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Study on the Construction and Operation Management of Urban Drainage Systems in the Alpine Plateau Region of Tibet

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Abstract

The construction and operation management of urban drainage systems in the alpine plateau region of Tibet face numerous unique challenges due to natural conditions such as high altitude, low temperatures, and frequent freeze–thaw cycles. This study systematically investigates the current status, existing problems, and underlying causes of urban drainage system development in Tibet through methods including field surveys, problem identification, operational failure analysis, and whole-process management evaluation. The results indicate that although the drainage network coverage rate in some central urban areas has exceeded 80%, it remains below 60% in certain counties and townships. In most towns, the temperature impact coefficient is lower than 0.4, while low temperatures, freeze–thaw cycles, and hypoxic conditions associated with high altitudes are identified as the primary factors affecting drainage system performance. Operational failures exhibit a cascading mechanism characterized by "pipeline freezing and structural deterioration → reduced conveyance capacity → increased equipment loading → declining treatment efficiency → overall system failure." To address these challenges, an integrated construction and operation management framework consisting of "engineering optimization, operational reliability enhancement, intelligent operation and maintenance management, and institutional and policy support" is proposed. This study establishes a problem identification system and a whole-process management evaluation framework for drainage systems in the alpine plateau region of Tibet, providing a useful reference for the construction and operation management of drainage infrastructure in similar cold and high-altitude regions.

Keywords

alpine plateau region; urban drainage system; operational failure; operation and maintenance management; optimization strategy

1. Introduction

Urban drainage systems constitute essential infrastructure for ensuring urban safety, improving living environments, and promoting ecological civilization

development. In recent years, with the rapid advancement of urbanization in Tibet, significant progress has been achieved in the construction of urban drainage facilities. However, owing to factors such as high altitude, low temperatures, frequent freeze–thaw cycles, and complex topography, drainage systems continue to encounter substantial challenges during the stages of planning, construction, operation, and maintenance management [1]. Problems such as insufficient pipeline network coverage, incomplete separation of stormwater and wastewater systems, pipeline freezing and blockage during winter, unstable operation of wastewater treatment facilities, and inadequate professional operation and maintenance (O&M) capacity remain prevalent in some towns and cities. These issues have adversely affected the functionality of drainage systems and the effectiveness of ecological environmental management [2]. Therefore, a systematic investigation into the construction and operation management of urban drainage systems in the alpine plateau region of Tibet is of considerable practical significance for improving infrastructure performance and promoting high-quality urban development.

Current studies on drainage systems in cold regions, both domestically and internationally, mainly focus on the following aspects. First, research on drainage engineering construction and anti-freezing design primarily addresses pipeline burial depth, thermal insulation measures, and adaptive infrastructure design for cold regions [3]. Second, studies on the low-temperature operation of wastewater treatment facilities mainly concentrate on process optimization, maintenance of microbial activity, and energy-efficient operational strategies under cold conditions [4]. Third, research on drainage system operation and maintenance management focuses on pipeline inspection and assessment, smart drainage systems, and life-cycle management approaches [5]. Fourth, investigations into municipal infrastructure in plateau regions have largely emphasized water supply security, wastewater treatment, and ecological environmental governance [6]. While these studies provide valuable references for drainage engineering in cold regions, most have focused on northeastern and northwestern China, with limited attention given to the construction and operational characteristics of drainage systems under the high-altitude, cold, and oxygen-deficient conditions of Tibet. Furthermore, existing studies generally address individual technical issues and lack a comprehensive perspective covering the entire process of system construction, operation, and management.

To address these research gaps, this study examines the actual conditions of urban drainage systems in Tibet by analyzing regional environmental characteristics and the current status of drainage infrastructure development. Major issues associated with engineering construction, facility operation, and maintenance management are systematically identified. Subsequently, the operational failure characteristics and underlying mechanisms of drainage facilities under alpine plateau conditions are investigated, and a whole-process management evaluation framework is established.

Based on these analyses, targeted optimization strategies for the construction, operation, and maintenance management of drainage systems suitable for Tibetan urban areas are proposed. The findings provide technical support for improving the quality and efficiency of urban drainage systems in Tibet and offer valuable references for the construction and operation management of drainage infrastructure in other alpine plateau regions.

