



**Geological Controls on Infiltration Potential in a Reclaimed Wetland Area: A Case
Study of Kishi Taldykol**

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ABSTRACT

The rapid urbanization in Astana has put more pressure on drainage systems. An example of such a region is the Kishi Taldykol (Small Taldykol) basin in the Esil district, where a system of lake and wetlands has been greatly altered by drainage and importation of sandy fill material to facilitate urban development. This research examines the geological controls on infiltration possibilities by laboratory characterization of six soil samples taken at two representative sites one in the native lacustrine profile and the other in the anthropogenic backfill. The Malvern Mastersizer 3000 was used to analyze particle size using laser diffraction and moisture content was determined using the gravimetric analysis. Findings show that the soil type in this area is mostly sandy loam in texture. Based on these findings, it is concluded that the study area is suitable for all 3 categories of Sustainable Urban Drainage Systems (SuDS): infiltration systems, storage systems and conveyance systems, and this kind of complex approach could show the more effective results.

TABLE OF CONTENT

1. INTRODUCTION	4
2. LITERATURE REVIEW	6
2.1 Principles of Sustainable Urban Drainage Systems (SuDS) and Infiltration Systems	6
2.2 Influence of soil texture on infiltration	7
2.3 SuDS performance under various environmental and climatic conditions	10
2.4 Common causes of underperformance of SuDS	14
3. STUDY AREA	15
4. METHODOLOGY	17
5. RESULTS	21
6. DISCUSSION	24
6.1 Interpretation of the results and comparison with previous study	24
6.2 Recommendations on SuDS elements for study area	26
7. CONCLUSION	28
8. REFERENCES	30
APPENDIX A	32
APPENDIX B	34

1. INTRODUCTION

In the last century, the natural hydrological cycle in urban cities has changed fundamentally due to the rapid urbanization. Replacement of natural areas with roads, roof tops and compacted ground surfaces, which is a process driven by urbanization as its core cause, significantly decreases the ability of the soil to absorb rainfall and accelerates surface runoff and intensity of urban flooding (Alemaw et al., 2020; Fletcher et al., 2015). Traditional "grey infrastructure" drainage systems, which only remove storm water, have been found to be less sufficient with the increasing population of cities. There are blue and green infrastructure approaches that complement grey infrastructure and increase their effectiveness (Fletcher et al., 2015). This new approach was introduced by the United Kingdom in the late 1980s known as Sustainable Urban Drainage Systems (SuDS). Instead of increasing the velocity of runoff, SuDS are designed to simulate hydrological behaviour of a catchment through facilitation of infiltration, temporary retention and treatment of stormwater near the source (Woods-Ballard et al., 2007). Local soil conditions are critically important in the effectiveness of any SuDS design. The soil texture and grain size distribution determine the viability of infiltration-based systems like the soakaways and permeable pavements.

Although the knowledge on SuDS is increasing, there is less information available to showcase the application of SuDS in extreme continental climates like that of Kazakhstan. The majority of documented SuDS implementation and performance studies have been conducted in temperate climates of the U.K., Western Europe, North America and Australia where the seasonal extremes are significantly less pronounced. Astana has a very different hydrological context to that which is presented in the typical guidance for SuDS, with the need to consider deep ground frost, spring snow melt and intense summer thunderstorms.

The general trend of global climate changes is highly reflected in the climate in Kazakhstan. Central Asia is experiencing a warming trend, which is more rapid than the global warming, and that extreme weather events are likely to occur more frequently in Central Asia (Zhou, 2014). These trends will be reflected as increased variability in precipitation for Astana, such as longer dry periods together with extreme precipitation events. Surface flooding is further complicated during the spring when the snow pack is melting, especially in low-lying areas built on reclaimed land where the snow pack is frozen and does not allow water to infiltrate and therefore concentrates on the surface. All of these conditions demonstrate the pressing need to adopt a more flexible and multipurpose urban drainage system.

SuDS refer to a wide range of techniques and engineered features such as infiltration systems (soakaways, infiltration trenches, permeable pavements), storage systems (detention basins, retention ponds), conveyance systems (swales, open channels) and source control measures (green roofs, rainwater harvesting) (Woods-Ballard et al., 2007). Not all of these elements are equally suitable for the climatic and geologic conditions of Astana. Pure infiltration systems are limited in effectiveness in regions with deep seasonal frost and shallow saturated zones, and storage and conveyance systems work better in regions that experience large volumes of runoff due to snow melt and flash floods. It is important to identify what categories of SuDS are most appropriate in this context and this is a key aim of this study.

The capital city of Kazakhstan, Astana, has a good potential and high relevance in the use of SuDS. The city has experienced intensive urban development, which resulted in ecologically sensitive terrain. An example of such a place is the Kishi Taldykol (Small Taldykol) basin in the southwestern Esil district, where a natural complex of lakes and wetlands has been significantly altered by drainage and the extensive import of sandy fill material to form a stable construction base. The resultant hydrogeological regime is very complicated: imported sandy backfill lies on top of the initial low-permeability lacustrine clay sediments and results in a stratified system, which is susceptible to perched aquifer formation and surface waterlogging. This is further impacted by the harsh climate of the continent, where ground is heavily frozen through winter, the spring snowmelt that results in a great amount of water over impermeable soil, and intensive thunderstorms in summer that create rapid surface runoff.

The aim of this project is to identify and compare soil materials from the former lake basin (Small Taldykol Lake) and surrounding backfilled areas in order to assess their geological controls on infiltration potential and implications for the efficiency of Sustainable Urban Drainage Systems (SuDS). To achieve this aim, the following objectives were defined:

- To characterize the grain size distribution and soil texture of samples collected from the former lake basin and surrounding areas.
- To compare lacustrine sediments with backfilled sandy materials, identifying differences in sorting, fine content, and vertical variability.
- To interpret the depositional origin of the identified soil materials and their influence on subsurface water movement.

- To evaluate the infiltration potential of the identified soil layers in relation to infiltration-based SuDS.
- To discuss the suitability and limitations of selected SuDS types (e.g. swales, permeable pavements, kerbs with gaps) in a reclaimed wetland environment.

The significance of this study lies in the intersection of applied hydrogeology, urban geology and sustainable urban development. The spring snowmelt season is a common cause of surface flooding of low-lying residential and administrative buildings, transport infrastructure disruption, and destruction of property in areas that were not developed with proper attention to the hydrogeological conditions. Kishi Tal dykol region, a former lake basin that is currently under the active construction of urban areas, is particularly susceptible to such occurrences. This study provides information that can be directly applied by the urban planners, the district administrations and geotechnical consultants involved in the infrastructure decisions through characterizing the physical properties of the soils in this location and assessing their implications in designing SuDS elements. The scope of this research is confined to soil characterization in the lab and qualitative evaluation of SuDS in literature research.

2. LITERATURE REVIEW

2.1 Principles of Sustainable Urban Drainage Systems (SuDS) and Infiltration Systems

During the past century, there has been a noticeable shift in the management of urban stormwater that has shifted away from concentrating on rapid conveyance towards a comprehensive strategy that incorporates hydrological, environmental, and social aims. This traditional "grey infrastructure" was developed with one purpose, thus avoiding local flooding by carrying the runoff to the water bodies. The drawbacks of such traditional systems, namely, the inability to flex and expensive modernization, have increasingly been evident in the complexity of rapid urbanization and climate change (Alemaw et al., 2020; Fletcher et al., 2015).

As a reaction to these systemic failures, Sustainable Urban Drainage Systems (SuDS) developed in the UK in the late 1980s as another philosophy to repair the natural hydrological balance of urban catchments. To control the runoff and guide technical interventions, "The Scope for Control of Urban Runoff" guidelines were developed and further were improved in and finalized the term of SuDS (Woods-Ballard et al., 2007).

SuDS can be considered to denote a wide variety of methods and engineering facilities that are aimed to replicate natural drainage functions by providing the opportunity to decrease runoffs, infiltrate, and reduce the amount of pollutants near the source (Zhou, 2014). There are 4 main criteria for assessing performance of SuDS: 1) hydraulics, 2) water quality, 3) amenity and 4) biodiversity (Woods-Ballard et al., 2007). This was first provided by D'Arcy as the concept of sustainable drainage triangle (quantity, quality, habitat/amenity) and in 1997 Jim Conlin was first who described SuDS as the term of stormwater technology (Fletcher et al., 2015). There is a big variety of SuDS components that are focused on making interaction between the built drainage system and the environment to manage the exceeded flow (See Table A1 in Appendix A). In some cases, it is also known that SuDS can increase its positive impact by treating surface runoff and improving water quality.

In general, SuDS are considered to be multifunctional. In particular, the vegetated systems of SuDS offer environmentally friendly solutions such as carbon sequestration, alleviation of the Urban Heat Island (UHI) effect, recreational space development, Green Infrastructure (GI), and infiltration systems (Charlesworth et al., 2016; Starkey et al., 2025; Helmreich et al., 2025; Lashford et al., 2020).

