Chapter

Desertification and Its Control along the Qinghai-Tibet Railway

Yuguo Liu, Jiufu Luo, Jinxing Zhou and Ming Cui

Abstract

The Qinghai-Tibet Railway is a magnificent project in the twenty first century. However, the problem of land desertification has arisen during the operation of the railway. Many sections of the railway roadbed are buried by sand. The ecological safety along the railway and the safe operation of the railway have attracted worldwide attention. This chapter will focus on the current situation of desertification along the Qinghai-Tibet Railway, such as key desertification sections and the temporal and spatial characteristics of the occurrence of desertification. At the same time, it introduces the characteristics of the dynamic conditions of railway desertification and the source of sand material. It is divided into two parts: biological measures and engineering measures to introduce desertification control along the railway. The biological measures focus on the selection of *Lolium perenne*, *Festuca sinensi*, *Elymus breviaristatus*, *Elymus nutans* and *Poa crymophila,* and other alpine native sand-fixing plant materials. The engineering measures will introduce the railway desertification comprehensive prevention and control technology system that combines solidification, resistance, and transportation.

Keywords: Qinghai-Tibet, railway, desertification, sand prevention and control, biological measures

1. Introduction

The Qinghai-Tibet Plateau is the highest and unique physical geographic unit in the world. It has a significant impact on the ecological environment of China and its neighboring countries. For a long time, poor traffic conditions in the plateau area have greatly restricted the overall economic and social development of the region. The Golmud-Lhasa section of the Qinghai-Tibet Railway started construction in July 2001 and opened to traffic on July 1, 2006. The Qinghai-Tibet Railway project has fundamentally changed the traffic conditions in the Qinghai-Tibet Plateau, and promoted the reform and opening up of the region, the overall economic and social development, and the improvement of the living standards of the Tibetan people.

The Qinghai-Tibet Plateau has the characteristics of high altitude, low temperature, little precipitation, simple ecosystem structure, weak anti-interference ability, and vulnerability to global environmental changes, showing strong vulnerability [1]. The permafrost section of the Qinghai-Tibet Railway is about 550 km, and the section with an altitude of more than 4000 m is 960 km. The terrain and landforms in the line area are changeable, with high altitude, deep-frozen soil, strong winter wind, low temperature, and large temperature difference between day and night. Plants are difficult to root and have a short growth period [2]. The plants only have a growth time of about 3 months. In addition, in recent years, due to the increasing global climate change and human disturbance, the trend of vegetation degradation is obvious. Once the vegetation in this area is destroyed, it is very difficult to restore [3]. The degraded grassland has become the source of railway sand-damaged materials [1]. In the long-term investigation and monitoring, it was discovered that the construction of the railway has changed the wind and sand environment along the line so that the wind and sand that could have passed through the border piled up near the roadbed. Sand accumulation on the trackbed directly affects the safe operation of railways [4]. At the same time, the accumulation of sand near the roadbed interferes with the protection measures of the railway's frozen soil, accelerated the melting of the frozen soil under the roadbed, caused the deformation of the roadbed, and caused greater harm to the safe operation of the railway. The sand disaster has seriously threatened the operational safety of the Qinghai-Tibet Railway, and it is one of the most severe sand-damaged lines in China [5].

However, there are still huge challenges in understanding the formation mechanism and distribution pattern of sand damage in the Golmud-Lhasa section of the Qinghai-Tibet Railway. Sand hazard prevention and control technologies were also just in their infancy. In the early stage of railway construction, the breeding and selection of native herbaceous plants used for vegetation restoration along the railway have been carried out, and certain results have been achieved. However, woody plants suitable for cold and dry environments have been extremely scarce. The supporting technologies for suitable artificial vegetation construction were insufficient. The traditional biological measures for sand prevention and control along the railway and the "tree, shrub, and grass" model are difficult to achieve. The existing sand prevention technologies along the railway have a series of problems such as high engineering cost, low efficiency, lack of materials required for biological measures, and imperfect comprehensive sand prevention and control system.

