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Statistics and Analysis of Leakage Cases in Metro Stations

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Abstract

In this paper, 53 cases of water leakage disease in metro stations from 1992 to 2023 are analyzed. Based on the statistics of leakage location, disease cause, risk source and the city where the station is located, the leakage location, disease cause, number of risk sources, type of risk sources and the city where the risk source is located are analyzed, and the occurrence form, location and reason of leakage in metro stations are obtained.

Keywords

Metro station; Leakage characteristics; Causes of seepage; Statistical analysis.

1. INTRODUCTION

As the core hub of urban metro transport, metro station has the characteristics of large personnel density, complex objective environment and difficult waterproofing. Compared with traditional ground engineering, underground space engineering has significant differences in terms of medium and environment. Underground space engineering takes rock and soil mass as the main medium and environment, while traditional ground engineering takes air and shallow soil layer as the main medium and environment, which leads to high cost and technical difficulty in underground space development [1-2]. At present, water leakage in metro stations is a common problem, which causes many adverse effects on station structure, service life and economic benefits. In order to reduce the leakage phenomenon in metro stations, based on a large number of leakage examples, the characteristics and rules of leakage occurrence are analyzed, and the effective causes and rules of leakage disease in metro stations are obtained. It is of great reference significance for metro station leakage prevention and control in the same city or similar hydrogeological conditions, and provides a theoretical basis for the design of metro station waterproof measures and the enhancement of metro station leakage prevention and control technology.

2. METHODS OF COLLECTING AND ANALYSING LEAKAGE CASES IN METRO STATIONS

Currently there are more statistical studies on metro fire accidents, metro construction accidents, metro operation indicators, and tunnel construction accident statistics[3-6].In the aspect of metro leakage, especially in the metro station leakage during the operation of the metro line, the statistics of metro station leakage disease include 53 cases of metro station disease. As shown in Figure 1, water leakage occurred in Jinsha Lake Station of Hangzhou Metro due to Jinsha Lake piping, and water leakage occurred in Luoyang Metro Shanghai Station due to rainfall.

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（a）Hangzhou Metro Jinshahu Station （b）Luoyang Metro Shanghai Market Station

Figure 1 Water leakage disease in metro station

The statistics of water leakage cases in the station are based on the diseases occurring in the underground station area during the operation stage of the urban metro, excluding the metro tunnel section and urban light rail traffic leakage accidents. The case sources are from 1992 to 2023, mainly from journal literature and news reports[7-8].Due to the limited source of cases and the degree of impact of diseases on station operation, some water leakage occurred, but the impact on the normal operation of the station and the life and property safety of passengers was slight, so no relevant information was found. Some cases are limited by data sources, and the leakage information is not fully obtained, and the cause and location of the accident are missing.

Case data analysis mainly includes leakage characteristics statistics and regularity analysis, in which the characteristics statistical analysis mainly includes the location of the leakage, the cause of the disease, the source of the disease, the type of risk source and the city where the station is located. The data analysis tools used in this statistics include bar charts, pie charts and tables. The analysis process is shown in Figure 2.

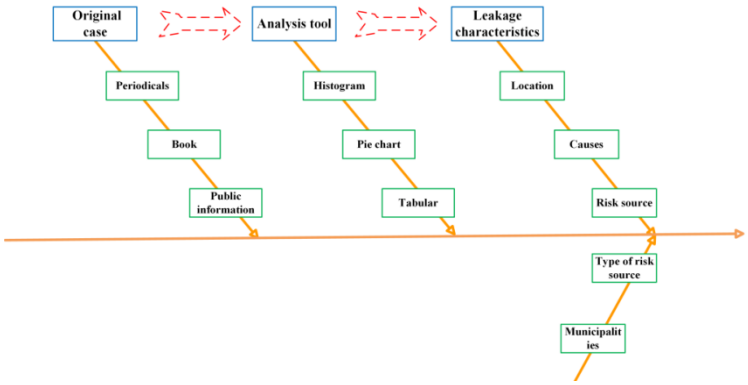

Figure 2 Metro station seepage disease analysis process

3. DISEASE CASE STATISTICS AND ANALYSIS

3.1. Leakage case statistics

The statistics collected a total of 53 cases of water leakage diseases in urban metro stations from 1992 to 2023. Due to the limitation of information sources, the causes and risk factors of