The term is applied in Europe as Sustainable Urban Drainage System (SUDS), and it is primarily aimed to ensure the preservation of the population's health and water resources as well as to avoid pollution and preserve biodiversity (Zhou, 2014). In Australia, Water Sensitive Urban Design (WSUD) was the suggested catchment-wide approach and engineering solution, where SuDS is an element of the design. WSUD is intended to integrate urban water management into the city landscape in order to reduce environmental degradation and harmonize the water-urban balance. In North America (United States and Canada) the strategy is called Low-Impact Development (LID) which focuses on natural processes interaction with the urban environment to conserve ecosystems. LID is focused on preserving the natural features with smaller-scale hydrological controls to mitigate the negative effects of urbanization. Examples of similar measures include Best Management Practices (BMP) in the US and Low Impact Urban Design and Development (LIUDD) in New Zealand (Zhou, 2014).

2.2 Influence of soil texture on infiltration

Efficiency of infiltration-based SuDS are mostly affected by the physical property of underlying soil to transmit water through the subsurface matrix. This property is based on soil

physics and hydrogeology principles, in which the grain size distribution is the key geological factor of hydraulic conductivity.

Freeze and Cherry (1979) describe infiltration as entry into the soil of water made available at the ground surface, together with the associated flow away from the ground surface within the unsaturated zone. The rate of water movement within a porous media is determined by the Hydraulic Conductivity (K), which is a parameter obtained by the Darcy Law. Although the fluid characteristics (viscosity and density) affect K value, the latter is directly connected to the geometry of the pore network in the soil, which is a direct function of the grain size distribution (Freeze & Cherry, 1979). In granular soil, the Effective Grain Size (D10), which is the particle size at which 10 percent of the mass of the soil is finer, is used to predict permeability. The higher the value of D10 means that there is a coarser pore and higher the fluid movement under gravitational force, while lower D10 value stands for smaller size of the pore space (silt and clay), where the capillary force limits fluid movement (Heath, 1983).

In addition, the sorting of the sediment is an important factor. Sorted soil (grains of similar size, e.g. beach sand) is generally more porous and permeable than a poorly sorted soil (a mixture of gravel, sand, silt and clay). In backfilled materials that are poorly sorted, fine particles (silts and clays) occupy the void spaces between coarse grains and as a result block movement and considerably decrease the hydraulic conductivity (Freeze and Cherry, 1979). The difference can be critical in reclaimed land area, where indigenous lacustrine deposits can be well-sorted, whilst imported backfill is usually heterogeneous and compacted.

In order to make an evaluation of SuDS suitability, the literature on hydrogeology categorizes soils according to their texture and a specific range of hydraulic conductivity. These relationships are summarized in Table 1, which shows the infiltration potential of different soil textures.

Soil Texture type	Effective GrainSize Range	Hydraulic Conductivity(K) (m/day)	Infiltration Potential	SuDS Suitability
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Clean Gravel	> 2.0 mm	$10^3 - 10^4$	Very High	Excellent for all infiltration SuDS; risk of rapid pollutant transport to aquifer.
Sand	0.063-2.0 mm	$10^1 - 10^3$	High	Ideal for soakaways, infiltration trenches, and permeable pavements.
Silty Sand	Mixed	$10^{(-1)} - 10^1$	Moderate	Suitable for permeable paving; may require partial underdrains.
Silt (Loess)	0.002-0.063 mm	$10^{(-3)} - 10^{(-1)}$	Low	Marginal for infiltration; requires large surface area or underdrains.
Clay	< 0.002 mm	$10^{(-7)} - 10^{(-3)}$	Very Low (Impermeable)	Unsuitable for infiltration; requires tanked systems, detention basins, or evapotranspiration strategies.

Table 1. Typical hydraulic conductivity (K) values and infiltration potential for unconsolidated sediments. *Note: Geological values adapted from Freeze & Cherry (1979) and Heath (1983); SuDS Suitability recommendations adapted from CIRIA (2007).*

Sand and Gravel (as shown in Table 1) have values of hydraulic conductivity that is greater than 10 m/day that facilitates rapid infiltration and is the best foundation to use in SuDS techniques. Conversely, fine-grained materials significantly slow down flow; even a small fraction of silt or clay can slow down K value, which will create Low potential of soil (Freeze and Cherry, 1979). In the case of the Kishi Taldykol area, indicating the boundary between the silty sand (moderate) and the clay (very low) layers is very important to establish whether infiltration trenches will work or they will just become a stagnant reservoir.

Nevertheless, geological texture is not the only factor in the urban setting. Compaction has a great impact on these values. Archer et al. (2020) showed that the infiltration rate of the backfill is often much lower than indicated by a surface texture because of anthropogenic compaction that destroyed the soil structure. A silty sand, which is identified as permeable, might become impermeable after being compacted during construction, which is a common case in reclaimed urban areas. Thus, Table 1 offers a geological baseline, but the real performance of backfilled

wetland setting is most likely to be affected by the level of compaction and vertical heterogeneity of fill material.

Another critical geological process that is applicable to reclaimed wetland conditions is the development of a perched aquifer. As shown in Fig.1, in stratified (layered) soils as in backfilled regions, a permeable layer (sand or backfill) can be imposed upon a layer with much less hydraulic conductivity (clay or loam) over the regional water table. The water flowing inside the upper sandy layer is slowed down by the clay layer and this makes the water collect and saturate the sand just above the boundary (Freeze and Cherry, 1979).

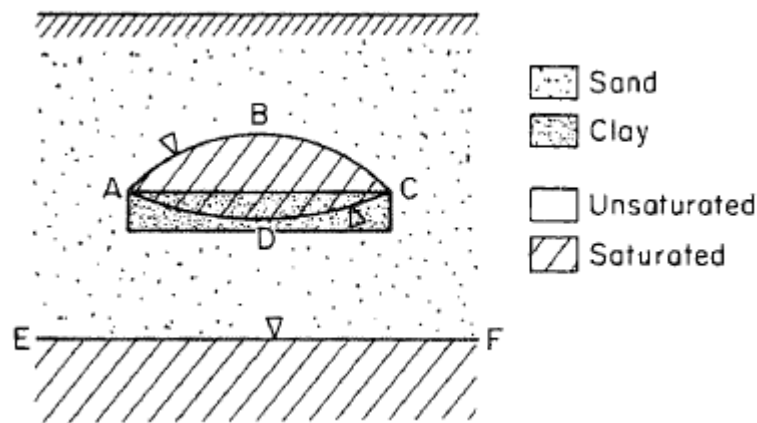


Figure 1. Perched water table ABC, inverted water table ADC, true water table EF (Freeze & Cherry, 1979)

This unconfined zone of saturation is called a perched aquifer, which creates risk in the context of SuDS. Although the table of the regional groundwater may be deep, a perched aquifer may develop quickly during the melt off or heavy precipitation, causing elevation of the water table. This effectively negates the storage capacity of the unsaturated zone as well as may cause failure of infiltration trenches and swales (Heath, 1983). In the case of the Kishi Taldykol region, determining these clay lenses in the backfill is just as important as the infiltration rate.

2.3 SuDS performance under various environmental and climatic conditions

Operational performance of SuDS varies broadly with respect to various factors: based on the specific type of facility selected (e.g. vegetated or. structural), harnesses of the site along with hydrogeological parameters, and even on the local climatic conditions. It has been proved that despite the possibility of SuDS in the case of frequent rainy weather, their work under extreme conditions or in hard soil conditions such as reclaimed backfield or wetlands field must be

carefully adjusted to the specific SuDS to the needs of this area (Archer et al., 2020; Monachese et al., 2025).

Vegetated SuDS, including swales and bioretention cells are based on interactions between soil and plants to treat water and pollutants. According to Helmreich et al. (2025), they believe that these systems require engineered ecosystems, with the root systems of vegetation keeping the soil structure and porosity, which is essential to effective infiltration.

Nevertheless, the hydrological efficiency of swales is closely in question with grain size and texture. Clay presence in underlying soils is characteristic of former lake basins. Conventional swales can serve as the main channel of water movement instead of infiltration (Zhou, 2014). According to Monachese et al. (2025), although such systems are efficient in decreasing the peak flows during the low intensity rainfalls, their effectiveness declines during the high intensity rainfalls in cases of too high infiltration.

Structural methods, including permeable pavements and infiltration trench, emphasize on the quick vertical drainage by using coarse grains. In the study by Archer et al. (2020), the comparison of infiltration rates indicates that the well-designed structural SuDS could sustain an average field-saturated hydraulic conductivity of 1,925 mm/hr, which was far much superior to that of the adjacent backfilled "green areas" that had a mean of only 56 mm/hr. This proves the fact that the structural SuDS tend to be more effective in reducing runoff at the moment in the regions with insufficient natural soil structure (Archer et al., 2020).

Detention basins and retention ponds become central in handling large amounts of runoff especially in flood prone areas and reclaimed areas. The MicroDrainage software used by Lachford et al. (2020) to model the SuDS management train in the UK found that detention basins were the best individual detention component in terms of storage volume and peak flow reduction. The simulation has shown that a management train that includes basins could decrease the peak runoff rates by almost 88% in relation to the traditional drainage (Lashford et al., 2020).

