk, which could range from new technologies to processes or objects. Conversely, the object at risk refers to what may be affected by the potential effects, for instance, social dynamics, human health, the environment, or a combination of these. To link these two components, the framework introduces a range of collective and individual factors, arguing that diverse socio-cultural elements among subjects lead to different motivations, levels of knowledge, beliefs, values, attitudes, and cultural norms. These factors collectively shape an individual's perception of risk. For instance, individuals with limited technical knowledge may rely on the perceptions of others within their social circles who have greater expertise. The framework suggests two main drivers of risk perception where all of the above can be categorized: social identity and cultural identity. These variables influence how individuals interpret information and, consequently, how they perceive risks within their respective contexts (Dobbie & Brown, 2014). Figure 8 illustrates the framework showing all influences identified to shape risk perceptions.

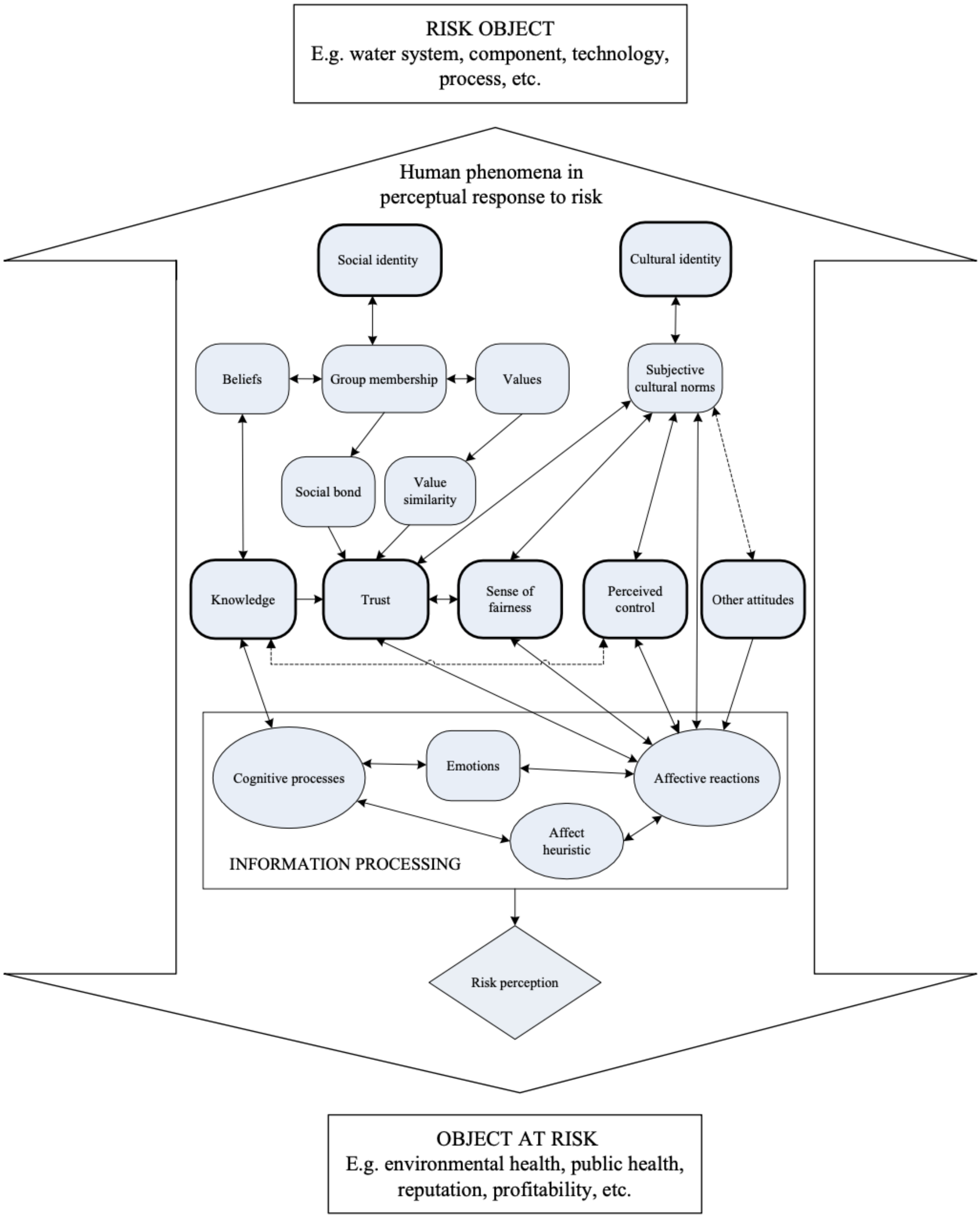

Figure 8. Influences on Risk Perceptions Framework
(Dobbie & Brown, 2014)

Given that part of the research topic focuses on analyzing the community's perception of impacts, this framework helps identify the social and cultural factors influencing these perceptions. It helps determine whether a participant's stance is influenced by factors such as a lack of knowledge about groundwater dynamics, their environmental values and motivations, their trust in government projects and decisions, and other relevant aspects. Therefore, this framework was selected to guide the data analysis process.

Table 2 summarizes the intended use of the two frameworks selected and discussed above for the data analysis process. A further detailed explanation of how each framework was applied to analyze the data collected is provided in Section 3.3.2.

Table 2. Intended use of selected frameworks.

Theoretical Framework	Application
SIA of Research Framework	Categorization of results into applied, geographical, and temporal impact dimensions.
Influences on Risk Perception Framework	Understand the factors shaping the community's risk perception.

3 RESEARCH DESIGN

This chapter outlines the methodology employed throughout the study. Section 3.1 describes the rationale behind selecting the Maya Train case as the subject of study, including the defined scope and boundaries. Section 3.3 delineates the approach for addressing the research questions and the intended insights from each. For each sub-question, it details the specific methods for data collection and the application of frameworks to analyze the gathered information.

3.1 CASE SELECTION

The research focuses on the Maya Train in Quintana Roo, Mexico, motivated by four reasons. Firstly, the project's recent start, with some segments inaugurated this year and others still under construction. This offers an opportunity to assess ongoing activities and anticipate potential challenges in the near future. Secondly, as a governmental initiative, the Maya Train is expected to prioritize citizens' interests, unlike private developments primarily driven by economic motives. Thus, understanding its impacts could influence decision-making processes to ensure groundwater is considered a significant stakeholder during its operation (Ekmekçi & Günay, 1997). Thirdly, the project has sparked significant societal discourse, leading to polarized opinions between those who strongly oppose it and those who fully support it (Centro Mexicano de Derecho Ambiental, 2023; González-Díaz, 2023). Lastly, a significant portion of the population lacks awareness of the karstic system's functioning and the critical dependence on groundwater (Hernández-Yac, 2022). These characteristics make the Maya Train an ideal case study for exploring the social implications of large-scale infrastructure projects in environmentally sensitive areas.

3.2 RESEARCH BOUNDARIES

The research focuses exclusively on the social impacts resulting from the degradation of groundwater systems due to the implementation of the Maya Train. It will consider current activities during construction and future activities associated with the expected increase in tourist activity and relocation during its operation. However, it will not address the positive or negative effects on the economy and tourism as productive activities unless they result directly from the identified impacts, as these aspects fall outside the defined boundaries of this study. Furthermore, although the train traverses several states in Southeastern Mexico, the geographical scope of this study is limited to the state of Quintana Roo.

3.3 METHODOLOGY

Figure 9 ilustrates the methodology implemented throughout the research project, which adopted a qualitative and inductive approach. This approach was guided by a document review from academic and grey literature sources, serving four main purposes. Firstly, it was conducted in Chapter 1 to gather background information on the soil characteristics of Quintana Roo, the history, current status, and societal perspectives on the Maya Train project. Secondly, this review guided the scoping decisions by creating the system representation to define the objectives and problem statement. Thirdly, it was used to select a framework that could guide the research methodology. Finally, it was employed to address the first and second research sub-questions. Moreover, the third and fourth sub-questions were answered exclusively through semi-structured interviews. The specific methods for each sub-question are elaborated upon in Sections 3.3.1 and 3.3.2.

