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Research on methods of organizing drainage from highways

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Abstract

This study presents a comprehensive analysis of existing methods for organizing surface drainage from highways, with a focus on their hydraulic efficiency and environmental impact. The research is based on the evaluation of traditional drainage systems widely used in Kazakhstan, including earthen ditches, and their comparison with modern integrated international solutions. The results show that conventional drainage approaches do not ensure stable hydraulic performance under real operating conditions due to the influence of time-dependent factors such as sedimentation, vegetation growth, and contamination of runoff. These factors lead to a significant reduction in drainage capacity, resulting in water accumulation, subgrade over-moistening, and accelerated deterioration of pavement structures. In addition, insufficient drainage contributes to increased risks of hydroplaning and environmental pollution caused by uncontrolled infiltration of contaminated runoff into soil and groundwater. A comparative analysis demonstrates that modern drainage systems provide higher efficiency by integrating water collection, regulation, and treatment processes, while also ensuring environmental protection. The study identifies key limitations of traditional design approaches and highlights the necessity of transitioning to advanced drainage solutions that consider dynamic hydraulic parameters and sustainability requirements. The findings of this research can be used to improve highway drainage design practices and to enhance the durability, safety, and environmental performance of road infrastructure.

Keywords: highways, drainage systems, surface runoff, hydraulic capacity, earthen drainage ditches, pavement durability, environmental impact, hydroplaning, integrated drainage systems

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Автомобиль жолдарынан су әкетуді ұйымдастыру әдістерін зерттеу

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Түйіндеме

Бұл зерттеуде автомобиль жолдарынан жер үсті суларын әкетуді ұйымдастырудың қолданыстағы әдістеріне кешенді талдау жасалып, олардың гидравликалық тиімділігі мен қоршаған ортаға әсері қарастырылды. Зерттеу Қазақстанда кеңінен қолданылатын дәстүрлі су әкету жүйелерін, соның ішінде топырақтан жасалған су бұру арналары (канавалар) мен оларды заманауи кешенді халықаралық шешімдермен салыстыруға негізделген. Нәтижелер көрсеткендей, дәстүрлі су әкету тәсілдері нақты пайдалану жағдайларында гидравликалық тұрақтылықты қамтамасыз ете алмайды, себебі тұнба жиналу, өсімдіктердің өсуі және ағын сулардың ластануы сияқты уақытқа тәуелді факторлар әсер етеді. Бұл факторлар су өткізу қабілетінің айтарлықтай төмендеуіне әкеліп, су жиналуын, жер төсемі негізінің артық ылғалдануын және жол жабыны құрылымдарының жедел бұзылуын тудырады. Сонымен қатар, жеткіліксіз су әкету гидропланирлеу қаупін арттырып, ластанған ағын сулардың топырақ пен жерасты суларына бақылаусыз сіңуі арқылы қоршаған ортаның ластануына әкеледі. Салыстырмалы талдау көрсеткендей, заманауи су әкету жүйелері суды жинау, реттеу және тазарту процестерін біріктіру арқылы жоғары тиімділікті қамтамасыз етеді, сондай-ақ қоршаған ортаны қорғауды жүзеге асырады. Зерттеу дәстүрлі жобалау тәсілдерінің негізгі шектеулерін анықтап, динамикалық гидравликалық параметрлер мен тұрақты даму талаптарын ескеретін жетілдірілген шешімдерге көшу қажеттілігін негіздейді. Зерттеу нәтижелері автомобиль жолдарын су әкету жүйелерін жобалау тәжірибесін жетілдіруге, сондай-ақ жол инфрақұрылымының беріктігін, қауіпсіздігін және экологиялық тиімділігін арттыруға қолданылуы мүмкін.

Түйін сөздер: автомобиль жолдары, су әкету жүйелері, жер үсті ағындары, гидравликалық өткізу қабілеті, топырақ су бұру арналары, жол жабынының ұзақ мерзімділігі, қоршаған ортаға әсері, гидропланирлеу, кешенді су әкету жүйелері

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Исследование способов организации водоотвода с автомобильных дорог

