JES, Vol. 50, No. 6, Nov 2022 DOI: 10.21608/JESAUN.2022.140354.1139 Part A: Civil Engineering

Journal of
Engineering Sciences
Faculty of Engineering
Assiut University
JES
مجلة
العلوم الهندسية
كلية الهندسة
جامعة أسيوط
journal homepage: http://jesaun.journals.ekb.eg

# Documenting and Analyzing the Harmful Impacts of The Seasonal Floods in Upper Egypt on Qena-Safaga Railway Track Infrastructure

Received 23 May 2022; Revised 12 August 2022; Accepted 12 August 2022

**Tarek S Abuzeid** [1]
**Mohamed A Ashour**[2]
**Hazem Mahmoud**[3]

**Keywords**
Torrents and Flash floods – Railway Infrastructure - Railway Track Drainage

## Abstract

In light of the world's current severe climatic changes, it has been observed that the frequency of flash floods and torrents is increasing at an accelerating rate in numerous areas, exposing civil infrastructure and property to significant damage and losses. Railways are one of the most essential components of the transportation sector's infrastructure, which is the prime engine for any development in all sectors. Recently, there have been many cases of torrents attacking some railway tracks in Egypt, especially in the east of the country, including the Qena-Safaga railway track, which is the main objective of this study to minimize the expected negative impacts. Torrents, or flash floods, are one of the most destructive natural hazards, especially in arid regions. Seasonally, these regions are exposed to heavy rains that cause serious flash floods with great negative impacts. In such conditions, the railway track needs maintenance, insurance, and protection against the risks of monsoon floods that hit those areas from time to time. The present study includes the most popular flash floods that attacked railway infrastructures all over the world and how they were protected, allowing them to successfully deal with these exceptional circumstances to maintain the integrity of the railway tracks and the efficiency of their performance. The study will present a classification of some previous flash floods that occurred in Egypt and some other places in the last few decades based on multiple criteria, including severity, lifetime, direction, impacts, and the types of harmful effects on infrastructure. The goal of the study is to introduce a practical manual and procedure for how to deal successfully with flash floods that may attack the under-study Qena-Safaga railway track.

## 1. Introduction

Occasionally, torrential rains and seasonal floods attack railway lines in some areas due to climate and local weather fluctuations, causing extensive damage to the infrastructure and negatively impacting the efficiency, quality, and discipline of the lines' operations. In Egypt,

---

[1] Lecturer, Civil Engineering Department, Faculty of Engineering, Assiut University,
[2] Professor, Civil Engineering Department, Faculty of Engineering, Assiut University,
[3] Civil Engineer, Egyptian National Railways, Egypt

https://doi.org/10.21608/JESAUN.2022.140354.11539

the eastern desert region, which is located between the River Nile and the Red-Sea, is seasonally exposed to heavy rains, causing serious flash floods in some areas such as the area between Qena governorate and Safaga city on the Red-Sea. In this area, the under-study railway line (Qena-Safaga railway track) is located to transfer the production of Abu-Tartor phosphate mines in the western desert of Egypt to Safaga port on the Red Sea for export worldwide. The track is subjected seasonally to major flash floods that cause damage to infrastructure elements, leading to shutdowns of service as well as increasing repair and maintenance costs. The current study aims to present the most common events of floods attacking railway track infrastructure all over the world and how they were treated to avoid or minimize the impacts. The study will document and analyze the devastating effects of common floods on the infrastructure of the Qena-Safaga track. In addition, discussing the characteristics of the region that would enhance the impact of the floods in the area. The study will also suggest some appropriate treatments that can help reduce the impact of the floods on the infrastructure of the Qena-Safaga railway, based on global treatments applied worldwide and according to the conditions of the study area. The available data used in this study was obtained officially from Egypt's National Railways Authority, while other data used was extracted from previous studies in the scientific research literature in this field.

## 2. Literature Review

Railway networks play an important social and economic role in contributing to the quick and safe transportation of passengers and goods. Performance and continuity of service are largely related to the efficiency and quality of the infrastructure. Railway track infrastructures, like all civilized infrastructures, are exposed to different types of natural hazards like earthquakes, flash floods, and climatic and environmental changes. At the same time, they must perform perfectly and safely all the time. So, the engineers in charge must be able to deal successfully and quickly with such expected events. Many researchers and engineers studied the destructive impacts of such events a long time ago and came up with many conclusions and recommendations for facing them and minimizing their negative impacts. The present paper introduces a survey of the most popular railway track infrastructure cases being attacked by flash floods and how they were treated and overcome to ensure the safety and performance of the attacked railway tracks as follows:

### 2.1 Documentation of Flood Impacts on Railway Infrastructure

Substructure, superstructure, drainage systems, and connection lines, according to Otto et al. [1], are the components of railway infrastructure. Also, Moran et al. [2] defined railway infrastructure elements of standard cross-section (substructure, superstructure, and contact line), as well as station buildings, bridges, signal towers, and other things such as power supply systems, etc. Figure 1 shows the main components of railway infrastructure. They also concluded that the element of standard cross-section (SCS) is the most important element, as shown in Figure 2. Most railway infrastructure components are exposed to various types of climate change impacts that have an impact on railway safety and service quality.

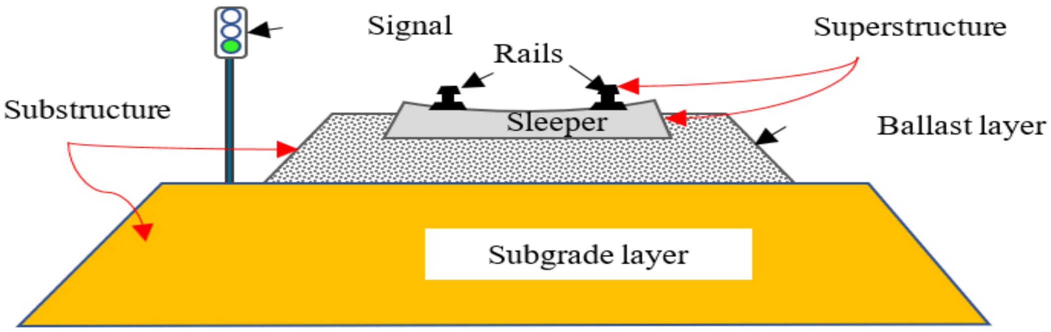


Figure 1 Main components of railway infrastructure.

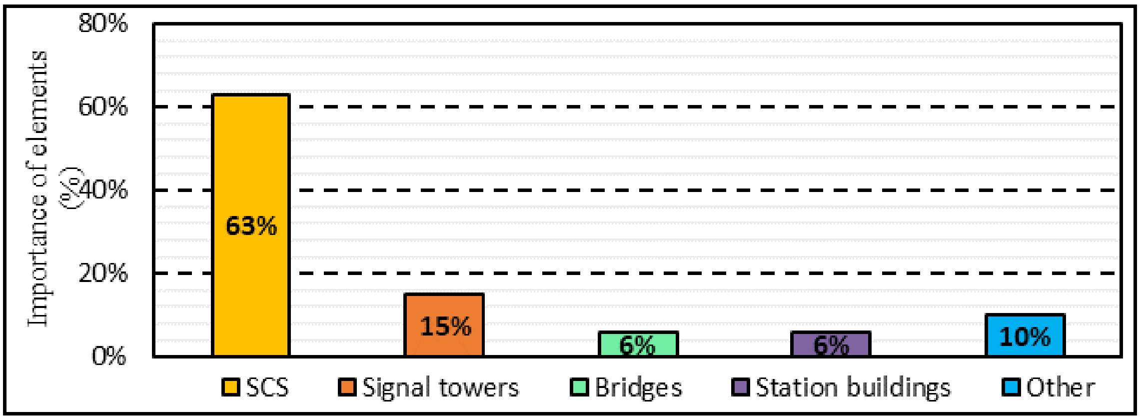


**Figure 2** The percentage of importance of infrastructure elements, Moran et al. [2].

## 2.2 Extreme weather impacts and consequences

Climate change has a significant impact on railway infrastructure and operations, as railway elements are more sensitive to changes in extreme weather conditions such as heavy rain, windstorms, temperature changes, frost, fog, and lightning. In some regions, extreme cold has an impact on railway performance as the train can derail owing to ice accumulation on the track, equipment failure, and switches freezing, resulting in time delays and higher maintenance and repair costs [3]. In arid regions, heavy rains, strong winds, high temperatures, and lightning are the most harmful weather phenomena that affect the safety of railway infrastructure and increase repair and maintenance costs, resulting in financial losses. Heavy rains cause floods that wash away ballast beds and collect water on and in underground tracks, leading to embankment failures and track settlement. In addition, flood waters carry trees and large objects, hitting bridge supports and causing structural damage. Strong winds cause debris, silt, and fine sand accumulation, and falling trees on the tracks, resulting in blocked tracks and delays. Also, high temperatures cause track buckling, deformations, and reduced efficiency of electrical devices, resulting in slower speeds. Figure 3 shows the impact of extreme weather in arid regions on the railway infrastructure and the consequences thereof. To illustrate the effects of various severe weather phenomena on each element of the railway infrastructure, Table 1 was constructed based on Figure 3. It is observed from Table 1 that the railway infrastructure elements are more sensitive to extreme weather phenomena, as well as floods, which have the greatest impact on the railway infrastructure, since most of their consequences are more serious than the consequences of other events, as shown in Figure 4 (constructed according to Table 1). Flooding can cause damage to embankments, bridges, stations, power supply systems, and other structures, causing delays and track closures for weeks or months, as well as increased maintenance and repair costs.