Detention basins, in the situation of reclaimed wetlands, replicate the natural storing. They also need large spaces, which may be limited in congested cities (Lashford et al., 2020). They are also not as reliant on the rate of soil infiltration, which is why they can be used on sites with a high groundwater or a surface with impermeable lacustrine clays, and where infiltration is impossible (Zhou, 2014).

There are specific problems with SuDS implementation in cold, continental climates that are not applicable in temperate areas. As emphasized by Zhou (2014), climate change is increasing

the intensity of the hydrological cycle which results in an increase of occurrence of the Rain on Snow events where warm rainfall is enhancing the melting of the snow and causing enormous volumes of runoff when potentially frozen and impermeable ground might be present.

In cold climates, the hydrological cycle is dominated by winter precipitation as snow and release in the spring as thaw. The “Spring Pulse” creates a big problem in which a huge amount of water is produced at a time when the ground can absorb it least. Nordic countries have shown that when the soil pores are filled with ice, the hydraulic conductivity rate of ground (K) experiences a reduction to near zero which effectively makes permeable surfaces non-permeable (Zhou, 2014). In the case of infiltration based SuDS such as swales or bioretention cells, they tend to be surface conveyance channels during the critical melt period (Fig. 2). The example of Canadian and Scandinavian environments show good performance in such conditions. In particular, using bioretention cells with internal water storage (IWS) zones, systems can operate anaerobically below the frost line so that even when surface infiltration is hindered, they could carry on with some treatment capacity. Also, there are designated snow storage areas next to sensitive infiltration areas that enable melt water to be pre-treated in snow storage areas prior to entering the SuDS device, avoiding thermal shock and clogging (Woods-Ballard et al., 2007). These processes indicate that the infiltration capacity is lower in winter, but the system performance may be maintained with the help of well-designed systems that consider the changes of phases in the water cycle.



Figure 2. Conveyance swale (Woods-Ballard et al., 2007)

The Sponge City project in China could be a relevant analogue for Astana, especially its pilot projects in the north and continental cities of Jinan and Baicheng. There is a shortage of water during summer and freezing during winter. It was observed that their infiltration methods are

frequently ineffective because of high silt content in soils, dust and ice coverage on soil (Zhou, 2014). As a solution, the northern Sponge Cities have been optimized by replacing pure infiltration trenches with sunken green spaces (see Fig. 3). These sunken areas allow for the temporary pooling of snowmelt on the surface, where it can slowly infiltrate or evaporate once the ground thaws, rather than forcing immediate vertical drainage (Zhou, 2014). The strategy is known as “Store first, infiltrate later”, which is important where the soils have low permeability.

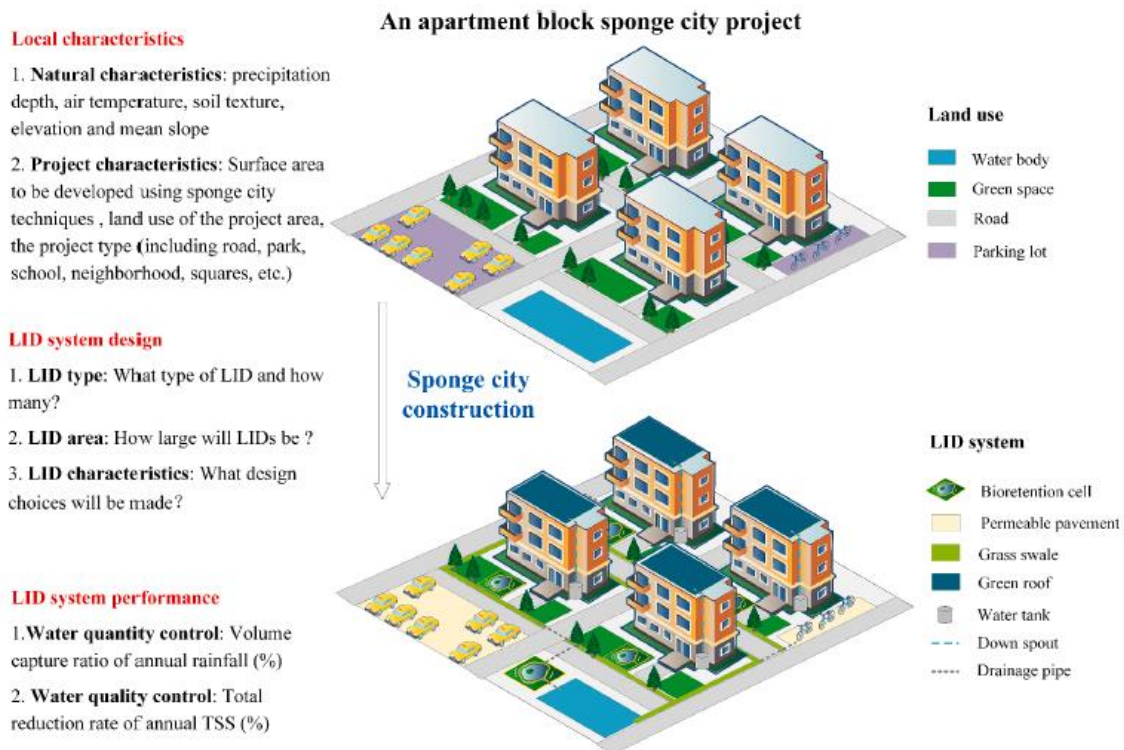


Figure 3. Conceptual model for a sponge city case and its key elements (Zhou, 2014)

The continental climates are also likely to experience high-intensity thunderstorms that cause flash floods besides the snowmelt. In reclaimed soil of urbanized catchment, the rate at which water flows to the drain is very low, because of soil sealing. Even though permeable pavements are useful in coping with the frequent and low intensity rains, they may be overwhelmed by high intensity flash floods when the underlying storage is full, or when the pavement is congested (Archer et al., 2020). One notable case of such treatment was the Cloudburst Management Plan that was worked out in Copenhagen after the devastating flash floods in 2011. The city restructured the street network to serve as water movement channels. During extreme events where the runoff is directed into large detention basins instead of flowing to the overwhelmed sewer system. Also, a related example was installed in the UK. In 2005, SuDS was installed as part of a car park at Red Kite House in Wallingford, Oxfordshire, UK (Fig. 4),

which is representative of a moderate-use car park, where it is in relatively heavy use during the day, 5 days of the week. It was designed as a total infiltration pavement where all the rainfall infiltrates into the underlying soils with no discharge from the system (Woods-Ballard et al., 2007). The car park consists of a permeable block surface within parking bays and impermeable block surface in the aisles. Kazakhstan, especially highly urbanized areas such as Astana, need such a strategy to infiltrate in summer floodings.

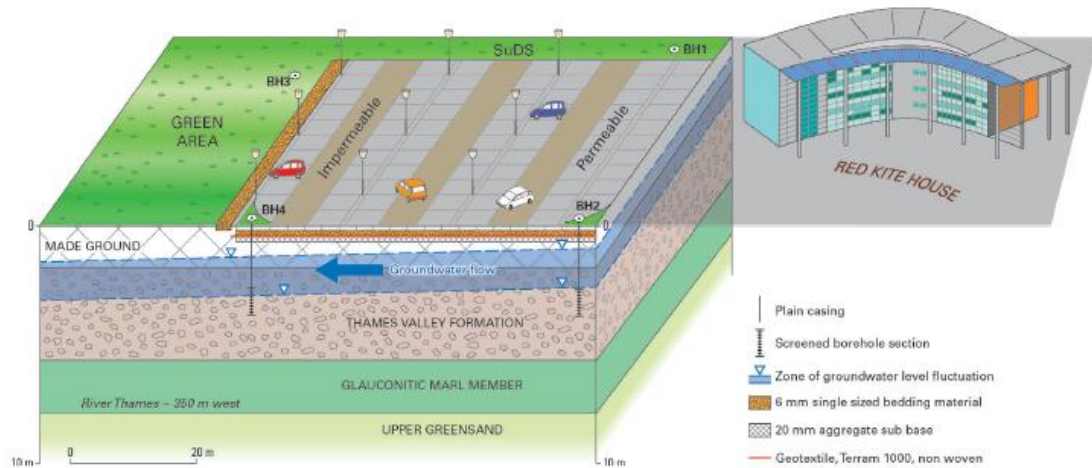


FIGURE 2 Site design and borehole (BH) construction

Figure 4. Site design and borehole (BH) construction (Woods-Ballard et al., 2007)

2.4 Common causes of underperformance of SuDS

Although the concept of SuDS seems to be theoretically advantageous, design flaws, maintenance problems and environmental pressures tend to undermine their effective implementation. Below the possible reasons for SuDS underperformance are provided.

A major system failure mode of filtration-dependent systems is clogging. The research by Zhou (2014) cites the literature in which infiltration trenches did not last as long as they were supposed to since fine sediments would accumulate. In the same way, the permeable pavements can be prone to surface sealing when the fine materials are carried away in the adjacent backfilled slopes or construction areas (Archer et al., 2020). In the case of vegetated systems such as swales, the sedimentation effect may cover the grass and decrease the channel conveyance capacity (Monachese et al., 2025).