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Аннотация
В данной работе представлен комплексный анализ существующих методов организации поверхностного водоотвода с автомобильных дорог с акцентом на их гидравлическую эффективность и экологическое воздействие. Исследование основано на оценке традиционных систем водоотвода, широко применяемых в Казахстане, включая грунтовые водоотводные канавы, и их сравнении с современными интегрированными международными решениями. Результаты показывают, что традиционные подходы к водоотведению не обеспечивают устойчивой гидравлической эффективности в реальных условиях эксплуатации вследствие воздействия временных факторов, таких как заиливание, зарастание растительностью и загрязнение стока. Эти факторы приводят к значительному снижению пропускной способности, что вызывает накопление воды, переувлажнение основания земляного полотна и ускоренное разрушение дорожных конструкций. Кроме того, недостаточное водоотведение способствует увеличению риска гидропланирования и загрязнению окружающей среды вследствие неконтролируемого проникновения загрязнённого стока в почву и грунтовые воды. Сравнительный анализ показывает, что современные системы водоотвода обеспечивают более высокую эффективность за счёт интеграции процессов сбора, регулирования и очистки воды, а также обеспечивают экологическую безопасность. В работе выявлены основные ограничения традиционных подходов к проектированию и обоснована необходимость перехода к более совершенным решениям, учитывающим динамические гидравлические параметры и требования устойчивого развития. Полученные результаты могут быть использованы для совершенствования практики проектирования систем водоотвода автомобильных дорог, а также для повышения долговечности, безопасности и экологической эффективности дорожной инфраструктуры.

Ключевые слова: автомобильные дороги, системы водоотведения, поверхностный сток, гидравлическая пропускная способность, грунтовые водоотводные канавы, долговечность дорожного покрытия, экологическое воздействие, гидропланирование, интегрированные системы водоотведения

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1. Introduction

The design of effective highway drainage systems is a fundamental engineering task that directly affects the operational quality, safety, and long-term sustainability of road infrastructure. The presence of excess surface water on roadways is one of the most significant factors contributing to the deterioration of pavement structures and the weakening of the subgrade [1]. Prolonged moisture exposure accelerates material degradation, reduces the bearing capacity of structural layers, and creates conditions for the premature development of cracks, potholes, rutting, and other forms of pavement distress. In addition to its destructive influence on structural performance, water accumulation on the pavement surface creates hazardous driving conditions by increasing the probability of hydroplaning, loss of tire–road adhesion, and traffic accidents [2]. Moreover, runoff generated on road surfaces often contains suspended solids, petroleum products, de-icing chemicals, heavy metals, and other pollutants, which may infiltrate the soil and groundwater or be discharged into nearby water bodies, thereby creating substantial environmental risks [3].

Despite the well-recognized importance of efficient water removal, the design of drainage systems in many countries, including Kazakhstan, still largely relies on conventional engineering solutions developed several decades ago. In practice, these solutions are commonly represented by open earthen drainage ditches and other standard surface runoff collection elements that are selected primarily based on generalized design norms rather than detailed hydraulic, geotechnical, and environmental assessment [4]. Although such systems are relatively simple, inexpensive, and easy to construct, their effectiveness under contemporary operating conditions is often limited. Existing design approaches frequently do not adequately account for local topography, traffic intensity, the waterproof nature of modern pavement surfaces, changing precipitation patterns, or the progressive loss of hydraulic performance during service life. As a result, traditional drainage systems often fail to provide stable and efficient removal of stormwater, especially under intensive rainfall events and prolonged operating loads.

A review of previous studies [5-10] indicates that research in the field of road engineering has more often focused on indirect consequences of inadequate drainage, such as aquaplaning, tire–pavement friction, wet-surface safety, and pavement failure under excess moisture conditions, rather than on the engineering performance of drainage systems themselves. While these studies are undoubtedly important, they do not fully address the question of whether existing drainage solutions are hydraulically and environmentally adequate for present-day requirements. In contrast, international research and engineering practice increasingly emphasize integrated drainage concepts in which water collection, conveyance, regulation, treatment, and environmental protection are considered as elements of a single system. Such approaches typically involve impermeable drainage channels, sealed collectors, treatment facilities, geosynthetic components, and sustainable runoff management measures aimed at reducing both infrastructure damage and ecological impact. This trend highlights a significant technological and methodological gap between traditional domestic practice and more advanced foreign solutions.