2. Current Status of Urban Drainage System Construction in the Alpine Plateau Region of Tibet

To further identify the key challenges associated with the construction, operation, and management of urban drainage systems in the alpine plateau region of Tibet, it is first necessary to examine the regional natural environmental characteristics and the current status of drainage infrastructure development. Natural conditions constitute fundamental factors influencing the planning, design, construction, operation, and maintenance of drainage systems, while the existing level of infrastructure development directly determines system performance and service capacity.

2.1. Regional Environmental Characteristics

The Tibet Autonomous Region is located in the core area of the Qinghai–Tibet Plateau, with an average elevation exceeding 4,000 m and a typical alpine plateau climate. Owing to its high altitude and complex topography, the region is characterized by low temperatures, large diurnal temperature variations, intense solar radiation, frequent freeze–thaw cycles, and uneven spatial and temporal distribution of precipitation.

For drainage systems, low-temperature conditions represent one of the most critical factors affecting operational performance. According to studies on cold-region engineering, the impact of temperature on drainage system operation can be expressed by the temperature influence coefficient:

$$K_t = \frac{T_a}{T_0} \tag{1}$$

where K_t is the temperature influence coefficient; T_a is the annual average regional temperature (°C); and T_0 is the reference temperature under normal conditions (20°C).

The annual average temperature of most Tibetan towns ranges from 0 to 8°C, resulting in calculated values of K_t generally below 0.4, indicating a significant influence of low-temperature conditions on drainage system performance. Furthermore, since most urban settlements are distributed along river valleys, available land for development is constrained by surrounding mountains and rivers, limiting the spatial flexibility of drainage network layouts. In some areas, the frost

penetration depth during winter reaches 1.0–1.5 m, imposing more stringent requirements on pipeline burial depth, anti-freezing measures, and manhole structural design. Consequently, alpine environmental conditions affect the entire life cycle of drainage systems through the combined influences of temperature, freeze–thaw action, and topographic constraints.

2.2. Current Status of Urban Drainage System Development

In recent years, driven by national ecological civilization initiatives and infrastructure improvement programs in Tibet, cities and counties across the region have gradually enhanced drainage infrastructure development, forming an urban drainage system primarily composed of wastewater treatment plants, sewer networks, and supporting facilities. Major cities such as Lhasa, Shigatse, and Nyingchi have established relatively complete wastewater collection and treatment systems, while wastewater treatment facilities have also been successively constructed in many counties and key towns.

In terms of infrastructure composition, the current drainage system mainly consists of sanitary sewer networks, stormwater drainage networks, wastewater treatment plants, and pumping stations. Due to differences in construction periods and funding availability, significant disparities exist in infrastructure development levels among different regions. Separate sewer systems have been adopted in some newly developed urban districts, whereas combined sewer systems or improper stormwater–wastewater connections remain in parts of older urban areas, adversely affecting wastewater collection efficiency and treatment performance.

To evaluate the level of drainage infrastructure development, the pipeline network coverage rate is introduced:

$$R = \frac{L_e}{L_p} \times 100\% \tag{2}$$

where R is the pipeline network coverage rate (%); L_e is the length of the constructed drainage network (km); and L_p is the planned network length (km).

According to field investigations, the drainage network coverage rate in the central districts of some Tibetan cities has exceeded 80%, whereas in certain counties and townships it remains below 60%, indicating substantial regional disparities in infrastructure development. The main characteristics of urban drainage system development in Tibet are summarized in Table 1.

