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Hydrological Investigation on Infiltration Capacity in Urban Areas

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1. INTRODUCTION

Flooding in urban areas is a complex and multifaceted issue, driven by an intricate interplay of environmental, social, and infrastructural factors. Among these, **climate change** stands as a predominant driver, intensifying the frequency and severity of extreme weather events, including heavy rainfall and storms. The **Intergovernmental Panel on Climate Change (IPCC)** highlights that as global temperatures rise, the hydrological cycle is being disrupted, leading to more intense precipitation events that urban systems are often ill-equipped to handle. This has led to widespread challenges for urban planners and policymakers, particularly in regions experiencing rapid urbanization.

Urbanization, characterized by the expansion of impervious surfaces such as asphalt and concrete, exacerbates flood risks by significantly reducing natural infiltration. In many cases, natural landscapes that once absorbed rainfall are replaced with buildings, roads, and other impermeable infrastructure, increasing surface runoff. Additionally, as cities grow, natural water bodies and green spaces are often encroached upon or removed altogether, further impairing the ability of urban areas to manage water efficiently.

Another critical factor is the **inadequacy of existing drainage infrastructure**. Many urban areas rely on aging systems that were designed for historical weather patterns and lower population densities. These systems are often unable to cope with the increasing volumes of water associated with modern extreme weather events. Poor maintenance and a lack of proactive investment exacerbate this issue, resulting in frequent blockages and system failures. Inadequate drainage design also fails to account for localized flooding, leaving low-lying neighborhoods particularly vulnerable.

The challenges posed by urban flooding are not uniform but vary depending on local conditions. For example, cities like **Copenhagen** and **Berlin** have invested significantly in modernizing drainage infrastructure and implementing sustainable urban drainage systems (SUDS), such as green roofs, permeable pavements, and rainwater harvesting. These measures aim to enhance water retention and infiltration while reducing runoff. Despite these advancements, many cities worldwide, particularly in developing regions, lack the resources or political will to implement such solutions, leaving them disproportionately exposed to the growing risks of urban flooding.

The consequences of urban flooding are far-reaching, affecting not only infrastructure but also public safety, economic stability, and environmental health. **Economic losses** due to property damage, disruptions to transportation networks, and business closures can be immense. Public health is also at risk, with floodwaters often carrying pollutants and increasing the prevalence of waterborne diseases. Furthermore, frequent flooding can lead to long-term environmental degradation, including soil erosion and the contamination of water sources.

Addressing urban flooding requires a **multi-pronged approach** that combines infrastructure upgrades, climate adaptation strategies, and sustainable urban planning. Proactive measures, such as enhancing infiltration through permeable surfaces, restoring natural waterways, and creating flood retention basins, are critical. Equally important is fostering community awareness and engagement, ensuring that residents understand the risks and are prepared to act during flood events.

In conclusion, urban flooding is not just an environmental issue but a socio-economic and infrastructural challenge that demands urgent attention. As climate change accelerates and urban populations continue to grow, cities must prioritize adaptive and resilient flood management strategies to safeguard communities, infrastructure, and ecosystems. This study aims to contribute to this critical discourse by exploring hydrological dynamics in urban areas, with a specific focus on the infiltration capacity of soils in flood-prone zones. By understanding these underlying processes, this research seeks to inform sustainable solutions that can mitigate the impacts of urban flooding and build more resilient cities.

1.1. INCREASING RISK OF FLOODING IN URBAN AREAS

Urban flooding is a growing challenge driven by an intricate combination of environmental, infrastructural, and socio-economic factors. The interplay between climate change, urbanization, and outdated infrastructure amplifies the risk, with significant consequences for urban resilience, public health, and economic stability.

1.1.1. CLIMATE CHANGE AND EXTREME WEATHER EVENTS

Global climate change has led to a marked increase in the intensity and frequency of extreme weather events, such as heavy rainfall and storms. Urban drainage systems, which were often designed based on historical weather data, are ill-equipped to manage the higher precipitation rates associated with climate change. The Intergovernmental Panel on Climate Change (IPCC) projects that these trends will worsen, necessitating immediate adaptation measures to mitigate risks. In addition, rising sea levels further exacerbate flood risks in coastal urban areas, overwhelming flood barriers and natural defenses.

1.1.2. URBANIZATION AND LAND USE CHANGES

Rapid urbanization transforms permeable landscapes into impermeable surfaces such as concrete, asphalt, and buildings, reducing the natural absorption capacity of the soil. This increases surface runoff, overwhelming existing drainage systems. As cities expand, the loss of wetlands, green spaces, and natural water retention areas further compounds the challenge, leaving urban areas more vulnerable to flooding during heavy rainfall. Moreover, poorly planned urban development often disrupts natural waterways, creating artificial bottlenecks that intensify flooding in certain areas.

1.1.3. OUTDATED AND INSUFFICIENT INFRASTRUCTURE

In many cities, drainage systems were built decades ago for lower population densities and less severe weather conditions. The lack of regular maintenance and upgrades to these systems leaves them unable to cope with modern demands. Poorly designed drainage systems, which fail to account for natural water flow patterns, contribute to localized flooding, especially in low-lying neighborhoods. Additionally, informal settlements often lack proper infrastructure, making them particularly vulnerable to flood damage.

1.1.4. SOCIO-ECONOMIC IMPLICATIONS

Urban flooding disproportionately impacts marginalized communities, who often reside in flood-prone areas with inadequate infrastructure. Economic losses from property damage, business disruptions, and repairs place a significant burden on individuals and local governments. Public health risks, including waterborne diseases, mold-related illnesses, and mental health stress, further exacerbate the socio-economic impacts of flooding.

1.1.5. MITIGATION STRATEGIES

Addressing the increasing risk of urban flooding requires a multi-pronged approach, including:

- **Infrastructure Upgrades**: Modernizing drainage systems to handle higher volumes of water and incorporating smart technologies for flood monitoring and early warning.
- **Sustainable Urban Planning**: Promoting green infrastructure, such as permeable pavements, rain gardens, and urban wetlands, to enhance water infiltration and storage.
- **Policy and Regulation**: Implementing zoning laws and building codes that prioritize flood resilience, especially in high-risk areas.
- **Community Engagement**: Educating residents about flood risks and involving them in decision-making processes to foster a culture of preparedness and resilience.

1.1.6. GLOBAL CASE STUDIES AND LESSONS LEARNED

Cities like Copenhagen and Berlin have successfully implemented sustainable urban drainage systems (SUDS), integrating green roofs, bioswales, and rainwater harvesting into their urban landscapes. These measures have significantly reduced surface runoff and enhanced urban resilience. On the other hand, cities in developing regions often face financial and institutional barriers, highlighting the need for international collaboration and funding support to address urban flooding equitably.

1.1.7. CALL TO ACTION

Urban flooding is no longer a sporadic challenge but a systemic risk that threatens cities worldwide. Governments, urban planners, and communities must work together to develop adaptive, resilient, and sustainable solutions. The urgency of the issue demands proactive investment in infrastructure, comprehensive urban planning, and a commitment to mitigating the impacts of climate change on urban areas.

1.2. IMPACT ON KÆRBY, AALBORG

Kærby, a neighborhood in Aalborg, Denmark, serves as a microcosm of the increasing flood risks facing urban areas worldwide. Recent years have seen a surge in heavy rainfall events in Aalborg, driven by changing climatic conditions, leading to frequent and severe flooding. This flooding has disrupted everyday life in Kærby, affecting both surface and underground water systems and exposing significant vulnerabilities in urban infrastructure.