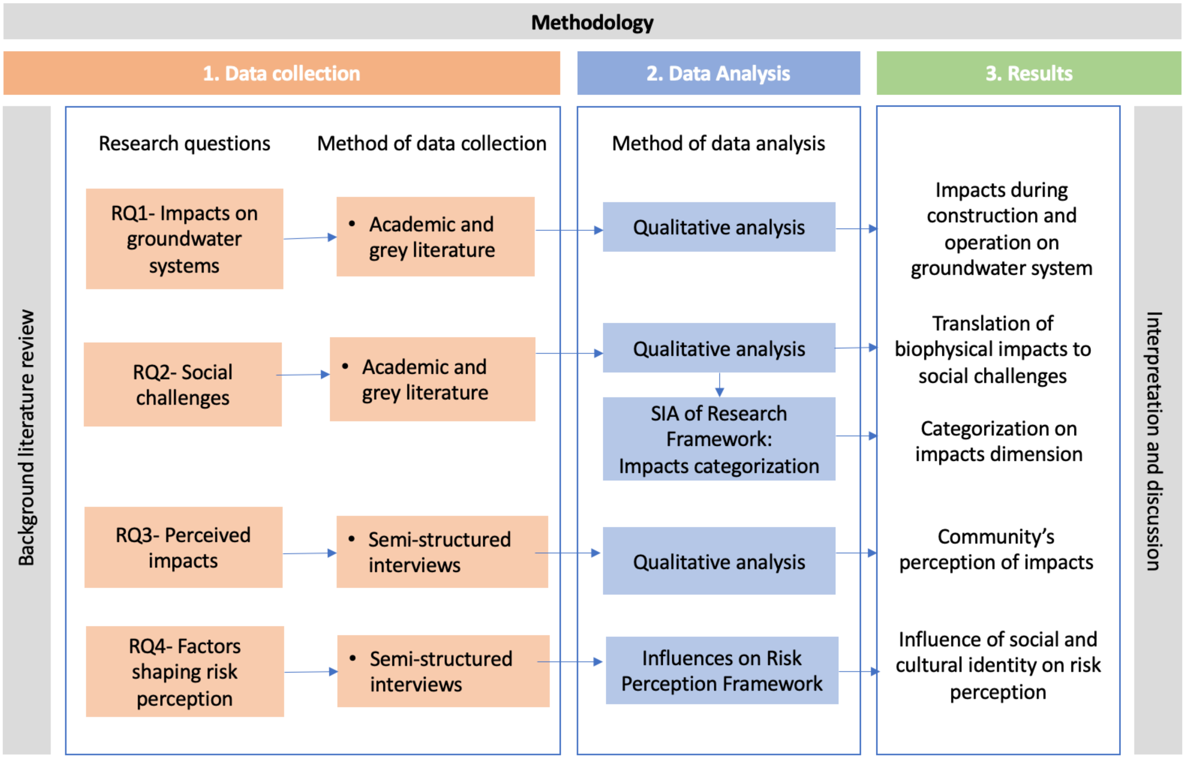

Figure 9. Research methodology
Own elaboration

3.3.1 Data Collection

Table 3 provides an overview of the data collection process, which is further detailed in the following section. It includes the information necessary to answer each of the research sub-questions, the sources from which the data was obtained, and the methods used.

Table 3. Data collection per research sub-question.

Research question	Data needs	Data sources	Data collection methods
Q1	Activities during construction and operation phase	Science Direct, SpringerLink, newspapers, local media, government publications, EIM	Desk research
	Potential threats to groundwater systems		
Q2	Social implications of groundwater systems deterioration	Scopus, SpringerLink, newspapers, local media, government publications, EIM	Desk research
	Scale of impacts (local/extended, direct/indirect, long-term/short-term)		
Q3	Percieved social impacts of groundwater systems deterioration	Local residents of Quintana Roo, Mexico	Semi-strucured interviews
Q4	Factors shaping community's perspectives	Local residents of Quintana Roo, Mexico and selected framework	Semi-strucured interviews

The first sub-question aims to identify specific past and future activities associated with the construction and operation of the Maya Train that potentially pose a threat to groundwater ecosystems and evaluate what this impact would be. To achieve this, desk research was conducted, encompassing a review of scientific and grey literature, publications, and newspapers. Scientific studies were primarily sourced from, ScienceDirect, and SpringerLink databases. The search terms used included "tourism water demand", "fuel spill risk groundwater", and "wastewater in Quintana Roo" along with other general search terms.

The second sub-question seeks to analyze how these identified biophysical impacts manifest in terms of social dynamics, health, and well-being within the local community, therefore, similar methods as those employed in question one were utilized. This includes conducting desk research on previous articles examining the social consequences of groundwater degradation, along with grey literature on the transition of impacts from environmental to social realms. The databases used were SpringerLink and Scopus, utilizing "alternative water sources" and "biocultural heritage" as search terms.

Lastly, the third sub-question aims to discover the perceived impacts of the local community and determine whether they align with the research findings, while the fourth sub-question seeks to explore the underlying reasons for these perceptions. To achieve this, semi-structured interviews were conducted with 10 members of the local community, allowing them to elaborate on their experiences and perceptions of impacts, including their level of awareness, and the rationale behind these perceptions. Further information about how the data collected was stored is detailed in Section 3.4. Semi-structured interviews were selected as they are ideal for gathering participants' personal information, views, and experiences (Family Health International, 2005). It was preferred over other qualitative methods, such as focus groups, to ensure that participants' responses reflected their true prior knowledge without being influenced by others. The semi-structured approach was also selected with the understanding that respondents have varying levels of knowledge about the topic. Therefore, this approach provides a structure for the interview while allowing flexibility to explore different directions based on participants' responses (Adams, 2015).

The participants interviewed were selected through purposive sampling, ensuring representation from diverse demographic groups. This approach provides a comprehensive understanding of the impacts from various perspectives within the community, including patterns within the sample, unusual variations, and trends across these variations (Palinkas et al., 2015). To cover different demographics, participants varied in terms of age, income level, education, and physical proximity of their households to the train tracks. These variables were adapted from the common types of demographic and community data outlined by the Agency for Toxic Substances and Disease Registry in their Public Health Assessment Manual. This manual focuses on studying communities potentially affected by an event or exposure, making it relevant to the case study and the reason it was chosen (ATSDR, 2022). However, other variables presented in this manual such as gender and ethnicity were excluded, as they were not considered directly relevant to this research. This decision was made to avoid collecting non-essential data, minimizing the risk of participant traceability (Central Connecticut State University, n.d.).

Similarly, to prevent the identification of participants, broad categories were selected as response options, allowing individuals to choose from different ranges rather than reporting their specific attributes (Central Connecticut State University, n.d.). For each of the four demographic attributes, three to four general ranges were provided, varying across three levels: low, medium, and high. However, ranges for route proximity were determined using more specific criteria. The distance from the four train stations (Cancún, Playa del Carmen, Puerto Morelos, and Tulum) to the farthest and nearest points within each city was first identified. An average distance of 2 to 7 km was determined, representing the range within which residents of these cities are likely to experience similar effects.

Points within 2 km were classified as nearly adjacent to the station or the tracks, while those beyond 7 km were considered distant. Table 4 shows the sample demographic attributes and categories discussed.

Table 4. Sample demographic categories.

Demographic attributes	Categories
Age	18-30 years old
	30-50 years old
	Over 50 years old
Income level	Low to medium
	Medium
	Medium to high
Level of education	None
	Primary education
	Secondary education
	Higher education
Route proximity	< 2 km
	2-7 km
	>7 km

In addition to the characteristics listed in Table 4, the sample encompassed individuals with traits that cannot be categorized but are considered representative of the diversity within the community. The initial sample was composed of one participant with environmental education, one individual from a lower economic status who did not complete high school and lacked an understanding of the biophysical processes, one long-time resident above the age of 60, a younger individual who recently relocated, and one native of Quintana Roo under the age of 25. Additionally, it included one participant residing less than 1 kilometer away from the train tracks, a hotel owner whose establishment had been operational for three years, as well as an individual from a disadvantaged community who relies directly on groundwater for daily needs, such as obtaining water from wells for household tasks. Moreover, another individual with an environmental background was included. Despite lacking a formal degree in the subject, he has worked with local NGOs for many years. Finally, another long-time resident of Quintana Roo was selected, but with different demographic categories as the third individual. Participants were assigned specific ID codes based on their characteristics, making it easier to refer to particular members in the following chapters.

Table 5 provides an overview of the distinctive traits of each participant and identification code, explaining their relevance or representativeness for the research sample, and indicating where they fall within the categories defined previously in Table 4.

Table 5. Local community's sample overview.

Participant	ID code	Distinctive traits	Demographic attributes
1	P1-Env	Background in environmental education	Age group: 18-30 years old
			Income: Medium-high
			Level of studies: Higher education
			Route proximity: 2-7 km
2	P2-LowEc	Disconnected from environmental and biophysical processes	Age group: 30-50 years old
			Income: Low to medium
			Level of studies: Primary education
			Route proximity: 2-7 km
3	P3-LongRes	Long-time resident of Quintana Roo	Age group: Over 50 years old
			Income: Medium to high
			Level of studies: Higher education
			Route proximity: 2-7 km
4	P4-Reloc	Younger recent migrant	Age group: 18-30 years old
			Income: Medium
			Level of studies: Higer education
			Route proximity: >7 km
5	P5-Native	Native of Quintana Roo	Age group: 18-30 years old
			Income: Medium
			Level of studies: Higher education
			Route proximity: 2-7 km
6	P6-<2km	Household adjacent to the train tracks	Age group: 18-30 years old
			Income: Medium
			Level of studies: Secondary education
			Route proximity: < 2 km
7	P7-Hotelier	Hotel owner	Age group: 30-50 years old
			Income: Medium to high
			Level of studies: Higher education
			Route proximity: 2-7 km

8	P8- Well	Direct daily use of groundwater through wells	Age group: Over 50 years old
			Income: Low to medium
			Level of studies: Secondary education
			Route proximity: >7 km
9	P9-EnvWork	Background working in the environmental field	Age group: 18-30 years old
			Income: Medium
			Level of studies: Higher education
			Route proximity: 2-7 km
10	P10-LongRes	Long-time resident	Age group: Over 50 years old
			Income: Medium
			Level of studies: Secondary education
			Route proximity: 2-7 km

The interview process took one and a half weeks, beginning on June 18th and concluding on June 27th. Interviews were scheduled for one per day; however, due to participants' availability, there were occasionally two interviews on the same day. Each interview lasted between 25 and 45 minutes, depending on the participant. The interviews with P1-Env, P3-LongRes, P4-Reloc, P5-Native, and P9-EnvWork were conducted online via Zoom, while those with P2-LowEc, P6-<2km, P7-Hotelier, P8-Well, and P10-LongRes were conducted by phone, given participants' preferences and availability. All interviews were conducted in Spanish, manually transcribed, and later translated into English using DeepL machine translation. The interview guide consisted of 15 questions divided into three sections: background information, environmental impacts, and social impacts, as detailed in Appendix 1.