Table 1. Current Status of Urban Drainage System Development in the Alpine Plateau Region of Tibet

Item	Drainage System Type	Network Coverage	Wastewater Treatment Facilities	Anti-freezing Measures	Level of Smart Management	O&M Capacity
Current Characteristics	Coexistence of separate and combined sewer systems	Relatively high in central urban areas, significant disparities among counties and towns	Basic coverage achieved in most counties	Insufficient implementation in some regions	Overall level of digitalization remains low	Relative shortage of skilled technical personnel

Overall, notable progress has been achieved in the development of urban drainage systems in Tibet. Infrastructure scale has continued to expand, and wastewater collection and treatment capacities have steadily improved. However, constrained by environmental conditions, construction limitations, and management capacity, some facilities still suffer from inconsistent construction standards, inadequate operational stability, and incomplete management systems. These issues not only hinder the effective functioning of drainage systems but also constrain improvements in urban water environment management. Therefore, a detailed analysis of the major problems affecting current drainage system construction and operation is required to provide a basis for subsequent optimization strategies.

3. Major Problems in Urban Drainage System Construction and Operation Management

3.1. Engineering Construction Issues

From the perspective of infrastructure development, the drainage network coverage rate remains relatively low in some counties and small towns, resulting in incomplete wastewater collection systems and insufficient sewage interception. In certain older urban districts, stormwater–wastewater separation projects have not been fully implemented, and improper or mixed pipeline connections persist, causing significant fluctuations in influent quality at wastewater treatment plants. Furthermore, due to relatively low construction standards in some projects, insufficient pipeline burial depths and inadequate anti-freezing measures have increased the risk of frost heave and structural deformation under winter low-temperature conditions. In addition, terrain constraints in mountainous areas often result in inappropriate pipeline gradients, thereby reducing wastewater conveyance efficiency.

3.2. Facility Operation Issues

The alpine environment is a critical factor affecting the operation of drainage facilities. Under winter low-temperature conditions, pipeline sections are susceptible to ice formation and blockage, leading to reduced drainage capacity. At wastewater treatment plants, the activity of biological treatment units decreases due to reduced microbial activity, thereby affecting treatment performance. Field investigations indicate that low-temperature frost damage, equipment aging, and inadequate maintenance practices are the primary factors affecting stable system operation.

3.3. Operation and Maintenance Management Issues

Insufficient operation and maintenance (O&M) capacity represents a major challenge facing current drainage systems. In some areas, the shortage of skilled technical personnel limits the effectiveness of facility maintenance and fault

response. Meanwhile, incomplete pipeline records and inadequate inspection and assessment activities hinder timely identification of operational conditions and infrastructure deterioration. In addition, the overall level of digitalization remains relatively low. The limited application of smart drainage platforms and online monitoring systems reduces management efficiency and weakens decision-making capabilities. The major issues associated with urban drainage system construction and operation management are summarized in Table 2.

Table 2. Classification of Major Problems in Urban Drainage Systems

Category	Engineering Construction		Facility Operation		O&M Management	
Major Issues	Insufficient network construction; inadequate anti-freezing design	Pipeline freezing and blockage; reduced treatment efficiency	Weak technical capacity; low level of digitalization	Major Issues	Insufficient network construction; inadequate anti-freezing design	Pipeline freezing and blockage; reduced treatment efficiency
Typical Manifestations	Low coverage rates; stormwater–wastewater cross-connections	Frost heave and deformation risks; reduced winter drainage capacity	Reduced biological treatment performance under low temperatures	Typical Manifestations	Low coverage rates; stormwater–wastewater cross-connections	Frost heave and deformation risks; reduced winter drainage capacity

3.4. Analysis of Causes

The aforementioned problems arise from the combined effects of environmental conditions, engineering practices, and management capacity. The relationships among these influencing factors are illustrated in Fig. 1. As shown in Fig.1, the alpine environment serves as the primary external condition influencing system performance, whereas engineering standards, operational performance, and O&M management capacity constitute the key internal factors. Overall, Tibetan urban drainage systems continue to face challenges related to insufficient environmental adaptability, inadequate operational stability, and weak management capacity. Among these factors, the long-term impacts of the alpine environment on facility performance are particularly significant. Therefore, a more detailed investigation of the operational failure characteristics of drainage facilities under alpine conditions is necessary to better understand the underlying mechanisms.