On the whole, in order for the Qinghai-Tibet Railway to become an environmentally friendly and safe railway, it is necessary to understand the distribution and characteristics of the severe and potential sand-damaged areas along the railway and strengthen the research on the mechanism and comprehensive prevention and control technology of sand damage along the railway. Urgent problems to be solved include degradation mechanism and protection technology of native vegetation around railways, rapid vegetation restoration technology, railway protection forest plant selection and planting supporting technology, and the combination of biology and engineering technology, etc. This chapter will introduce the distribution pattern and cause mechanism of sand damage, the research and development and integration of vegetation restoration technology, and the research and integration of engineer and plant sand control technology along the Qinghai-Tibet Railway.

2. The distribution pattern and cause mechanism of sand disasters along the Qinghai-Tibet Railway

In terms of space, the sand disasters along the Qinghai-Tibet Railway are mainly distributed from Golmud (K815 + 380) to Tibet's Cuona Lake (K1531 + 280). The sand damage in this section is not evenly distributed, mainly concentrated in the Hongliang River (K1104 + 690), Tuotuo River (K1224 + 810), Za'gya Zangbo (K1445 + 560) river valleys, and the areas on both sides of the river and Cuona Lake section (K1528 + 710 to K1531 + 280) and other areas [6]. The railway section with severe sand damage is 78.8 km (**Figure 1**).

In terms of time, the Qinghai-Tibet Railway has many windy days in winter and spring. Especially the main plateau, including Tuotuo River, Wudaoliang, Amdo,