Another important shortcoming of many existing drainage design methods is the insufficient consideration of dynamic and time-dependent factors affecting system performance [11-13]. The hydraulic efficiency of drainage elements changes throughout their service life due to sediment accumulation, vegetation growth, clogging, erosion, and contamination by runoff from the roadway surface. These processes alter the roughness characteristics of drainage channels, reduce flow velocity, decrease discharge capacity, and ultimately lead to water stagnation and reduced system reliability. The long-term consequences of such performance loss include embankment over-moistening, subgrade saturation, erosion of slopes, instability of earth structures, and accelerated deterioration of pavement layers. At the same time, many conventional design approaches remain focused on initial geometric parameters and do not adequately assess how drainage performance evolves over time. Environmental considerations are also often treated as secondary, even though the infiltration of polluted runoff into surrounding soils and groundwater may substantially increase the anthropogenic impact of highways on natural ecosystems.

Under current climatic, operational, and environmental conditions, these limitations make it necessary to reconsider traditional approaches to highway drainage design. A modern drainage system should no longer be viewed merely as a simple means of diverting water away from the pavement surface. Instead, it should be treated as a multifunctional engineering system that ensures hydraulic efficiency, structural protection, operational safety, and environmental sustainability throughout the life cycle of the road. This requires not only the reassessment of conventional design solutions, but also the adaptation of international best practices and modern materials to local engineering conditions [14].

Therefore, there is a clear need for a comprehensive analysis of existing methods for organizing surface drainage from highways and for the development of more rational, reliable, and environmentally sound engineering solutions. The aim of this study is to analyze current methods of highway surface drainage, identify the principal limitations of traditional approaches, and develop design-oriented recommendations aimed at improving water removal efficiency, increasing pavement durability, and reducing the environmental impact of roadway runoff.

2. Materials and methods

2.1 Analysis of Recent Studies and Publications.

An analysis of scientific and technical sources indicates that, in domestic practice, limited attention has been paid to the scientifically grounded design of road drainage systems. One of the earliest systematized engineering approaches to the organization of surface runoff from road pavements can be attributed to the solution presented in the works of A.K. Birulya [15]. In subsequent years, the development of this field was reflected in the studies of B.F. Perevoznikov [15], as well as in the works of foreign authors — Ogbozige [4], Aranda [16], Havryshchuk [17], and Chu [1], which addressed specific aspects of drainage facility performance and their influence on the operational condition of pavement structures.

It should be emphasized that the engineering solutions developed during that period generally met the requirements of their time, when environmental considerations and the prevention of environmental pollution by surface runoff were not regarded as priority tasks in road design. In the 1980s–1990s, attempts were made to improve the structural schemes of drainage systems [18,19]; however, these efforts did not lead to a fundamental revision of the approaches applied. In the current regulatory and technical framework, as well as in a number of prospective design developments [16], despite advances in construction technologies and materials, the open drainage ditch remains the key element of road drainage systems.

At the same time, an analysis of European and international experience [20-22] demonstrates the application of more integrated and technologically advanced solutions aimed not only at water removal, but also at runoff regulation, treatment of contaminated water, and reduction of anthropogenic environmental impact. This indicates the existence of a significant gap between domestic and foreign practice in the field under consideration.

Table 1. Comparison of traditional highway drainage approaches in Kazakhstan and modern international solutions

Parameter	Traditional systems (Kazakhstan)	Modern systems (EU practice)
Type	Earthen ditches	Integrated drainage systems
Hydraulic capacity	Decreases over time	Stable
Roughness	Variable, uncontrolled	Controlled
Environmental impact	High (infiltration)	Low (sealed systems)
Maintenance	Frequent	Optimized
Durability	Low	High

As shown in Table 1, international practice applies more integrated and environmentally oriented drainage solutions than those commonly used in Kazakhstan.

The purpose of this study is to analyze existing methods for designing surface drainage systems for highways and to develop a rational engineering solution aimed at reducing the impact of atmospheric precipitation on pavement structures.

2.2 Analysis of Road Drainage Design Methods.

In the road design practice of the Republic of Kazakhstan, an earthen drainage ditch is predominantly used as the basic element of the surface drainage system, with various structural configurations depending on the engineering–geological and topographical conditions of the route alignment [23].

When designing roads outside populated areas and with relatively low embankments, side ditches are traditionally provided, which may be constructed either with or without reinforcement of the slopes and bottom. This solution is characterized by structural simplicity, ease of construction, and relatively low cost, which has led to its widespread adoption. At the same time, these advantages essentially exhaust its benefits.

According to the requirements of regulatory documents [24], the transverse road profile is formed with a cross slope that ensures the removal of surface runoff from the carriageway to the shoulders and then along the embankment slopes into earthen drainage ditches. From a theoretical standpoint, such a scheme is considered operable. However, under the operating conditions of highways in Kazakhstan, the impact of excessive runoff from impermeable pavements on pavement durability, as well as the volume of pollutants entering soil and groundwater together with surface runoff, has not been sufficiently studied.