3.3.2 Data Analysis

Table 6 provides an overview of the data analysis methods and the frameworks used for processing information for each research question. Further details are provided in the following section.

Table 6. Data analysis per research sub-question.

Research question	Data analysis method
Q1	Content analysis
Q2	Thematic analysis
	Social Impact Assessment of Research Framework
Q3	Thematic analysis
	Narrative analysis
Q4	Influences on Risk Perception Framework

The first research sub-question was answered through a qualitative analysis, employing an inductive approach, where insights were derived from a detailed examination of the data, identifying key patterns and concepts (Thomas, 2006). To achieve this, a content analysis was conducted to identify the occurrence of specific terms across the literature (Columbia Mailman School of Public Health, n.d.). The data gathered was analyzed by processing the findings from the documents and authors selected, generating a compilation of specific impacts related to groundwater. For better visualization, these impacts were categorized into four areas: alterations to the karst topography, water quality, water availability, and the loss of flora and fauna species.

Subsequently, the data collected from the document review was used to address the second research question and was processed through a thematic analysis, identifying commonalities in the social implications and potential challenges resulting from environmental changes (Kiger & Varpio, 2020). These were categorized into applied (direct or indirect), geographical (local or extended), and temporal (short-term or long-term) impact dimensions using the "Social Impact Assessment of Research Framework" described in Chapter 2. Direct impacts were defined as immediate consequences of the biophysical change, while indirect impacts were secondary effects. Local impacts are confined to the project site, while extended impacts encompass the entire state of Quintana Roo. Finally, short-term impacts refer to those occurring soon after the initial event, while long-term impacts are those that would take time to manifest.

The third research question was initially addressed through a thematic analysis, processing the information obtained from the interviews to identify keywords and similarities in participants' responses (Kiger & Varpio, 2020). These findings were then compared with the results from the first and second questions. Additionally, a narrative analysis was conducted to examine the interview responses focusing on how participants shared their stories to understand the broader implications of their perspectives (Smith & Monforte, 2020). This approach allowed for a deeper interpretation of their perceived potential impacts, drawing on their lived experiences in the region, background, and observations of similar developments over recent years.

Lastly, the fourth question was addressed using the "Influences on Risk Perception Framework" described in Chapter 2 to analyze the data gathered from the interview responses and the findings from the previous question. This assisted in analyzing how aspects such as beliefs, values, social bonds, and subjective cultural norms influence the community's knowledge, trust, sense of fairness, and other qualities. These factors, in turn, shape how individuals process information. Therefore, the interview responses were also compared with participants' demographic attributes, providing insight into their risk perceptions regarding the train's implementation.

3.4 ETHICAL CONSIDERATIONS AND DATA MANAGEMENT

The study adheres to the University of Twente's ethics guidelines and the GDPR privacy law. The data collected includes personally identifiable information, such as the state of residency and professional background. To prevent traceability to specific individuals, all data was pseudonymized and assigned an ID code before storage and analysis, with the coding stored separately from the data set. Participants' identities were kept private, with their gender and specific details randomized when referenced in the text. Verbal consent was obtained from all participants prior to each interview, allowing for the recording, temporary storage, and use of the information provided. To ensure the secure storage of audio and video data, files were kept private on an external USB drive, accessible only to the researcher and, if requested, the BMS Ethics Committee. Participants were also informed that the Committee might have access to these recordings and that they would be deleted after the study receives final approval. To minimize bias, the study employed data triangulation from multiple sources, and the author refrained from expressing personal opinions or adopting a specific stance on the topic, focusing solely on analyzing the findings derived from the collected data.

4 RESULTS

This chapter presents the results obtained by analyzing the data collected by document reviews and interviews. Section 4.1 addresses the first research sub-question by elaborating on the biophysical impacts on the groundwater system as identified in the project's Environmental Impact Manifestation and additional studies. Section 4.2 answers the second sub-question, examining the social impacts resulting from these environmental changes. Finally, Section 4.3 responds to the third sub-question by presenting the perceptions of a sample of the local community regarding these impacts.

4.1 BIOPHYSICAL IMPACTS OF DISRUPTIONS TO THE GROUNDWATER SYSTEM

In 2022, WWF Mexico, alongside the environmental consultancy Consultores en Gestión, Política y Planificación Ambiental S.C., conducted a technical assessment of the potential socio-environmental impacts outlined in the train's EIM submitted by the National Fund for Tourism Promotion (FONATUR). According to this document, for analysis purposes, Tramo 5 of the project was divided into two parts: the Northern section, which extends from Cancún Airport to the north of Playa del Carmen, and the Southern section, which goes from Playa del Carmen to Tulum. The identified impacts can be categorized into four main areas: alterations to the karst topography, changes in water quality, variations in water availability, and the loss of flora and fauna species. The specific impacts identified were as follows: five severe adverse impacts on landforms, two moderate adverse impacts on soil, seven irrelevant impacts on water, and one severe adverse impact on water. Additionally, there was one critical adverse impact and one severe adverse impact on flora, four severe adverse impacts, and five moderate adverse impacts on fauna, all occurring during the preparation, construction, and operation stages (Consultores en Gestión Política y Planificación Ambiental, 2022). However, according to the Center for Biological Diversity (2022), five of these impacts, rated as severe and moderate, should have been evaluated as critical. The method of classification is difficult to understand, as the EIM does not show the values assigned for each subfactor (nature, intensity, extent, persistence, among others), nor does it describe the calculations. It only mentions the resulting value of significance. Nevertheless, regardless of their impact category,

The first direct recognized impact is the alteration of the physicochemical characteristics of groundwater due to the generation, handling, storage, and improper disposal of solid waste, liquid waste, special management waste, and hazardous waste (Consultores en Gestión Política y Planificación Ambiental, 2022). These issues arise during the train's construction, through the transportation of materials, the injection of cement to seal caves for the elevated track, and the improper disposal of leftover materials, which can infiltrate the subsurface. Additionally, during its operation, the influx of people at train stations, the potential improper waste disposal, and an inefficient regional waste management system can further exacerbate this problem.

Moreover, the EIM determines that there is a high impact on the karst system and topography due to potential sinking and collapses caused by the operation of heavy machinery during construction and the weight and vibrations generated by the train in operation. In the southern section of Tramo 5, a karstic risk was identified in four zones, classified from low to severe high risk as follows: 27.47 km of the section have low risk, 19.67 km moderate risk, 8 km high risk, 4.7 km severe risk, and 7.79 km severe high risk (Consultores en Gestión Política y Planificación Ambiental, 2022).

Additionally, it is expected that the train will boost tourist influx and migration to the state (Consultores en Gestión Política y Planificación Ambiental, 2022). This suggests that the current development model will persist, requiring the expansion of infrastructure, such as new hotels, residences, and restaurants, which will have indirect water requirements as large amounts of water are needed for their construction and operation (Gössling Stefan et al., 2012). Furthermore, this will lead to increased water consumption, as the arrival of tourists will raise demand. Over time, if this increase is greater than the aquifer's natural recharge, which is expected to decline due to climatic conditions, it could result in the overexploitation of the aquifer. This would lower groundwater levels and affect long-term availability. Notably, there has been a historical degradation of the aquifer between 2002 and 2012, particularly evident in its northeast part, corresponding to areas experiencing population growth and agricultural expansion (J. A. Sánchez et al., 2016). Likewise, several studies highlight that the expansion of economic activities, population growth, and infrastructure development raises the potential for inducing irreversible effects on groundwater (Cejudo et al., 2023; Kane, 2016; J. A. Sánchez et al., 2016). The neighboring state of Yucatán exemplifies this issue, having experienced the water-intensive consequences of tourism, with an estimated decrease in freshwater resources of nearly 60% over the past 20 years (Chabin, 2023).

In coastal areas, excessive groundwater extraction can also lead to saltwater intrusion into the aquifer. When extraction rates exceed recharge rates, the interface between saltwater and freshwater moves inland, eventually contaminating freshwater wells with saltwater, which is challenging to remediate (Greene et al., 2016). There are measures such as subsurface dams to help control saltwater intrusion; however, they are also costly (Chang et al., 2019). Ultimately, the increasing population rate can lead to ongoing indirect pollution impacts. For instance, a study conducted by Demidof et al. (2022), assessed the ecological risk of metals in an urban natural protected area in Quintana Roo, revealing that not only large industrial cities can experience significant urban contamination, but also rapidly growing tourist cities are prone to it. Urbanization can affect the caves and underwater systems within these natural protected areas through untreated or improperly managed wastewater discharge, landfills, and urban waste leakage, among other factors.