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leakage were not obtained in some cases, and the sources of all cases are shown in Table 1. The urban metro line traffic network is crisscrossed, mainly distributed in the urban area and the surrounding areas, and a single metro line contains multiple metro stations. Due to the characteristic of metro station, the leakage time of metro station occurs collectively according to line or region. Even if multiple stations leak water at the same time, some stations leak water at the same location and cause. Therefore, the statistics are based on the collective leakage incidents. The detailed table includes the city where the station is located, the location of the leakage, the cause of the disease, and the direction of the risk factors. Through the statistical analysis of typical station leakage, the characteristics and causes of station leakage disease are summarized from different angles, and the potential laws of station leakage are revealed.

Table 1 Sources of leakage disease cases in metro stations

City	Metro station
Beijing	Line 13 Xierqi Station, Line 5 Puhuangyu Station, Line 6 Jin Anqiao Station, Line 10 Zhichun Road Station,Line 10 Tuanjiehu Station, Line 10 Liangmaqiao Station and other stations, Xidan Station, Line 1 Yonganli Station, Line 1 Guomao Station,Line 15 Wangjing Station, Line 5 Dongsi Station, Line 10 Jiaomen West Station, Line 4 Zoo Station, Line 2 Chongwenmen Station, Line 4 Taoranting Station
Hangzhou	Line 1 Chengzhan Station, Xianghu Station, Anding Road Station, Linping Station, Jinshahu Station
Guangzhou	Line 21 Shenzhou Road Station, Line 1 Yuanqian Station, Line 13 Guanhu Station, Xinsha Station, Line 2 Baiyun Park Station, Line 6 Chang涎 Station, Huanghuagang Station, Line 6 Yantang Station, Line 3 Kecun Station
Shanghai	Nanjing West Road Station, Line 2 Zhongshan Park, Nanpu Bridge Station, Zhongshan Park Station, Line 12 Guilin Park Station, Line 10 Xinjiangwancheng Station, Line 11 Xujiahui Station, Line 2 Dongchang Road Station
Qingdao	Line 3 Wusi Square station
HongKong	Sai Ying Pun Station, Hai Yi Peninsula Station, Kennedy Town Station, Sai Ying Pun Station and University of Hong Kong Station
Nanning	Line 1 Baihualing Station Foziling Station
Wuhan	Zhongnan Road station, Meiyuan community station
Shenzhen	Chegongmiao Station, Yantian Road Station, Luohu Station, Longcheng Park Station, Line 4 Futian Port, Line 9 Mayer Ling Station
Chengdu	Line 1 Guangfu Station
Luoyang	Line 1 Shanghai Railway Station
Xi'an	Line 1 Banpo Station, Line 2 Xiaozhai Station, Line 2 multiple stations

3.2. Analysis of leakage characteristics

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The statistical leakage cases are distributed in different cities, with different geology and climate, leakage characteristics, disease causes and disease risk sources. Statistical analysis from different angles, multi-angle exploration of the internal law of leakage disease, comprehensive understanding of station leakage conditions, characteristics and risk factors, is conducive to explaining the essence of station leakage, so as to reduce the occurrence of leakage.

3.2.1 By leakage position

The subway station is composed of main structure and auxiliary structure, the main structure includes roof plate, side wall, bottom plate, platform, station hall, equipment room, management room, etc. The auxiliary structure mainly includes entrance, pedestrian passage, wind pavilion, etc. The auxiliary structure of the elevated subway station has a ceiling. The subway station is a large underground building, its main structure is made of a large number of concrete pouring, in the construction of the main structure will be set deformation joints, induction joints and settlement joints, these special structural "joints" are classified in the subway station detailed structure[9].When the leakage location is classified, it is difficult to divide the station hall, platform, equipment room and management room, so they are all classified as station hall.

According to the above classification form of station structure, a total of 53 cases of water leakage diseases in stations are classified and counted. The statistical results of water leakage locations are shown in Table 2 and Figure 3.