1.2.1. SURFACE WATER FLOODING

Heavy and sudden rainfall events cause rapid water accumulation on streets, parking lots, and other impermeable surfaces in Kærby. The existing drainage infrastructure, originally designed for less extreme weather conditions, often fails to handle this influx of water. Consequently:

- **Transportation Networks**: Flooded streets disrupt mobility, halting public transportation and isolating neighborhoods.
- **Property Damage**: Homes, businesses, and community buildings experience water intrusion, leading to costly repairs and insurance claims.
- **Public Safety Risks**: Floodwaters often carry debris, pollutants, and pathogens, posing direct hazards to residents and increasing the risk of waterborne diseases.

These impacts are further aggravated by the reduction of green spaces and natural water absorption areas, as urban development in Kærby has prioritized impermeable surfaces such as roads and buildings.

1.2.2. GROUNDWATER CHALLENGES

In addition to surface flooding, Kærby faces compounding risks from groundwater interactions. High groundwater levels in the area exacerbate the flooding problem in several ways:

- **Soil Saturation**: During heavy rains, soils quickly become saturated, reducing their capacity to absorb additional water. This leads to pooling on the surface and prolonged waterlogging in low-lying areas.
- **Basement Flooding**: High groundwater levels increase the risk of seepage into basements and underground structures, damaging personal property and threatening structural stability.
- **Flood Dynamics**: The convergence of surface and groundwater creates complex flooding patterns that are difficult to predict and manage, especially during prolonged or sequential rain events.

1.2.3. INFRASTRUCTURE VULNERABILITIES

Kærby's infrastructure is particularly susceptible to the effects of flooding, revealing weaknesses in the urban fabric:

- **Road Damage**: Prolonged exposure to water weakens road surfaces, causing potholes, cracks, and erosion, which require frequent and costly repairs.
- **Building Foundations**: Water infiltration can erode and destabilize building foundations, leading to structural damage and, in severe cases, rendering buildings unsafe for habitation.
- **Utility Disruptions**: Floodwaters damage electrical systems, underground cables, and water supply pipelines, disrupting essential services and leaving residents without power or clean water for extended periods.
- **Economic Losses**: Businesses in Kærby suffer operational downtime due to property damage and accessibility issues, while residents face financial strain from repair costs and potential relocation.

1.2.4. BROADER ENVIRONMENTAL AND SOCIAL IMPACTS

The repeated flooding in Kærby also has broader implications for the community and environment:

- **Ecosystem Degradation**: Floodwaters can carry pollutants such as oil, pesticides, and heavy metals into nearby water bodies, degrading ecosystems and impacting biodiversity.
- **Social Inequity**: Vulnerable populations, such as low-income families, are disproportionately affected, as they often live in flood-prone areas and lack resources for recovery.
- **Mental Health Concerns**: Frequent flooding events create stress and anxiety among residents, undermining the overall quality of life in the neighborhood.

1.2.5. OPPORTUNITIES FOR RESILIENCE

Despite these challenges, Kærby also represents an opportunity for innovative flood management practices:

- **Green Infrastructure**: Expanding green spaces, creating rain gardens, and implementing permeable pavements can enhance the area's water absorption capacity.
- **Drainage System Upgrades**: Modernizing drainage systems to accommodate heavier rainfall volumes and incorporating real-time monitoring technologies can improve flood resilience.
- **Community Involvement**: Engaging residents in flood preparedness programs and participatory urban planning can foster a sense of shared responsibility and enhance emergency response capabilities.

1.3. IMPORTANCE OF HYDROLOGICAL INVESTIGATIONS

Hydrological investigations play a pivotal role in understanding and mitigating urban flooding risks, especially in vulnerable areas like Kærby. These studies provide the scientific foundation for informed decision-making in urban planning, flood management, and climate adaptation strategies. By integrating hydrological insights, cities can build resilience against the growing threats posed by extreme weather events and urbanization.

1.3.1. IDENTIFYING FLOOD-PRONE AREAS

Mapping and analyzing water flow patterns in the urban environment is critical for pinpointing areas most susceptible to flooding. Hydrological investigations help:

- **Flood Risk Assessment**: Identify high-risk zones based on topography, drainage efficiency, and soil infiltration capacity.

- **Prioritization of Interventions**: Enable targeted investment in protective measures, such as retention basins or levees, in the most flood-prone areas.
- **Modeling Future Scenarios**: Simulate the impacts of projected climate conditions, urban expansion, or infrastructure changes on flooding patterns, ensuring proactive mitigation planning.

1.3.2. ASSESSING EXISTING INFRASTRUCTURE

Urban drainage and flood management systems often fail due to design limitations, aging infrastructure, or lack of maintenance. Hydrological studies provide:

- **Performance Evaluation**: Assess the capacity of current drainage systems to handle peak water volumes during heavy rainfall.
- **Bottleneck Identification**: Highlight weaknesses, such as undersized pipes, blocked culverts, or inadequate stormwater storage, that exacerbate flooding.
- **Guidance for Upgrades**: Inform necessary infrastructure improvements, such as increasing pipe diameters, adding retention basins, or incorporating smart flood monitoring systems.

1.3.3. INFORMING SUSTAINABLE URBAN PLANNING

Hydrological insights are essential for integrating flood resilience into urban development. By understanding water dynamics, cities can:

- **Promote Green Infrastructure**: Incorporate solutions like green roofs, permeable pavements, and urban wetlands to enhance natural water absorption and reduce surface runoff.
- **Restore Natural Waterways**: Revitalize rivers and streams that have been constrained or buried by urban development, creating natural flood buffers.
- **Optimize Land Use**: Guide zoning decisions to limit construction in flood-prone areas while encouraging sustainable practices in urban expansion.

1.3.4. ADAPTING TO CLIMATE CHANGE

With increasing unpredictability in rainfall patterns and storm intensities, hydrological investigations provide a critical basis for adapting flood management strategies:

- **Designing Resilient Systems**: Develop drainage and retention systems that can handle the larger and more frequent storms anticipated under changing climatic conditions.
- **Flexible Planning**: Use real-time hydrological monitoring and predictive modeling to adjust flood control measures dynamically as conditions evolve.
- **Incorporating Redundancy**: Build multiple layers of flood protection, such as emergency overflow channels and secondary reservoirs, to cope with extreme events.

1.3.5. ENHANCING COMMUNITY SAFETY AND WELL-BEING

Flooding directly impacts the health, safety, and socio-economic stability of urban populations. Hydrological investigations contribute to:

- **Risk Mitigation**: Reduce the likelihood of hazardous flooding by identifying and addressing vulnerabilities in the urban landscape.
- **Health Protections**: Minimize exposure to contaminated floodwaters that spread diseases and pollutants.
- **Emergency Preparedness**: Equip communities with early warning systems and flood response plans based on reliable hydrological data.
- **Economic Stability**: Prevent the financial and infrastructural losses associated with repeated flooding, protecting livelihoods and local economies.

1.3.6. ADVANCING BROADER ENVIRONMENTAL GOALS

Hydrological studies extend their benefits beyond flood control by contributing to environmental conservation and sustainability:

- **Groundwater Recharge**: Optimize stormwater infiltration to replenish aquifers and reduce dependence on external water sources.
- **Ecosystem Preservation**: Protect wetlands, rivers, and other natural habitats that serve as critical flood buffers and biodiversity hotspots.
- **Climate Mitigation**: Design urban landscapes that enhance carbon sequestration and reduce urban heat island effects, fostering a healthier environment.

1.3.7. CONCLUSION

Hydrological investigations are indispensable for building flood-resilient cities. By identifying vulnerabilities, optimizing infrastructure, and informing sustainable planning, these studies empower communities like Kærby to adapt to climate change, safeguard residents, and ensure long-term urban sustainability. Investing in comprehensive hydrological assessments today is essential to mitigate tomorrow's risks and create thriving urban ecosystems.