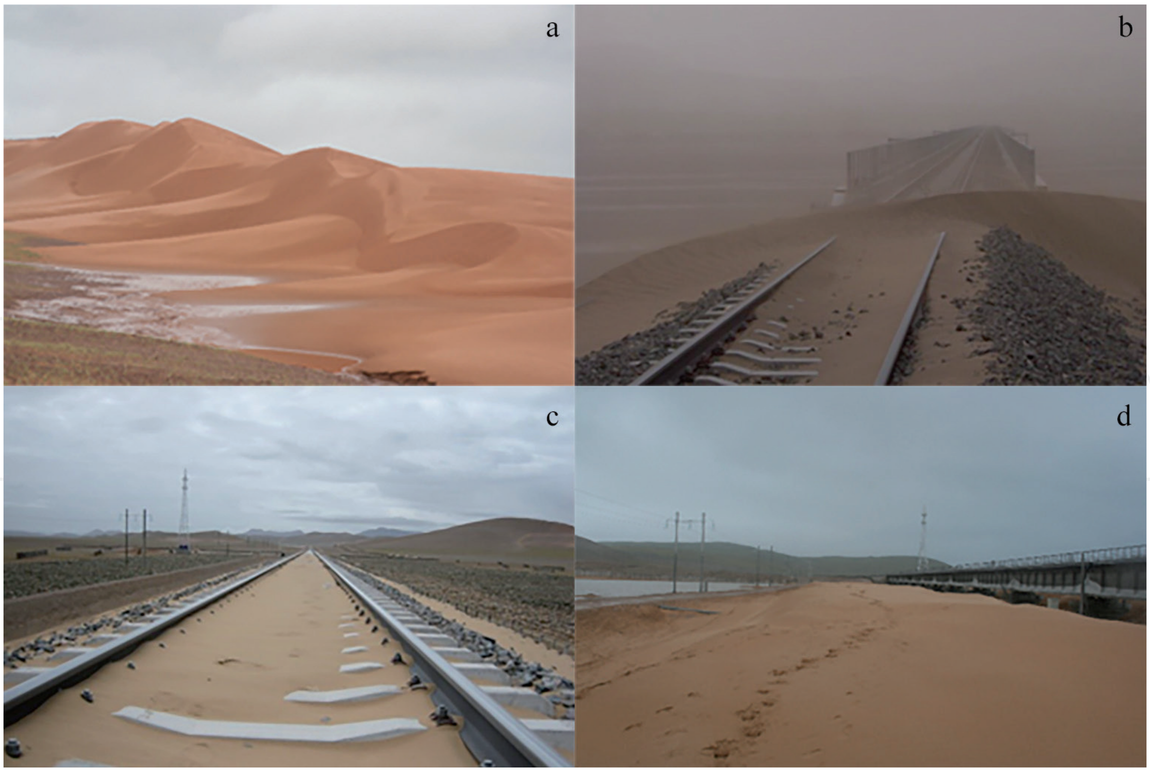

Figure 1.
Sand disasters along the Qinghai-Tibet Railway. (a) Hongliang River section, (b) Tuotuo River section, (c) Za'gya Zangbo section, (d) Cuona Lake section.

and other areas, the number of strong wind days is more than 100 days. Moreover, the climate is relatively dry in winter and spring. For example, in the Tuotuo River area, according to the observation data of the weather station for many years, the average annual wind speed is greater than 4 m s^{-1}. The number of windy days is more than 140 days. The number of sandstorm days in the year is 15–22 days. The annual precipitation is about 200 mm, mainly from June to September (about 85%). There is no snow cover in winter and spring, and the surface is extremely dry. At the same time, this period is also a period of high winds, with the highest wind speed reaching 32 m s^{-1}. Therefore, the Qinghai-Tibet Railway sand disaster occurred in these seasons.

The main body of the Qinghai-Tibet Railway is located in the rapids area in the middle of the westerly belt. Observation of sandstorms on the Hongliang River, Tuotuo River, Cuona Lake, and other road sections with severe sand damage revealed that the wind along the railway is strong and the amount of sand transported is relatively large. The sanding wind has a single wind direction and a long duration. It is dominated by westerly winds. These conditions have provided sufficient impetus for wind-sand activities [6]. The sand materials along the Qinghai-Tibet Railway mainly come from river sediments, desertified meadows and grasslands, and lake sediments. River facies sediments are mainly concentrated in river valley areas. Affected by topography and wind, sand materials develop from the river valley area to the two banks. The wind-sand disasters are particularly serious on the downwind bank of the river valley. This type of sand material is mainly distributed in the valleys and banks of the Hongliang River, the Xiushui River, the Beilu River, the Tongtian River, the Tuotuo River, the Za'gya Zangbo, and the Basuoqu River. Sandy meadows and grassland sand sources are typical non-point source sand sources, which are widely distributed. The main damage area is the Tuotuo River section. The impact of sandy meadows and grassland sand sources on railways mainly has two aspects. On the one hand, under favorable wind conditions, sand particles accumulate on the roads and directly harm the railway. On the other hand, sand particles enter the river valley with water flow, and deposit in the river valley area, becoming an important source of river facies sediments. Lake sediments are also an important source of sand material along the Qinghai-Tibet Railway, especially the Cuona Lake section, which has also become the most severe sandstorm area along the Qinghai-Tibet Railway. In addition, the sources of sand along the Qinghai-Tibet Railway also include rock weathered debris, sandy Gobi, wind erosion of ancient dunes, and activation of fixed dunes. The sources of these wind-sand disasters either directly harm the railways, or compound with each other, and superimposed on the railways.