One of the indicators characterizing the efficiency of a drainage system is the velocity of surface water conveyance. According to [25], the velocity of stormwater flow in a ditch is determined by Equation (1).

The velocity of rainwater flow in a drainage channel is expressed as:

$$V_{ch} = \frac{1}{n}\left(\frac{h_l}{2}\right)^{2/3} i^{1/2}(1) \qquad (1)$$

where: V_{ch}— average flow velocity in the ditch, m/s;
n— roughness coefficient of the channel bed;
h_l— flow depth in the channel, m;
i— longitudinal slope of the ditch bottom.

The value $\frac{h_\ell}{2}$ Equation (1) effectively represents the hydraulic radius of the flow for the given cross-sectional shape, which allows the use of a simplified form of Manning's equation.

Determination of Stormwater Runoff Discharge

The hydraulic capacity of a drainage ditch is determined by the water discharge:

$$Q = V_{\mathrm{ch}} \cdot \omega \qquad (2)$$

where: Q— water discharge, m³/s;
ω— cross-sectional flow area, m².

Substituting Equation (1) into Equation (2), we obtain:

$$Q = \frac{1}{n}\left(\frac{h_l}{2}\right)^{2/3} i^{1/2} \cdot \omega \qquad (3)$$

Trapezoidal Cross-Section of the Ditch

If the ditch has a trapezoidal cross-section, with bottom width $b$and side slope coefficient m, then:

$$\omega = h_l(b + mh_l) \quad (4)$$
$$P = b + 2h_l\sqrt{1 + m^2} \quad (5)$$
$$R = \frac{h_l(b+mh_l)}{b+2h_l\sqrt{1+m^2}} \quad (6)$$

where: P— wetted perimeter, m;
R— hydraulic radius, m.
Thus, the final expression for discharge takes the form:

$$Q = \frac{1}{n}\left(\frac{h_l}{2}\right)^{2/3} i^{1/2} \cdot h_l(b + mh_l) \quad (7)$$

The obtained relationship shows that the hydraulic capacity of a ditch is determined not only by its geometry and longitudinal slope, but also by the roughness of the channel bed. However, in the regulatory practice of Kazakhstan, when assigning ditch parameters, primary emphasis is placed on geometric dimensions, while:
– the temporal variability of the roughness coefficient (vegetation overgrowth, silting) is not analyzed;
– the reduction in hydraulic capacity due to contamination from road surface runoff is not taken into account;
– the influence of actual discharge on slope erosion and the subsequent infiltration of polluted water into the soil is not assessed.

Table 2. Influence of key hydraulic and operational parameters on drainage system performance

Parameter	Increase leads to	Effect on system
Roughness (n)	↓ velocity	↓ discharge
Slope (i)	↑ velocity	↑ discharge
Sedimentation	↑ roughness	↓ capacity
Vegetation	↑ resistance	flow obstruction

Table 2 demonstrates that drainage efficiency is influenced not only by design geometry, but also by time-dependent operational factors that are usually neglected in standard practice.

As a result, the hydraulic capacity of the ditch decreases over time, leading to embankment flooding, subgrade over-moistening, and accelerated deterioration of the pavement structure.

3. Results

The analysis of existing highway drainage practices demonstrates that the efficiency of surface water removal is primarily determined by the hydraulic capacity of drainage elements, which depends on a combination of parameters, including channel geometry, longitudinal slope, and surface roughness. However, in current design practice, the emphasis is placed mainly on geometric characteristics, while the influence of operational factors—such as sedimentation, vegetation overgrowth, and contamination of runoff—is largely neglected. As a result, the actual hydraulic performance of drainage systems decreases over time, leading to water accumulation and reduced functionality [16].

The study demonstrates that traditional drainage solutions, particularly earthen ditches, are unable to ensure stable and efficient stormwater removal under real operating conditions. Although such systems are simple in design and cost-effective at the construction stage, their performance is highly sensitive to maintenance practices. In practice, clogging, slope erosion, and sedimentation significantly reduce flow velocity and discharge capacity, leading to periodic flooding of the road embankment and excessive moisture accumulation in the subgrade.