**Table 1**: Effects of extreme weather phenomena on railway infrastructure elements based on Fig. 3.

| **Element** | **Weather Phenomena** | | | |
|---|---|---|---|---|
| | Strong wind | High temperature | Lightening | Heavy rains / flooding |
| Substructure | | | | ✓ |
| Superstructure | ✓ | ✓ | ✓ | ✓ |
| Bridge | ✓ | ✓ | | ✓ |
| Building | ✓ | | | ✓ |
| Signal towers | ✓ | ✓ | | ✓ |
| Overhead line | ✓ | | ✓ | ✓ |
| Power supply systems | ✓ | ✓ | | ✓ |
| Controlling and safety devices | | | ✓ | ✓ |

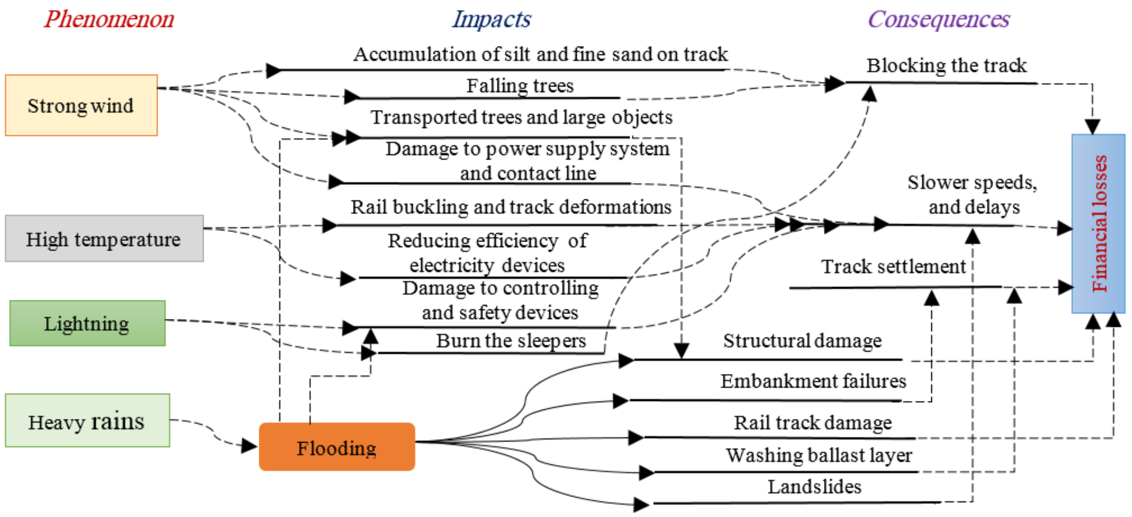


Figure 3 The impact of extreme weather in arid regions on the railway infrastructure and its consequences.

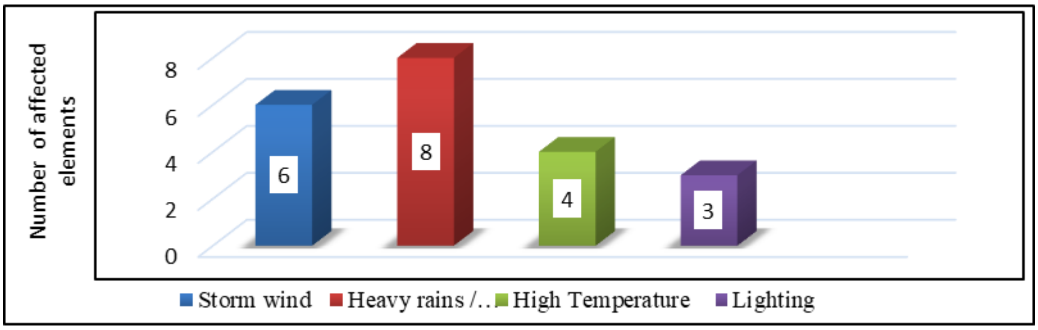


Figure 4 Number of railway infrastructure elements affected by different extreme weather phenomena.

## 2.3 Cases of flood impacts and losses

Floods are one of the frequent natural disasters that cause great human and economic losses. The common types of floods that affect railway track performance are tidal flooding, fluvial flooding, flash flooding, groundwater flooding, flooding from sewers, and flooding from man-made infrastructure. Flash floods are known to be the most dangerous type of flood because they are very fast-moving as well as unpredictable [4]. It can also occur in rivers without warning, causing severe damage to assets and life [5]. Many cases of flood damage to railway infrastructure elements such as substructure, superstructure, bridges, signals, stations, and railway equipment have occurred around the world, affecting the performance and operation of railway tracks. Following a comprehensive review of the literature on past floods, Table 2 was created to list the most common cases from throughout the world, including Egypt, along with their location and date of occurrence as documented by researchers and authors. Table 2 contains 13 cases of flood attacks on railway infrastructure in 11 countries, including Egypt, along with the resulting damage and references. From the table, floods have serious direct and indirect negative impacts on both railway infrastructure and rail operations. To illustrate flood impacts on each element of the railway infrastructure, Table 3 was constructed depending on Table 2, where the impact of the flood on each element of the railway infrastructure was determined by the following built-up equation.

$$\text{Flood impact (\%)} = \text{Importance (\%)} * \text{Impact frequency} \tag{1}$$

Where: Importance (%) according to importance of railway infrastructure elements was determined by [2] (See Figure 1). Impact frequency was based on Table 2
It is clear from Table 3 as well as Figure 5 that the most harmful effects were on the standard cross-section (substructure, superstructure, and contact line) (13 cases). The remaining cases varied between destroying a railway bridge (8 cases) and the accumulation of debris and mud on the track and stations (3 cases). Also, there were many cases of damage to signal boxes and rail equipment. This is due to failure of other elements, such as failure of bridges, signals, and railway equipment, which is mainly associated with (SCS) failure, as shown in Figure 6.

**Table 2** Some cases of flood damage to railway infrastructure

| Event | Impacts | Country of study | Reference |
|---|---|---|---|
| **2006 March River flood** | Major damage to railway tracks. | Austria | [2] |
| | Damage to rail bridge. | | |
| | Damage to connection system, and buildings. | | |
| | Closure line for several months. | | |
| **2010 River floods** | Damage to part of the central railway system. | Tanzania | [8] |
| | Train services stopped for more than three months. | | |
| **2015 flash floods in the Machak River.** | Damage to the main Machak River rail bridge. | India | [9] |
| | Washing away rail tracks. | | |
| **River floods** | Damage to railway tunnel. | England | [10] |
| | Closing railway tunnel for several months. | | |
| **2010 heavy rain 180 mm /12 hours** | Damage to railway tracks and delays due to covering the railway with water and transported debris. | France | [3] |
| **1993 Mississippi River floods** | Damage to railway infrastructure. | USA | [11] |
| | Damage to bridge, and bridge foundation | | |
| **2008 flash floods** | Damage to 15 railway lines. | USA | [12] |
| | Damage to 9 rail bridges. | | |
| | Damage to rail bed, signals, and other facilities. | | |
| | Closures of 56 track lines for several weeks. | | |
| **2018 mud floods / Heavy rains** | Damage to railway infrastructure. | Russia | [6] |
| | Damage to bridge | | |

| Event | Impacts | Country of study | Reference |
|---|---|---|---|
| | Accumulation of landslide on tracks | | |
| **2021 flash floods** | A total of 600 kilometers of tracks affected by floods. | Germany | [7] |
| | Damage to 80 stations. | | |
| | Damage to 7 regional railway lines. | | |
| | Damage to more than 50 rail bridges, and 180 level crossings. | | |
| | Damage to 40 signal boxes, and rail equipment. | | |
| | Large accumulation of debris and mud on tracks, systems, and stations. | | |
| **2021 flash floods** | Damage to railway networks | Belgium | [7] |
| | Blocking many railway lines | | |
| | Replacing 70,000 tons of ballast. | | |
| | Replacing tens of thousands of sleepers. | | |
| | Reconstructed more than 10 Km. of railway embankments. | | |
| | Damage to stations. | | |
| | Damage to bridges. | | |
| **2021 flash floods** | Serious damage to railway line. | Netherlands | [7] |
| **November 2020 flash flood** | Damage to Marsa Matrouh - Alexandria railway line | Egypt | (Egyptian Railway). |
| | Washing away the substructure. | | |
| | Closure the line and track delays. | | |
| **November 2021 flash flood / heavy rains** | Failure of the railway embankment of the Aswan - High Dam railway line at several places. | Egypt | (Egyptian Railway). |
| | Failure of signaling system. | | |
| | Presence of water ponded next to the line. | | |
| | Reduced speeds to 5 km/h and track delays. | | |