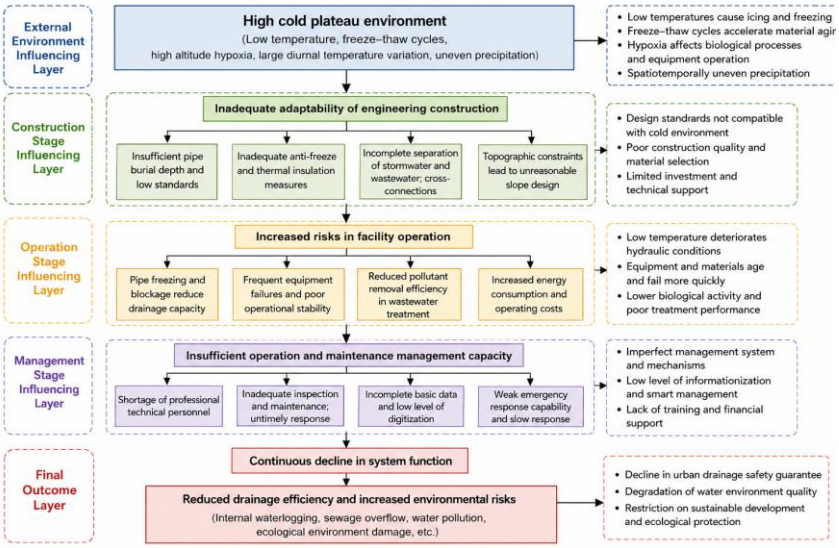


Figure 1. Mechanism of Problem Formation in Urban Drainage Systems

4. Analysis of Operational Failure Characteristics of Drainage Facilities under Alpine Conditions

4.1. Mechanisms of Alpine Environmental Impacts

Most urban areas in Tibet are located at high elevations and experience low winter temperatures as well as frequent freeze–thaw cycles. Under low-temperature conditions, wastewater flow velocity within drainage pipelines decreases, and localized water accumulation is prone to freezing. Repeated freeze–thaw cycles accelerate pipeline joint loosening, manhole cracking, and equipment deterioration. Furthermore, hypoxic conditions associated with high-altitude environments reduce microbial activity within wastewater treatment systems, thereby affecting pollutant removal efficiency.

To quantitatively evaluate the influence of alpine environmental conditions, the Environmental Impact Index (E) is defined as:

$$E = \alpha T + \beta F + \gamma H \tag{3}$$

where: E = Environmental Impact Index; T = low-temperature impact factor; F = freeze–thaw cycle factor; H = high-altitude impact factor; α, β, and γ = weighting coefficients. An increase in the value of E indicates a greater adverse impact of alpine environmental conditions on drainage facility operation.

4.2. Typical Failure Modes of Drainage Facilities

Based on field investigations, drainage facility failures under alpine conditions can be categorized into three major types: network failures, equipment failures, and functional failures. Their principal characteristics are summarized in Table 3. The

interactions among these failure modes exhibit a distinct cascading relationship, as illustrated in Figure 2.

Table 3. Typical Failure Modes of Drainage Facilities under Alpine Conditions

Failure Type	Typical Manifestations	Consequences
Network Failure	Freezing blockage; leakage	Reduced conveyance capacity
Equipment Failure	Pumping station malfunction; equipment shutdown	In-terruption of system operation
Functional Failure	Reduced treatment efficiency	Fluctuation of effluent quality