Table 3. Main limitations of traditional highway drainage systems and their consequences

Category	Problem	Consequence
Hydraulic	Capacity reduction	Flooding
Structural	Erosion	Instability
Environmental	Pollution infiltration	Soil contamination

As summarized in Table 3, the deficiencies of traditional drainage systems can be classified into hydraulic, structural, and environmental categories.

Quantitative analysis based on hydraulic relationships confirms that the discharge capacity of drainage channels is strongly influenced not only by cross-sectional parameters and slope, but also by the roughness coefficient, which varies over time. The lack of consideration of this variability in regulatory design approaches leads to a systematic overestimation of drainage efficiency. Consequently, even systems designed in accordance with standards may fail to meet actual operating requirements.

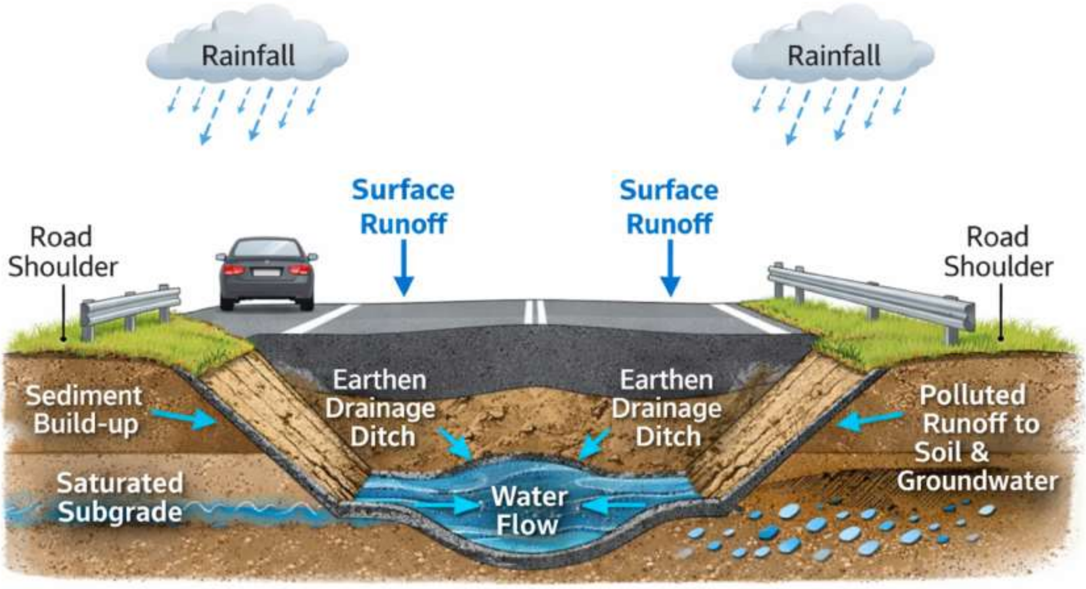

Figure 1. Consequences of insufficient drainage efficiency in highway infrastructure [author’s material]

The results also indicate that insufficient drainage directly affects pavement performance. Excess moisture in the subgrade accelerates structural degradation, reduces bearing capacity, and shortens the service life of road infrastructure. In addition, the accumulation of water on the pavement surface increases the risk of hydroplaning, thereby negatively impacting traffic safety.

A comparative analysis of international practices reveals that modern drainage systems are designed as integrated engineering solutions that combine efficient water removal with environmental protection measures. These systems incorporate impermeable materials, controlled runoff collection, and treatment facilities, which prevent the infiltration of contaminated water into soil and groundwater. In contrast, domestic approaches remain focused on simple water diversion without addressing environmental risks.