**Table 3** Flood impact on railway infrastructure elements

| Element | SCS | Signal | Bridge | Station | Other |
|---|---|---|---|---|---|
| Importance (%) | 63 | 15 | 6 | 6 | 10 |
| Impact frequency | 13 | 5 | 8 | 3 | 4 |
| Flood impact (%) | 819 | 75 | 48 | 18 | 40 |

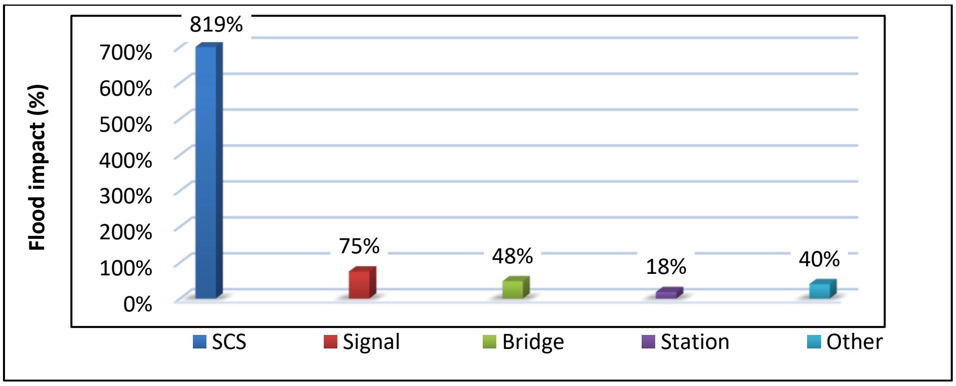


Figure 5 Flood impact on railway infrastructure elements, where (SCS) refer to standard cross section (Substructure, Superstructure, and contact line).

Figure 6 Some cases of flood damage, (a) Railway bridge scour; (b) Railway infrastructure damage in Russia [6]; (c) Rail damage in Austria [2]; and (d) Rail damage in Belgium [7].

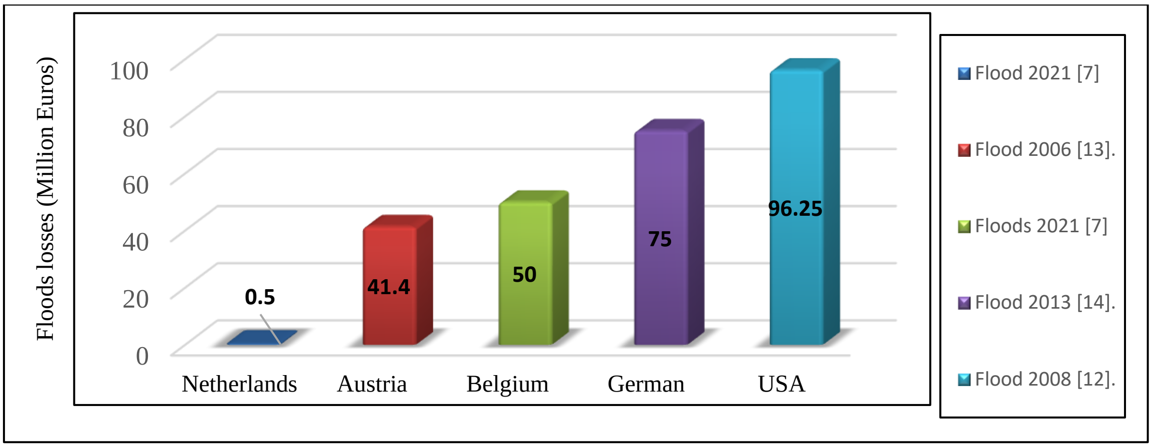


Figure 7 Some cases of financial losses due to floods

Flood damage to railway infrastructure has exposed many countries around the world to large financial losses, some of which are estimated to be in the billions of euros. Figure 7 shows flood losses in some countries in the millions of euros.

## 2.4 Treatments to reduce Flood Impact

In all parts of the world, there are many treatments that have been implemented to help prevent or reduce the effects of floods on railway safety and to ensure safe operation. Table 4 was created to show some treatments to lessen their impact.

**Table 4** Treatments implemented to reduce the impact of floods on railway infrastructure based on popular cases in the world.

| Element | Appropriate treatments to reduce impacts | Reference |
|---|---|---|
| **Substructure and superstructure** | Increasing track line stability by replacing track weight with a larger suitable weight. | [8] |
| | Protecting the track from water flood by diverting it away from flood prone areas to high-altitude | |
| | Using basalt as a natural material suitable for railway ballast to quickly drain the water surface. | [15] |
| | Using the sub-ballast layer as a way for improving drainage and prevent the inter penetration of the subgrade and ballast. | [16] |
| | The construction of high-altitude drains at locations that have a high difference in elevation helps collect flood waters before they reach the track. | |

| Element | Appropriate treatments to reduce impacts | Reference |
|---|---|---|
| | Constructing drains on the sides of the track to collect flood waters before they reach the track | |
| | Use of membrane barriers that prevent water entry, and inflatable water-filled bulkheads as a defense system to protect the track from flood water. | [17] |
| | Excavate a trench in subgrade slopes to drain the water trapped between ballast and subgrade. | [18] |
| **Track equipment and building** | Installing or shifting buildings and equipment to a level higher than the expected flood level. | [17] |
| | Installing pumping stations near the flood-prone area to quickly pump flood water. | |
| | Constructing bridges have wide spans to allow large objects to pass through without damaging the abutments. | [19] |
| **Bridge** | Lining the base of the bridge with high-quality rocks to prevent scouring. | |
| | Installation of a railway bridge with a sharp nose pier to reduce flood water stress. | [20] |
| **Draining system** | Installing an efficient track drainage system to keep track dray and safe. | [16] |
| | Culvert maintenance such as repair of damaged culverts, cleaning plugged culverts, and periodically, removing the accumulation of sandy sediments and rock crumbs from inside and in front of culverts. | |
| | Using box culverts with broken inclined headwalls on both sides and an inclination angle of 30° to improve the performance efficiency of culverts against flooding by improving the head loss. | [21] |

## 3. Collection Data

### 3.1 Geological features

The track under-study is located within an area in Upper Egypt between latitudes 25° 48' N and 26° 48' N and longitudes 32° 48' E to 34° 12' E. It is bordered to the east by the Red Sea and the Nile River from the west. It is also bordered to the north by the Qena-Safaga Road and to the south by the Qena-Qussier Road, as shown in Figure 8. The study area is characterized by its extreme complexity and undulation, with its extreme height above mean sea level, as it contains the Red Sea Mountain chains. According to [22], the area is divided into several geomorphological zones, the first of which is the coastal plain, which includes the extended lowlands bordering the Red Sea at the contour Line (200 m). This area is occupied by formations that belong mostly to the Quaternary geological age, where it consists of river sediments, outwash plains, wadi, and terrace deposits. On the other hand, to the west, where the area extends from the eastern bank of the Nile at Qena to the contour Line (200 m), includes the flat and lowlands. The second range includes the coastal highlands and includes the areas to the west of the coastal plain of the Red Sea, and it is represented by some isolated and scattered hills, which consist mainly of deposits of evaporite, and limestone intertwined with shale. The third range includes the Red Sea Mountain chains, which extend parallel to the coast of the Red Sea in a "northwest-southeast" direction. The track passes through the three zones as it runs from km zero to km 85, where the lowlands and some scattered hills are.

It also extends within the Red Sea Mountain chains from km 85 to km 185, and then continues from km 185 to km 232 parallel to the coast of the Red Sea, as shown in Figure 9.