After the completion of the Qinghai-Tibet Railway, due to the appearance of the roadbed, the original relatively stable dynamic balance of the plateau sand movement was disturbed spatially, and the flow field structure and transportation and accumulation conditions of the near-surface sand flow were changed, resulting in the deposition of sand materials near the railway. The hazards of sandstorms were highlighted. Through the wind tunnel simulation experiment on the characteristics of the flow field of the Tuotuo River section of the Qinghai-Tibet Railway, the formation mechanism of the sand damage of the roadbed was studied in combination with the flow field structure on both sides of the roadbed and the horizontal gradient distribution of the wind speed profile. It was found that when the airflow passed through the railway subgrade, there were obvious obstructed uplift areas, current gathering acceleration areas, deceleration and subsidence areas, and dissipation and recovery areas. The railway subgrade affected the characteristics of wind-sand flow by changing the movement state of the airflow, the separation of the boundary layer, and the size of the return zone. The formation mechanism of railway sand hazards was mainly determined by the functional zones where the air currents were located on both sides of the railway. When the wind-sand flow run near the railway subgrade, as the airflow encountered obstacles and rises, energy consumption was large, the wind speed of the bottom airflow decreased, and sand particles accumulated at the foot of the windward slope of the railway in the way of falling and depositing, causing sand burial on the railway subgrade. The airflow on the windward side of the subgrade mainly caused wind erosion to the middle of the subgrade or the shoulder of the subgrade due to the uplift and the acceleration of the current collection due to obstacles. When the airflow crossed the railroad track on the leeward side due to decelerating settlement and vortex movement, the sand carrying capacity was drastically reduced, and the sand flow was in a state of supersaturation, which will inevitably accumulate a large amount of sand particles carried on the leeward slope [7, 8].

3. Vegetation restoration along the Qinghai-Tibet Railway

The vast majority of areas where the Qinghai-Tibet Railway crosses are of grassland vegetation, mainly distributed from Xidatan to Yangbajing. The process of railway construction and operation greatly affects the grassland ecosystem along the route. The grassland ecosystem along the railway is aging and degraded. In addition, during the construction of the railway, engineering sites, such as borrow pits and roadbed slopes have a huge impact on the grassland ecosystem along the line. The research and development of vegetation restoration technologies for grasslands of different site types is imminent. Based on this, we screened suitable plant species for difficult sites such as degraded alpine grasslands, roadbed slopes, and borrow sites to establish a stable and healthy plant community [9, 10].

3.1 Vegetation restoration on the railway construction affected land

Before vegetation restoration is carried out on the borrow site, the area to be restored shall be prepared. In areas with greater impact on the landscape, high requirements for re-vegetation, and topsoil coverage, topsoil backfilling can be implemented, and the soil can be modified by applying biological fertilizers. In areas with a general impact on the landscape, mature sheep dung and yak dung can be used to improve the soil. At the same time, when sowing the seeds of perennial herbaceous plants, mix with seed base fertilizer. For the bare land in the arid section of the alpine grassland in the north of the Tanggula Mountain of the Qinghai-Tibet Railway, *Elymus nutans*, *Poa crymophila*, *Leymus scalenus*, and *Roegneria thoroldiana* can be selected as the main plants to regenerate alpine vegetation. For the bare land of the low-lying saline-alkali area, *Puccinellia distans*, *Poa crymophila*, *E. nutans*, *Leymus chinensis*, and *Puccinellia tenuiflora* are the main plants for rebuilding alpine vegetation. For the bare land between Tanggula Mountain Pass and Amdo in the alpine meadow area south of Tanggula Mountain, vegetation restoration should focus on topography and soil improvement. Use the natural succession of vegetation to restore the natural vegetation of the soil taking and spoiling ground. But for borrow sites that are close to the railway line and affect the landscape, *E. nutans*, *Elymus sylvestris*, *E. dahuricus*, etc. can be planted. For bare lands such as the soil removal field between Amdo and Sangxiongla Mountain Pass along the railway, *E. nutans* can be selected as the main regenerated grass species. For the bare land from the Sangxiongla mountain pass to Yangbajing along the railway, *E. nutans* and *E. sylvestris* can be selected as the main grass species for alpine meadow regeneration and can be matched with *Elymus dauri* and auxiliary grass species such as *P. tenuiflora*, *Leymus sativus*, *Festuca arundinacea*, and *Bromus inermis* [1, 11].