The vegetated SuDS are also susceptible to biological failures that are absent in structural systems. Helmreich et al. (2025) point out that there is the risk that the biocides or an abundance of nutrients in urban runoff can cause a decrease in the soil microbiome, which is fundamental

in nutrient cycling. The stresses of drought during summer and salt deposits during winter may cause bare patches of soil in swales, then they become eroded and compacted, and, as a result, undergo hydraulic failure (Helmreich et al., 2025).

One of the failures that have not received much attention is the contact with ground water. (Archer et al., 2020) revealed that a highly efficient SuDS device will not work in the case of insufficient capacity of the underlying aquifer. Low-permeability of clays may occur in the former lake basins, which may slow down vertical percolation and accumulate infiltration trenches (Archer et al., 2020; Charlesworth et al., 2016). This highlights the fact that in a complex geological environment generic SuDS designs do not work as in that environment the infiltration rate is not homogeneous as it is assumed to be.

Other than technical design, governance and regulatory frameworks can be the most important obstacles to successful implementation of SuDS. One Spanish case study has established the absence of national standards and technical requirements as a key barrier to adoption (Andres-Domenech et al., 2021). The barriers were divided into social/governance, regulatory and technological domains, and governance and regulatory ones have been admitted as the most difficult because of the lack of economic resources.

Likewise, application of SuDS in developing countries is characterized with certain structural impediments. The issue of irregular housing plans, absence of proper policies, sophisticated high-density drainage systems, mixed sewer systems become a challenge when it comes to large-scale implementation. The lack of standard design criteria, as well as decision support tools, makes the choice of suitable models difficult, and the process of integrating models between various geographical scales consumes a lot of data preparation (Zhou, 2014).

3. STUDY AREA

The research site falls in the Kishi Tal dykol (Small Tal dykol) lake basin in the southwestern area of the capital city of Kazakhstan (Fig. 5). The site is geographically located on the floodplain of the rivers Nura and Ishim, where a historical feature of a system of interrelated steppe lakes and wetlands was formed. The study area is in the active urban development area of Esil district of the city, where the rapid development of the residential and administrative infrastructure of the city is being observed.

In the past, Kishi Tal dykol has served as a natural evaporation basin and a wetland biodiversity. Nevertheless, the region experienced a dramatic anthropogenic change in recent years to ensure urbanization and construction. This was done by draining the lake basin partially and filling it

back with large volumes of imported soil materials, to form a stable construction platform. Most of the original water body has been covered or divided into small, isolated ponds as observed in the field investigation and has changed the landscape of a natural wetland into a complex mosaic of the reclaimed land and the remains of the lacustrine features.

The severe and extreme continental climate of Astana controls the hydrological functioning of the study area and poses certain drainage design challenges. There is long and harsh weather throughout the winter period with temperatures going as low as -30°C resulting in deep penetration of frost in the soil. Summers are short, hot, and dry. The average precipitation is about 300-350 mm per year. Though this value is on the lower side, it is not equally distributed. The two important events that dominate the hydrological cycle are the spring snowmelt and summer flash floods. The meltdown accumulated winter precipitation in a tremendous mass of snowmelt in March-April in a very short thaw period. The ground is usually still frozen (impermeable) at this time, with the result that surface runoff and surface ponding are likely to be severe in the low-lying reclaimed land such as Taldykol. Thunderstorms of high intensity and short duration take place during summer (June-July). The geology of the Kishi Taldykol region is characterized by the native lacustrine sediments and the anthropogenic backfill. The historic lake bed is composed of alluvial-lacustrine deposits of Quaternary. They are normally cohesive fine-grained soils (clays, silty clays and loams) which are naturally low in hydraulic conductivity (K). These layers also serve as an aquitard, limiting the downward percolation of water and maintaining the inherently high ground water table in the region. The wetland areas were filled up to enable construction of the site. Observations made in the field reveal that this fill material is more sandy which was probably imported to stabilize the structure and enhance drainage.

The interaction between these two distinct geological units, the permeable sandy backfill overlying the impermeable native clay, creates a complex hydrogeological environment. One more important issue is that in wet seasons, the perched aquifer is overfilled with extreme precipitation, when the soil becomes saturated with water and this leads to flooding.



Figure 5. The map of study area (black borders show the constructed area in Kishi Taldykol, red borders show the study area)

4. METHODOLOGY

The sampling method was designed to capture the distinct geological variability of the Kishi Taldykol area. Sampling was done through conventional excavation techniques from the location shown in Fig. 6. Two sampling points were selected:

- Point 1 (Native Lacustrine Profile): Located within the historic boundary of the lake basin. Samples 1B and 1C represent native soil materials, while 1A (Bottom) was identified as adjacent construction backfill.
- Point 2 (Anthropogenic Backfill): Located in an area reclaimed approximately 10 years ago using imported quarry sand.

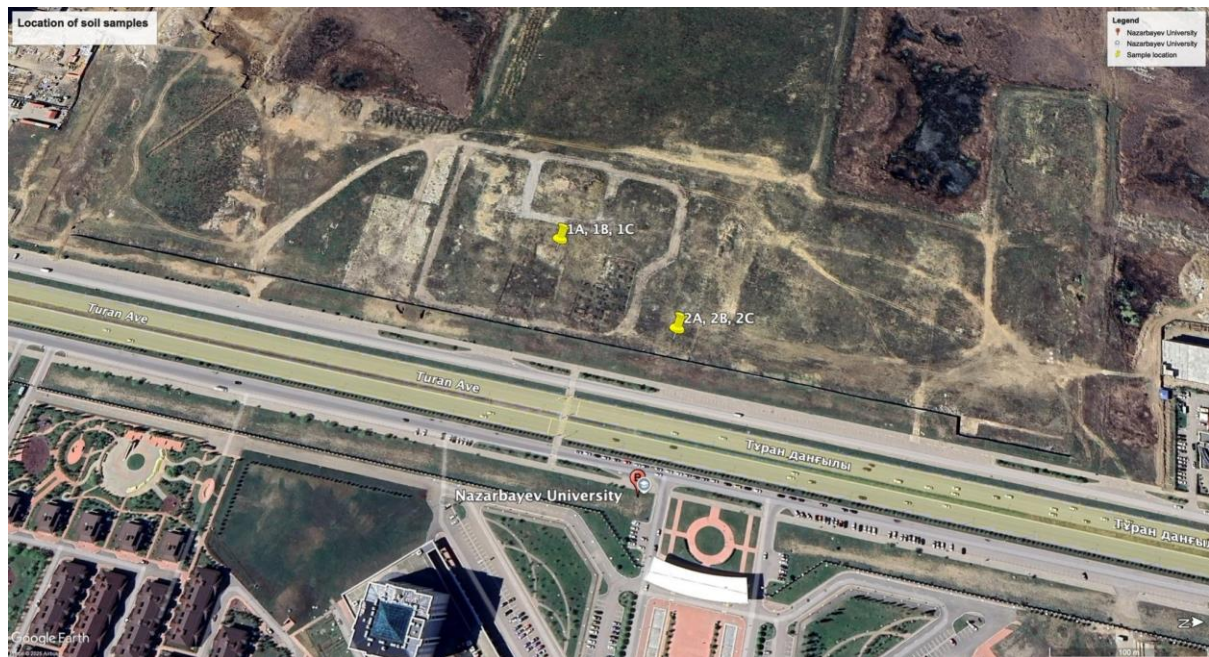


Figure 6. The location of samples 1B, 1C, 2A, 2B, 2C

A total of six (6) soil samples were collected across three depth intervals (Top, Middle, Bottom) at each location. Each sample has its own colour shown in Table 2. It is noted that in both cases samples taken from deeper zones have dark brown colour, while those taken from surface are lighter in colour. This is an indicator of moisture in the soil content giving them darker shades of brown.

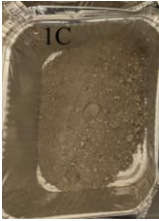
Sample name	Depth	Colour
1 A (bottom)	343.9 m (a.s.l)	 Dark brown
1 B (middle)	344.2 m (a.s.l)	 Brown
1 C (top)	345 m (a.s.l)	 Light brown
2 A (bottom)	2.5 m	 Dark brown
2 B (middle)	1.5 m	 Brown
2 C (top)	0.2 m	 Light brown

Table 2. 6 soil samples from Kishi Taldykol' and their characteristics

Before being subjected to laser granulometry, the samples of raw soil were subjected to pre-treatment which isolated the organic fraction and made a homogeneous sample for further analysis. The step-by-step sample preparation is seen in the following diagram:



Figure 7. Soil sample preparation procedure (*Note: AI generated image*)

Since laser granulometer is used for small particles, to get rid of the particles more than 2 mm in size, a sieve method was used. Then, samples were put in a special drying oven at 105°C over a period of about 12 hours as specified in ASTM D2216 standard (Howard, 1989). This effectively evaporated pore water and burnt organic components that could bias the results of grain size. To evaluate the saturation level, two standard hydrological parameters were calculated from the weight differences:

1. Gravimetric Water Content (θ_g): This measures the mass of water relative to the mass of the dry soil particles. It is calculated using the formula 1 (Hillel, 1998):

$$\theta_g = \frac{W_{before} - W_{after}}{W_{after}} \times 100$$

(1)

2. Total Moisture Content (MC, Wet Basis): This calculates the percentage of the original total mass that consisted of water and volatile organics. It is calculated using the formula 2 (Hillel, 1998):

$$MC = \frac{W_{before} - W_{after}}{W_{before}} \times 100$$

These samples were then homogenized by a mortar and pestle until homogeneous mass was obtained. This was to make sure that aggregates of cemented soil were broken down into particles before they were analysed.