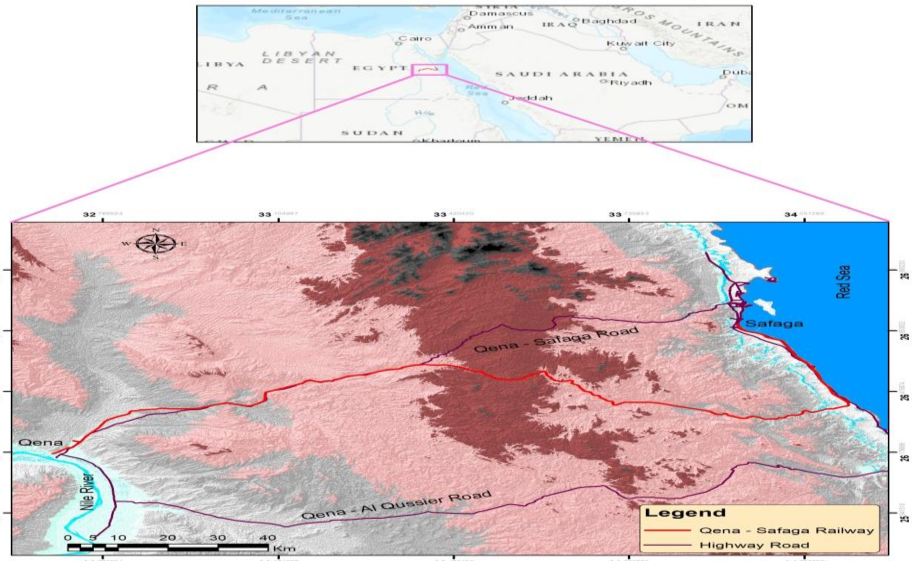


Figure 8 GIS map of the case study area

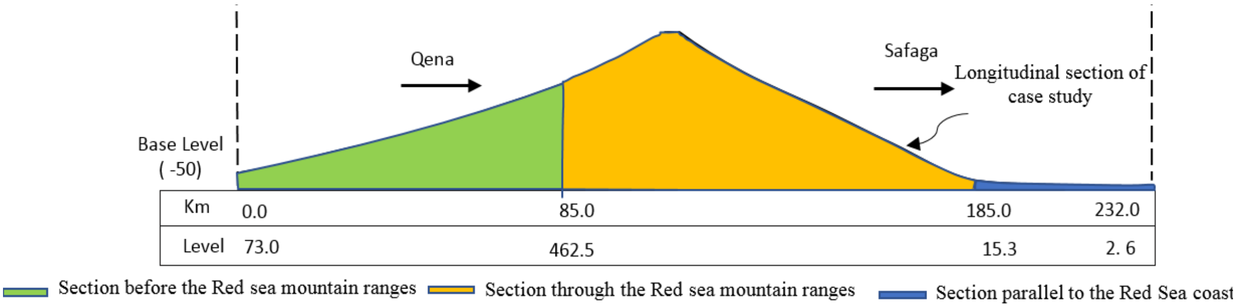


Figure 9 Sections of the track under-study within the case study area

## 3.2 Topographical features

The topography of the study area is characterized by large differences in elevation, causing high-energy flows to descend from the Red Sea Mountain ranges and high hills and become more destructive. As it is somewhat lower in height in Qena governorate and Safaga city, while it reaches its highest point in the middle of the territory, where the minimum height is zero and the maximum elevation is 1112 meters, as shown in Figure 10.

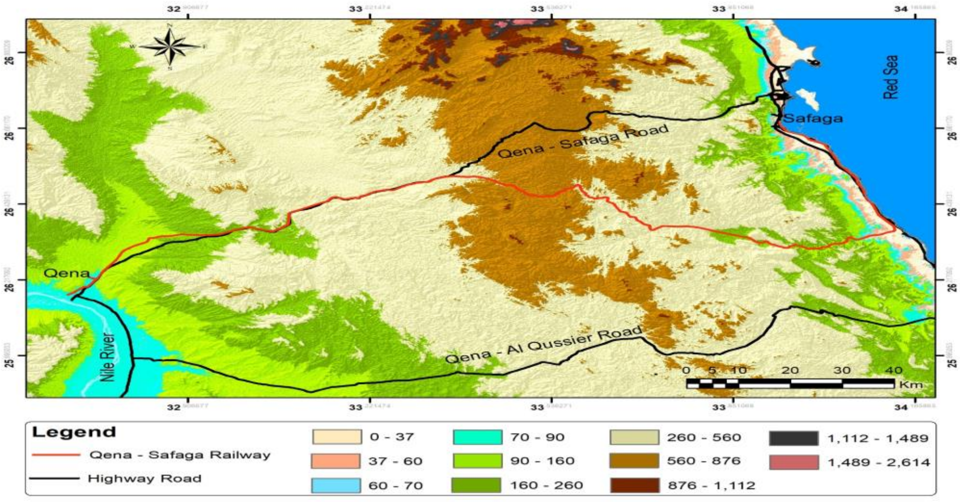


Figure 10 Topographic map of case study area generated by GIS.

### 3.3 Meteorological Features

The climate of the region varies from season to season, being very hot in summer and very cold in winter. Although the climate of the area is dry with little rainfall, the heavy monsoon rains between October and February cause flash floods. Meteorological data for the region from 1913 to 2000 was recorded from various stations by the Egyptian Meteorological Authority. It was found that, according to the climatic data recorded by Qena station, the average maximum temperature in the summer is 41.7 °C, the average minimum temperature in the winter is 7.2 °C, the total annual rainfall rate is 3.47 mm, and the degree of aridity is 0.2, while the average minimum temperature is 5.6 °C depending on Luxor station, the maximum degree of aridity is 0.44, and the total annual rainfall rate is 4.38 mm, which were given by Hurghada station as indicated in Figures 11, and 12 [23].

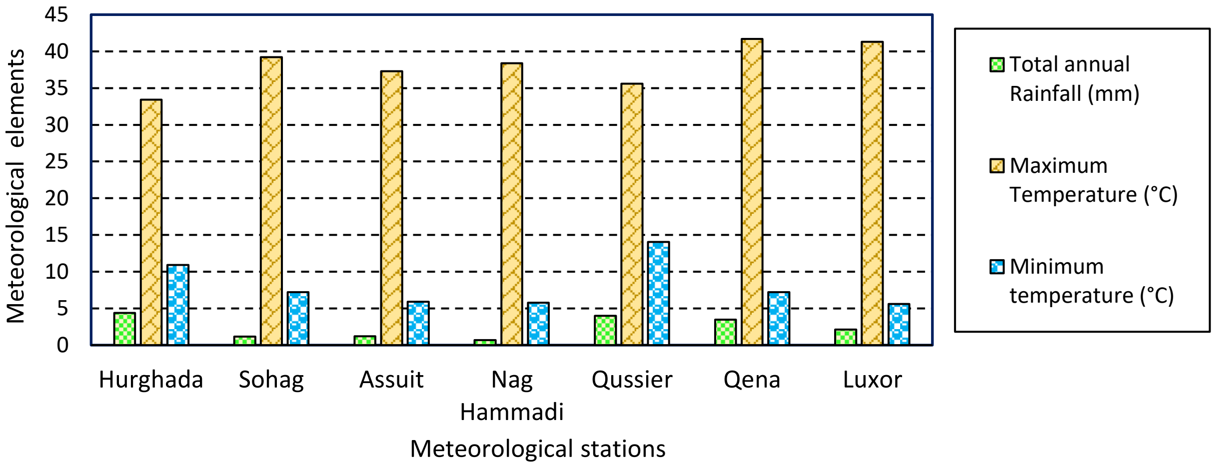


Figure 11 The climatic data for case study area recorded by different stations [23].

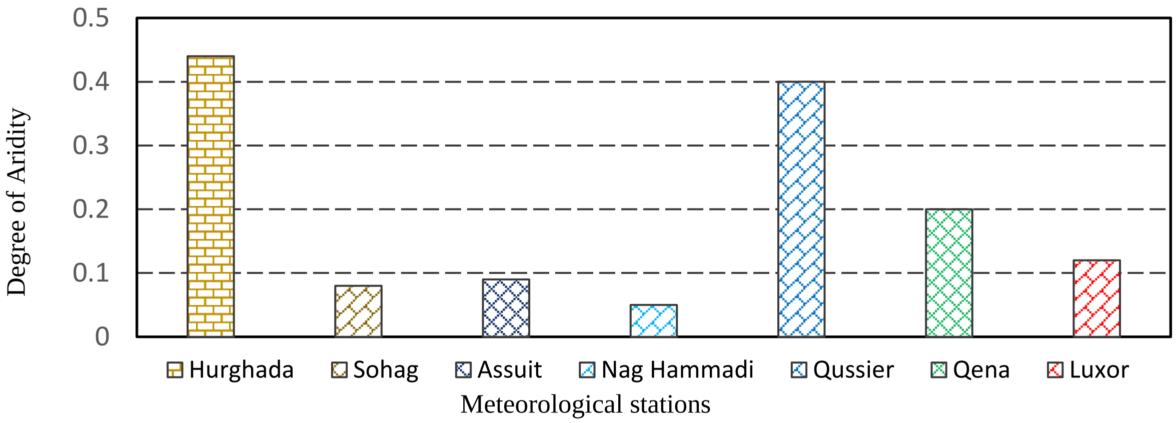


Figure 12 Degree of Aridity for case study area recorded by different stations [23].