1.4. OBJECTIVES OF THE STUDY

This study is centered on conducting a comprehensive hydrological investigation in Kærby, Aalborg, employing advanced methodologies such as the capillary zone test and the double-ring infiltration test. These methods are critical for understanding the complex interactions between soil properties, water infiltration, and urban flooding dynamics. The primary objectives of the study are:

1.4.1. EVALUATE INFILTRATION RATES

- **Goal**: Measure and analyze soil infiltration rates in Kærby to identify areas where water absorption is limited.
- **Methodology**: Use data from the capillary zone and double-ring infiltration tests to quantify how water penetrates various soil types.
- **Outcome**: Provide insights into soil permeability and potential bottlenecks in water absorption, which can inform targeted flood prevention measures.

1.4.2. ASSESS SURFACE RUNOFF POTENTIAL

- **Goal**: Determine the likelihood of surface water runoff across different areas in Kærby based on infiltration test results.
- **Analysis**: Identify locations with high impermeability or compacted soils that exacerbate water accumulation.
- **Application**: Develop predictive models to guide urban planners in designing effective stormwater management systems, such as retention basins and permeable pavements.

1.4.3. EXAMINE SOIL SATURATION LEVELS

- **Goal**: Analyze soil saturation dynamics to understand how they influence water retention and absorption during heavy rainfall events.
- **Focus**: Explore the relationship between soil texture, porosity, and water saturation to pinpoint areas at heightened risk of waterlogging and flooding.
- **Implications**: Inform strategies for improving drainage efficiency and mitigating the impact of saturated soils on infrastructure and vegetation.

1.4.4. DEVELOP A COMPREHENSIVE FLOOD RISK PROFILE

- **Goal**: Synthesize findings into a detailed flood risk profile for Kærby, highlighting vulnerable zones and recommending mitigation strategies.

- **Relevance**: Equip policymakers, engineers, and urban planners with actionable insights to reduce flood risks and enhance resilience.

1.5. SIGNIFICANCE OF THE STUDY

Understanding the hydrological processes that underpin flooding in urban areas like Kærby is essential for developing adaptive and resilient urban environments. With the increasing frequency and intensity of extreme weather events due to global climate change, Kærby's low-lying topography, rapid urbanization, and aging infrastructure leave it particularly vulnerable to severe flooding. This study contributes critical knowledge to address these challenges effectively.

1.5.1. ENHANCING FLOOD MITIGATION STRATEGIES

By analyzing infiltration test results, including those derived from Double-Ring Infiltrometer and Suction Box Tests, this study provides:

- **Data-Driven Insights**: Detailed measurements of soil texture, hydraulic conductivity, and water retention capacity inform the design of tailored flood mitigation strategies.
- **Sustainable Urban Drainage Solutions (SUDS)**: Recommendations for integrating features such as rain gardens, bioswales, permeable pavements, and retention basins into Kærby's urban landscape to manage stormwater sustainably.

1.5.2. SUPPORTING URBAN PLANNING AND POLICY DEVELOPMENT

The findings of this research are directly applicable to urban planning and policymaking:

- **Drainage Infrastructure Upgrades**: Provide a roadmap for modernizing existing systems to handle larger water volumes and improve overall efficiency.
- **Optimized Land Use Planning**: Guide zoning and development practices to reduce flood risks while supporting sustainable urban growth.
- **Climate-Resilient Policies**: Inform long-term strategies to balance environmental sustainability with economic and social development.

1.5.3. BROADER ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACTS

This study extends its relevance beyond Kærby by addressing critical global concerns:

- **Case Study for Similar Urban Areas**: Serve as a replicable framework for other cities facing comparable challenges of urban flooding and climate adaptation.
- **Global Hydrology Discourse**: Contribute to advancing scientific understanding of the relationship between urban hydrology, soil dynamics, and climate change.
- **Economic Stability**: Highlight cost-effective, long-term solutions that reduce infrastructure damage and enhance local economies by minimizing flood-related disruptions.

1.5.4. ADVANCING COMMUNITY WELL-BEING

Effective flood management transcends infrastructure and engineering, impacting community health, safety, and quality of life:

- **Public Safety**: Protect residents from the direct dangers of flooding, such as accidents, displacement, and waterborne diseases.
- **Improved Urban Livability**: Create greener, more sustainable urban spaces that enhance the overall quality of life for Kærby's residents.
- **Strengthened Community Resilience**: Empower residents with knowledge and preparedness measures to respond effectively to future flood events.

1.5.4.1. CLIMATE ADAPTATION AND SUSTAINABILITY

As climate change accelerates, this study emphasizes the importance of proactive, sustainable approaches to urban flooding:

- **Adaptive Infrastructure**: Design systems that can flexibly respond to future climate scenarios, including increased rainfall intensity and duration.
- **Carbon Sequestration**: Promote green infrastructure solutions that not only manage water but also contribute to carbon capture and climate mitigation efforts.

1.5.4.2. LONG-TERM VISION

Ultimately, the study underscores the interconnectedness of environmental health, socio-economic resilience, and urban sustainability. Protecting neighborhoods like Kærby from flooding is about more than just mitigating immediate risks; it's about creating cities that thrive in the face of climate challenges. The insights gained here will serve as a critical resource for shaping resilient urban futures, ensuring that Kærby and similar communities remain safe, vibrant, and sustainable for generations to come.