As with the train's construction, the development of tourist infrastructure carries the risk of chemicals and materials infiltrating the bedrock, contaminating groundwater (Pásková et al., 2024). Furthermore, filling caves that once facilitated water flow, either with cement or due to collapses, can alter natural water courses, impacting cenotes and underground rivers crucial for both water supply and local biodiversity. As reported on the project's EIM, all of these activities will potentially endanger individuals of species classified under various risk categories as per NOM-059-SEMARNAT-2010, a regulation aimed at identifying and protecting endangered wild flora and fauna (Consultores en Gestión Política y Planificación Ambiental, 2022; Gobierno de México, 2021). The train will pass through the protected natural area of Calakmul, which hosts 20 endangered species, 59 threatened, and 91 requiring special protection. Additionally, it will traverse the protected natural area Balamkú, where 26% of the flora and fauna species are under special protection status (López Puerta, 2023). The increase in pollution and water scarcity will threaten these species and the wildlife that lives in aquatic ecosystems or depends on them to fulfill their biological processes. The caves are habitats for animals such as bats and fish and serve as vital water sources for mammals and birds that inhabit the Maya jungle, such as jaguars, ocelots, howler monkeys, and spider monkeys (BBC News Mundo, 2022; López Puerta, 2023). This puts endemic species native to the region at risk, such as the Astyanax fasciatus mexicanus, the Toh bird which nests in cenotes, and the endangered blind swamp eels. (BBC News Mundo, 2022; Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2017; Radio Fórmula, 2022). The potential extinction of a species wouldn't only impact the species itself but also have a cascading effect on the entire food chain. Predators that rely on these species for food would also be impacted, leading to broader ecological consequences (George et al., 2023). For instance, the decline or loss of certain fish species can affect the survival of birds and mammals that feed on them, thereby altering the structure and function of the entire ecosystem.

Furthermore, within the environmental assessment, FONATUR indicated potential accident risks due to insufficient maintenance of the trains (Consultores en Gestión Política y Planificación Ambiental, 2022). If a freight wagon carrying materials such as fuel derails, it could cause major impacts by contaminating the soil, which would subsequently infiltrate into groundwater. This process would occur first through the adsorption of the substances onto soil particles, followed by the diffusion of contaminants through the pore spaces in the soil until they reach groundwater (Arellano-González et al., 2023). These types of petroleum byproducts contain toxic substances that once in the ground, cause persistent contamination in the geological environment (Kalibatiene & Burmakova, 2022). Once the fuel reaches a body of water, it can remain in that environment for long periods due to its low degradability, requiring complex cleanup technologies (Fingas, 2021). Additionally, if the water dynamics at the point of entry have relatively high flow rates, these toxic substances will be transported through underground rivers by advection. This term involves the migration of contaminants with groundwater flow, reaching distant areas and eventually entering the sea, leading to widespread environmental impact. For instance, beyond the long-term consequences of water pollution on wildlife discussed previously, an accident of this nature can result in the rapid death of various species, including fish and invertebrates (Arellano-González et al., 2023).

On the other hand, there is a whole set of challenges associated with land-use changes that are not considered within the initial impacts of the EIM but were estimated by the Center for Biological Diversity (2022) in their technical analysis report. Firstly, soil erosion caused by the movement of machinery, both for the construction of the train and the development of tourism infrastructure, is a significant concern. This erosion can indirectly impact the aquifer by altering the characteristics of the surface soil (such as soil porosity and pore size distribution), affecting its infiltration capacity and the landscape's fragility. These changes can either increase infiltration points by exposing more permeable soil layers, creating new entrances to the underwater cave system for contaminants, or decrease this infiltration capacity, reducing the soil's permeability. Consequently, the latter would reduce the aquifer's recharge capacity, affecting groundwater levels (Owuor et al., 2016). Moreover, erosion can lead to increased sedimentation in surface water bodies. These sediments can eventually infiltrate and reach aquifers, impacting groundwater quality. Sedimentation alters water quality on physical, chemical, and biological levels (Lake James Environmental Association, n.d.). It is associated with a higher nutrient concentration, which harms aquatic environments, blocks streams, and reduces the storage capacity of reservoirs (Lake James Environmental Association, n.d.; Vale et al., 2023). This occurs by sediment accumulating over time, filling the areas intended for water storage, and decreasing the reservoir's water-holding capacity (Whelan & Hotchkiss, 2024).

4.2 SOCIAL IMPACTS OF DISRUPTIONS TO THE GROUNDWATER SYSTEM

The identified biophysical impacts of the train project extend beyond environmental degradation, influencing the local communities. This section explores how changes to the natural environment, such as groundwater contamination and soil erosion, manifest as broader social challenges, affecting public health, livelihoods, and community dynamics. To facilitate comprehension, the results are presented in four sections. Each section corresponds to a different area of impact as identified in section 4.1: karst topography, water quality, water availability, and biodiversity loss. Within these sections, four tables are presented that summarize the direct translation of impacts. The first column of each table indicates the previously identified environmental consequences, followed by their associated social impacts and challenges, while the third to fifth column categorizes them in impact dimensions.

The initial identification of these challenges was supported by existing literature, while the categorization of impacts reflects the author's perspective and interpretation. Consequently, this categorization is specific to this research, and if the scoring is to be replicated in another study, it should be reassessed. The categorization was conducted by analyzing only the social challenges that arise after the biophysical impact has occurred. For Table 7, Table 8, Table 9, and Table 10 each dimension was classified as follows: In the applied dimension, direct impacts refer to immediate consequences resulting directly from the biophysical change, while indirect impacts are secondary outcomes resulting from these direct consequences. In the geographical dimension, local impacts refer specifically to the site of infrastructure construction or accident location, while extended impacts spread across the entire state. Lastly, in the temporal dimension, short-term impacts do not necessarily imply brief duration but rather those that will have an effect soon after the biophysical impact occurs. Conversely, long-term doesn't refer to impacts that take time to eradicate, but those that may take time to fully manifest. It's worth noting that some social challenges may repeat across different environmental impacts due to similar influences. The challenges specific to each impact are listed first, followed by those that overlap across categories.

4.2.1 Translating Karst Topography Biophysical Impacts to Social Challenges

First, the social impacts stemming from the alteration of karst topography are significant. Since the train project aims to bring new real estate development to the area, the collapse of the bedrock would not only endanger passengers in the affected wagon, but if the sinking area is extensive, it can cause damage to surrounding properties, imposing financial burdens on residents due to repair costs or displacement. Additionally, there would be high remediation costs for authorities to repair that section of the railway and address the resulting consequences. Moreover, it is important to note the historical significance of these caves, as archaeologists have discovered fragments of ancient ceramics and human remains within them. For instance, in 2022, a skeleton dating back 8000 years was found inside a cave system in Tulum, just a few meters away from the train's route. Given the distance from the cave entrance, archaeologists suggest that the skeleton may have been there before rising sea levels flooded the caves (Stevenson, 2022). This indicates that there is a high probability of more remains scattered around the now-flooded caves. If a collapse seals certain underwater rivers, it would block access for future divers, preventing the community from fully uncovering its prehispanic value. Although the INAH has made efforts to discover and safeguard prehispanic artifacts, according to archaeologists working on the train project, this is a task that would take years and the time they were given was very limited (Sieff & Leaming, 2022). For the local community, this results in the loss of cultural and historical heritage.

Furthermore, alterations in flow patterns facilitate the migration of contaminants in the aquifer, making groundwater unfit for consumption or other uses, thereby constraining available water resources (Arellano-González et al., 2023). As highlighted in Chapter 1, nearly 70% of groundwater extraction in Quintana Roo is allocated for agricultural purposes (National Geographic, 2018). Therefore, reduced availability of high-quality water not only impacts households but also agricultural activities, resulting in decreased productivity and affecting the livelihoods of those who rely on agriculture as their primary source of income. Moreover, to avoid overexploitation of the aquifer, people may explore alternative water sources such as rainwater harvesting or desalinated water for drinking and irrigation purposes (Younos et al., 2023). However, given that now the aquifer is the sole source of drinking water, the current infrastructure is designed primarily for groundwater extraction. Transitioning to alternative sources would involve higher purification costs (Chabin, 2023).

Additionally, soil erosion can cause destabilization by removing essential layers and protective vegetation needed for structural support. This could weaken building foundations, leading to potential structural failures (Johnstone et al., 2010). For authorities, this means facing high repair and maintenance costs, and in the event of a failure, it poses safety risks for residents. Similarly, erosion resulting from the constant development of new infrastructure near the tracks can lead to increased sediment runoff into nearby water bodies, eventually reaching the aquifer (United States Environmental Protection Agency, 2024). These sediment loads degrade the quality of water that is extracted for drinking and agricultural use.

Finally, increased permeability and the larger presence of contaminants in the system would compromise the quality of water that residents rely on for their basic needs and economic activities. Conversely, longer recharge periods may result in a low water table during certain times, disrupting existing extraction mechanisms, decreasing well yield, and making it more difficult and expensive to access groundwater resources (Van der Gun & Lipponen, 2010). This can lead to seasonal scarcity and an unreliable water supply, which is already a challenge for part of the population (Murray, 2007).

Table 7 summarizes how the five identified impacts on karst topography manifest as social challenges and their respective categorization on impact dimensions.

Table 7. Translation of karst topography biophysical impacts to social impacts.