The Malvern Mastersizer 3000 laser diffraction particle size analyzer was used to determine the particle size distribution (PSD). This tool relies on the laser diffraction concept (Mie theory) of which particles move through a focused beam of laser which diffracts the light at angles that are inversely proportional to the particle size. When the particles are large, they will scatter the light at low angles, whereas when they are small, they will scatter the light at larger angles. In each sample multiple measurement runs were carried out to make sure that results are repeatable and reliable. Averaging of these runs was done with the device software to give a representative grain size distribution curve. Using the data generated from Mastersizer 3000, the percentages of sand, silt, and clay were obtained as the total percentage of cumulative volumes at the standard particle size boundaries (Soil Science Division Staff, 2017):

- Clay: $< 2 \mu\text{m}$
- Silt: $2 \mu\text{m} - 50\mu\text{m}$
- Sand: $> 50\mu\text{m}$

5. RESULTS

Before and after the drying of samples their weights were measured to quantify the mass loss. This loss indicates how much water was evaporated and organic was removed (Table 3).

Soil sample	Weight before, mg	Weight after, mg	Difference, mg	Gravimetric Water Content (θ_g)	Total Moisture Content, MC(%)
1A (bottom)	86.93	81	5.93	7.3	6.8
1B	146.3	142.41	3.89	2.7	2.7

1C (top)	98.37	96.31	2.06	2.1	2.1
2A (bottom)	186.15	119.25	66.9	56.1	35.9
2B	99.62	90.49	9.13	10.1	9.2
2C (top)	152.63	150.84	1.79	1.2	1.2

Table 3. Weight of soil samples before and after drying

The most significant result of this analysis is the enormous difference in weight of Sample 2A (the bottom layer). In this sample, about 35.9% of Moisture Content (66.9mg) was lost. This extreme loss quantitatively validates that the deeper strata at point 2 are heavily water-saturated and located close to groundwater.

Such a high level of saturation is a strong indication that the level was close to the regional ground water table or there was also a localized perched aquifer above the native impermeable clays. On the other hand, there were slight variations in the mass of the surface and intermediate samples (1C, 2C, 1B), which are typical of arid, unsaturated soils that were present in Astana due to the dry, continental climate conditions at the time of the experiment (non-precipitation).

The graph below (Fig. 8) represents a Particle Size Distribution (PSD) analysis for soil samples 1A, 1B, 1C, 2A, 2B, 2C. X-Axis shows the particle size in micrometers on a logarithmic scale. The Y axis represents the percentage of each particle size in the sample. Multimodal distribution in all graphs since the particle sizes are different showing the diverse composition of soil. The PSD graph for each sample is shown in Appendix B.

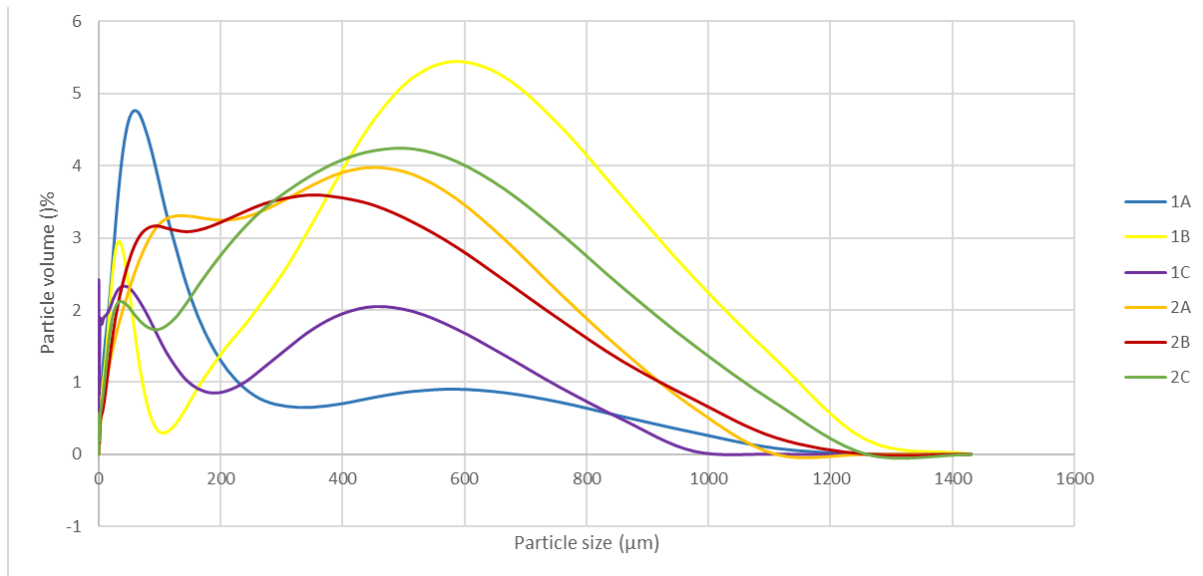


Figure 8. PSD graph with 6 soil types

The obtained results from Mastersizer 3000 are represented in Table 4 showing the percentage of sand, silt and clay in soil samples. The values are obtained through calculation of the continuous cumulative volume distributions. Particularly, the exact volume percentage was summed up across 3 standard particle size thresholds: clay ($< 2 \mu\text{m}$), silt ($2\text{--}50 \mu\text{m}$), and sand ($> 50 \mu\text{m}$). Further, these values were cross-referenced with USDA triangle to identify the exact soil type classification, which is shown in Figure 9.

Sample ID	Sand (%)	Silt (%)	Clay (%)	Soil type
1C (Top)	34	49	17	Loam
1B (Middle)	58	37	5	Sandy loam
1A (Bottom)	49	45	6	Sandy loam
2C (Top)	66	30	4	Sandy loam
2B (Middle)	68	28	4	Sandy loam
2A (Bottom)	70	27	3	Sandy loam

Table 4. Grain size distribution and soil textural classification

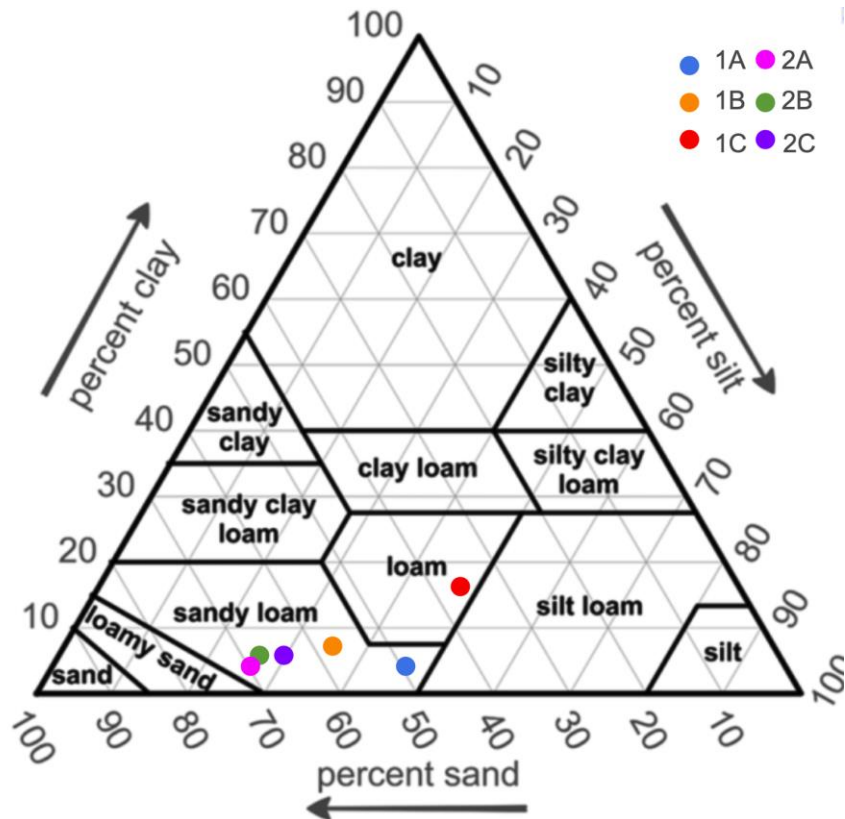


Figure 9. USDA soil textural triangle with samples' identification (Soil Science Division Staff, 2017)

In point 2, the soil has a texturally homogenous profile at all the three depths measured. Although these samples are categorized as sandy loam due to dominant sand composition (66% to 70%), the presence of fines (comprised of silt and clay 30% to 34% of the volume) is very high. Point 1, on the contrary, shows a significant increase in vertical heterogeneity. The upper layer (1C) is a Loam, with a significant fine proportion (66%). The texture changes to Sandy loam as the profile continues to deepen to samples 1B and 1A, although the silt fraction is quite high (37% to 45%).