2. LOCATION OF STUDY

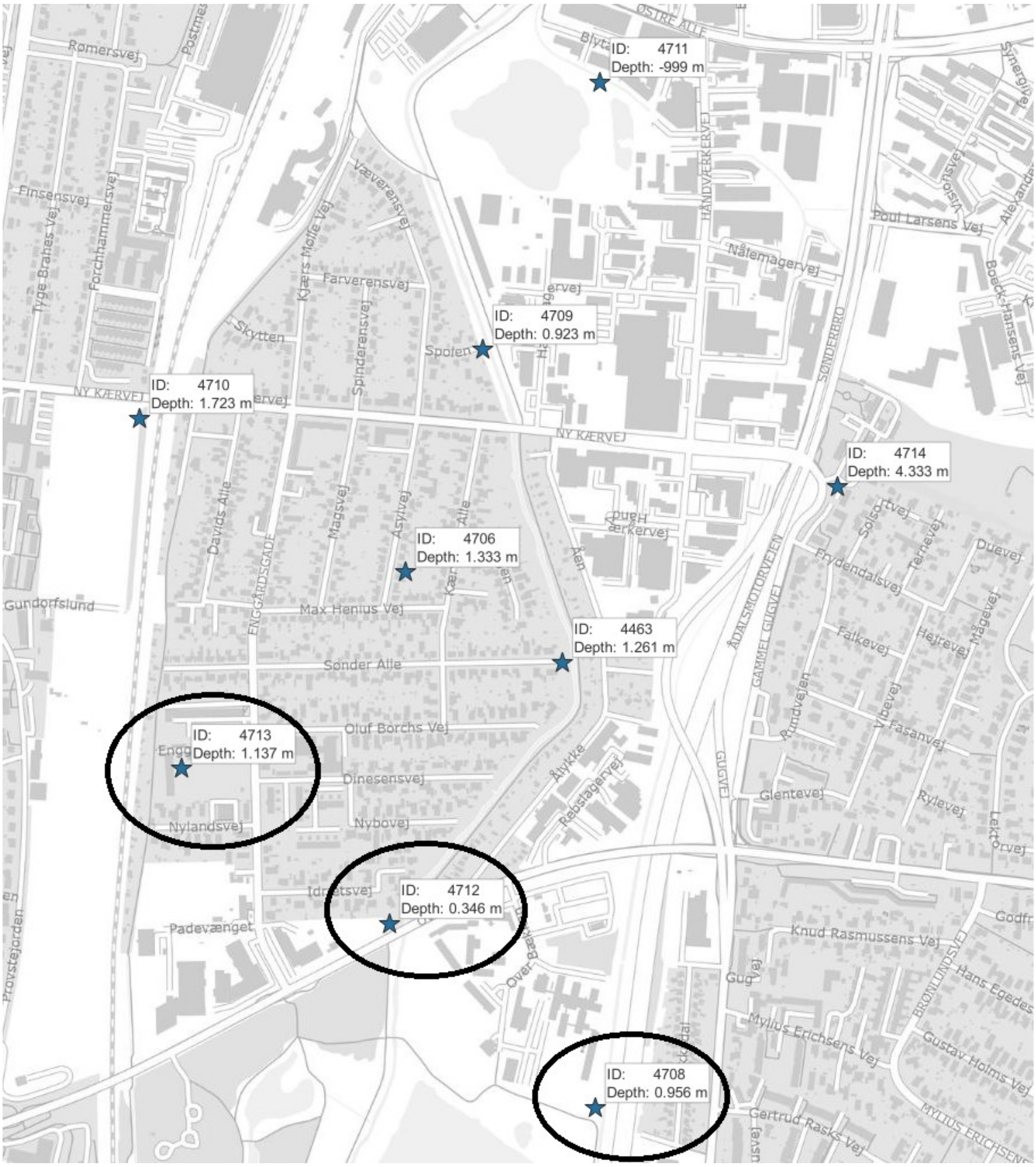

Fig 1 - Location of study

Map showing the study area in Kærby, Aalborg. Symbols indicate sampling sites, with blue circles representing infiltration test locations and red squares indicating soil sampling points.

2.1. FIELD CHOOSING PROCEDURE

The neighborhood of Kærby in Aalborg, Denmark, is characterized by a temperate climate with high rainfall variability. Its topography consists primarily of low-lying areas, increasing susceptibility to surface water accumulation. This region's proximity to major water bodies compounds flood risk, especially during heavy rainfall events. The impact on Kærby extends beyond residential flooding; it influences infrastructure stability, water quality, and the socio-economic resilience of the community.

2.2. SOCIO-ECONOMIC IMPORTANCE

Kærby, located in Aalborg, Denmark, exemplifies the challenges posed by urban flooding. In recent years, heavy rainfall events have led to significant surface and groundwater flooding, causing damage to properties, public infrastructure, and local economies. The inability of existing drainage systems to manage sudden influxes of water highlights the need for comprehensive hydrological assessments. By understanding the unique water dynamics in Kærby, this study aims to provide insights into effective flood prevention and management strategies tailored to local conditions.. Importance of Site Selection for Soil Sampling

Accurate soil sampling is a fundamental step in understanding soil characteristics and their implications on water infiltration, retention, and overall hydrological behavior. The choice of sampling location directly influences the reliability of data collected, impacting subsequent analyses and conclusions. This section outlines the methodology for selecting and preparing the sampling site, emphasizing the preliminary steps taken to ensure accurate and representative soil samples.

2.3. PRELIMINARY SITE ASSESSMENT WITH PIPE INSERTION

The initial phase of site preparation involves assessing the soil profile through the insertion of a pipe into the ground. This step serves multiple purposes:

- **Soil Composition Assessment**: By inserting a pipe, we can obtain an immediate sense of the soil's texture, compaction, and presence of different layers such as sand, silt, clay, or gravel.
- **Identification of Potential Obstructions**: Rocks, roots, or other obstacles can influence sampling success. The pipe's resistance during insertion helps identify these potential issues.
- **Evaluation of Soil Moisture Content**: The ease or difficulty of driving the pipe can provide initial clues about soil moisture levels, further informing subsequent sampling efforts.

2.4. TOOLS AND TECHNIQUES EMPLOYED

Equipment Used:

- **Hammer and Pipe**: A heavy-duty hammer (as seen in Figure [X]) is used to drive a hollow pipe into the soil. The pipe serves as a temporary conduit for assessing soil conditions.
- **Supporting Accessories**: The setup also includes stabilizing tools and measurement instruments to ensure precision in evaluating soil characteristics.

Procedure:

1. **Pipe Insertion**: The process begins with positioning the pipe vertically at the intended sampling location. Using the hammer, the pipe is carefully driven into the soil to the desired depth.
2. **Initial Observations**: As the pipe penetrates the ground, observations regarding the resistance encountered, changes in insertion speed, and audible cues (e.g., hitting hard layers) are documented.
3. **Site Suitability Verification**: The data obtained from the pipe insertion informs whether the location is suitable for collecting soil samples. Factors considered include soil uniformity, compaction, and the presence of layers that may affect infiltration tests.

2.5. VISUAL DOCUMENTATION AND EXPLANATION

- **Figure [X]**: This image captures the insertion of the pipe using a hammer. The operator is seen applying force to ensure the pipe penetrates the soil surface. This step helps evaluate the ease of soil penetration and the presence of different soil layers.

- **Figure [Y]**: Depicts the range of tools used during the preliminary site assessment, including the hammer, gloves for safety, and other relevant equipment.
- **Figure [Z]**: Shows the aftermath of pipe insertion, illustrating the pipe in place and providing a visual context for the subsequent soil sampling process.

2.6. BENEFITS OF THE PRELIMINARY ASSESSMENT APPROACH

The described approach offers several advantages:

- **Improved Data Accuracy**: By understanding soil properties before sampling, it becomes possible to select the most representative locations for testing.
- **Efficient Sampling Strategy**: Knowing the soil composition and structure in advance reduces the risk of unproductive sampling efforts and minimizes disruptions during data collection.
- **Enhanced Safety and Efficiency**: Assessing soil resistance and obstructions beforehand ensures safer operations for field personnel and minimizes wear on sampling equipment.

2.7. TRANSITION TO DETAILED SAMPLING

After confirming the suitability of the location based on the preliminary pipe insertion assessment, the next steps involve detailed sampling. This includes collecting undisturbed soil cores, performing infiltration tests, and analyzing soil properties in the laboratory. Each of these stages builds on the insights gained during the initial assessment, ensuring a comprehensive understanding of soil behavior in the study area.

- **Figure [X]**: This image captures the insertion of the pipe using a hammer. The operator is seen applying force to ensure the pipe penetrates the soil surface. This step helps evaluate the ease of soil penetration and the presence of different soil layers.

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Fig 2 – the exact location of test

3. BASIC CHARACTERISTICS OF TOPSOIL AND SUBSOIL

3.1. INTRODUCTION TO SOIL PARTICLE SIZE DISTRIBUTION

Soil particle size distribution (PSD) is a critical factor in determining the physical properties of soil, influencing various aspects such as water infiltration, drainage, aeration, and fertility. The distribution of particle sizes within soil can be analyzed through a process known as sieve analysis, which separates the soil into different fractions based on size. This method allows for the calculation of the percentage of soil retained on each sieve, which can then be used to infer the soil's textural class and predict its behavior under different environmental conditions. Soil particle size distribution has a profound influence on water movement, retention, and capillary rise. Coarse-textured soils, such as sand and gravel, promote rapid water movement due to larger pore sizes. However, this rapid drainage can exacerbate drought stress in periods of low rainfall. Fine-textured soils, such as clay, offer higher water retention capabilities but are prone to waterlogging.

3.2. CALCULATING PERCENTAGES IN SOIL PARTICLE SIZE DISTRIBUTION

The calculation of the percentages retained and passing through each sieve is an essential step in understanding soil texture. Here’s how this is typically done:

1. **Sample Preparation**: A known weight of the soil sample is first dried and then placed on a stack of sieves arranged from largest to smallest mesh size.
2. **Sieve Analysis**: The stack is subjected to vibration or mechanical shaking, allowing smaller particles to pass through the sieves while larger particles are retained.
3. **Weight Measurement**: After sieving, the soil retained on each sieve is weighed. The weight of the particles retained on each sieve is recorded as the "grain weight."
4. **Percentage Calculation**:
   - **Weight Retained**: The weight retained on each sieve is calculated as a percentage of the total soil sample weight. This is done using the formula:

$$Weight\ Retained\ (\%) = \left(\frac{Grain\ Weight\ (g)}{Total\ Sample\ Weight\ (g)}\right) \times 100$$

- **Cumulative Weight Retained**: This is calculated by adding the weight retained on each sieve to the cumulative weight retained on the previous sieves. This helps in understanding the overall texture of the soil and the distribution of particle sizes.
- **Passing Percentage**: The percentage of the soil that passes through each sieve is calculated by subtracting the cumulative weight retained from 100%. This represents the finer fractions of the soil that can influence properties like water retention and capillary action.