Karst topography				
Biophysical impacts	**Social impacts and challenges**	**Applied**	**Geographical**	**Temporal**
Sinking and collapses in karstic risk areas.	Injuries or deaths.	Direct	Local	Short
	Property damage.	Direct	Local	Short
	Residents displacement.	Indirect	Local	Short
	Financial burdens.	Indirect	Local	Short
	High remediation costs.	Direct	Local	Short
	Loss of cultural and historical heritage.	Direct	Extended	Long
Alteration of natural groundwater flow by sealing or collapsing caves.	Water scarcity for domestic and agricultural use.	Direct	Extended	Short
	Disruption in local economies.	Indirect	Extended	Short
	Increased dependence on alternatve water sources.	Indirect	Extended	Long
Soil erosion caused by machinery use in the train's construction.	Potential structural failures.	Direct	Local	Short
	Higher maintenance costs.	Indirect	Local	Short
	Safety hazards for residents.	Indirect	Local	Short
Soil erosion caused by machinery use in tourism infrastructure construction.	Increased sedimentation in water bodies.	Direct	Extended	Long
	Poor water quality for drinking and agriculture.	Indirect	Extended	Long
Alteration (increase or decrease) of soil's permeability	Poor water quality if permeability increases and water scarcity if permeability decreases.	Direct	Extended	Long

	Unreliable water supply.	Indirect	Extended	Long

4.2.2 Translating Water Quality Biophysical Impacts to Social Challenges

The social impacts associated with water quality manifest in the following ways. First, altering the physical and chemical characteristics of groundwater due to construction and operation activities, along with the resulting waste, leads to the degradation of water essential for drinking and food production (Consultores en Gestión Política y Planificación Ambiental, 2022). This poses significant public health risks for consumers (Cejudo et al., 2023). For instance, excessive sodium levels present in water can lead to increased blood pressure and cardiovascular diseases. However, the health impacts vary depending on the nature of pollutants, whether they are toxic metals, persistent organic pollutants, or emerging contaminants such as antibiotics or microplastics, their concentration levels, and the duration of exposure. Exposure can occur through drinking water with high metal concentrations, consuming food irrigated with contaminated water, or skin contact, such as swimming in cenotes. However, the transport and dilution of these substances depend on aquifer flow velocity and size. Additionally, regions with limited surface water recharge and shallow parts of the aquifer with slow water flow are more prone to pollutants accumulating to alarming levels (Xie et al., 2023). This general increase in health issues across the population would eventually raise healthcare costs, as there would be a greater demand for medical services and treatments related to waterborne illnesses (Kunz et al., 2024).

On the other hand, the salinization of freshwater affects its potability. Besides having a low quantity of water, the one available would be of poor drinking quality. Although desalination is playing an increasingly important role in addressing water scarcity, making it potable requires extended and complex purification processes, leading to higher costs for local authorities and increased household expenses due to the rising prices of water (World Bank, 2019). This is unless these costs are shifted from locals to the tourism industry (Chabin, 2023).

Furthermore, apart from the activities mentioned earlier, the degradation of water quality and associated health risks can also result from the infiltration of materials and chemicals during real estate construction and from improper waste and wastewater disposal in urban development. In addition, this contamination from urban waste and wastewater continues over time, with adverse social consequences. For instance, if these underground systems, which attract foreign divers and tourists, become heavily polluted, they will lose their appeal, leading to a decline in tourism. This decrease would harm local economies dependent on tourist influx, including tour guides, establishments, small businesses, and artisans who sell their products to visitors (Pásková et al., 2024).

Alternatively, the pollution resulting from a potential fuel spill, whether due to derailment or collapse, poses greater risks to human health compared to previously mentioned sources of pollution. Even if people are not in direct contact with the spill site, contaminants can reach wells and cenotes used by the community. Although prolonged exposure to hydrocarbons has been shown to have severe consequences, such as increased rates of kidney failure, this typically refers to larger spills that take longer to identify (Arellano-González et al., 2023). Assuming that the accident risk referred to by FONATUR would be an isolated incident, the large aquifer volume may dilute the impact of a relatively small spill. However, this will depend on the oil type and the environmental and spill conditions (Fingas, 2021). Nevertheless, localized exposure to water with even a trace amount of hydrocarbon levels above safe environmental standards can still pose a public health risk for communities near the spill site, especially since most rural households draw water directly from wells without treatment or municipal intervention (UNESCO, 2023; Xie et al., 2023). As a result of this persistent and direct contamination, residents in the affected area may need to relocate to safer places, posing financial burdens on communities and incurring high costs for local authorities to remediate the contamination.

Finally, the higher presence of sediments that can carry pollutants and pesticides resulting from erosion introduces social challenges previously discussed in the context of desalinization, although arising from different circumstances (Lake James Environmental Association, n.d.). This includes extended purification processes, thereby increasing purification costs and eventually impacting water prices for residents.

Preserving water quality is particularly relevant in the region as the aquifer of the Yucatán Peninsula has been significantly affected in recent years. The neighboring state of Yucatán exemplifies how persistent pollution has already impacted people and continues to do so. Wastewater discharge from large pig farms has increased nitrogen and phosphorus levels in groundwater, resulting in critical pollution conditions in twenty-six municipalities (A. Sánchez, 2023). Some of these areas now have water unsuitable for drinking or domestic use, a threat Quintana Roo is also prone to from its projected urbanization.

Table 8 summarizes the seven identified impacts affecting water quality, illustrating their implications for social challenges and their corresponding impact dimensions.

Table 8. Translation of water quality biophysical impacts to social challenges.

Water quality				
Biophysical impacts	Social impacts and challenges	Applied	Geographical	Temporal
Alteration of groundwater physicochemical characteristics caused by train's construction waste and activities.	Degradation of drinking water quality.	Direct	Extended	Short
	Contaminated food.	Indirect	Extended	Short
	Potential health issues.	Indirect	Extended	Long
	Increased healthcare costs.	Indirect	Extended	Long
Alteration of groundwater physicochemical characteristics caused by train's operation waste and activities.	Degradation of drinking water quality.	Direct	Extended	Short
	Contaminated food.	Indirect	Extended	Short
	Potential health issues.	Indirect	Extended	Long
	Increased healthcare costs.	Indirect	Extended	Long
Groundwater salinization from excessive extraction.	Extended water treatment process for purification.	Direct	Extended	Short
	Higher purification costs for public water systems.	Indirect	Extended	Short
	Rising household water prices.	Indirect	Extended	Long
Chemical and material infiltration from tourism infrastructure construction.	Degradation of water quality.	Direct	Extended	Short
	Potential health issues.	Indirect	Extended	Long
	Decreased tourist influx.	Indirect	Extended	Long

Chemical and material infiltration from improper urban waste and wastewater disposal.	Disruption in local economies.	Indirect	Extended	Long
	Degradation of water quality.	Direct	Extended	Short
	Potential health issues.	Indirect	Extended	Long
Chemical and material infiltration from accident and derailment risks.	Severe health risks from exposure to hazardous materials.	Indirect	Extended	Long
	Evacuation and displacement of affected communities.	Direct	Local	Short
	High remediation costs.	Direct	Local	Short
Increased sediment infiltration from surface bodies due to erosion.	Extended water treatment process for purification.	Direct	Extended	Short
	Rising household water prices.	Indirect	Extended	Long
	Higher purification costs for public water systems.	Indirect	Extended	Short

4.2.3 Translating Water Availability Biophysical Impacts to Social Challenges

Of the three identified impacts related to water availability, the first is the overexploitation of the aquifer due to the construction and operation of new infrastructure and the water demand from urbanization. This overuse means that localized water reserves will be depleted, particularly for those who rely on individual wells and do not receive regional water supply, leading to scarcity for both domestic and agricultural use. The insufficient water supply creates competition for water resources, not only between sectors but also between communities (Rodella et al., 2023). This competition could ultimately elevate water prices and increase the cost of food products that require water for cultivation.

The second impact discussed was a reduction of aquifer recharge capacity, which would translate into social challenges in the following ways. First, the gradual decline in groundwater levels means that there would be periodic water supply shortages for domestic and agricultural use, creating competition for water resources. Although this doesn’t necessarily imply permanent scarcity, the slower recharge rate means there will be times when water is available and times when it won't be sufficient to supply the entire population. Additionally, this creates higher extraction costs since deeper wells need to be installed (Rodella et al., 2023).

Finally, a reduced storage capacity in the existing reservoirs due to increased sedimentation poses the same type of challenges described previously. There would be shortages during dry periods, as the volume that reservoirs can hold is less. This lack of supply for the agricultural sector could lead to reduced productivity, disrupting the economy of people who depend on it as their primary source of income (Rodella et al., 2023).

Ensuring water availability and taking action to preserve it are particularly relevant as Mexico is the second most water-stressed country in Latin America, ranking 24th worldwide. This means that the water demand exceeds the existing resources, making it impossible to meet the population’s needs (Tinoco Morales, 2024). The consequences of aquifer exploitation, reduced storage capacity, and slower recharge capacity could be seen in the region, similar to what has been observed in the northern and central parts of the country in recent years. In 2022, Monterrey faced a severe shortage due to a lack of rain and management, where the government implemented measures like restricting daily water access to six hours and reducing water pressure (Cullell, 2022; Flores, 2023; Patel & Tierney, 2022). Additionally, this year, Mexico City is also struggling with record-low reservoir levels, leading to water rationing (Chow & Linares, 2024). This has led to significant changes in residents' livelihoods, as they often go days without water and must make the best use of the small amounts they can store when water is available (Paddison et al., 2024).

Table 9 presents the three impacts described on water availability and the corresponding social challenges they imply, along with their impact dimensions.

Table 9. Translation of water availability biophysical impacts to social challenges.