3.2 Vegetation restoration in desert areas

The desert area is mainly distributed in the section from Golmud to Kunlun Mountain. The average soil moisture content in this section is extremely low, less than 4%. Vegetation coverage is very low, except for a few areas where vegetation coverage is higher, often less than 30%. The species richness is also very low. Land desertification is serious. Super xerophytic shrubs and semi-shrubs grow sporadically in some areas. This is the result of an extremely difficult habitat that has long been adapted to dry climates and severe water shortages. The drought-tolerant species of Chenopodiaceae, Tamaricaceae, Zygophyllaceae, and other drought-tolerant plants form the arid and semi-arid desert vegetation landscape. For vegetation restoration in this area, shrubs such as *Sympegma regelii*, *Calligonum mongolicum*, *Salsola abrotanoides*, *Nitraria tangutorum*, *Ceratoides latens*, *Ephedra przewalskii,* and *Oxytropis aciphylla* can be selected. Among them, *S. regelii* is suitable for mild saline-alkaline deserts, *C. mongolicum* is suitable for gravel deserts, *S. abrotanoides* is suitable for gravel deserts, and *C. latens* is suitable for Gobi and desert areas.

3.3 Vegetation restoration in alpine grassland and alpine meadow

The alpine grassland area is mainly distributed between Xidatan and Fenghuoshan. The total coverage of natural vegetation is between 40% and 60%. Cold and drought-tolerant herbs such as *Stipa purpurea*, *Elymus nutans*, *Poa poophagorum*, *Carex moorcroftii*, *Saussurea arenaria*, *Leontopodium pusillum*, *Kobresia robusta*, *Ajania przewalskii*, *Littledalea racemosa*, *Roegneria thoroldiana*, etc. can be used. The alpine meadow area is mainly distributed from the north of Tanggula

Mountain to Jiuzina Peak. In the case of not being destroyed, the total coverage of natural vegetation is often 100%. Plants available for this segment include *Kobresia pygmaea*, *Kobresia littledalei*, *Kobresia humilis*, *Poa* spp., and *Festuca* spp. plants.

3.4 Excellent herbaceous plants tolerant to sand burial

Sand materials accumulate in the area along the Qinghai-Tibet Railway with severe sand damage. Ordinary plant species are easily buried by sand, causing vegetation restoration to fail. Sand burial resistance test was carried out on five native herbaceous plants: *Lolium perenne*, *Festuca sinensi*, *Elymus breviaristatus*, *Elymus nutans* and *Poa crymophila* [12].

The depth of sand burial had a significant effect on the plant height and root length of 5 grasses. At the same time, seeds with a high thousand-grain weight have a high germination rate. At a burial depth of 0–6 cm, the plant height of *L. perenne* showed an upward trend and then a downward trend, while the root length showed an increasing trend. The maximum plant height and maximum root length appeared at the buried depth of 4 cm and 6 cm. The plant height and root length of *F. sinensi*, *E. breviaristatus* and *E. nutans* all showed a trend of first increasing and then decreasing. For the maximum plant height and root length, *F. sinensi* appeared at 1 cm and 2 cm burial depths, *E. breviaristatus* appeared at 3 cm burial depths, and *E. nutans* appeared at 2 cm and 3 cm burial depths. However, *P. crymophila* failed to emerge at a depth of more than 3 cm in the sand. The maximum plant height appears at a burial depth of 0–1 cm, and the maximum root length appears at a burial depth of 2 cm.

Therefore, in the process of vegetation restoration and reconstruction, seeds with good quality and high thousand-grain weight should be selected for the restoration of moderate sand-buried vegetation with a thickness of 1–3 cm in order to increase the rate of seed emergence and increase the rate of seedling colonization. At the same time, *L. perenne*, *F. sinensi*, *E. breviaristatus* and *E. nutans* can be used for vegetation restoration in areas with severe sand damage along the line. *Poa crymophila* can be used for vegetation restoration in mild sand-damaged areas where the accumulation rate of sand material is low.