6. DISCUSSION

6.1 Interpretation of the results and comparison with previous study

The gravimetric moisture analysis gives a clear understanding of the hydrology of the two sampling points despite having a small set of data. The most outstanding observation is the significant difference in the soil profile. Just as is typical of a continental climate at a time of dry conditions, the majority of samples are dry near the surface.

Beginning with sample 1C (MC 2.1%), 1B (MC 2.7%), 2C (MC 1.2%), and 2B (MC 9.2%), each of them has typical moisture levels of unsaturated near-surface soils. It is a normal hydrogeological trend that the surface (2C) to the middle layer (2B) increases in moisture slightly. The fact that evaporation is less intense further down the depth would mean that steady decline in moisture through a downward mechanism is completely consistent with the normal behavior of the vadose zone (Fig. 10).

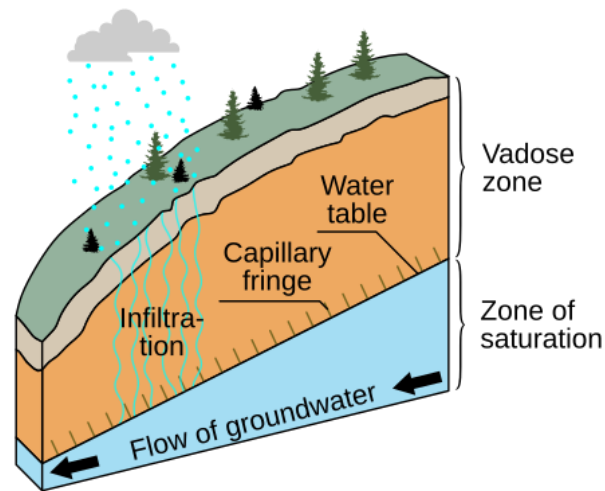


Figure 10. Cross-section of a hillslope with the depiction of vadose zone and zone of saturation. (U.S. Geological Survey, n.d.)

Sample 1A (lower part of Point 1) contains a total moisture content of 6.8 %, which is higher than in 1B. Sample 2A is an important outlier. It registered a gravimetric water content of 56.1 % and a total moisture content of 35.9 %. The gravimetric water content for a sandy loam is expected to be 40-60%, depending on how densely the soil is packed. Hence, the Sample 2A has 56.1% of θ_g suggesting that it is at maximum saturation capacity at the time of collection.

This extreme saturation can be explained in 2 different ways. Either the bottom of the excavation at Point 2 was at the base of the regional shallow water table or infiltrating water has accumulated above the underlying native clay layer. The second situation is the case of perched aquifers. The site is a former lake basin; the naturally shallow water table and permeable sandy backfill, which is deposited on top of the low-permeability clays, are highly likely to be present and can act in combination with either of the two mechanisms. The native clay is an aquitard that prevents the deeper draining of water, but compels it to stagnate in the sandy layers near the surface. However, the saturation of Sample 2A is a critical finding

irrespective of the specific mechanism. It demonstrates that at a depth of about 2.5 meters, no storage space is available to infiltrate the urban stormwater.

There is a previous study that also analyzed soil samples taken from the NU area (Raiymkulov, 2024). The most important result of the comparison between this and previous study is the textural contrast between the two categories of samples. According to this study, the composition of the average grain size of silt and clay is 41.85% and 58.14% respectively, with no significant sand fraction. Using USDA triangle, they are categorized as clay. So, a big difference is noted between 2 case studies, one showing impermeability (previous study case) and another one with higher permeability (actual study). This will definitely impact the choice of SuDS elements.

The reason behind the difference in the samples could be explained by the historical development of this area. The NU campus was constructed on the ground that was not under the lake or wetland conditions. It has terrestrial soils, presumably, aeolian or alluvial deposits that have undergone soil formation processes in the semi-arid steppe climate of the region. At the Kishi Taldykol site, however, until recently, it was the lake basin. Due to intensive urbanization, the city growth led to the use of the lake as a potential construction site, which led to burial of the lake with sand.

6.2 Recommendations on SuDS elements for study area

Generally, the SuDS components might be categorized as infiltration systems (soakways, permeable pavement), storage systems (ponds and basins), conveyance systems (swales and channels), and source control systems (green roofs) (Woods-Ballard et al., 2007). The first three categories might be used in this case study of Astana.

Infiltration-based SuDS such as soakaways and permeable pavements operate by directing stormwater into the soil profile where it can be absorbed by the soil and move down to recharge the groundwater. Their applicability directly depends on the hydraulic conductivity (K) of the soil, which depends on the grain size distribution as noted in the literature review. According to the textural classification of the samples of this study (Table 4), the large part of the profile belongs to the sandy loam category with the sand contents between the 49% and 70% and silt fractions between the 27% and 45%. Sandy loam has a moderate potential of infiltration and can be used in permeable paving and partial underdrains.

However, the most significant result that limits the use of infiltration systems in this location is the high degree of saturation of Sample 2A. This is evidence of regional shallow groundwater or a perched aquifer that has formed above underlying native clay aquitard. Either way, there is practically no unsaturated storage capacity below about 2.5 metres.

Permeable pavements are a more suitable infiltration system in this case. Instead of directing the entire water to the depth, permeable block paving in parking or the pedestrian zones might be used to absorb the low to moderate intensity rainfall events. This water will pass through the surface into the lower granular base, which in turn will gradually infiltrate into the upper sandy loam horizon. Considering the limitations above, it would be recommended to include underdrain pipes to avoid waterlogging and offer a discharge channel during high saturated or frozen conditions. Decrease in surface runoff during summer thunderstorms would have a significant impact in terms of decreasing high water flows to the drainage system. It is also worth mentioning that permeable pavements are much prone to clogging by fine sediments that would be meaningful in this site as there is the silt and clay fraction.

Considering the hydrogeological limitations of Kishi Tal dykol, surface storage facilities, mainly detention basins and retention ponds, would probably be the most effective SuDS elements in this case. In contrast to infiltration systems, detention and retention ponds do not depend on permeability. They work by temporarily storing stormwater on the surface to enable attenuation of peak flows before they are subsequently released into the environment or gradually evaporated and infiltrated. This allows them to be highly effective in areas where the ground water is shallow, impermeable clay layers, and frozen ground cover.

Detention basins would be especially applicable in the two major hydrological events at this location: the spring snowmelt and flash flooding in the summer. Once the ground is mostly impermeable in the spring thaw period, when the frost penetration causes large volumes of snowmelt runoff, the basin would intercept the runoff and temporarily store the large amounts of water during the thaw period. The literature findings note that these storage elements have the potential to decrease peak runoff rates by up to 88% relative to conventional drainage structures (Lashford et al., 2020), which is a significant positive change compared to the current state.

The conveyance category of SuDS consisting of swales and open drainage channels are designed to fulfill both the purpose of conveying surface runoff and some infiltration and

water quality enhancement. Swales are the most reasonable in Kishi Taldykol since they are surface conveyance elements that direct stormwater off impermeable surfaces to detention storage.

With the help of sandy loam texture, during dry summer conditions shallow-rooted vegetation systems could be planted and sustained in a swale base. This will provide surface roughness that will lead to slower flow of water and less erosion. However, when the depth changes to near-saturated conditions and when the ground is frozen in winter and early spring, infiltration in the swale base will be either insignificant or not present during the most dangerous runoff. Instead, the swales are supposed to be designed as conveyance structures with sufficient cross-sectional area and longitudinal gradient to accommodate the snowmelt and storm flows that are linked up to the proposed storage systems.

The cold-climate design strategies that are reported in Nordic and Canadian settings are applicable in this case. Specifically, the application of special snow storage areas near swales, where the melting snow would be treated or held until it gets to the main drainage channel, may be used to control the amounts of concentrated water generated in the spring thaw (Woods-Ballard et al., 2007). Moreover, the Copenhagen Cloudburst Management model, which restructures street networks to serve as water conveyance channels during extreme events, provides an urban-scale prototype that could be applied to the road and pathway network of the developing area of Kishi Taldykol as more urbanization takes place.

To conclude, the findings of the soil investigation indicate that the most suitable structure to apply to Kishi Taldykol is a SuDS management train composed of conveyance swales, detention storage basins, and selectively placed permeable pavements with underdrains. Solutions that involve only infiltration like soakaways are not advisable due to the presence of a shallow saturated zone. Any detailed design would need additional geotechnical research such as borehole drilling, groundwater observation throughout seasons, and hydraulic modelling of the volumes of catchment run off during design storm events.