Water availability				
Biophysical impacts	**Social impacts and challenges**	**Applied**	**Geographical**	**Temporal**
Aquifer overexploitation due to increased tourist water demand.	Diminished local water reserves.	Direct	Extended	Short
	Competition for water resources.	Indirect	Extended	Long
	Raising food prices.	Indirect	Extended	Long
	Water scarcity for domestic and agricultural use.	Direct	Extended	Short
	Rising water prices.	Indirect	Extended	Long
Reduced aquifer recharge capacity.	Gradual decline in groundwater levels.	Direct	Extended	Long
	Chronic water shortages for domestic and agricultural use.	Direct	Extended	Long
	Higher extraction costs for public water systems.	Indirect	Extended	Short
	Competition for water resources.	Indirect	Extended	Long
Reduced water storage capacity of reservoirs.	Reduced agricultural productivity.	Indirect	Extended	Long
	Water shortages during dry periods.	Direct	Extended	Short
	Disruption in local economies.	Indirect	Extended	Long

4.2.4 Translating Biodiversity Loss Biophysical Impacts to Social Challenges

Lastly, the endangerment of species already at risk from both the permanent pollution of water and water scarcity, as well as the immediate death of aquatic species from fuel spills, will result in a loss of biocultural diversity and heritage. These two factors are relevant as they shape communities' understanding of the land and its biodiversity, shaping their interaction with visitors and contributing to the development of responsible tourism (Griffiths, 2024). In the long term, the loss of species may contribute to a decline in tourist influx, as visitors are attracted to this area not only for its cenotes but also for its rich biodiversity and natural environment. This decline would disrupt the local economy, which relies on tourism (Bellani, 2024). Additionally, the long-term disruption of the food chain translates to disruptions in communities' food supply, especially for fishing zones, ultimately affecting food security. In response to these changes, locals may need to make dietary adjustments, which may not damage their livelihoods but will certainly alter them.

Table 10 summarizes the social challenges associated with each of the identified biophysical impacts of biodiversity loss and their dimensions.

Table 10. Translation of biodiversity loss biophysical impacts to social challenges.

Biodiversity loss				
Biophysical impacts	**Social impacts and challenges**	**Applied**	**Geographical**	**Temporal**
Endangerment of at-risk and endemic species due to pollution and water scarcity.	Loss of biocultural diversity.	Direct	Extended	Short
	Decreased tourist influx.	Indirect	Extended	Long
	Disruption in local economies.	Indirect	Local	Long
Death of fish and invertebrates from potential fuel spills due to accidents or derailments.	Loss of biocultural diversity.	Direct	Local	Short
Disruption of the food chain from the death of individual species.	Disruption of food sources, food supply, and food security.	Direct	Extended	Long
	Livelihoods changes such as dietary adjustments.	Indirect	Extended	Long

4.3 COMMUNITY RISK PERCEPTIONS

Local perceptions of the Maya Train project and its social and environmental impacts varied across the sample, with participants tending to recognize visible impacts or those spread through awareness campaigns, while indirect consequences were less frequently perceived. All participants were aware of the project and its promotion, although only two had used it. Throughout this section, detailed characteristics of each participant are provided the first time they are mentioned. Thereafter, participants are referred to by their ID Codes assigned in Table 5 for easier identification. Gender references are randomly assigned as a stricter privacy measure. Specific participant details are mentioned only when knowing who made a particular response supports the analysis within the theoretical framework. However, if the information adds context without having to distinguish individual characteristics, it is included without specifying the participant's code.

4.3.1 Perceived Environmental Impacts

First, the public perception of ongoing environmental changes since the project started primarily focused on visible surface effects, such as logging, stone drilling, and cement injection. However, these perceptions weren't based on firsthand experience, but rather on images and videos circulated by Greenpeace, news media, and social media. Two videos were mentioned as being particularly influential: one showing a diver in a cave where the sounds of drilling and machinery could be heard from above, and another featuring a local expert showing cement-covered soil from a cave outlet.

Additionally, the individual living almost adjacent to the tracks (P6-<2km) mentioned incidents of jaguars appearing on his property, even attacking dogs, which in his words, had never happened before. He assumes that the noise, vibrations, and machinery have driven the jaguars from the jungle into more populated areas. Although this issue was not considered in Section 4.1 as it is not a direct consequence of groundwater deterioration, it has clear social impacts by threatening the safety and lifestyle of residents whose homes are more exposed.

4.3.1.1 Land and Soil

When asked about the physical changes they've observed in the land and soil of the state, not particularly related to the project but in recent years, all participants identified coastal erosion and land-use changes due to deforestation. Despite attributing these changes to various activities, such as wind patterns, the responses consistently pointed to the construction of beachfront hotels and the placement of stone or sandbag barriers along the coast as the primary causes. These activities are directly related to the increase in tourism and the associated real estate development.

Furthermore, four participants mentioned that the highway has experienced collapses in the past: the younger recent migrant (P4-Reloc), a long-time resident (P10-Res), the individual with environmental studies (P1-Env), and the one with previous environmental work experience (P9-EnvWork). However, their answers varied when asked about the causes of these changes. The first two attributed the collapses to poor construction, while the latter two referred to the fragility of the underground cave system.

Most participants believe that the operation of the train can further exacerbate these changes. However, P2-LowEc and the hotel owner (P7-Hotelier) could not see a direct relation between the train and soil changes. P7-Hotelier identified only coastal erosion impacts, noting that no new hotels would be built on the coast, as it is already occupied by existing infrastructure. Instead, new construction would occur in the jungle terrain closer to the train, which means it wouldn't directly affect the shoreline. On the other hand, the rest of the participants who felt the train would worsen these issues, couldn't initially explain why, mentioning they lacked the technical knowledge. Afterward, they assumed that the constant passing of the train, along with its weight and vibration, could make the ground unstable, causing it to collapse. Furthermore, the long-time resident (P3-LongREs), the younger recent migrant (P4-Reloc), and the native of Quintana Roo (P5-Native) agreed that the train would increase human traffic and intervention, which ultimately destroys natural habitats. Moreover, both interviewees with environmental backgrounds (P1-Env) and (P9-EnvWork) did relate the train's operation specifically to potential soil erosion.

4.3.1.2 Regional Water Systems

First and foremost, it is relevant to mention that all participants receive water to their households from the regional supply. However, only one of them (P8-Well) relies on groundwater extracted from wells for daily activities, as the public supply is unreliable and inconsistent. Likewise, two participants have additional wells at home that they use for irrigation.

Regarding the perceived changes in water sources in recent years, participants mentioned they hadn't seen any changes in quantity but did note a decline in quality, particularly due to large hotel chains disposing of organic waste into the water. P4-Reloc compared the water quality to that of central Mexico and noted that the local water has significantly more minerals. Additionally, P3-LongRes and P5-Native mentioned that some cenotes have become more turbid, especially those popular among visitors.

Residents' opinions varied regarding the potential for the project's implementation to exacerbate these existing water problems or create new ones. P1-Env, P3-LongRes, P5-Native, and P9-EnvWork believed the train had already negatively impacted aquifers, mainly concerned about water contamination. They mentioned the disposal of materials and construction-related contamination as evidence of ongoing pollution, as documented in the videos and pictures mentioned previously. Additionally, they specifically linked future impacts to train operations and increased urbanization. Their primary concern stems from past experiences with improper wastewater disposal by hotels, fearing similar practices by the new establishments. An additional concern is the potential rise in recreational activities, such as swimming in cenotes. Besides, increased use also raises the likelihood of potential littering. Moreover, P1-Env and P9-EnvWork also expanded on the impact of increased water consumption due to this growing population of residents and tourists. P10-LongRes and P8-Well couldn't specify a particular water-related impact but highlighted the train's extensive route as a potential source of pollution at least somewhere along its stretch. Finally, P2-LowEc and P7-Hotelier were unsure of the relation between both elements, reasoning that the train operates above ground and station users wouldn't intentionally litter into water sources.

Despite concerns about water quality, most participants lacked detailed knowledge of underground water systems. Only P1-Env and P9-EnvWork, with their environmental backgrounds, showed familiarity with concepts like groundwater, aquifers, and karstic soil. Others acknowledged a limited understanding, having heard activists mention aquifers as important resources, but couldn't explain their specific functions. Phrases like "understand the basics" were recurrent in this interview question. On the other hand, P2-LowEc and P10-LongRes admitted no prior exposure to the concepts of an aquifer or kast. However, the term "limestone" was familiar to P1-Env, P3-LongRes, P5-Native, P6-<2km, P7-Hotelier, P9-EnvWork, and P10-LongRes, due to what they called "local knowledge" that recognizes limestone as prevalent in the Yucatán Peninsula. However, only the two environmentally-focused participants understood its connection to karstic soil and its specific implications.

4.3.2 Perceived Social Impacts

Initially, residents said their livelihoods haven't been affected since the project started. Only P1-Env reported personal impact, as he actively participated in protests and long walks organized by local collectives. He recalls initial denial from authorities regarding logging or physical damage. Therefore, these collectives focused on raising awareness about construction activities by documenting visible impacts near the train tracks. Furthermore, P3-LongRes and P7-Hotelier noted that there was increased traffic when construction first began on the highway. Additionally, the changes to the highway, including moving lanes before shifting construction towards the jungle, took almost a year to restore to its original state, disrupting their commutes between cities.