Table 2 Leakage location statistics table

position	station hall	entrance	detailed structure	pedestrian passage	roof plate	sidewall	bottom plate	elevated roof
frequency	14	21	5	7	4	1	1	1
percentage	25.9	38.9	9.3	13	7.4	1.9	1.9	1.9

The leakage locations of all the subway stations are divided into 8 types, which are station hall, entrance, detailed structure, pedestrian passage, roof plate, side wall, bottom plate and elevated roof. From the analysis results, it can be seen that entrance, station hall, detailed structure, pedestrian passage and roof plate are the main locations where the leakage occurs

There were 21 cases of water leakage at the entrance, accounting for 38.9% of the total cases. There were 14 cases of water leakage in the station hall, accounting for 25.9% of the total; Water leakage at the detailed structure was 5 cases, accounting for 9.3% of the total cases; There were 7 cases of water leakage in pedestrian passages, accounting for 13% of the total cases. There were 4 cases of water leakage in the roof plates, accounting for 7.4% of the total cases. Among them, entrances and station halls are the main leakage locations, accounting for more than 60%, and these two locations are vulnerable to heavy rainfall, operating period management and other facilities inside and outside the subway station.

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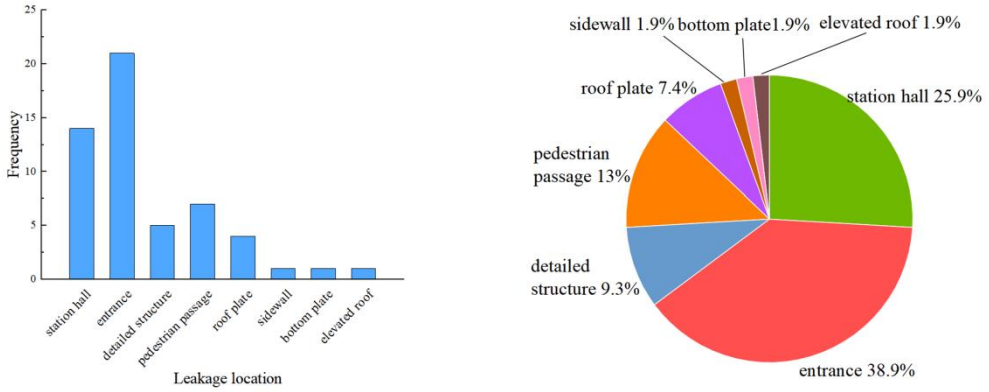


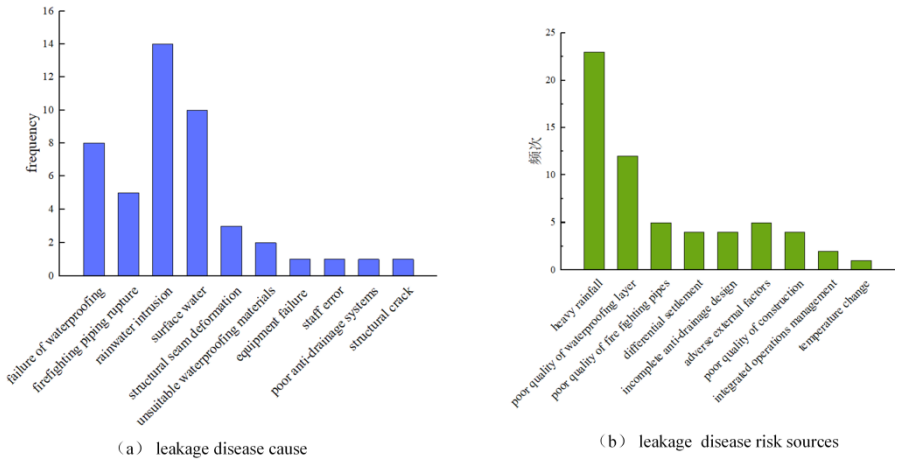
（a）Statistics of leakage positions （b）Leakage positions distribution

Figure 3 Leakage positions

3.2.2 By disease cause and disease source

In subway operation, the main structure and flexible waterproof layer are covered by architectural decoration, and the potential leakage hidden trouble is often not easy to be found. The waterproof ability of subway station is related to all aspects of the station, including concrete structure, detailed structure, flexible waterproof layer, fire pipe, anti-drainage system, operation management and so on. In addition to the problem of its own waterproof performance, the leakage of the station is mainly affected by natural factors and human factors.