5. **Soil Classification**: Based on the percentage retained and passing through the sieves, the soil can be classified into various categories such as sand, silt, and clay. This classification helps in predicting the behavior of soil in terms of its hydraulic properties.

3.3. EFFECTS OF GRAIN SIZE ON SOIL BEHAVIOR

The size of soil grains significantly influences the soil's physical properties, particularly water movement and retention:

3.3.1. WATER PENETRATION IN SOIL

- **Coarse-Grained Soils (Sand and Gravel)**:
  - **High Permeability**: Coarse particles create larger pore spaces within the soil, which allows water to move quickly through the soil. This high permeability is advantageous in preventing waterlogging and promoting rapid drainage.
  - **Low Water Retention**: Because water moves quickly through coarse soils, they tend to retain less water, which can be a disadvantage in arid environments where water conservation is critical.
- **Fine-Grained Soils (Silt and Clay)**:
  - **Low Permeability**: Fine particles have much smaller pore spaces, which slows down the movement of water through the soil. This low permeability can lead to waterlogging in areas with poor drainage.
  - **High Water Retention**: Fine soils have a higher capacity to retain water, which can be beneficial for plant growth but may require careful management to avoid excessive moisture.

3.3.2. CAPILLARY RISE

Capillary rise refers to the movement of water upwards through the soil, against the force of gravity. This phenomenon is influenced by the size of the soil particles:

- **Fine-Grained Soils**:
  - **Higher Capillary Action**: Fine particles, such as clay and silt, have small pores that create a strong capillary force. This allows water to rise to greater heights in these soils. The high capillary action is beneficial for maintaining moisture in the root zone of plants, especially in arid regions.
- **Coarse-Grained Soils**:
  - **Lower Capillary Action**: In contrast, coarse-grained soils with larger particles and pore spaces have weaker capillary forces. As a result, water does not rise as high in these soils. This can be advantageous in preventing water from accumulating in the upper soil layers, which might otherwise lead to surface evaporation and salt buildup.

3.4. PRACTICAL IMPLICATIONS OF SOIL PARTICLE SIZE DISTRIBUTION

Understanding the particle size distribution in soil is critical for several practical applications:

- **Agriculture**: Farmers rely on knowledge of soil texture to manage irrigation and improve crop yields. For instance, sandy soils may require more frequent watering, while clay soils might need improved drainage.
- **Civil Engineering**: Engineers assess soil particle size distribution to design foundations, roads, and drainage systems. Coarse soils are typically preferred for load-bearing structures due to their stability and drainage properties.
- **Environmental Management**: Soil texture influences how contaminants move through the soil and into groundwater. Understanding these dynamics is crucial for environmental protection and remediation efforts.

  To address the challenges identified in this study, practical steps are essential for implementation. Local governments in Kærby could integrate green infrastructure solutions such as rain gardens, permeable pavements, and bioswales to enhance water infiltration and reduce runoff during heavy rainfall. For agricultural areas, incorporating organic soil amendments and implementing contour plowing techniques can improve soil water retention and minimize erosion. Community engagement programs focused on soil conservation and sustainable water use can also amplify the impact of these interventions, ensuring that residents and stakeholders actively participate in managing water resources effectively.

3.5. CONCLUSION

Soil particle size distribution is a fundamental property that influences numerous aspects of soil behavior, particularly its ability to retain and transmit water. Coarse-grained soils, such as sand and gravel, tend to facilitate rapid water movement due to their high permeability, making them suitable for applications requiring effective drainage. In contrast, fine-grained soils, such as silt and clay, retain water more effectively, which can be advantageous for plant growth but may lead to waterlogging in certain scenarios. By accurately calculating the percentages of soil retained and passing through various sieves, this study provides critical insights into the soil's texture, structure, and potential hydrological behavior under different environmental conditions.

The significance of this knowledge extends beyond basic soil classification. In agriculture, understanding soil texture allows for optimizing irrigation practices and improving crop yield by balancing water availability and drainage. In civil engineering, it guides the selection of appropriate soil types for construction projects, ensuring stability and durability of foundations, roads, and drainage systems. From an environmental perspective, soil texture data is essential for predicting contaminant movement, mitigating erosion, and restoring degraded ecosystems.

These findings play a crucial role in this study by informing water management strategies tailored to Kærby's unique soil characteristics. For instance, areas with predominantly coarse-textured soils might require measures to slow down water infiltration and reduce surface runoff, while zones with finer soils may need improved drainage to prevent waterlogging. This nuanced understanding of soil particle size distribution not only aids in flood risk management but also supports sustainable urban planning and ecological preservation efforts.

In the following sections, the results of the sieve analysis conducted on the soil samples will be presented in detail. These findings will serve as the basis for developing targeted water management strategies that address the specific challenges of the study area, enhancing both urban resilience and environmental sustainability.

3.6. SOIL SAMPLES

Our soil samples has been divided to two soils:

1- Top soil (40cm depth)
2- Sub soil (40-70cm depth)

3.6.1. THE TEST PROCEDURE

The sieve analysis test is a fundamental method in soil mechanics and sedimentology for determining the particle size distribution of granular materials, such as soil or aggregate. This test involves passing a soil sample through a series of sieves with progressively smaller mesh sizes to quantify the percentage of material retained on each sieve. The results are used to assess the soil's textural classification, permeability, and suitability for various engineering or agricultural applications.

3.6.2. PROCEDURE

1. **Preparation of Soil Sample**:
    a. A representative soil sample is collected and dried to remove all moisture content.
    b. The total weight of the sample is recorded for use in calculating percentages.
2. **Stacking the Sieves**:
    a. Sieves are arranged in a stack, with the coarsest sieve (largest opening) at the top and the finest sieve (smallest opening) at the bottom. Below the last sieve, a pan is placed to collect fine particles that pass through the smallest sieve.
3. **Shaking or Vibrating**:
    a. The soil sample is placed on the top sieve and the stack is subjected to mechanical shaking or manual vibration for a specific period (e.g., 10-15 minutes). This ensures that soil particles are separated based on size.
4. **Weighing Retained Soil**:
    a. After sieving, the material retained on each sieve is carefully weighed and recorded. The weight of material in the pan is also measured.
5. **Calculating Percentages**:
    a. **Weight Retain**: The weight of soil retained on each sieve is expressed as a percentage of the total sample weight.
    b. **Cumulative Weight Retain**: The cumulative percentage of soil retained is calculated by summing the weights retained on the sieve and all sieves above it.
    c. **Percentage Passing**: The percentage of material passing through each sieve is determined by subtracting the cumulative percentage retained from 100%.

3.6.3. HOW THE RESULTS IN THE TABLE WERE GENERATED

1. **Column Definitions**:
    a. **Pan**: Refers to the mesh size of each sieve in microns or millimeters.
    b. **Plate Number**: Identifier for the sieve plate used in the test.
    c. **Plate Weight (g)**: The empty weight of the sieve plate before testing.
    d. **Total Weight (g)**: The weight of the sieve plate with the retained soil after sieving.
    e. **Grain Weight (g)**: The weight of the soil retained on that sieve (calculated as the difference between the total weight and plate weight).
    f. **Weight Retain (%)**: The proportion of the total sample weight retained on each sieve, expressed as a percentage.
    g. **Cumulative Weight Retain (%)**: The total percentage of soil retained on the given sieve and all larger sieves.

h. **Passing (%)**: The proportion of soil that passed through each sieve, calculated as *100−Cumulative Weight Retain100 - \text{Cumulative Weight Retain}*100−Cumulative Weight Retain.