Regarding expected future changes, P7-Hotelier expects many benefits, as more visitors will increase the occupancy of his hotel, not only during high seasons. Likewise, P2-LowEc, originally from a rural community several hours away, expects that new hotels and developments will create job opportunities, potentially attracting his family members to migrate to the city for work. However, other participants showed concerns about a range of negative impacts on their current way of life. P1-Env, P3-Res, P4-Reloc, and P9-EnvWork anticipated issues like population growth, increased contamination, environmental degradation, and urbanization. They also raised the concern of the long distances between train stations and city centers, which would require additional van services, increasing traffic congestion. Furthermore, P5-Native and P3-Res highlighted the potential for rising costs as an initial consequence of a tourist influx. They provided examples like Cancún, Playa del Carmen, and Tulum, where rising numbers of international residents have driven up the cost of rent, food, and services, displacing local residents. Lastly, P8-Well expressed concern about his water supply. Since he relies on this source for daily domestic needs, he fears he will have to continue using it even if it becomes contaminated.

4.3.2.1 Local Economy

Residents generally agreed that the project's economic impact hasn't yet been substantial, as some parts are still under construction and the operational segments have only been running for a few months. However, their perspectives on the future varied significantly. First, P2-LowEc, P7-Hotelier, P8-Well, and P10-Res anticipated positive outcomes, including job opportunities in the construction and operation of new infrastructure, alongside increased tourism that would benefit small businesses. P1-Env, P6-<2km, and P4-Reloc acknowledged these potential benefits but expressed concern about their sustainability, particularly because environmental degradation in the coming years could stop attracting tourists, ultimately harming the local economy.

On the other hand, P3-Res, P5-Native, and P9-EnvWork highlighted potential drawbacks for local businesses, arguing that in the last years, new tourism infrastructure has benefited international enterprises and marginalized local companies. P8-Well added another concern: the high train fares for local workers. From his perspective, the cost-benefit ratio is not positive for daily commutes within cities, as the train is primarily designed for travel between states.

4.3.2.2 Health and Security

Conversely, only a handful of participants could link the project to an impact on their health and security. P5-Native mentioned that perhaps the rushed work conditions, driven by the need to complete the project within the current presidential term, might not have been conducted under the best safety protocols. P1-Env and P9-EnvWork highlighted health risks that can arise from threatening natural water resources and consuming low-quality water. P3-Res and P10-Res were unsure about specific impacts but speculated on potential long-term auditory effects for people living near the train and related health risks from increased combustion. Additionally, P3-Res expressed concerns about social security, noting that increased delinquency has occurred in the past with more investors moving into the area, suggesting that not all newcomers may have positive intentions. The arrival of wealthy individuals alongside others could create a more complex social dynamic.

5 DISCUSSION

The findings can be understood as a comparison between academic-oriented findings and social perceptions, given that impacts were first extracted from an academic analysis and later compared to how residents perceive them. The following chapter delves into the key highlights from the analysis of socio-environmental impacts and explores how participants' social and cultural identities shaped their risk perceptions on the Maya Train, answering the fourth research sub-question.

5.1 COMPARISON OF ACADEMIC FINDINGS WITH COMMUNITY PERCEPTIONS

As presented in Chapter 4, most impacts are related to water quality, with seven biophysical impacts and twenty-three associated social challenges. This is followed by karst topography, with five biophysical impacts and sixteen related challenges. Water scarcity follows with three biophysical impacts and twelve challenges, and lastly, biodiversity loss, with three biophysical impacts and six associated social challenges. The social impacts that were most frequently associated with different activities include potential health issues, unreliable water supply, high remediation costs, rising water prices, decreased tourist influx, and disruption in local economies. Furthermore, for karst topography, there is an equal amount of direct and indirect impacts, as well as local and extended impacts, with most of these likely to occur in the short term. For water quality, more impacts are indirect, extended, and short-term. While challenges related to water availability are primarily indirect, long-term, and extended. Finally, the impacts on biodiversity loss are equally divided between direct and indirect, with most being extended and long-term.

Furthermore, the community perceived mostly water quality concerns due to increased tourism, the destruction of natural habitats, and the risk of collapses. They estimated an initial tourist boom followed by a decrease in tourism that could threaten the local economy. Additionally, they identified social impacts unrelated to groundwater deterioration but still affecting their livelihoods, such as displacement by large international businesses. Their risk awareness began with notable construction impacts on groundwater systems. However, most of their current concerns are rooted in past experiences of poor management, unplanned development, and urbanization. Consequently, they fear the social impacts that will arrive with the new infrastructure and the influx of visitors the train will bring when it becomes fully operational.

Comparing the risks and challenges identified by the community with those recognized by scholars reveals a significant gap in public understanding. The sample group is not fully aware of how environmental processes interrelate and how small effects on one process can impact others. However, these findings may not fully represent the public understanding of the entire population of Quintana Roo. For instance, despite concern about water quality, the sample did not mention any impacts related to public health, even when encouraged to make a connection, focusing instead on unsafe work conditions. Additionally, they failed to connect the indirect consequences of the impacts they did identify. For example, while they recognized the risk of collapses, they did not consider property damage, displacement, or the financial burdens that could follow. Furthermore, their water concerns were mainly focused on quality, without considering shortages, declines in water levels, or how it would hinder agricultural production. None of the participants mentioned the possibility of having to explore alternative water sources, soil erosion, or contaminated food. Ultimately, most impacts they identified were physical, recognizing collapses and biodiversity loss, while not considering the loss of biocultural or historical heritage. This indicates a need for increased awareness and education on the broader implications of environmental changes and how they affect various aspects of life.

5.2 SOCIAL AND CULTURAL IDENTITY AS SHAPERS OF RISK PERCEPTION

Moving beyond the general trends observed in the interview sample, this section delves into the interpretation of the social factors shaping individual perceptions based on the theoretical framework. The responses show that knowledge and group membership are the most influential factors, however, beliefs, values, trust, and a sense of fairness also play a role in shaping their points of view. These factors and their influence are explored in detail below.

First, group membership in this research relates to how a person's social bonds provide access to different types of information. For instance, participants connected to a community actively discussing the Maya Train online or visiting the tracks are likely to be exposed to more information about its potential risks. This is evident in both individuals with an environmental background and involvement with local collectives. However, this can also limit their exposure to diverse opinions, such as those of rural workers who view opportunities mainly through an economic lens. For instance, P2-LowEc prioritizes immediate economic needs over environmental concerns, focusing on income opportunities for his social bond, in this case, his family. Moreover, the native participant, although very young, was highly aware of various impacts. This could be attributed to the influence of his social group, which includes long-time residents and relatives who share their past experiences and perspectives.

Furthermore, the analysis revealed that participants' beliefs and values significantly shaped their point of view. For instance, P3-Res and P5-Native, despite not having technical knowledge or a deep understanding of ecological processes, showed perspectives shaped by growing up with a deep respect for nature and living by what they called “natural” values. This made them more sensitive to environmental damage compared to, for instance, an investor who is relocating solely to expand their business.

Moreover, interviews revealed a significant difference in trust levels in authorities among participants. Those with strong, pre-existing opinions on the government, either positive or negative, often showed bias in their responses, focusing less on environmental and social concerns. Those who expressed distrust towards governmental actions and decisions voiced concerns about future impacts. In contrast, individuals who appeared less concerned or informed about social consequences often referenced the project's sustainability and assurances from authorities regarding for instance, tree transplanting instead of logging. Trusting that authorities would prioritize the public's best interests.

Conversely, the influence of a sense of fairness can be observed, for instance, in P4-Reloc, who has no previous experience with how new infrastructure can destroy natural environments but can still empathize with locals and understand that development and displacement are not solutions, even though she is a newcomer herself. Similarly, LongRes-3 is shaped by a sense of fairness as he mentioned that he considers it unjust that the project has skipped many laws and regulations. This perception has led him to hold back support for the project and encouraged him to research its potential implications, which explains his knowledge of several impacts.

Ultimately, knowledge (or mainly the lack thereof) seems to be the major shaper of individuals' perceptions. For instance, P1-Env and P9-EnvWork showed a high understanding of most issues. Although they did not mention many indirect social consequences identified in Section 4.2, they still discussed significantly more details than the rest of the sample. This can be attributed to their years of studying or working in the field, providing them with prior knowledge about ecological processes and their interconnections, which they could relate to the current situation in the region. In contrast, limited knowledge about the specifics of the project, the environment, and its interconnectedness significantly impacted participants' ability to grasp potential consequences. For instance, none of the participants mentioned the risk of fuel spills because they were unaware that the train will also transport materials, as it is primarily promoted for passenger transport. Moreover, when motivated to estimate consequences, they had to base their guesses on the information they had available and assumed to be correct. For example, discussions of soil and land impacts only emerged after more explanation was given on the topic, suggesting a lack of awareness regarding the karst system's fragility and the interconnectedness of the cenotes system. Similarly, P2-LowEc and P7-Hotelier's confusion regarding surface activities and their underground impact demonstrated a gap in their understanding of surface runoff through limestone pores. Furthermore, initial awareness of construction activities like drilling and cement injection didn't translate to concerns about public health or agricultural impacts. This suggests that while participants recognized potential harm, they didn't comprehend the likelihood or severity of the consequences. This is particularly relevant as a lack of understanding about what's at risk hinders effective mitigation strategies.

It is also relevant to note that not all of this knowledge needs to come from an academic background, a significant portion comes from experience. Although some participants lacked specific environmental background or formal research on the topic, they understood some issues because they had witnessed the changes urbanization and tourism had caused in the region, such as increased sargassum, coastal erosion, and coral bleaching. For instance, while they may not fully comprehend underground rivers and flow dynamics, they know cenotes lead to the sea, recognizing their significance. Additionally, even participants with limited exposure to terms like "karst" identified collapse as a potential impact, having witnessed sinkings occur previously on the highway due to car vibrations. They reasoned that similar accidents could also occur with a train of that size. This illustrates how, in this case, empirical knowledge rather than technical knowledge shapes their perceptions.