7. CONCLUSION

This research has explored the hydrogeological characteristics of Kishi Taldykol reclaimed lake basin, located in Astana, with the aim of evaluating the hydrogeological suitability of the site to Sustainable Urban Drainage Systems (SuDS). Analysis of six soil samples in the

laboratory by laser diffraction particle size analysis and gravimetric moisture determination indicated that the backfilled profile consists of mostly sandy loam in texture, with sand fractions that vary between 49% and 70%. Although there is a moderate permeability at the surface, the most notable observation is that the saturation is near-complete at around 2.5 metres depth at Point 2 (gravimetric water content 56.1%), suggesting that there is a shallow perched aquifer or regional groundwater table above the underlying native lacustrine clays.

Based on these findings, it is proposed that a SuDS approach combining detention storage, conveyance swales, and well-designed permeable pavements with underdrains would be the most viable approach considering the condition of the soil and the harsh continental climate. The history of the site as a wetland and lake basin provides a good justification to reestablish the aspects of surface water storage as part of the urban drainage design. Since the Esil district is a rapidly expanding area, the following recommendations are given for the future urbanisation in this part of the city. New construction projects should have surface water storage components, such as detention basins or retention areas, especially in former lake basins. They temporarily store stormwater to attenuate peak flows before gradual release. This is a universal choice specifically in this area since it does not depend on infiltration potential of the soil. Second, the use of conveyance swales are important for snowmelt and storm flows. They could be integrated in the existing projects and direct stormwater off impermeable surfaces to detention storage. Third, as part of the infiltration systems, permeable pavements with underdrains are recommended for parking areas and pedestrian zones, as they can offer an additional runoff reduction while maintaining the pavement's functionality. Lastly, future works should be accompanied by site-specific geotechnical investigations, such as borehole drilling and monitoring of the groundwater at different times of the year, to characterize subsurface variability and prevent the potential for groundwater saturation problems. Incorporating these into the planning and regulation processes of the Kishi Taldykol development area would result in a more resilient urban development in the longer term and lower the risk of flooding for future users and infrastructure.

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APPENDIX A

Component	Description	Example
Constructed wetlands	Constructed wetlands are ponds with shallow areas and wetland vegetation to improve pollutant removal and enhance wildlife habitat.	
Filter drains and perforated pipes	Filter drains are trenches that are filled with permeable material. Surface water from the edge of paved areas flows into the trenches, is filtered and conveyed to other parts of the site. A slotted or perforated pipe may be built into the base of the trench to collect and convey the water.	
Infiltration devices	Infiltration devices temporarily store runoff from a development and allow it to percolate into the ground.	
Pervious surfaces	Pervious surfaces allow rainwater to infiltrate through the surface into an underlying storage layer, where water is stored before infiltration to the ground, reuse, or release to surface water.	
Green roofs	Green roofs are systems which cover a building's roof with vegetation. They are laid over a drainage layer, with other layers providing protection, waterproofing and insulation.	

Component	Description	Example
Filter strips	These are wide, gently sloping areas of grass or other dense vegetation that treat runoff from adjacent impermeable areas.	
Swales	Swales are broad, shallow channels covered by grass or other suitable vegetation. They are designed to convey and/or store runoff, and can infiltrate the water into the ground (if ground conditions allow).	
Infiltration basins	Infiltration basins are depressions in the surface that are designed to store runoff and infiltrate the water to the ground. They may also be landscaped to provide aesthetic and amenity value.	
Wet ponds	Wet ponds are basins that have a permanent pool of water for water quality treatment. They provide temporary storage for additional storm runoff above the permanent water level. Wet ponds may provide amenity and wildlife benefits.	
Extended detention basins	Extended detention basins are normally dry, though they may have small permanent pools at the inlet and outlet. They are designed to detain a certain volume of runoff as well as providing water quality treatment.	

Table A1. SuDS components and their description (Woods-Ballard et al., 2007)