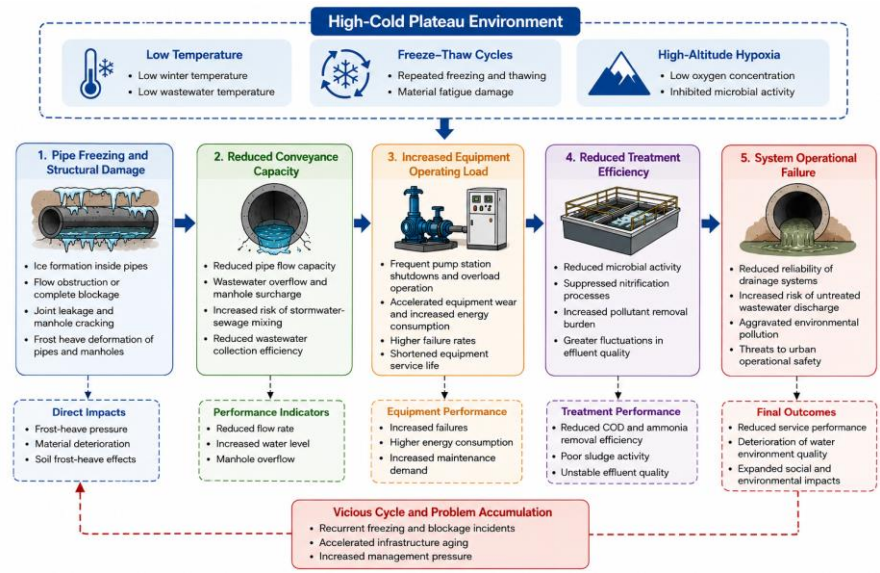


Figure 2. Failure Propagation Pathway of Drainage Facilities under Alpine Conditions

4.3. Whole-Process Management Evaluation

To comprehensively evaluate the levels of drainage system construction, operation, and management, a Whole-Process Management Evaluation Index is established:

$$M = \sum_{i=1}^{n} W_i X_i \tag{4}$$

where: M = Whole-Process Management Evaluation Index; X_i = score of the i-th evaluation indicator; W_i = corresponding weighting coefficient.

The evaluation framework comprises three dimensions: Engineering Construction, focusing on pipeline network completeness and anti-freezing design quality; Facility Operation, emphasizing equipment integrity and treatment compliance rates; Operation and Maintenance Management, including staffing levels, inspection and maintenance practices, and the degree of digitalization.

The analysis indicates that although the construction level of drainage systems in some Tibetan towns has improved significantly, operational risks remain relatively high during winter conditions. In particular, facility operation and O&M management have become critical factors affecting system stability. Overall, alpine

environmental conditions influence drainage facilities through the combined effects of low temperatures, freeze–thaw cycles, and hypoxia, resulting in failure patterns characterized by pipeline freezing, equipment malfunction, and declining treatment efficiency. These findings provide the basis for developing targeted optimization strategies.

5. Optimization Strategies for the Construction and Operation Management of Drainage Systems in the Alpine Plateau Region of Tibet

The alpine environment is the key factor affecting the stable operation of drainage facilities. To address issues related to insufficient engineering adaptability, elevated operational risks, and inadequate O&M capacity, a whole-process optimization management framework tailored to the characteristics of Tibetan towns should be established.

5.1. Engineering Optimization Measures

During the planning and design stage, factors such as low temperatures, frequent freeze–thaw cycles, and complex terrain should be fully considered. For newly constructed pipeline networks, appropriate burial depths should be determined, and thermal insulation, anti-freezing, and frost-heave-resistant designs should be strengthened. In older urban areas, stormwater–wastewater separation projects and rehabilitation of aging pipelines should be systematically implemented. In mountainous towns, drainage network layouts should be optimized to enhance wastewater collection and conveyance capacity.

5.2. Measures for Ensuring Facility Operation

To mitigate elevated operational risks during winter, inspection and monitoring programs should be established for critical pipeline sections and key equipment. Operational monitoring should be intensified during cold seasons. Furthermore, operational parameters of wastewater treatment processes should be optimized to improve pollutant removal efficiency under low-temperature conditions.

5.3. Optimization of O&M Management Models

A management framework integrating professional operation and maintenance with intelligent supervision should be established. Comprehensive facility archives and pipeline databases should be developed, while online monitoring systems and smart drainage platforms should be promoted to enable dynamic management of facility operating conditions. Simultaneously, professional training programs should be strengthened to improve fault response and emergency management capabilities.

5.4. Institutional and Policy Recommendations

A standards system tailored to the characteristics of alpine plateau regions should be established for drainage facility construction and O&M management, including requirements for anti-freezing design, operational maintenance, and safety management. Financial investment should be increased, and performance evaluation and supervision mechanisms should be improved to establish a long-term framework that promotes coordinated development among construction, operation, and regulatory activities.

Overall, improvements in engineering adaptability should serve as the foundation, while operational reliability and intelligent O&M should constitute the core focus, supported by institutional and policy frameworks. Through these efforts, a drainage system construction and management model suited to the unique conditions of the alpine plateau region of Tibet can be gradually established.