2. **Analysis of Data**:
   a. Using the sieve stack, the percentages were calculated for all the soil retained and passed through each sieve.
   b. The data was then plotted on a semi-logarithmic graph to visualize the particle size distribution.

3.6.4. INTERPRETATION OF RESULTS

1. **Textural Classification**:
   a. The graph shows the relative proportions of coarse, medium, and fine particles in the soil sample. The steepness of the curve indicates the uniformity of particle sizes—steeper curves suggest a more uniform particle size distribution, while gradual curves indicate a well-graded soil with a mix of particle sizes.
2. **Hydrological Implications**:
   a. The particle size distribution determines soil permeability. Coarser soils, with higher percentages of larger particles, allow water to infiltrate quickly, while finer soils, dominated by smaller particles, retain water for longer periods and drain more slowly.
3. **Engineering Relevance**:
   a. In civil engineering, sieve analysis is essential for evaluating soil suitability for construction projects such as roads, foundations, or drainage systems. A well-graded soil is often preferred for stability, whereas poorly graded soils may require modification.

3.6.5. SIGNIFICANCE

The results of the sieve analysis are critical for understanding soil behavior in the context of your study. By determining the particle size distribution:

- You can predict how the soil will perform in applications such as **flood management, infiltration studies, and irrigation planning**.
- The data informs decisions regarding soil amendments or design adjustments in urban environments to optimize drainage and reduce surface runoff.

3.6.6. TOP SOIL

Fig 3-sample is including the gravels and stones

Table 1-soild distribution

pan	plate number	plate w (g)	total w (g)	grain w (g)	wieght retain	c weight retain	passing
2000	10008	3.86	3.87	0.01	0.01%	0.01%	99.99%
1000	4086	3.16	8.15	4.99	5.0%	5.01%	94.99%
500	4084	3.16	20.01	16.85	16.9%	21.90%	78.10%
250	10081	3.17	49.24	46.07	46.2%	68.08%	31.92%
200	10079	3.17	16.4	13.23	13.3%	81.35%	18.65%
125	10096	3.18	16.67	13.49	13.5%	94.87%	5.13%
75	10045	3.2	7.22	4.02	4.0%	98.90%	1.10%
63	3067	3.19	3.58	0.39	0.4%	99.29%	0.71%
pan	4041	3.21	3.92	0.71	0.7%	100.00%	0.00%

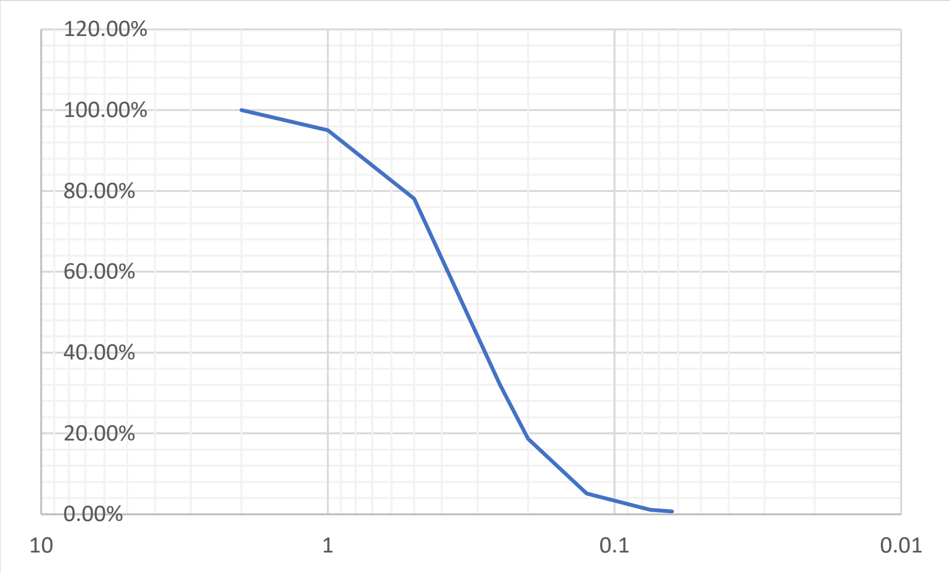

Fig 4-soil distribution chart

- **Y-Axis**: "Percentage of Soil Retained (%)"
- **X-Axis**: "Particle Size (mm)" or "Particle Size (µm)" (depending on the actual unit used in your data).

Table 2-analaysing the soil contents

Soil Fraction	Percentage (%)	Characteristics	Implications for Hydrological Behavior
Coarse Fraction (>250 microns)	68.08	Predominantly sandy and gravelly.	Good drainage and high permeability, reducing surface runoff and improving infiltration rates.
Medium Fraction (125-250 microns)	13.5	Includes fine sand particles.	Contributes to drainage while maintaining some water-holding capacity.
Fine Fraction (<125 microns)	18.65	Consists of silt and clay particles.	Crucial for water retention and soil fertility; can reduce permeability and increase waterlogging risk.

Table 3-analysing the soil content

Soil Fraction	Sieve Size Range (µm)	Content (%)
Clay (< 2 µm)	<63 (Pan)	0.23%
Silt (2-20 µm)	63-125	0.23%
Fine Sand (20-200 µm)	125-200	31.92%
Coarse Sand (200-2000 µm)	200-2000	67.66%

3.6.7. SUB SOIL

Fig 5- Sub soil

Table 4- soil distribution

size	plate number	plate w (g)	total w (g)	grain w (g)	wight retain	c weight retain	passing
2000	10008	3.86	3.93	0.07	0.1%	0.1%	99.9%
1000	4086	3.16	24.91	21.75	21.9%	22.0%	78.0%
500	4084	3.16	26.7	23.54	23.7%	45.6%	54.4%
250	10081	3.17	32.66	29.49	29.7%	75.3%	24.7%
200	10079	3.17	10.34	7.17	7.2%	82.5%	17.5%
125	10096	3.18	11.58	8.4	8.5%	91.0%	9.0%
75	10045	3.2	7.75	4.55	4.6%	95.6%	4.4%
63	3067	3.19	5.09	1.9	1.9%	97.5%	2.5%
pan	4041	3.21	5.72	2.51	2.5%	100.0%	0.0%

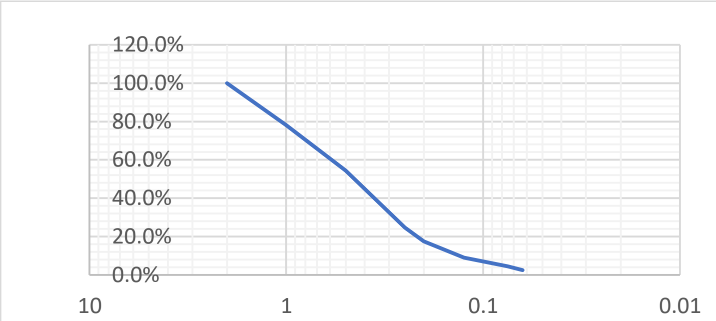

Fig 6-soil distribution chart

- **Y-Axis**: "Percentage of Soil Retained (%)"
- **X-Axis**: "Particle Size (mm)" or "Particle Size (µm)" (depending on the actual unit used in your data).

Table 5- Analaysing the soil contents

Soil Fraction	Percentage (%)	Characteristics	Implications for Hydrological Behavior
Coarse Fraction (>250 microns)	75.3%	Predominantly sandy and gravelly.	High permeability, good drainage, reduces surface runoff, improves infiltration rates.
Medium Fraction (125-250 microns)	8.5%	Includes fine sand particles.	Contributes to drainage while maintaining some water-holding capacity.
Fine Fraction (<125 microns)	16.2%	Consists of silt and clay particles.	Crucial for water retention, can reduce permeability, and increase waterlogging risk.