4. Sand prevention and control technology along the Qinghai-Tibet Railway

The frequent occurrence of sand disasters along the Qinghai-Tibet Railway has seriously threatened the safe operation of the railway. For a long time, the prevention and control of sand disasters along the Qinghai-Tibet Railway have mostly adopted the management model of "distant resistance and adjacent fixation". That is, high vertical sand barriers such as sand retaining walls are built in sections far away from the railway to block wind and sand flow, and low vertical sand barriers such as stone grids are built to fix sand surfaces in sections near the railway [13]. But in fact, this governance model does not scientifically determine the source of wind and sand and the path of wind and sand movement. The function of the sand retaining wall to block the wind and sand flow is not fully utilized. The stone grid sand barrier is often buried by the wind and sand and loses its effectiveness. A large amount of accumulated sand has posed a huge threat to railway tracks and roadbeds [14]. Therefore, the Qinghai-Tibet Railway Company needs to spend a lot of manpower, material resources, and financial resources for manual and mechanical sand removal in the road area every year. In addition, due to the lack of sand barrier construction materials such as stone grids in some areas, has objectively pushed up the cost of prevention and control of sandstorms on the Qinghai-Tibet Railway.

In view of this, on the basis of scientifically determining the characteristics and mechanism of sand damage along the Qinghai-Tibet Railway, and fully combining the natural conditions and the degree of land desertification along the Qinghai-Tibet Railway, the wind-sand disaster prevention system along the Qinghai-Tibet Railway has been explored and developed. It broke the traditional governance model of "distant resistance and adjacent fixation". The system mainly includes: (1) proposed the "source control, comprehensive prevention and control" governance technology model. By clarifying the source and path of sand materials, the protection and restoration of the source can be carried out to achieve source control. (2) Developed a governance technology system that combines "fixation, resistance, and transmission". Based on the site conditions of sand-damaged sections and the suitability of sand-fixing materials, a series of "sand-fixing" technologies suitable for use along the Qinghai-Tibet Railway has been developed, including the use of soil modification and mulching technology, planting bag technology, and multi-grass mixed planting technology for rapid vegetation reconstruction and rapid sand fixation technology using environmentally friendly chemical sand fixation agents. The "blocking" sand technology mainly refers to the use of new High-density polyethylene (HDPE) sand barrier materials. By comparing the single-width sand transport under the conditions of natural sand transport and HDPE sand fixation barriers, the sand control efficiency of HDPE below 1 m from the ground surface can reach 67.82%, of which the sand control efficiency can reach 86.34% below 20 cm from the ground surface. The sand transport technology is mainly to invent the sand transport railway subgrade. It is mainly suitable for the severe sandstorm section of railway embankment where the main wind direction is single and the angle is large or perpendicular to the railway line, in order to reduce the threat of sandstorm. (3) Invented the technology of combining biological sand fixation with engineering sand control. It combined high vertical sand barriers, cement board grid sand barriers and vegetation restoration measures. The cold-resistant, drought-resistant, and sand-tolerant native plants selected by the project were used as vegetation restoration materials, including Elymus, Poa, and Fescue spices [15, 16].