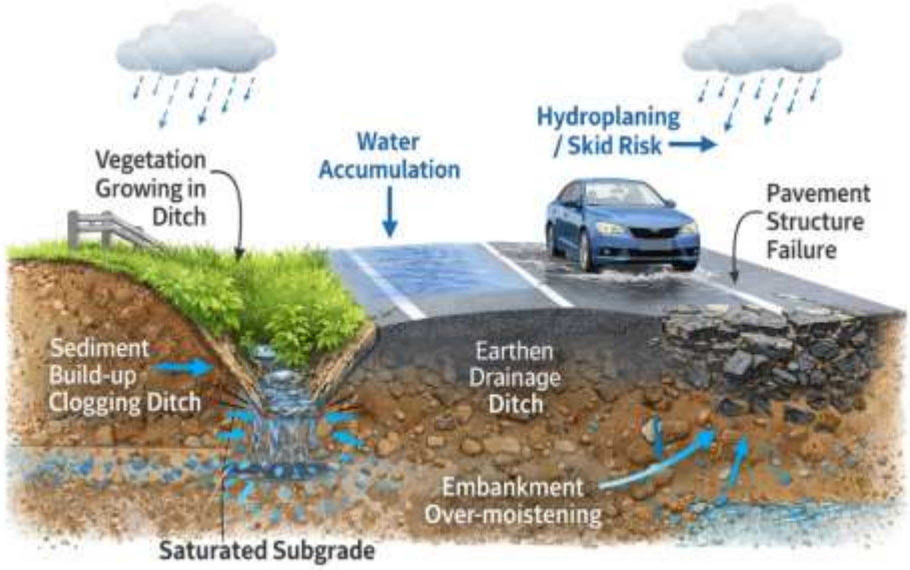

Figure 2. Conceptual comparison of traditional and modern highway drainage systems [author's material]

As shown in Figure 2, modern drainage systems differ from traditional earthen ditch solutions by combining hydraulic functionality with environmental protection.

Figure 3. Modern integrated drainage systems [author's material]

Figure 3 illustrates the concept of modern integrated drainage systems, which combine impermeable drainage channels, controlled runoff collection, and treatment facilities. Unlike traditional systems, these solutions ensure both hydraulic efficiency and environmental protection by preventing the infiltration of contaminated runoff into soil and groundwater.

Furthermore, the study identifies that the environmental impact of highway drainage is often underestimated. Surface runoff from roads contains pollutants that, in the absence of proper collection and treatment, penetrate surrounding ecosystems. The lack of impermeable drainage structures contributes to soil contamination and deterioration of natural water bodies.

The findings confirm that existing drainage systems do not meet modern requirements for reliability, durability, and environmental safety. Their limited hydraulic capacity, combined with the absence of integrated design approaches, results in both technical and ecological inefficiencies.

These shortcomings highlight the necessity of transitioning to advanced drainage solutions that ensure stable hydraulic performance and minimize environmental impact.

4. Discussion

The results of this study clearly demonstrate that existing approaches to highway drainage design are insufficient to meet modern technical and environmental requirements. The widespread reliance on traditional solutions—primarily earthen drainage ditches—reflects a design philosophy focused on simplicity and low initial cost rather than long-term performance and sustainability. While such systems may theoretically ensure surface water removal, their actual effectiveness under real operating conditions is significantly lower due to the influence of dynamic factors that are not accounted for in standard design procedures.

One of the key findings of this research is the discrepancy between the calculated and actual hydraulic capacity of drainage systems. Regulatory design approaches assume constant parameters, particularly the roughness coefficient; however, in practice, this parameter changes over time due to silting, vegetation growth, and contamination of runoff. This leads to a progressive reduction in flow velocity and discharge capacity, ultimately resulting in water accumulation and system failure. Similar limitations have been identified in previous studies; however, they have not been systematically incorporated into design a methodology, which explains the persistence of ineffective solutions.

In comparison with international practice, the gap becomes even more evident. Modern drainage systems are increasingly designed as multifunctional engineering systems that integrate hydraulic efficiency with environmental protection. These systems include impermeable channels, filtration and treatment facilities, and controlled discharge mechanisms, which not only ensure effective water removal but also prevent the pollution of soil and water resources. In contrast, domestic approaches remain largely focused on the simple diversion of runoff, without addressing its quality or environmental impact. This difference reflects a broader shift in engineering priorities, where sustainability and ecological safety are becoming key design criteria.

The implications of inadequate drainage extend beyond technical performance. The study confirms that excessive moisture in the pavement structure significantly accelerates degradation processes, reduces bearing capacity, and shortens the service life of highways. From an economic perspective, this results in increased maintenance and rehabilitation costs. At the same time, safety risks associated with water accumulation—particularly hydroplaning—highlight the direct link between drainage efficiency and traffic safety. Thus, drainage should be considered not as an auxiliary element, but as a critical component of road infrastructure design.

An important contribution of this study is the identification of the need for a more comprehensive approach to drainage design. Such an approach should include:

(i) consideration of time-dependent changes in hydraulic parameters;
(ii) integration of environmental protection measures into drainage systems;
(iii) application of modern materials and technologies that ensure impermeability and durability;
(iv) implementation of monitoring and maintenance strategies aimed at preserving system performance over time.