In this statistics, the external adverse factors are mainly the water pipe rupture in the surrounding buildings or construction sites, the sudden piping in the nearby waters, and other events that promote the sharp increase of water and groundwater outside the subway station. Limited by objective conditions, the disease causes and sources of some cases of divine water leakage are unknown, and the data are analyzed after they are removed. The statistics of leakage disease causes and disease risk sources are shown in Figure 4.



（a） leakage disease cause （b） leakage disease risk sources

Figure 4 Leakage disease causes and risk sources statistics

Water leakage disease causes and disease risk sources are not one-to-one correspondence, and the risk sources of the same disease cause may be different. Within the scope of case statistics, the corresponding relationship between disease causes and risk sources is shown in Table 3.

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Table 3 Statistics on the relationship between disease causes and risk sources

Cause of disease		Risk sources		Relative proportion
waterproof layer fails	8	poor quality of construction	3	37.5%
		poor quality of waterproofing layer	5	62.5%
firefighting piping rupture	5	poor quality of fire fighting pipes	5	100%
rainwater intrusion	14	heavy rainfall	14	93.3%
		poor quality of construction	1	6.7%
surface water	10	heavy rainfall	5	50%
		adverse external factors	5	50%
unsuitable waterproofing materials	2	incomplete anti-drainage design	2	1
equipment failure	1	integrated operations management	1	1

Continued Table 3 Statistics on the relationship between disease causes and risk sources

Cause of disease		Risk sources		Relative proportion
staff error	1	integrated operations management	1	1
poor anti-drainage systems	1	incomplete anti-drainage design	1	1
structural crack	1			
Structural joint deformation	3	differential settlement	2	66.7%
		temperature change	1	1

A single risk source can cause different leakage reasons, resulting in leakage cases. The distribution of all risk sources and the number of sources causing leakage diseases are shown in Figure 5.

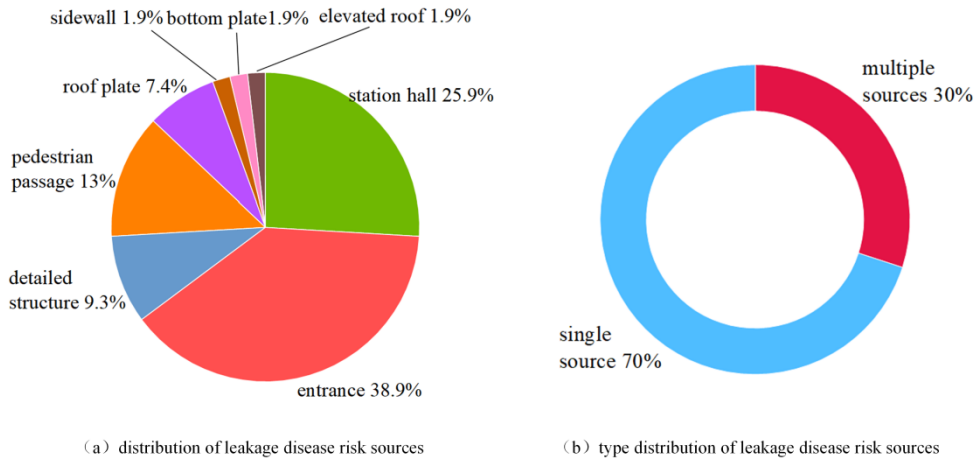

Figure 5 Distribution of leakage disease risk sources

It can be seen from Table 3 that the risk sources of leakage diseases are not single, in which rainwater backflow is caused by heavy rainfall weather. A large amount of rainwater accumulates on the road surface and exceeds the station entrance steps to form backflow. Surface water is caused by heavy rainfall weather and external adverse factors. Heavy rainfall

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and nearby water sources suddenly send water to the station, causing a large amount of water on the surface above the station, and leaking water is formed when the waterproof is not tight or the waterproof layer fails and other positions, mainly distributed at the entrance and the top of the station hall. The failure of waterproof layer mainly comes from two aspects: poor construction quality and poor quality of waterproof layer. The cracking of the fire fighting pipe inside the station is caused by the poor quality of the pipe. The joint deformation of the structure comes from the thermal expansion and cold contraction of the structure and caulking waterproof material caused by the uneven settlement of the main structure and the temperature change.