APPENDIX B

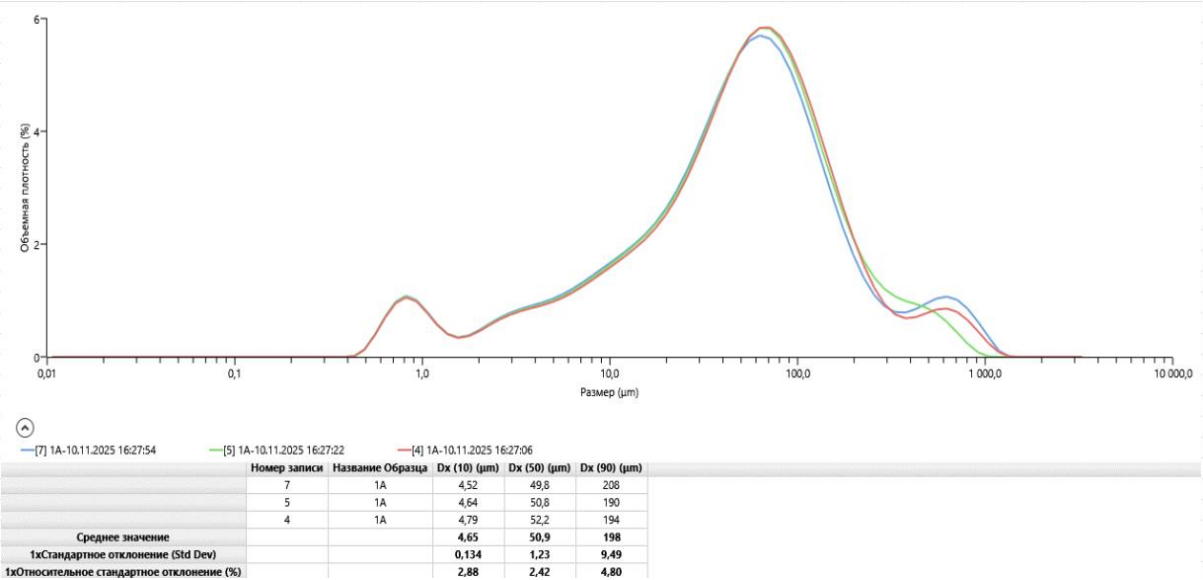


Figure B1. PSD result of sample 1A

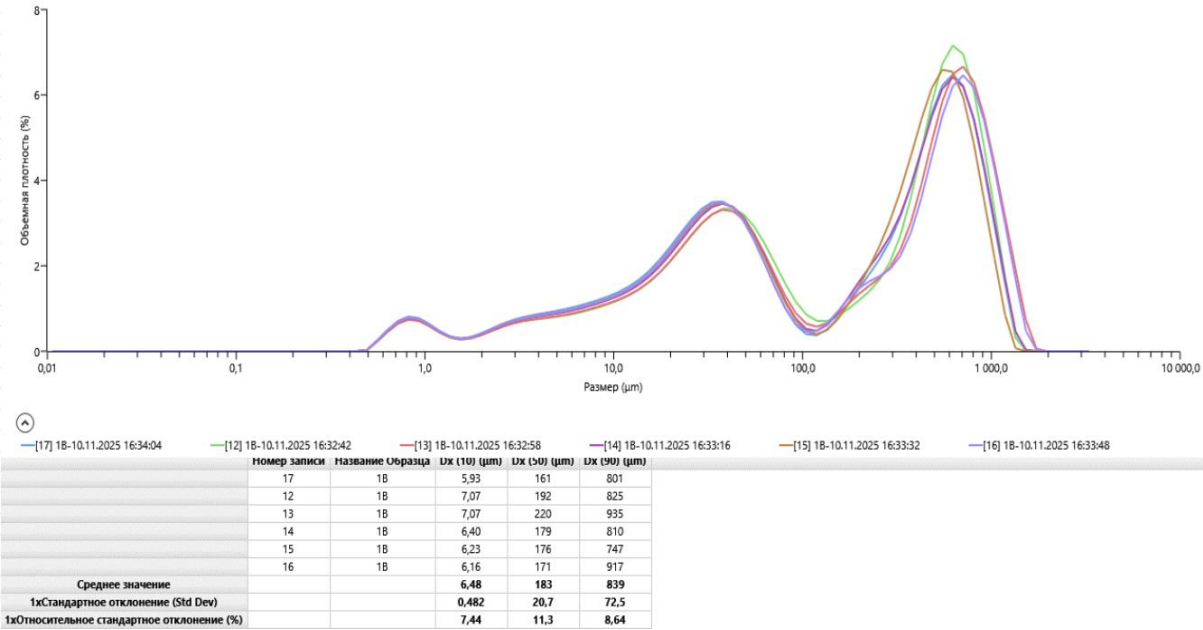


Figure B2. PSD result of sample 1B

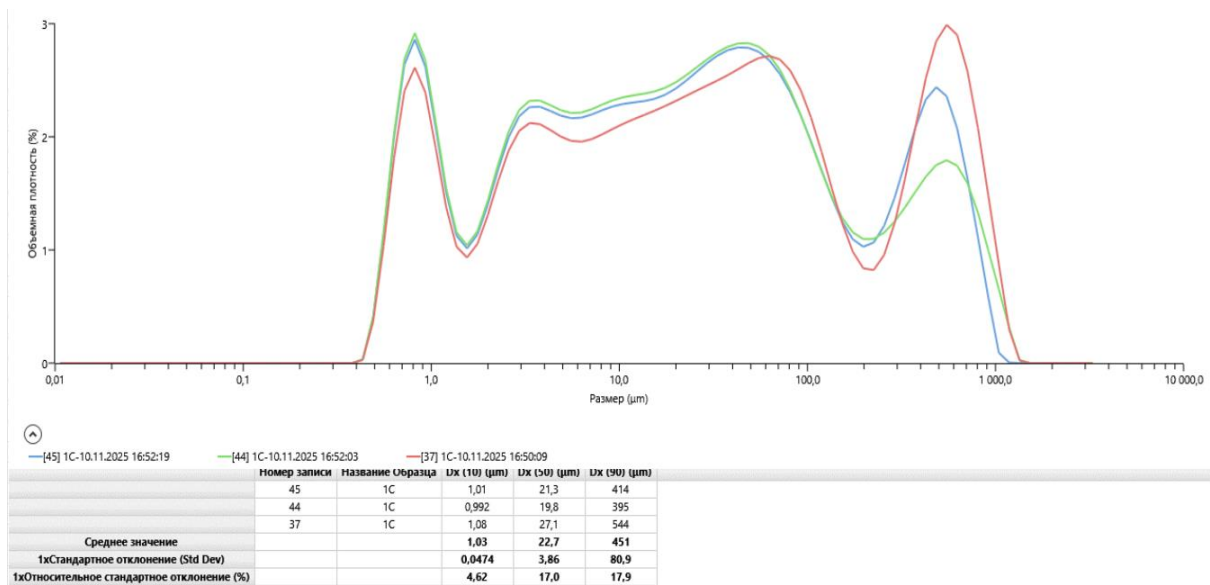


Figure B3. PSD result of sample 1C

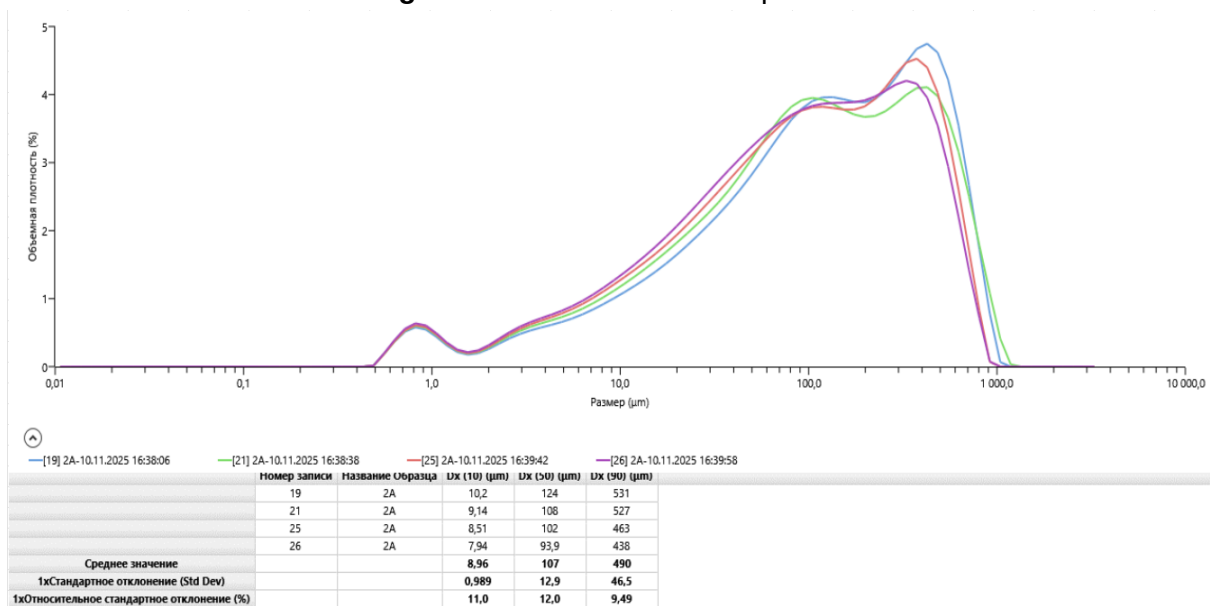


Figure B4. PSD result of sample 2A

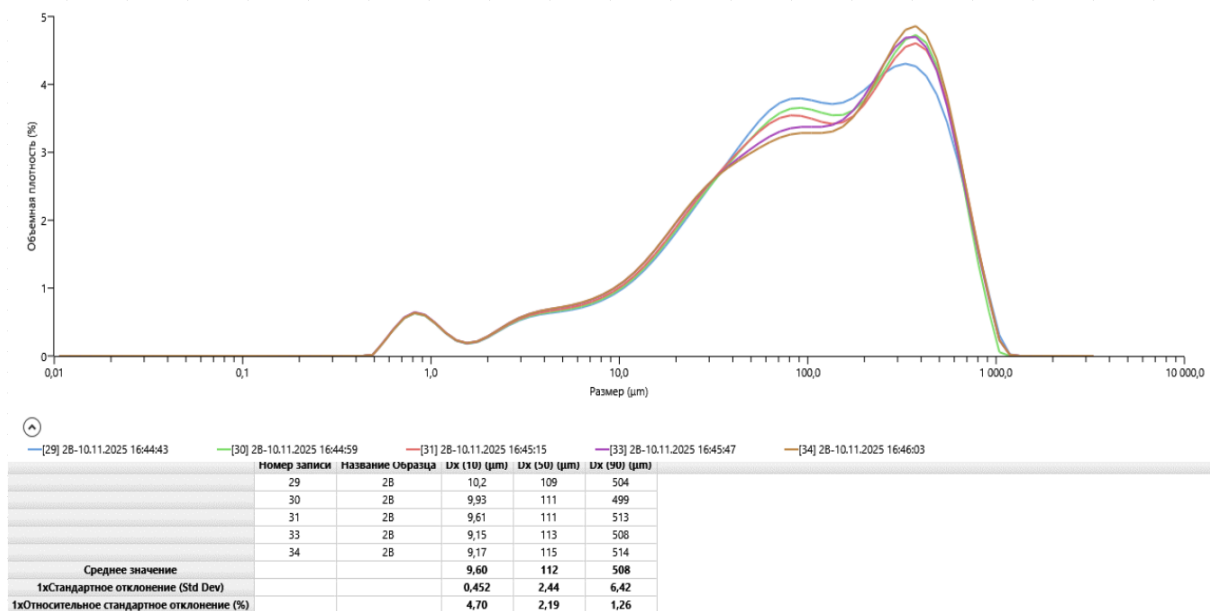


Figure B5. PSD result of sample 2B

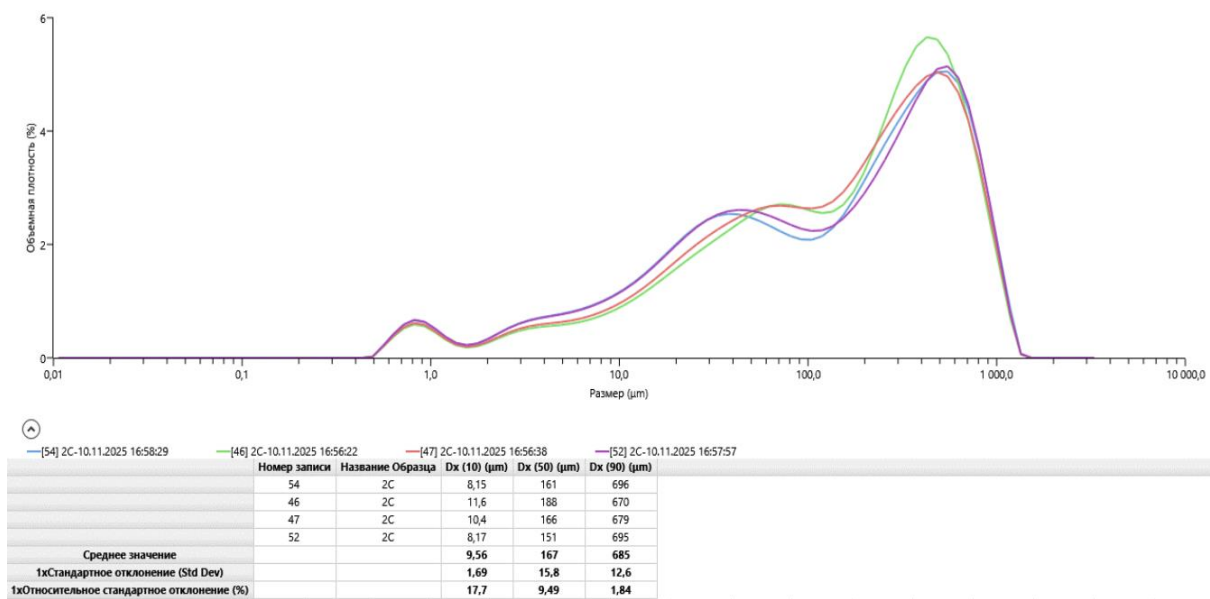


Figure B6. PSD result of sample 2C