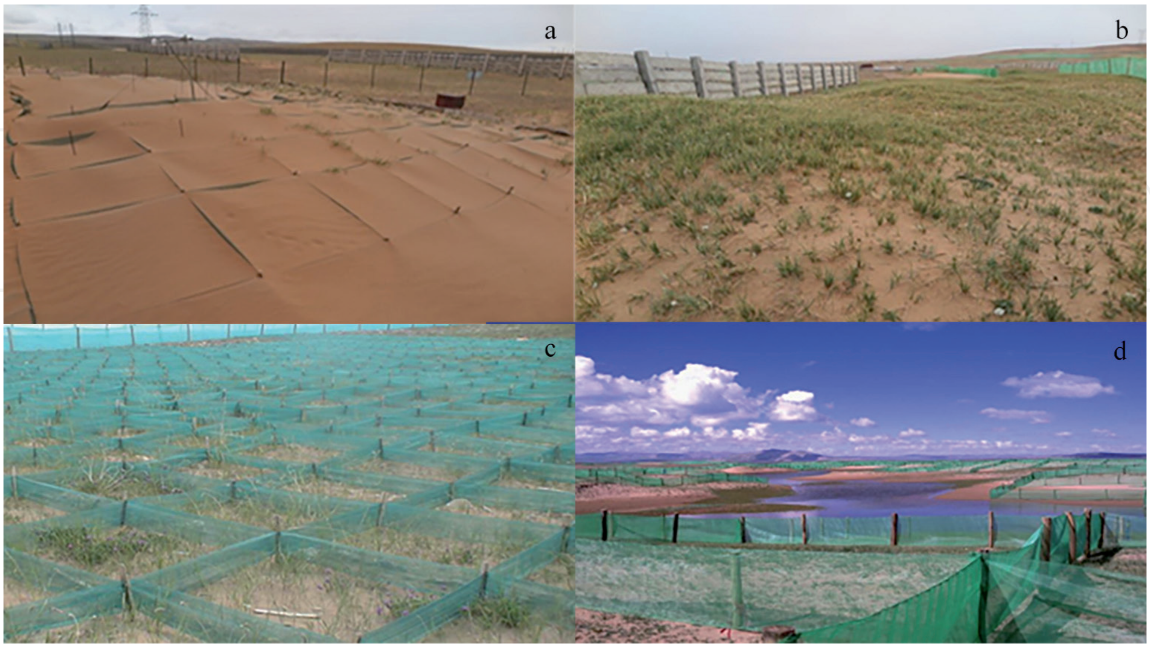

Figure 2.
Sand prevention and control technology along the Qinghai-Tibet Railway. (a) The promotion and application of the concept of "sand fixing in the distance". (b) Biological measures + engineering measures realize the control of sand materials from the source. (c) Low vertical net sand barriers are combined with biological measures to control sand sources. (d) High vertical net sand barriers are combined with biological measures to control sand sources.

The above-mentioned sand disaster control technology has been demonstrated and promoted in the severely sand-hazard sections of the Qinghai-Tibet Railway such as Hongliang River, Xiushui River, Beilu River, Tuotuo River, Tongtian River, Za'gya Zangbo, Cuona Lake, etc (**Figure 2**). The Qinghai-Tibet Railway Company adopted it in the prevention and control of the 78.8 km railway section of severe sand damage. It overcomes the shortcomings of using long-distance resistance and adjacent fixation in the past to intercept sand near the railway subgrade. This has effectively curbed the occurrence of railway sand disasters. Thus, the safe operation of the Qinghai-Tibet Railway is ensured.

5. Conclusion

With the operation of the Qinghai-Tibet Railway, severe wind and sand disasters gradually appeared along the line, threatening the safety of the railway. There is 78.8 km of severe sand-damaged roads along the route, distributed in 7 sections from Golmud to Nanshankou, Hongliang River, Xiushui River, Beilu River, Tuotuo River, Southern of Tanggula Mountain to Za'gya Zangbo, and Cuona Lake. Sand disasters mainly occurred from November to April of the following year. "Wind and drought in the same season" makes the wind and sand activities have sufficient power conditions and material basis. The airflow encounters resistance and rises on the windward side and slows down and settles on the leeward side, resulting in the accumulation of sand on both sides of the railway subgrade. The uplift of the airflow and the acceleration of the current collection cause wind erosion in the middle of the roadbed and the road shoulder. The low clearance height of the bridge caused sand accumulation on both sides of the railway bridge. The sand along the line is rich in materials and has complex sources. The main sources of sand include river and lake sediments, desertified meadows, and grasslands. Based on the distribution pattern and cause mechanism of sand damage along the railway, the Qinghai-Tibet Railway Sand Hazard Integrated Prevention and Control Technology System, which combines engineering and biology, and solidification, resistance, and transportation, can effectively prevent the occurrence of railway sand damage, thereby ensuring safe railway operation.

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