Table 6-analysing the soil content

Soil Fraction	Sieve Size Range (µm)	Content (%)
Clay (< 2 µm)	<63 (Pan)	0.83%
Silt (2-20 µm)	63-125	0.83%
Fine Sand (20-200 µm)	125-200	24.70%
Coarse Sand (200-2000 µm)	200-2000	70.30%

3-7. ORGANIC MATTER

Table 7-dry soil weight

plate number	depth (cm)	plate weight (g)	(plate +weight soil) g	weight soil (g)	(plate + dry soil)gr	dry soil gr
46	40	30.505	78.265	47.76	77.78	47.275
49	40	31.87	81.085	49.215	80.6	48.73
12	40	30.13	76.14	46.01	75.65	45.52
59	40-70	31.07	69.62	38.55	68.2	37.13
77	40-70	28.755	59.895	31.14	58.725	29.97
24	40-70	31.035	70.31	39.275	68.955	37.92

Table 8-organic matter

plate No.	Weight of Dry Soil (g)	Weight of Organic Matter (g)	Organic Matter Content (g/g dry soil)	Organic Matter Content (%)
46	47.275	0.485	0.01025	1.03%
49	48.73	0.485	0.00995	1.00%
12	45.52	0.49	0.01076	1.08%
59	37.13	1.42	0.03824	3.82%
77	29.97	1.17	0.03904	3.90%
24	37.92	1.355	0.03573	3.57%

3.7.1. OVERVIEW OF THE ORGANIC MATTER TEST

The **Loss on Ignition (LOI) method** is a widely used procedure for determining the organic matter content of soil by measuring the weight loss after subjecting the soil sample to high temperatures (typically between 360°C and 550°C). This high-temperature environment combusts the organic material in the soil, leaving behind only the mineral fraction. The difference in weight before and after combustion represents the organic matter content, making this method both straightforward and reliable for soil studies.

This method is particularly effective for understanding soil fertility, nutrient cycling, and carbon sequestration potential. The organic matter in soil plays a critical role in maintaining soil structure, water retention capacity, and nutrient availability, making it a cornerstone of soil health and productivity assessments.

3.7.2. RESULTS OF THE ORGANIC MATTER TEST

The results of the test reveal clear differences in organic matter content across different soil depths, highlighting the influence of depth-dependent processes on organic matter distribution:

- **40-70 cm Depth (Plate Nos. 59, 77, 24)**:
  - Organic matter content ranges from **3.573% to 3.904%**, indicating higher organic accumulation at this depth.
- **0-40 cm Depth (Plate Nos. 46, 49, 12)**:
  - Organic matter content ranges from **0.995% to 1.076%**, reflecting lower organic matter in the upper soil layers.

These variations can be attributed to several factors, including:

1. **Soil Formation Processes**:
   a. Deeper soil layers often preserve organic matter better due to slower microbial activity and less exposure to oxygen, which limits the rate of decomposition.
2. **Microbial Activity**:
   a. The microbial breakdown of organic matter is typically more active in surface soils, leading to faster decomposition and turnover.
3. **Organic Matter Accumulation**:
   a. The accumulation of organic materials, such as plant residues, in deeper layers suggests limited decomposition processes and potentially higher input from leaching organic compounds.

3.7.3. IMPLICATIONS OF ORGANIC MATTER VARIATIONS

The observed differences in organic matter content have significant implications for understanding soil properties and management strategies:

1. **Soil Fertility**:
   a. Organic matter is a primary source of nutrients like nitrogen, phosphorus, and sulfur. The higher organic matter content in the **40-70 cm depth** indicates greater nutrient reserves at this level, which may benefit deep-rooted crops.
   b. Conversely, the low organic content in the **0-40 cm depth** highlights the need for additional organic inputs, such as compost or manure, to enhance fertility.

2. **Water Retention Capacity**:
    a. Organic matter increases the soil's ability to hold water by improving porosity and reducing bulk density. The higher organic matter in the deeper layers suggests better water retention at **40-70 cm**, which could help plants access moisture during dry periods.
    b. The lower organic matter in the surface layers could result in faster drying and reduced water availability for shallow-rooted crops.
3. **Soil Health and Stability**:
    a. Organic matter contributes to the aggregation of soil particles, improving soil structure and preventing erosion. The reduced organic matter in the **0-40 cm depth** could make this layer more prone to compaction and erosion.
4. **Carbon Sequestration**:
    a. Soils with higher organic content serve as carbon sinks, contributing to climate change mitigation. The data suggests that deeper layers in the study area could play a critical role in long-term carbon storage.

3.7.4. DETAILED ANALYSIS

3.7.4.1. ANALYSIS FOR 0-40 CM SOIL DEPTH (PLATE NOS. 46, 49, 12):

The soil samples from this depth exhibit **low organic matter content** ranging from **0.995% to 1.076%**. This suggests that the surface layers are undergoing active decomposition, likely due to:

- Higher microbial activity driven by oxygen availability.
- Faster organic matter turnover caused by frequent exposure to weathering and biological processes.

The low organic content could limit this layer's fertility and water-holding capacity, necessitating soil management practices such as:

- **Addition of Organic Amendments**: Regular application of compost, manure, or biochar to replenish organic matter.
- **Conservation Tillage**: Reducing soil disturbance to slow organic matter decomposition and promote its accumulation.
- **Cover Cropping**: Planting cover crops to increase organic matter inputs and protect the soil surface from erosion.

3.7.5. ANALYSIS FOR 40-70 CM SOIL DEPTH (PLATE NOS. 59, 77, 24):

The samples from this depth exhibit **higher organic matter content**, ranging from **3.573% to 3.904%**. The increased organic content at this level can be attributed to:

- Reduced oxygen availability, which slows down microbial decomposition and preserves organic material.
- Leaching of dissolved organic compounds from the upper layers, contributing to organic matter accumulation at greater depths.

This deeper organic matter plays a crucial role in maintaining **soil health and productivity** by:

- Supporting deep-rooted crops that rely on moisture and nutrients from this layer.
- Acting as a reservoir for long-term carbon storage, reducing atmospheric CO2 levels.
- Improving the water retention and buffering capacity of the subsoil, which benefits plant growth during drought conditions.

Conclusion

The **Loss on Ignition method** provides valuable insights into the distribution of organic matter across different soil depths. The **higher organic content at 40-70 cm** suggests that this layer has a greater capacity for water retention and nutrient storage, making it critical for

deep-rooted plants and long-term carbon sequestration. In contrast, the **lower organic content at 0-40 cm** highlights the need for targeted management interventions to enhance fertility and mitigate the risks of erosion and compaction.
By understanding these depth-specific variations, land managers and agricultural practitioners can implement strategies to optimize soil productivity and sustainability. This knowledge is particularly relevant for regions like Kærby, where soil health is vital for both agricultural output and environmental conservation.
The variations in organic matter content across the analyzed depths have significant implications for **soil properties, agricultural productivity**, and **land management strategies** in the study area. Understanding these differences enables targeted interventions to optimize soil health and functionality.

1. SOIL STRUCTURE AND STABILITY

Organic matter is essential for enhancing soil structure by promoting the aggregation of soil particles, leading to a **friable and well-aerated structure**. Aggregated soils allow for better root penetration, water infiltration, and gas exchange.

- In the **0-40 cm depth**, the relatively **low organic matter content** indicates a **denser, more compact structure**, which could limit root growth, reduce aeration, and hinder water infiltration. This compactness also increases the risk of **surface runoff** during heavy rainfall events, potentially exacerbating erosion and flooding.
- In contrast, the **40-70 cm depth**, particularly in Plates 59 and 24, shows **higher organic content**, suggesting better soil aggregation at this depth. This improved structure can reduce soil compaction and enhance the soil's ability to withstand environmental stresses, such as drought or heavy rains.