### 3.4 Morphometric characteristics

Since the track extends a long distance in the area, it is exposed to the hazards of several wadis. The section from km zero to km 100 is subjected to the hazards of the eastern sub-basins of the main basin of Wadi Qena, while the section track from km 100 to km 232 is subjected to the hazards of wadi basins that drain into the Red Sea, as indicated in Figures 13. Hazard maps for these areas have been prepared depending on GIS analysis. It was found that the hazard degree of wadi Qena sub-basins, which affects the section of track from km zero to km 100, ranges from very low to very high, as shown in Figure 14 [24]. However, the hazard degree of wadis basins that drain into the Red Sea, which affects the section of track from km 100 to km 185, ranges from low to moderate, as shown in Figure 15 [25], and constructed Table 5.

**Table 5** Hazard degree of wadis affecting the track under-study

| Section | Related wadi | Hazard degree | Reference |
|---|---|---|---|
| Km. (00.00) – Km. (34.00) | Wadi Qena | Very Low– Low | **[24]** |
| Km. (34.00) – Km. (100.00) | | Very High | |
| Km. (100.00) – Km. (185.00) | Wadi El Queih | Low | **[25]** |
| Km. (185.00) – Km. (232.00) | Wadis of Safaga, Naqarah - Gasous, Gawasis | Moderate | |

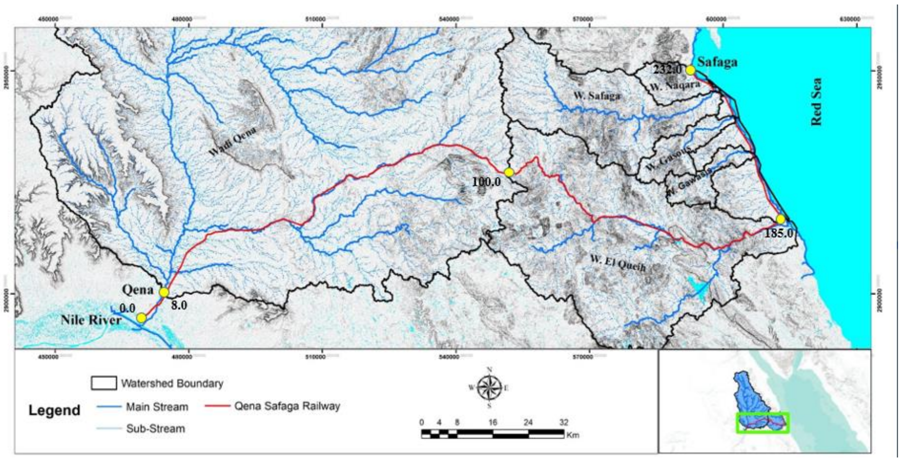
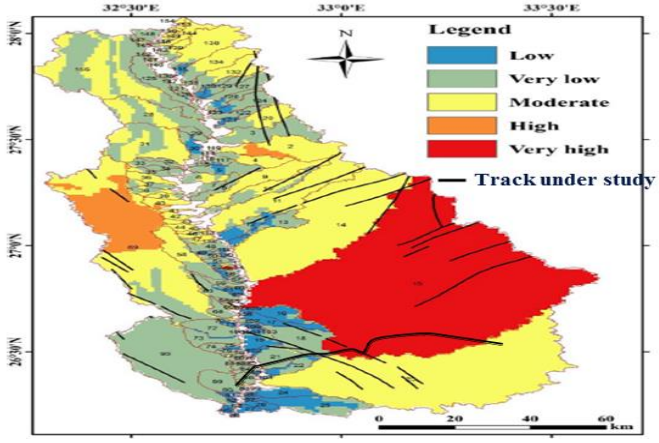


Figure 13 GIS map of drainage network distribution of different wadis in case study area, W: Wadi.



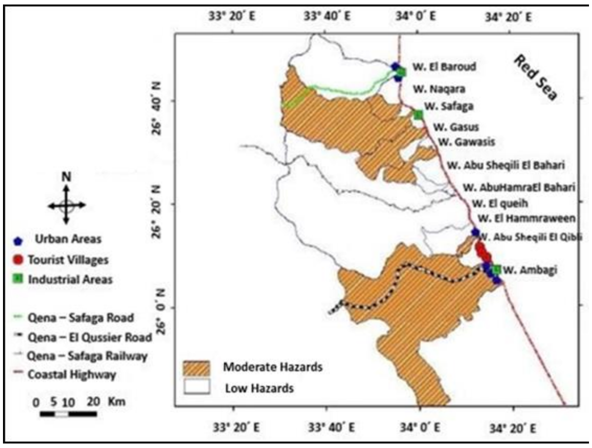


Figure 14 Hazard degree map of Wadi Qena sub-basins prepared by GIS analysis [24]

Figure 15 Drainage basin hazard map [25]

### 3.5 Documentation of under-study line flooding attacks

Documenting flood damage to railway infrastructure plays an important role in providing suitable support and thus reducing damage. According to Egyptian Railway and [26], Table 6 documents the popular flash floods that hit the line infrastructure and their impacts in 1990, 1994, and 1996.

**Table 6** Documentation of flash floods and their consequences in 1990 and 1996, (Egyptian Railway), and (*) according to [26]

| **Flood and Impacts** | **22,23,24 October 1990** | **22,23,24 October 1990*** | **October 1994*** | **November 1996** |
|---|---|---|---|---|
| **Capacity / Speed** | ----- | ----- | Max. Rainfall per day 28 mm/ | 40 million m³, 70 km / h |
| **Impact position** | Different locations from km. 62 to km. 96 | Different locations from km. 124 to km. 152 | Different locations from km. 202 to km. 232 (Along Red Sea coast) | Different locations from km. zero to km. 8, from km. 34 to km. 94, and from km. 221 to km. 232 |
| **Substructure Failures** | Substructure failures in various locations totaling 21,000 m³ | Substructure failures in various locations | Substructure failures in various locations | Substructure failures in various locations totaling 86,000 m³ |
| **Superstructure Failures** | About 3km of the superstructure was damaged. | Superstructure failures in various locations | Superstructure failures in various locations | About 11.8 km of the superstructure was damaged. |
| **Stations** | Damage to 2 Station buildings at km (65,79). | ---- | ---- | ---- |
| **Signal Towers** | Damage to 4 Signal towers at km (65,84,85,91). | ---- | ---- | ---- |
| **Bridge** | ---- | ---- | ---- | Damage to one bridge at km 4.7. |

According to the table, flash floods in the area can cause massive damage to infrastructure elements of the track under study, such as substructure, superstructure, bridges, stations, equipment, signaling devices, and so on.

## 3.6 Analysis and Discussion

### *3.6.1 Factors enhancing flood impact on case study*

By studying the area, conducting field investigations, and documenting floods and their impact on the case study, the main factors enhancing flood impact investigations in the case study can be summarized as follows:

#### *3.6.1.1 Intersection of the track with wadis streams*

Flood behavior is influenced by the area's meteorological, geomorphological, and geological conditions as well as the characteristics of related drainage basins in terms of intensity, frequency, direction, and ability to damage. Therefore, dealing with such floods is not easy. Sections of the track under study that directly intersect with the wadi's streams are more susceptible to flood damage than others. To determine the locations of these sections, hydrological modeling of the area was done using GIS technique. It was found that the track sections directly intersect with the streams are the section between km 0.0 and km 8.0 at its intersection with the outlet of Wadi Qena, where the valley drains into the Nile River; the section between km 34.0 and km 100.0 at its intersection with the eastern streams of Wadi Qena ; the section between km 100 and km 185 at its intersection with the streams of wadi El Quieh, where the streams descend from the Red Sea mountain ranges and run within the wadi in an enclosed area; and The section along the Red Sea coast between km185 and km232, where it intersects with the streams of wadis that drain into the Red Sea, as shown in figure 16.

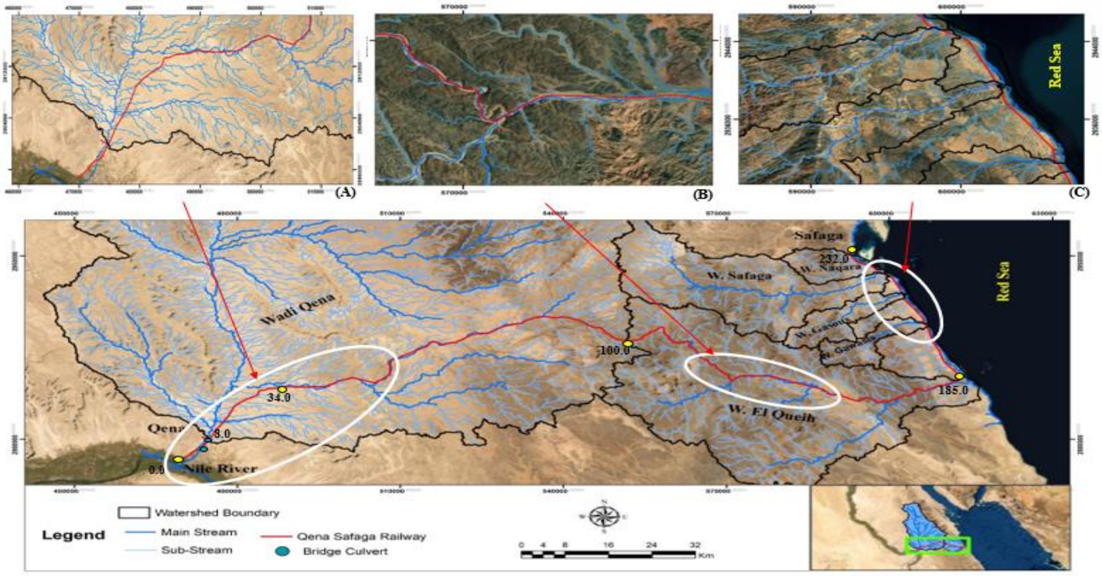


Figure 16 GIS map of wadis streams and their intersection with track sections: (A) Section intersecting with Wadi Qena, (B) Section intersecting with sloping streams from the Red Sea mountains ranges through wadi El Quieh, and (C) Section intersecting with wadis draining into the Red Sea.