6. Conclusions

Urban drainage system construction and operation management in the alpine plateau region of Tibet exhibit significant regional characteristics due to factors such as high altitude, low temperatures, and frequent freeze–thaw cycles. Based on the actual conditions of urban drainage infrastructure in Tibet, this study systematically investigated issues related to drainage system construction and operation management through current-status analysis, problem identification, operational failure analysis, and whole-process management evaluation, and proposed targeted optimization strategies. The major conclusions are as follows:

(1) A drainage infrastructure system centered on sewer networks and wastewater treatment facilities has largely been established in Tibetan urban areas; however, significant regional disparities remain. The drainage network coverage rate exceeds 80% in some central urban districts but remains below 60% in certain counties and townships. Deficiencies persist in anti-freezing design, network completeness, and intelligent infrastructure development.

(2) The alpine environment is the key factor affecting drainage system performance. The results indicate that the temperature influence coefficient is generally below 0.4 in most Tibetan towns. Low temperatures, freeze–thaw cycles, and high-altitude hypoxic conditions jointly affect drainage facility operation, with freezing and freeze–thaw damage being the primary causes of facility failure.

(3) Drainage facility failures under alpine conditions exhibit a distinct cascading pattern characterized by "pipeline freezing and structural deterioration → reduced conveyance capacity → increased equipment loading → declining treatment efficiency → overall system failure." Pipeline freezing and blockage, increased equipment failures, and reduced treatment efficiency represent the dominant failure modes.

(4) Whole-process management evaluation reveals that operation and maintenance management remains relatively weak in some Tibetan towns. Insufficient technical

personnel, low levels of digitalization, and inadequate inspection and maintenance practices are major factors affecting system stability.

(5) An integrated construction and management framework comprising "engineering optimization – operational reliability enhancement – intelligent O&M management – institutional and policy support" is proposed. This framework can effectively improve system reliability and whole-process management performance, providing valuable guidance for drainage infrastructure construction and O&M management in Tibet and other alpine plateau regions.

References

[1] Xu, X., Zhao, Q., Kong, X., Zhang, L., Zhang, X., Yu, T., ... & Xia, Q. (2025). Hydrological Response of an Enclosed Karst Groundwater System to Drainage Induced by Tunnel Excavation in a Typical Anticline Geo-Structure. Water, 18(1), 87. DOI: https://doi.org/10.3390/w18010087

[2] Zhuoma, Y., Ouzhu, Z., Tajie, S., Danzhen, G., Zhuoma, C., Zhuoga, S., ... & Gao, J. (2026). Monitoring and simulation of typical glacial lake outburst debris flow in Xizang, China. Journal of Earth System Science, 135(3), 142. DOI: https://doi.org/10.1007/s12040-026-02769-5

[3] Yang, R., Peng, X., & Yimin, W. (2025). Evolution of freezing in drainage ditches of high-speed railway tunnels in cold regions. Cold Regions Science and Technology, 104778. DOI: https://doi.org/10.1016/j.coldregions.2025.104778.

[4] Schneider, P., & Reincke, H. (2025). Mitigating qualitative water shortage in Northern Germany: case study for antifreeze irrigation solutions in fruit production. In Handbook of Nature-Based Drought Solutions (pp. 715-729). Elsevier. DOI: https://doi.org/10.1016/B978-0-443-29993-3.00034-5.

[5] Chen, Y., Cowling, P., Polack, F., Remde, S., & Mourdjis, P. (2017). Dynamic optimisation of preventative and corrective maintenance schedules for a large scale urban drainage system. European journal of operational research, 257(2), 494-510. DOI: https://doi.org/10.1016/j.ejor.2016.07.027.

[6] Yusnita, M., Wulandari, E., & Nugroho, L. D. (2025). Performance Analysis and Operation and Maintenance Cost Requirements for Rapak Di Drainage. Enrichment: Journal of Multidisciplinary Research and Development, 2(12), 1516-1528. DOI: https://doi.org/10.55324/enrichment.v2i12.319.