At the same time, the study has certain limitations. The analysis is primarily based on existing design practices and theoretical relationships and does not include large-scale experimental validation under different climatic and operating conditions. In addition, economic assessments of the proposed solutions require further detailed investigation. Future research should focus on developing quantitative models that account for the variability of hydraulic parameters, as well as on testing innovative drainage systems under real field conditions.

Overall, the findings indicate that a transition from traditional, simplified drainage schemes to integrated and adaptive systems is necessary. Such a transition will allow not only to improve the durability and reliability of road infrastructure, but also to significantly reduce its negative impact on the environment.

5. Conclusion

This study evaluated existing methods for organizing surface drainage from highways and assessed their effectiveness under modern operating conditions. The analysis confirms that traditional drainage solutions widely used in current practice do not provide sufficient hydraulic efficiency and fail to meet contemporary requirements for durability, safety, and environmental protection.

It was established that the predominant use of earthen drainage ditches, despite their simplicity and low construction cost, leads to several operational problems. Their hydraulic capacity decreases over time due to silting, vegetation growth, and contamination, which are not adequately considered in standard design approaches. As a result, water accumulation occurs, contributing to embankment over-moistening, reduced bearing capacity of the subgrade, and accelerated deterioration of pavement structures.

The study also demonstrated that insufficient drainage has a direct negative impact on traffic safety and environmental conditions. The presence of surface water increases the risk of hydroplaning, while uncontrolled runoff contributes to soil and groundwater contamination. These findings highlight the need to reconsider the role of drainage systems as a critical component of highway infrastructure rather than a secondary design element.

A comparison with international practice revealed a significant gap between domestic and advanced foreign approaches. Modern drainage systems are designed as integrated solutions that combine efficient water removal with runoff regulation and treatment, ensuring both technical performance and environmental safety. In contrast, existing approaches remain limited to basic water diversion without addressing long-term sustainability.

Based on the obtained results, it is concluded that improving highway drainage systems requires a transition to more advanced engineering solutions. Such solutions should incorporate consideration of time-dependent hydraulic parameters, application of durable and impermeable materials, integration of environmental protection measures, and implementation of regular monitoring and maintenance strategies.

The findings of this study can be used as a basis for further development of scientifically grounded and economically efficient drainage design methods aimed at increasing the service life of highways and reducing their environmental impact.

Conflict of Interest. The corresponding author declares that there is no conflict of interest.

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References

1. Chu, X., Campos-Guereta, I., Dawson, A., & Thom, N. (2023). Sustainable pavement drainage systems: Subgrade moisture, subsurface drainage methods and drainage effectiveness. *Construction and Building Materials*. https://doi.org/10.1016/j.conbuildmat.2022.129950.
2. Yang, S., Park, H., & Baek, C. (2023). Fatigue Cracking Characteristics of Asphalt Pavement Structure under Aging and Moisture Damage. *Sustainability*. https://doi.org/10.3390/su15064815.
3. Gillis, P., Parrott, J., & Helm, P. (2022). Environmental Fate and Effects of Road Run-Off. *Archives of Environmental Contamination and Toxicology, 82*, 159 - 161. https://doi.org/10.1007/s00244-021-00906-3.
4. Ogbozige, F. (2025). Hydrologic analysis and hydraulics design of surface drainage for stormwater: A neglect of vital aspect. *KIU journal of science engineering and technology*. https://doi.org/10.59568/kjset-2025-4-1-06.