As can be seen from Figure 5, the main causes of leakage diseases in the station are rainwater backflow, surface water, failure of waterproof layer, rupture of fire pipes and deformation of structural joints. The main risk sources of station leakage diseases are heavy rainfall weather, poor quality of waterproof layer, poor quality of fire pipe, uneven settlement, incomplete design of water prevention and drainage, external adverse factors, poor construction quality. Water leakage diseases can be caused by multiple risk sources, and in the case data that can identify the risk sources, 30% of water leakage diseases come from multiple risk sources.

3.2.3 By type of risk source

According to the classification of risk sources, it can be divided into natural factors, uncontrollable sudden factors, station waterproof system, other facilities in the station, and integrated operation management. The specific classification of sources is shown in Table 4.

Table 4 Risk source type statistics

risk source	type	percentage
heavy rainfall differential settlement temperature change	natural factor	46.7%
poor quality of waterproofing layer poor quality of construction incomplete anti-drainage design	Station waterproofing	33.3%
adverse external factors	Uncontrollable sudden factors	8.3%
poor quality of fire fighting pipes	Other facilities in the station	8.3%
integrated operations management	integrated operations management	3.3%

As can be seen from Table 4, natural factors mainly include heavy rainfall weather, differential settlement and temperature change, and station waterproofing mainly includes poor quality of waterproof layer, poor construction quality and incomplete design of waterproof and drainage. Natural factors accounted for 46.7% of the risk sources, station waterproofing accounted for 33.3% of the risk sources, natural factors and station waterproofing accounted for 80% of the total risk sources. Uncontrollable sudden factors, other facilities in the station and integrated management of operations accounted for relatively less, totaling 20%. Most of the natural factors and uncontrollable sudden factors are force majeure factors, and the waterproof of the station, other facilities in the station and comprehensive management can reduce the probability of leakage through human intervention.

Therefore, the waterproof system performance of the station can be enhanced by controlling the quality of the waterproof layer, improving the design of anti-drainage and improving the

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construction quality, enhancing the quality of the public facilities inside the station represented by the fire extinguishing pipeline, strengthening the comprehensive pipeline of the station during operation, and enhancing the waterproof ability of the station structure, so as to reduce the occurrence of leakage and disease. On the other hand, the damage of uneven settlement can be reduced by improving the main structure design, deformation monitoring, raising the entrance and exit steps, adding waterproof doors, gap waterproof measures, and improving the municipal drainage system outside the station, so as to reduce the surface water in heavy rainfall weather, so as to reduce the occurrence of leakage diseases such as rainwater backpouring and water leakage at the entrance and exit.

3.2.4 By the city where the station is located

According to the statistics of the city where the station leakage occurs, the correlation between the station leakage disease and the city existence can be obtained. According to the frequency of leakage disease, the relationship between station leakage and the city is analyzed. The frequency of station leakage cases and the statistical results of the city are shown in Figure 6.