### *3.6.1.2 Culvert sites*

In the hopes of reducing the impact of seasonal flooding, many culverts have been constructed along the Qena-Safaga track. As a result, the Qena-Safaga track's main drainage system for dealing with flood water is culverts, as shown in Figure 17 (Egyptian Railway).

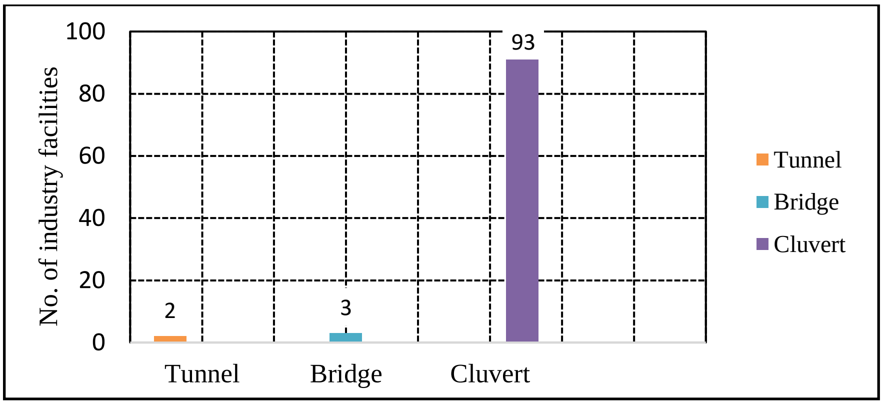


Figure 17 No. of industry facilities (Culvert, bridge, and tunnel) along the under-study track (Egyptian railway).

The positions of these culverts were identified within the GIS system to confirm the accuracy of their positions with wadis streams. As indicated in Figure 18, the culvert positions matched the streams except for some locations.

Although many culverts were installed at flood impact sites, many track sections were damaged by flooding, as shown in Figure 20. This is due to the accumulation of sandy sediments and rock crumbs inside and in front of culverts that reduce their ability to drain flood water, resulting in massive amounts of flood water collecting in front of them and causing track infrastructure damage as well as culvert erosion due to the high velocity of the sand-laden flood water, as shown in Figure 19.

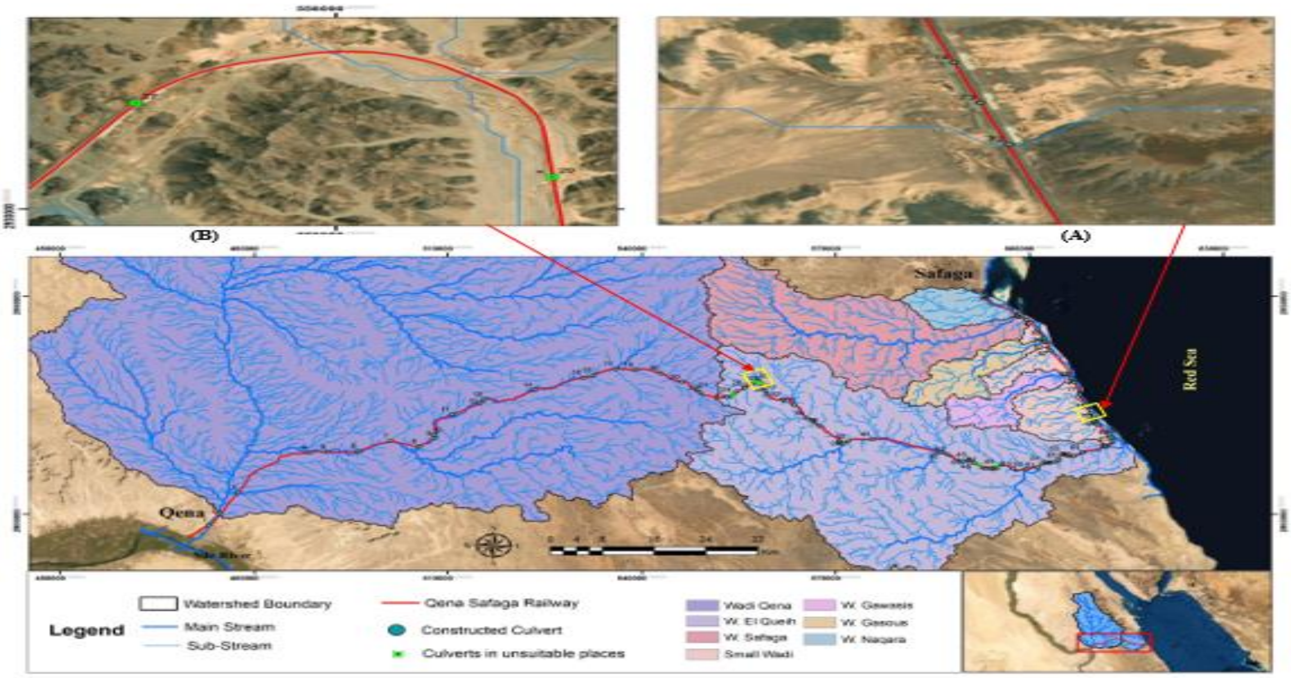


Figure 18 Track culverts indicated within GIS map of wadis streams: (A) Example of constructed culverts, (B) Example of culverts in unsuitable places.

Figure 19 Flood erosion for a sediment-filled culvert wall (Egyptian Railways).

## 3.7 Treatment methods

### *3.7.1 Implemented methods*

Flood damage can be greatly reduced by using appropriate treatment methods as well as taking preventive and precautionary measures. Several protective methods and treatments have been implemented to reduce flood impact based on the factors described above that enhance flood impact on the track under study. The following table compares some of these treatments to treatments used in other cases around the world.

The table shows that some of the implemented treatments are effective to some extent, while others are not, particularly with high-energy floods, as shown in figure 20. As shown in Figures 21 and 22, the table also includes some treatments for other cases as a suitable alternative to the treatments implemented for the track under study.

**Table 7** Comparison between treatments implemented to reduce flood impact on track under-study and treatments for other cases

| Protection method | Case under Study | Other cases | Reference |
|---|---|---|---|
| Floodwall | (A) Stone-built barriers<br>▪ It is often built using sandstone, with a height of about 0.7 m.<br>▪ It is frequently ineffective when dealing with high-flow flood water, resulting in wall failure. | ▪ Use sandbag floodwalls as a temporary floodwall.<br>▪ Use water-filled barriers made of impermeable membranes. It can protect about 7 feet of depth. Also, it can be removed, stored, and reused in subsequent flood events. | [27] |
| Increase embankment width | ▪ Increasing the current embankment width from 7 m to 11 m at track sections from km 90 to km 152 facing streams.<br>▪ It can increase the main embankment stability and their resistance to rushing flood waters as well as reduce damage.<br>▪ The added embankment can be damaged by high-flow flood water. | ▪ Depending on flood depths and site topography, use reinforced concrete flood walls or reinforced concrete block with varying heights.<br>▪ It is more erosion resistant and withstands greater floodwater pressure. It requires less space.<br>▪ More expensive. | [28] |
| Lined Embankment | ▪ Sandstone is often used as a lining material.<br>▪ It is often ineffective with severe floods, resulting in subgrade scour. | ▪ The use of limestone as a lining material is technically suitable for reducing subgrade seepage. | [29] |

Figure 20 Examples of ineffective implemented treatment methods: (A) Failure of Stone-built barriers, (B) Embankment failure.

### *3.7.2 Required treatment*

Because of their proximity to the high-energy flows, the track sections directly intersecting with the wadi flows are considered the most dangerous. However, it was noted that these sections did not receive appropriate care, making them more vulnerable to damage than other sectors. As a result, the following constructed table 9 shows some of the treatment methods required for some critical sections to reduce flood impact. Some of these required treatment methods are illustrated in Figures 23, and 24.