Among the demographic categories outlined in Table 4, age group was found not to significantly influence the level of awareness within the sample. Similarly, proximity to the route did not cause significant variation in results, as the tracks are parallel to the highway, meaning most individuals are within the same distance range. However, due to his proximity, P6-<2km demonstrated awareness of certain impacts that others didn't, particularly local effects such as species moving into urbanized areas. Furthermore, the level of education was only found to be relevant when it specifically related to environmental subjects. Finally, as income level relates to economic status, it did influence some individuals' perceptions. Economic qualities influence accessibility to resources, including information, which in turn shapes an individual's perception of the issue. In this case, those with greater access to technological resources can gather information from diverse sources and form more informed opinions. For example, if individuals only have access to free national television or printed newspapers where updates about the project are limited, they won't be able to formulate a detailed list of consequences, except for what is covered in these sources. In contrast, individuals with access to alternative media such as email updates from NGOs or social media platforms can access contrasting information. For instance, a resident with higher income may have easier access to non-official online media and digital platforms where they can research and discuss these issues with experts, gaining deeper understanding compared to those with limited resources.

Ultimately, it's worth noting that in addition to the impacts already encountered, a future issue for authorities to consider in mitigating these impacts is that not only do people without access to regional water supply extract groundwater, but others do so as well, possibly due to convenience or pricing reasons. However, in the long run, without regulation, these individuals could either be exposed to contaminated water or contribute to contamination through domestic runoff via these access points.

5.3 LIMITATIONS

While this study provides valuable insights into the socio-environmental consequences of groundwater deterioration caused by the Maya Train and how residents perceive these risks, it is important to acknowledge some limitations. First, there was a lack of access to the original Environmental Impact Manifestation. The official governmental website where this document was published is no longer accessible online. Consequently, the potential impacts explored in this research were extracted from an external consultancy that analyzed the EIM when it was still available (Consultores en Gestión Política y Planificación Ambiental, 2022).

Furthermore, it was a challenge to ensure that the interview questions were general enough to avoid bias or would redirect participants toward specific answers, yet specific enough to gather meaningful data. To assess the participants' true level of knowledge regarding the consequences, the interview questions were not sent in advance to prevent them from preparing or researching. However, this approach complicated drawing definitive conclusions about the community's perceptions based on a single interview. For instance, participants might have been hesitant or forgotten to mention a specific impact they were aware of but didn't recall at the moment. Therefore, their responses may not fully reflect their complete understanding or beliefs.

Additionally, the initial sample was selected to avoid including individuals from similar categories; however, limitations arose during the interview stage. An elderly individual who had recently relocated to the region and a communal landholder whose land was purchased for the train's implementation were initially considered for the study. However, they refrained from participating before the scheduled meetings. To maintain the intended sample size, the ninth and tenth participants were approached, although they had similar attributes to other participants.

The frameworks used in this study were relevant to address the main research question and provided valuable insights. However, future studies could benefit from incorporating additional variables and optimizing resource allocation to gain a more comprehensive understanding of community perceptions. The Social Impact Assessment of Research Framework contributed to a thorough identification of impacts and enhanced the robustness of the research. Nevertheless, this resulted in limited time and resources available for the final stages of the study. Additionally, the Influences on Risk Perception Framework, while useful, included a limited range of elements related to cultural and social identity. As this was the primary framework for evaluating perceptions, it overlooked a broader range of potential variables.

Finally, the sample provides an example of what people from different groups may perceive, but it is not fully generalizable. Each individual's background shapes their perspective of the project and consequential risks, and these vary widely among the population. Therefore, the sample's risk perceptions do not necessarily represent the perception of the entire local community. While the sample provides valuable insights into the perceptions of different groups and is sufficient for an exploratory study, it doesn't cover the full range of experiences and viewpoints within the broader population. If more time and resources had been available, expanding the sample size and incorporating a more diverse range of participants would have been beneficial. This could have included reaching out to additional demographic groups, such as those directly affected by land acquisition or displacement, and selecting representatives from each municipality. This approach would ensure that the opinions of individuals from all regions are included, as their experiences and impacts vary based on location and available resources. Ultimately, a larger and more diverse sample would have enhanced the study's ability to generalize the findings to the entire local population.

6 CONCLUSION

This study sheds light on the public perception of the diverse environmental and social consequences of the Maya Train in Quintana Roo, focusing on the potential disruption to groundwater systems. It addressed the main research question by identifying that the local community perceives certain direct social challenges as significant while being largely unaware of indirect and long-term ones, with perceptions varying based on social and cultural contexts. Despite recognizing some challenges, the number of perceived issues is relatively few compared to the broader range of impacts identified in academic research.

The first research sub-question was addressed by identifying eighteen biophysical impacts of groundwater system degradation. These impacts were categorized into four main areas: seven for water quality, five for karst topography, three for water scarcity, and three for biodiversity loss.

Subsequently, the second sub-question was answered by identifying thirty-three different social impacts resulting from these biophysical changes. These impacts were classified based on their nature as either short-term or long-term, direct or indirect to the biophysical changes, and having localized or extended consequences. There were twenty-three social impacts related to water quality, sixteen related to karst topography, twelve related to water scarcity, and six related to biodiversity loss.

In addressing the third research sub-question, the local community's perception of potential social challenges proved to be limited, revealing a gap in the sample's understanding of environmental processes, groundwater systems, and their relation to the community. The study identified a discrepancy between academic findings and community perceptions. While both sides recognized issues such as deteriorating water quality, urbanization, rising prices, decrease in tourist influx, and disruptions in the local economy, the community failed to identify indirect consequences such as public health issues, displacement, decreased agricultural productivity, or loss of historical heritage. Moreover, they did not perceive impacts related to water availability, such as seasonal shortages or reduced recharge capacity.

Moreover, to answer the fourth research sub-question of identifying the factors shaping the sample's perception, the study highlights the importance of considering social and cultural contexts when evaluating public perceptions of large-scale environmental projects. The factors influencing community risk perceptions include group membership, beliefs and values, trust, sense of fairness, academic and empirical knowledge, and access to resources linked to economic status. In contrast, age, level of education, and route proximity showed minimal effect.

The findings from this study offer valuable insights that extend beyond the specific case of the Maya Train in Quintana Roo. The observed gaps in public understanding of environmental and social impacts highlight the need for both public and private sectors to improve transparency when communicating the consequences of large-scale infrastructure projects. The results emphasize the importance of effective communication and education strategies to enhance public awareness, particularly in regions experiencing similar environmental changes. These insights can also inform future research, ensuring that both the scientific community and affected populations are better aligned in addressing and mitigating the impacts of major infrastructure developments. Furthermore, future studies can build on the factors identified to influence community risk perception by expanding the theoretical framework. This could move beyond the elements established in the Influences on Risk Perceptions Framework to include additional factors that may affect individuals' processing of information. By integrating these new variables, future research can offer a more comprehensive understanding of how people interpret and respond to environmental and social challenges.

Ultimately, it is relevant to note that the sample comprised only 10 individuals from the community. Although efforts were made to select participants with diverse demographic groups, they do not represent the entire population. Likewise, results are based on interviewees' responses during a single interview, potentially overlooking impacts they might be aware of but couldn't recall during the interview. Therefore, further research with a larger and more representative sample, along with incorporating multiple contact approaches with participants is necessary to draw more definitive conclusions about public perceptions.

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APPENDIX

INTERVIEW QUESTIONS

Introduction and background

1. Can you tell me a little bit about yourself and your background?
    a. Age, occupation, household size, and location.
    b. How long have you lived in Quintana Roo?

Topic background

2. Are you aware of the Maya Train project? If so, what have you heard about it?
3. How do you feel about its construction in general?

Perceived environmental impacts

4. Have you noticed any changes in the natural environment in your community since the construction or operation of the train began?
    a. If so, can you describe any specific change you've observed?
5. Have you seen any changes in the land or soil around your community in recent years? (such as erosion or land stability)
    a. What do you think might be causing these changes?
    b. Do you think the operation of the train could further exacerbate these changes?
6. How do you access water for your household (wells, public supply, etc.)
7. Have you noticed any changes in water quality or availability in recent years? If so, what changes?
    a. Do you think the operation of the train could further exacerbate these changes?
8. Are you familiar with the concept of groundwater and aquifers?
9. Do you think the Maya Trai could affect the underground water system here? How?

Perceived social impacts

10. Have you experienced any changes in your livelihood since the project started? Can you explain?
    a. If you haven't, do you think you will experience any of these changes as a consequence of the train's operation in the following years?
11. How do you think the Maya Train project has affected local businesses and the local economy?
    a. How do you think it will affect them in the following years?
12. Do you feel that the project has impacted or will impact the community's safety/security in any way?
    a. If you had to relate the train to public health, how would you do it?

If this topic has not been covered in previous questions:

13. What do you think are the biggest benefits of the Maya Train project for the community?
14. As a citizen, what are your main concerns about the implementation of the train?
    a. Do you have any suggestions for how these could be managed or mitigated?
15. Is there anything else you would like to share about your experience or perceptions regarding the Maya Train?