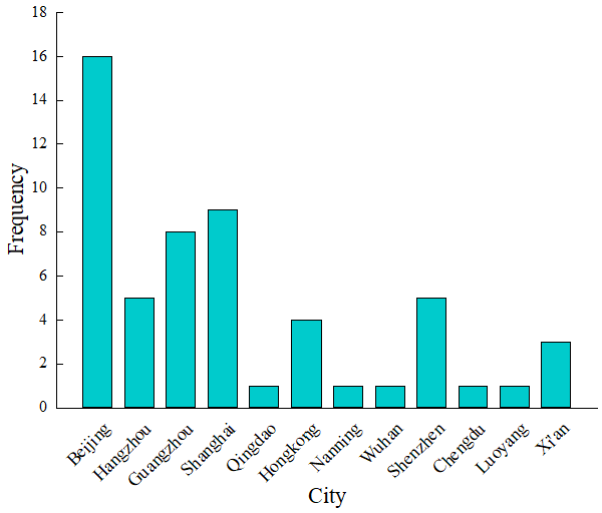

Figure 6 Leakage case the city where the station is located

As shown in Figure 6, the leakage frequency of subway stations in Beijing is the highest, and the leakage frequency of subway stations in other cities is significantly different, exceeding that of Shanghai for 7 times. In Shanghai, Guangzhou, Shenzhen, Hangzhou, Hong Kong and Xi 'an, the frequency difference was small, and the frequency of other cities was 1. Urban subways are mostly built in bustling areas, which can not only exert transportation capacity, but also promote social and economic activities. Therefore, the natural climate, geological environment, human activities and hydrological environment of the subway traffic network in the same city are not very different. When water leakage caused by natural factors such as heavy rainfall and sedimentation, it usually occurs in multiple subway stations. There are two possible reasons for the maximum frequency of leakage in Beijing:

(1)Beijing subway was built early and opened early, and the structural design theory, construction and construction technology, construction engineering materials and underground waterproof materials were immature in the early stage of domestic subway development. After about 30 years of operation, potential problems gradually emerged.

(2)Beijing has a lot of rainfall, especially during the summer flood season, there are more heavy rainfall days.

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In Shanghai and Hangzhou, subway station leakage occurred many times, mainly due to the unique geological conditions, mainly in silt, fine sand, soft strata and other bad strata, and the thickness is large. Shanghai developed underground space to build a subway, and the image of "hole in tofu" is even more metaphorized. Hangzhou's underground water conservancy conditions are more complicated, which undoubtedly increases the difficulty of waterproof subway stations[10]. Formation settlement and uneven structure settlement caused by bad geology are one of the main causes of water leakage in Shanghai metro stations.

More frequent water leakage in Beijing, Shanghai, Guangzhou, Hangzhou, Shenzhen, Hong Kong, with the eastern and southern coastal areas. Abundant underground water resources bring greater pressure to the waterproof system. Heavy rainfall and typhoon weather are more frequent, and the number of leakage in subway stations will increase accordingly.

4. CONCLUSION

In this paper, 53 cases of water leakage in urban subway stations from 1992 to 2023 are analyzed statistically. The leakage location, disease causes, number of risk sources, types of risk sources and the city where the station is located are analyzed statistically, and the following main conclusions are drawn:

(1)The leakage position of the station is divided into eight places, which are station hall, entrance, detailed structure, pedestrian passage, roof plate, side wall, bottom plate and elevated ceiling. Among them, entrance, station hall, pedestrian passage, detailed structure and roof plate were the main leakage locations, with 21, 14, 7, 5 and 4 cases, accounting for 38.9%, 25.9%, 9.3%, 13% and 7.4%, respectively.

(2)The main causes of leakage diseases are waterproof layer failure, rainwater intrusion, firefighting piping rupture, surface water, structural joint deformation, unsuitable waterproof material, equipment failure, staff error, poor drainage system and structural cracks, of which rainwater backflow, surface water, waterproof layer failure, fire pipe rupture and structural joint deformation are the most common. There were 14, 10, 8, 5, and 3 times that led to leakage.

(3)The main risk sources of leakage diseases include heavy rainfall weather, poor quality of waterproof layer, poor quality of fire pipes, uneven settlement, and incomplete design of drainage and prevention. Heavy rainfall and poor waterproof quality were the main sources, accounting for 38.3% and 20% respectively. The source of leakage disease is not single, of which 30% leakage disease comes from multiple risk sources.

(4)Risk sources can be divided into five types: natural factors, station waterproof system, uncontrollable sudden factors, other facilities in the station, and integrated operation management. Among them, natural factors and station waterproof system are the main risk sources of station leakage disease, accounting for 46.7% and 33.3%.

(5)Station leakage occurs more frequently in cities, mainly located in the eastern and southern coastal areas of China. For example, Beijing, Guangzhou, Shanghai, Shenzhen, etc., the construction of subway traffic in these cities started earlier, which is restricted by technology and materials, and is greatly affected by natural factors such as heavy rainfall and geology in coastal areas.

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