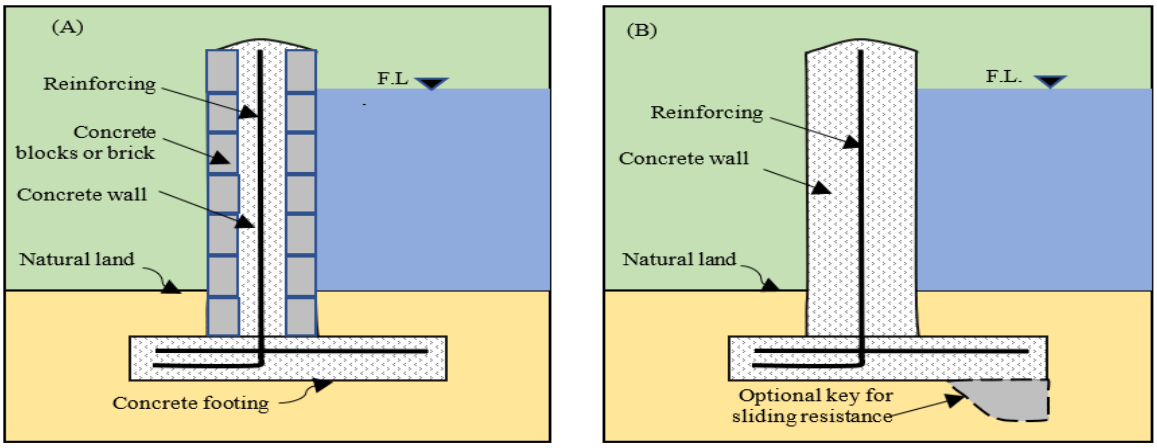


Figure 21 Concrete cantilever floodwall reinforcement: (A) Concrete blocks or bricks wall, and (B) Concrete wall [27]

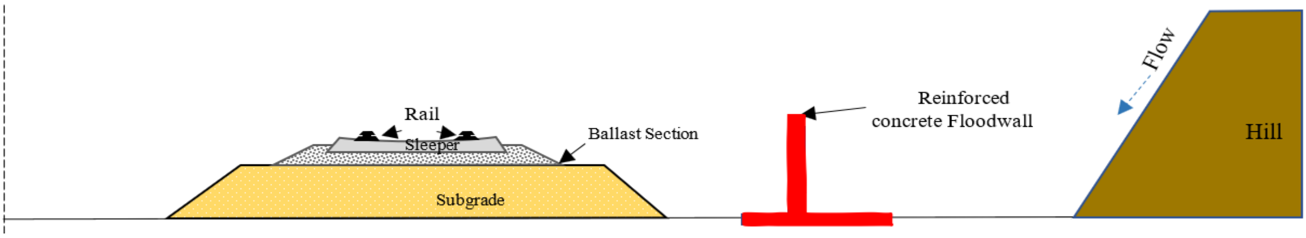


Figure 22 Schematic drawing of flood wall constructed on track side to face flooding.

**Table 8** Required treatment methods for some critical sections to reduce flood impact.

| Section | Protection method | Description | Reference |
|---|---|---|---|
| Bridges intersecting with wadi Qena catchment at km 4.7 and km 7.8 | ▪ Energy dissipation | ▪ Installation of trapezoidal–triangular labyrinth weirs on the catchment floor can provide the maximum amount of flow energy dissipation.<br>▪ Leading to reducing erosion and bridge damage. | [30] |
|  | ▪ Increasing width of catchment bed | ▪ Gradually increasing bed width can reduce flooding speed and using cofferdam protection method. | [20] |
| Track sections subjected to streams steep slope at (km 85-km 185) and (km 202-232) | ▪ Sediment traps. | ▪ It is built on sites where steep slopes meet mountains to break the energy and erosive power of debris flow.<br>▪ Reducing the accumulation of sediments inside and in front of culverts. | [31] |
|  | ▪ High-altitude drains. | ▪ Constructed at high altitudes to collect flood water.<br>▪ Preventing high-energy flood water from reaching the track. | [16] |
| Culvert sites | ▪ Installing a grille in front of culvert openings to prevent sand, rocks, and debris from entering<br>▪ Periodically, remove the accumulation of sandy sediments from inside culverts.<br>▪ Lining the floor in front of culverts for a sufficient distance may help to prevent erosion and culvert damage. |  |  |

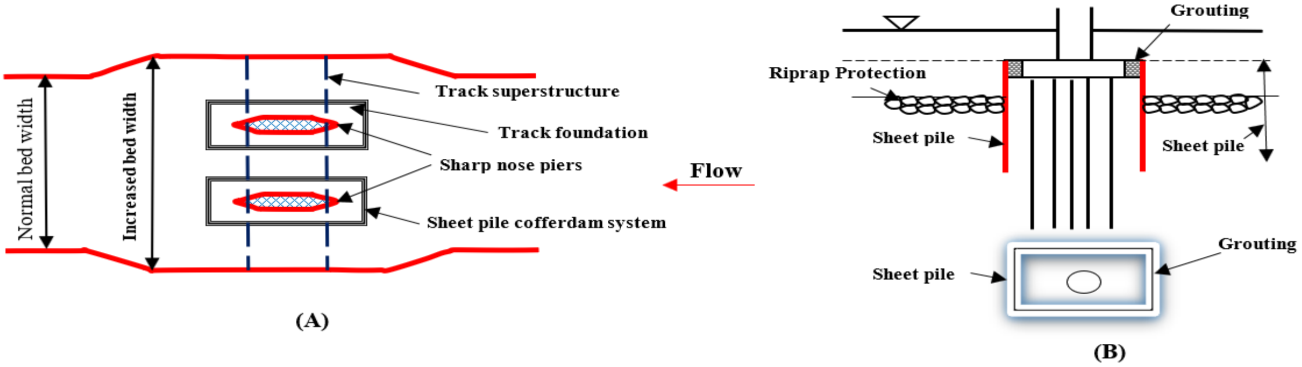


Figure 23 Schematic drawing of the flood protection methods required for the track bridge locations at km 4.7 and km 7.8: (A) Bed width increase method, (B) Cofferdam protection method [20]

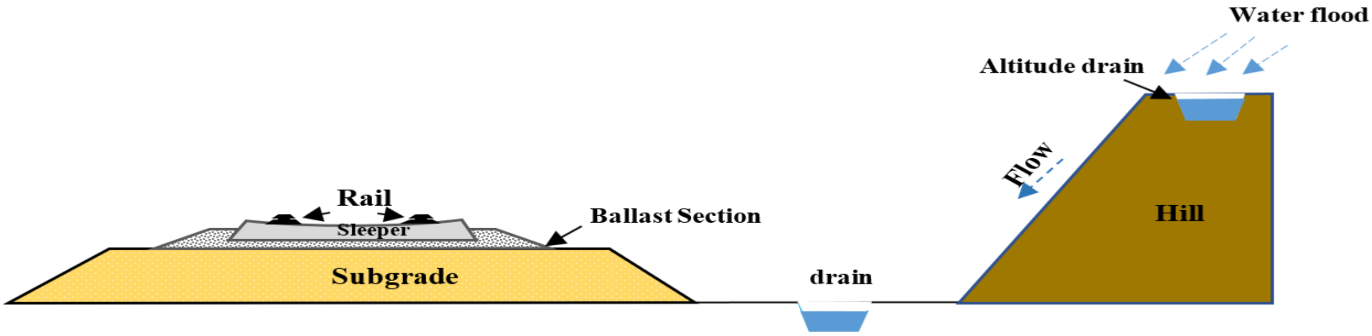


Figure 24 Schematic drawing of high – altitude drain to collect water flood before reaching the track.

## 4. Conclusions and Recommendations

The main objective of this study was to monitor, document, and analyze the harmful effects of seasonal floods and torrential rains on the safety of the railway track in the Eastern desert region of Upper Egypt through some available technical data and record official information about such events and how they were treated. The study also reviewed and studied the most popular similar cases of railway tracks that were flooded all over the world and how their harmful effects were treated and overcome, in addition to discussing the technical precautions recommended and implemented for more safety against such periodic events in some special places that are exposed to flash floods and torrents.

The most important outputs of the present research and comparative study can be briefly summarized as follows:

(1) It is proven that the most dangerous type of flood affecting the safety of the railway track's infrastructure is flash floods, because they usually occur suddenly through torrential heavy rains within a very short time. Also, such events may occur in some desert places that may be isolated or somewhat away from the supporting technical points, making it difficult to provide the needed services as quickly and appropriately as possible.

(2) The utmost importance should be given to the work of monitoring weather data and information, in terms of expected heavy rains, strong wind speeds, high temperatures, and lightning, as an early warning indicator for torrents and flash flooding.

(3) According to the GIS technique, the track sections are between km 0.0 and km 8.0 and between km 34.0 and km 100.0 at its intersection with wadi Qena; the section between km 100 and km 185 at its intersection with the streams of wadi El Quieh; and the section along the Red Sea coast between km 185 and km 232, where it intersects with the streams of wadis that drain into the Red Sea, are the most vulnerable to flood damage.