5. Sambito, M., Severino, A., Freni, G., & Neduzha, L. (2021). A Systematic Review of the Hydrological, Environmental and Durability Performance of Permeable Pavement Systems. *Sustainability, 13*, 4509. https://doi.org/10.3390/su13084509.
6. Tota-Maharaj, K., Karunanayake, C., Kunwar, K., Chadee, A., Azamathulla, H., & Rathnayake, U. (2024). Evaluation of Permeable Pavement Systems (PPS) as Best Management Practices for Stormwater Runoff Control: A Review. *Water Conservation Science and Engineering, 9*. https://doi.org/10.1007/s41101-024-00259-7.
7. García-Haba, E., Hernández-Crespo, C., Martín, M., & Andrés-Doménech, I. (2023). The role of different sustainable urban drainage systems in removing microplastics from urban runoff: A review. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2023.137197.
8. Yunianta, A., Suripin, S., & Setiadji, B. (2020). Application of Sustainable Road Drainage System: Simulation by Using SWMM Program. *Civil Engineering and Architecture, 8*, 55-65. https://doi.org/10.13189/cea.2020.080203.
9. Ssempeera, P. (2023). Integrated Drainage Systems Planning and Design for Municipal Engineers. . https://doi.org/10.1201/9781003255550.
10. Kayhanian, M., Li, H., Harvey, J., & Xiao, L. (2019). Application of permeable pavements in highways for stormwater runoff management and pollution prevention: California research experiences. *International journal of transportation science and technology, 8*, 358-372. https://doi.org/10.1016/j.ijtst.2019.01.001.
11. Lee, W., Kwon, S., Kang, J., & Jun, H. (2025). Estimation and Application of Pipe Roughness Considering Diameter and Service Life in Urban Drainage Systems. *Journal of the Korean Society of Hazard Mitigation*. https://doi.org/10.9798/kosham.2025.25.3.43.
12. Chai, J., Miura, N., & Nomura, T. (2004). Effect of hydraulic radius on long-term drainage capacity of geosynthetics drains. *Geotextiles and Geomembranes, 22*, 3-16. https://doi.org/10.1016/s0266-1144(03)00048-7.
13. Kanso, T., Tedoldi, D., Gromaire, M., Ramier, D., Saad, M., & Chebbo, G. (2018). Horizontal and Vertical Variability of Soil Hydraulic Properties in Roadside Sustainable Drainage Systems (SuDS)—Nature and Implications for Hydrological Performance Evaluation. *Water*. https://doi.org/10.3390/w10080987.
14. Ghavami, M., Hosseini, M., Zavattieri, P., & Haddock, J. (2019). Investigating the Need for Drainage Layers in Flexible Pavements. . https://doi.org/10.5703/1288284316881.
15. Gertsog, V. N., Dolgikh, G. V., & Kuzin, N. V. (2015). Calculation of pavement structures based on smoothness criteria. Part 1: Substantiation of smoothness standards for asphalt concrete pavements. *Magazine of Civil Engineering, 57*(5), 38–47. https://doi.org/10.5862/MCE.57.4
16. Aranda, J., Sánchez-Juny, M., Sanz-Ramos, M., & Beneyto, C. (2023). Design of Drainage Downspouts Systems over a Road Embankment. *Water*. https://doi.org/10.3390/w15203529.
17. Havryshchuk, V., & Kaskiv, V. (2020). Mathematical model for the duration of runoff formation determined from the road surface. *Heliyon, 6*. https://doi.org/10.1016/j.heliyon.2020.e05687.
18. Li, J., Orland, R., & Hogenbirk, T. (1998). Environmental road and lot drainage designs: alternatives to the curb-gutter-sewer system. *Canadian Journal of Civil Engineering, 25*, 26-39. https://doi.org/10.1139/l97-044.
19. Startin, J., & Lansdown, R. (1994). Drainage from Highways and Other Paved Areas: Methods of Collection, Disposal and Treatment. *Water and Environment Journal, 8*, 518-526. https://doi.org/10.1111/j.1747-6593.1994.tb01144.x.
20. Chang, N., Lu, J., Chui, T., & Hartshorn, N. (2017). Global policy analysis of low impact development for stormwater management in urban regions. *Land Use Policy, 70*, 368-383. https://doi.org/10.1016/j.landusepol.2017.11.024.

21.

22. Kasprzyk, M., Szpakowski, W., Poznańska, E., Boogaard, F., Bobkowska, K., & Gajewska, M. (2022). Technical solutions and benefits of introducing rain gardens - Gdańsk case study.. *The Science of the total environment*, 155487 . https://doi.org/10.1016/j.scitotenv.2022.155487.
23. Grigg, N. (2024). Stormwater Management: An Integrated Approach to Support Healthy, Livable, and Ecological Cities. *Urban Science*. https://doi.org/10.3390/urbansci8030089.
24. Tulebekova, A., Zhussupbekov, A., Zhankina, A., Aldungarova, A., & Mamyrbekova, G. (2024). Practical experience in the construction of roads in difficult soil conditions. *Journal of Water and Land Development*. https://doi.org/10.24425/jwld.2024.149115.
25. Government of the Republic of Kazakhstan. (2008). *On approval of the state program “Digital Kazakhstan”* (No. P080000307). Retrieved March 25, 2026, from https://adilet.zan.kz/rus/docs/P080000307
26. Kondratov N.A.Development of transport infrastructure in the Arctic zone of Russia// Geographical bulletin. 2017. No4(43).P. 68–80. doi10.17072/2079-7877-2017-4-68-80