(4) The positions of the constructed culverts were identified within the GIS system to confirm the accuracy of their positions with wadis streams. It was found that the positions of all culverts agreed with the streams except for a few culverts.

(5) Sediment accumulation inside and in front of the existing track culverts reduces their efficiency in floodwater drainage, causing damage to the track infrastructure.

## Data Availability

The underlying research data used in this work was officially obtained from Egypt's National Railways Authority, while other used data was extracted from the results of previous studies in the field's scientific research literature.

## Acknowledgements:

The authors would like to extend their sincere thanks and gratitude to the officials of the Egyptian National Railways Authority for the technical support and provision of the official technical data, without which this study would not have been completed and introduced. Deep thanks and appreciation to them and their colleagues' engineers from the authorities in Qena.

## References

[1] OTTO, A., KELLERMANN, P., THIEKEN, A. H., COSTA, M. M., CARMONA, M., & BUBECK, P. (2019) Risk reduction partnerships in railway transport infrastructure in an alpine environment. International journal of disaster risk reduction, No. **33**, PP. 385-397.

[2] MORAN A.P., A.H.THIEKEN, A. SCHÖBEL, AND C. RACHOY , (2010) Documentation of flood damage on railway Infrastructure .Definition of Object Classes, P.7, Classification of Structural Damage ,pp. 9-11,. Springer, Berlin, Heidelberg.

[3] KOJO H., P. LEVIÄKANGAS, R. MOLARIUS AND A. TUOMINEN (2011) Extreme weather impacts on transport systems . VTT Technical Research Centre of Finland, ISBN: 978-951-38-7509-1, (2011).

[4] HASNAYN M. M. (2016) Railway subgrade behavior under flood conditions: an experimental study at full-scale , (Doctoral Dissertation, Heriot-Watt University).

[5] JAVELLE, P., C. SAINT-MARTIN, L. GARANDEAU, AND B. JANET (2019) Flash flood warnings: Recent achievements in France with the national Vigicrues Flash system. United Nations Office for Disaster Risk Reduction, Contributing Paper to the Global Assessment Report on Disaster Risk Reduction (GAR 2019), No. 60.

[6] KOSTIANAIA, E. A., KOSTIANOY, A. G., SCHEGLOV, M. A., KARELOV, A. I., & VASILEISKY, A. S. (2021) Impact of regional climate change on the infrastructure and operability of railway transport . Transport and Telecommunication Journal, Vol . 22, No. 2, PP. 183-195.

[7] NIKOS PAPATOLIOS, (2021) Belgium-Germany: estimated costs for flood damage repairs reach billions, railfreight. Com, https://www.railfreight.com/railfreight/2021/07/20/belgium-germany-estimated-costs-for-flood-damage-repairs-reach-billions/.

[8] UNITED REPUBLIC OF TANZANIA MINISTRY OF TRANSPORT, (2016) Environmental Impact Statement for the Proposed Flood Protection Measures for Central Railway Line Kilosa to Dodoma Section (174 km) in the United Republic of Tanzania,. (2016).
https://www.jica.go.jp/english/searchResults/index.html?q=Flood%20Protection%20Measures%20for%20Central%20Railway%20Line.

[9] RAO, K. D., SHRAVYA, A., RAO, V. V., DADHWAL, V. K., AND DIWAKAR, P. G. (2017) Flash flood disaster threat to Indian rail bridges: a spatial simulation study of Machak River flood, Madhya Pradesh. Current Science, pp.1028-1033.

[10] CLARK B., J. PARKIN., M. EVERARD, N. QUINN AND G. PARKHURST (2016) Flood resilience on the railways–solutions,appraisal and decision-making"., 48th Universities' Transport Studies Group UK annual Conference ,(2016).

[11] MILLS, BRIAN, AND JEAN ANDREY (2002) Climate change and transportation: potential interactions and impacts." The potential impacts of climate change on transportation, Vol.77, PP 1:12.

[12] CHANGNON, STANLEY A. (2009) Impacts of the 2008 floods on railroads in Illinois and adjacent states. Transactions of the Illinois State Academy of Science, Vol. **102**, No. 3 and 4, pp. 181-190, (2009).Transportation Conference, Washington, D.C., (2002).

[13] KELLERMANN, P., SCHÖBEL, A., KUNDELA, G., AND THIEKEN, A. H (2015) Estimating flood damage to railway infrastructure–the case study of the March River flood in 2006 at the Austrian Northern Railway, Natural Hazards and Earth System. Sciences, Vol.**15**, No.11, PP. 2485- 2496.

[14] HEINZ-PETER, BERG (2017) Risks and consequences of weather hazards on railway infrastructure." Journal of Polish Safety and Reliability Association Summer Safety and Reliability Seminar. Vol. **8**. No. 1.

[15] CLAISSE. P. , AND C. CALLA (2006) Rail ballast: conclusions from a historical perspective". In Proceedings of the Institution of Civil Engineers-Transport ,Vol. **159**, No. 2, pp. 69-74, Thomas Telford Ltd.

[16] TZANAKAKIS K.. (2013) The Railway track and its long term behaviour, Springer , Heidelberg, New York, Dordrecht London, ISBN: 978-3-642-36050-3.

[17] NETWORKRAIL (2021) How flooding on the railway causes delays – and what we're doing to reduce it, www.networkrail.co.uk/ https://www.networkrail.co.uk/running-the-ailway/looking-after-the- railway/delays-explained/flooding/.

[18] LI, DINGQING, AND STEPHEN WILK. (2021) Recent studies on railway-track substructure at TTCI." Transportation Safety and Environment, Vol.**3**, No.1, PP. 36-49, (2021).

[19] Bridge Masters, (2017) protecting bridges from flood damage, https://bridgemastersinc.com/protecting-bridges-flood-damage/.

[20] SALEM, M. T., ALI, M. I., & TURK, A. A. E. S. (2020) Analysis of a new railway model facing floods. https://www.researchgate.net/publication/341024801_Analysis_of_a_new_railway_model_facing_floods

[21] ASHOUR M. A., S. EL-ATTAR , T.E. ALY, AND A.A. ABDO (2014) Impact of the headwall inclination of under desert roads cluverts discharge efficiency, M.Sc.. Thesis, Faculty of Engineering, Assiut university, Assiut, Egypt.

[22] MAMDOUH, A. (2014) Towards a Sustainable Development of the Golden Triangle of the Red Sea Governorate." A research project prepared by National Authority for Remote Sensing and Space Sciences, Egypt.

[23] EL-SAWY, E. K., BEKHIET, M. H., AND ORABI, A. (2011) Geo-environmental studies on wadi qena, eastern desert, egypt. By using remote sensing data and gis." Al-Azhar Bulletin of Science, Vol. 22, No. **2**-D, PP. 33-60.

[24] TAHA, M. M., ELBARBARY, S. M., NAGUIB, D. M., AND EL-SHAMY, I. Z. (2017) Flash flood hazard zonation based on basin morphometry using remote sensing and GIS techniques: A case study of Wadi Qena basin, Eastern Desert, Egypt." Remote Sensing Applications: Society and Environment, Vol. **8**, PP.157-167.

[25] YOUSSEF A. M., B. PRADHAN, A. F. D. GABER, AND M. F. BUCHROITHNER (2009) Geomorphological hazard analysis along the Egyptian Red Sea coast between Safaga and Quseir, Natural Hazards and Earth System Sciences, Vol. **9**, No. 3, PP. 751-766.

[26] SABER SH., S. HASHIM, M. EL-MALKY, M. AND M. HASSANIN, (2018) Application of management of disaster of floods hazards [27] FEMA. "Selecting appropriate mitigation measures for floodprone structures." (2007). https://www.fema.gov/sites/default/files/2020-08/fema_551.pdf

[28] Conrad, D., Kapur, O., Mahadevia, A., Maldonado, D., Moline, J., Overcash, G., and Squerciati, J. "Engineering principles and practices for retrofitting flood-prone residential structures", (2012). Available Online: https://biotech.law.lsu.edu/blog/fema259_ch5f.pdf

[29] Ali M. A., Kim, J. G., Awadallah, Z. H., Abdo, A. M., and Hassan, A. M. "Multiple-Criteria Decision Analysis Using TOPSIS: Sustainable Approach to Technical and Economic Evaluation of Rocks for Lining Canals". Applied Sciences, Vol. 11, No. 20, PP. 9692, (2021).

[30] Ghader A., Daneshfaraz R., Dasineh, M., and Di Francesco S. "Energy dissipation and hydraulics of flow over trapezoidal–triangular labyrinth weirs". Water, Vol.12, No. 7, PP. 1992, (2020).

[31] Piton G., and Recking A. " Design of sediment traps with open check dams. I: hydraulic and deposition processes". Journal of Hydraulic Engineering, Vol.142, No. 2, PP. 1-11, (2016).

# الملخص العربي