Management Implications:

- Employing practices such as **reduced tillage** and **compost application** can improve soil structure in the upper layers by increasing organic matter content and preventing further compaction.
- For areas prone to erosion, strategies like **mulching** or establishing **cover crops** can help protect the surface soil and prevent organic matter loss.

2. WATER RETENTION CAPACITY

Organic matter significantly increases the soil's ability to **retain water** by enhancing porosity and decreasing bulk density. This improved water-holding capacity is critical for supporting plant growth, particularly in areas with irregular rainfall patterns.

- In the **40-70 cm depth**, soils with higher organic matter content (Plates 59 and 24) likely exhibit **better water retention properties**. These deeper layers can serve as a reservoir of moisture during dry periods, benefiting deep-rooted plants.
- In contrast, the **0-40 cm depth**, with lower organic content, may lose water more quickly due to reduced porosity and higher bulk density. This could leave shallow-rooted crops vulnerable to drought stress.

Management Implications:

- **Irrigation strategies** should account for the water-holding differences between depths, ensuring crops can access moisture from both shallow and deep soil layers.
- Adding **organic amendments** such as compost or manure to the surface layer can improve its water-holding capacity, reducing the need for frequent irrigation and improving drought resilience.

3. SOIL FERTILITY AND NUTRIENT SUPPLY

Organic matter is a primary source of essential nutrients, such as nitrogen (N), phosphorus (P), and potassium (K), which are critical for plant growth and microbial activity. The organic matter content influences both the availability of nutrients and the soil's ability to retain them.

- The **low organic matter content** in the **0-40 cm depth** indicates limited nutrient reserves, potentially requiring external inputs such as fertilizers to sustain crop growth. This layer may also experience **nutrient leaching**, further depleting its fertility.
- The **higher organic content in the 40-70 cm depth**, particularly in Plates 59 and 24, suggests a **greater nutrient reservoir** at this level. However, the organic matter in Plate 77 is comparatively lower, highlighting localized variability in nutrient availability that may require **site-specific management strategies**.

Management Implications:

- Incorporating **organic fertilizers** or **cover crops** in areas with low organic matter can help replenish nutrient levels.
- Practices like **crop rotation** and **intercropping** can improve nutrient cycling and reduce the risk of nutrient depletion.

4. LONG-TERM SOIL HEALTH

Sustaining or increasing organic matter content is essential for maintaining the **long-term health and productivity of soils**. Organic matter enhances soil resilience by improving its capacity to respond to environmental stresses such as drought, heavy rainfall, or salinization.

- The relatively low organic matter content in the **0-40 cm depth** highlights the importance of **active soil management practices** to boost organic levels in this layer. This may involve strategies such as:
  - **Cover Cropping**: Planting cover crops like clover or rye to increase organic inputs and protect the soil from erosion.
  - **Organic Amendments**: Applying compost, crop residues, or biochar to replenish organic matter levels and improve soil quality.
  - **Reduced Tillage**: Minimizing soil disturbance to prevent the breakdown of organic matter and preserve soil structure.

Management Implications:

- Long-term soil health programs should focus on building organic matter across all depths to enhance the soil's physical, chemical, and biological properties.
- Monitoring organic matter levels over time can help assess the effectiveness of soil management practices and adjust them as needed.

5. BROADER IMPLICATIONS

The findings on organic matter variations have broader implications for **agricultural sustainability**, **water management**, and **climate resilience**:

- **Agricultural Productivity**: By improving organic matter content, soil fertility and water retention can be optimized to support higher crop yields.
- **Flood Mitigation**: Soils with higher organic matter can retain more water during rainfall events, reducing surface runoff and flood risks.
- **Carbon Sequestration**: Increasing organic matter content also contributes to global efforts to mitigate climate change by storing carbon in soils and reducing atmospheric CO_2 levels.

CONCLUSION

The organic matter content across different depths highlights significant variations in soil structure, water retention, and nutrient availability, each of which requires targeted management strategies. Improving organic matter content, particularly in the **0-40 cm layer**, is critical for addressing challenges related to soil fertility, erosion, and drought. Conversely, leveraging the organic-rich deeper layers can enhance water storage and nutrient reserves for long-term agricultural productivity and environmental sustainability. These findings provide a foundation for developing **site-specific soil management practices** that balance productivity with sustainability.

BROADER IMPLICATIONS

These findings extend beyond basic soil characterization and have significant applications in **agriculture, environmental management, and urban planning**. In agriculture, understanding the distribution of organic matter enables the **optimization of irrigation and fertilization strategies**, ensuring crops receive adequate water and nutrients while reducing input costs. The **higher organic matter content in the 40-70 cm layer** enhances water retention, potentially acting as a buffer during droughts and supporting deep-rooted crops.

From an environmental perspective, the water retention properties of the deeper layer may play a critical role in **mitigating drought impacts** and **improving groundwater recharge**, helping to maintain the hydrological balance in the study area. Conversely, the **compact nature of the 0-40 cm layer**, with lower organic matter content, highlights the need for targeted management practices to improve infiltration. This is particularly relevant in **urban settings**, where reduced infiltration can exacerbate surface flooding during extreme rainfall events. Addressing these challenges will be essential for enhancing resilience against climate change and supporting sustainable development.

CONCLUSION

In conclusion, the data reflects a **relatively uniform distribution of organic matter** with slight variations at greater depths, as observed in Plates 59, 24, and 77. The **0-40 cm layer** is characterized by a potentially **compact structure**, which could restrict water infiltration and root growth. In contrast, the **40-70 cm layer** shows slightly higher organic matter content in some areas, enhancing its **water retention capacity**, **nutrient availability**, and **soil sustainability**.

These insights are critical for managing soil health and sustainability. In agriculture, organic matter directly influences **crop yield, water management, and soil conservation**, underscoring the need for targeted practices like **cover cropping**, **organic amendments**, and **reduced tillage**. In urban environments, addressing the variability in organic content and compaction can inform strategies for **flood risk mitigation** and **stormwater management**.

The findings of this study emphasize the importance of **site-specific soil management practices** to address localized variability and improve overall soil functionality. By leveraging these insights, stakeholders can develop solutions that balance productivity, environmental sustainability, and climate resilience.

4. SOIL-WATER RETENTION AT THREE MOISTURE (SUCTION) LEVELS AND EFFECTIVE POROSITY

Table 9-results of the wieght of soil samples after each suction tests

number	depth(cm)	Weight Pf 0 (gr)	weight (pf 2)	weight (pf 2.5)	weight (pf 2.9)1	weight (pf 2.9)2	total prorosity (cm*3p/cm*3s)	effective porosity (cm*3p/cm*3s)
s9	13	146,335	144,34	142,65	141,35	140,89	0,463207547	0,422357547
s5	16	166,78	162,67	160,725	159,315	158,745	0,415358491	0,296858491
s6	14	199,125	193,245	190,07	187,135	186,45	0,292	0,17695
s12	22	185,185	183,325	181,48	179,5	179,185	0,360792453	0,202842453
s15	22	180,32	177,375	174,465	172,635	172,475	0,354264151	0,262264151
s13	30	104,46	102,01	100,255	99,04	98,615	0,66045283	0,51565283
s3	30	188,125	186,975	186,335	185,595	185,57	0,317773585	0,244423585

Table 10- water content (red results are errore)

Number	initial (gr)	pf 2 (gr)	pf 2,5 (gr)	pf 2,9 (gr)
s9	0.04	0.0209	0,004	-0,009
s5	0.1185	0.0774	0.05795	0.04385
s6	0.11505	0.05625	0.0245	-0,00485
s12	0.15795	0.13935	0.1209	0.1011
s15	0.092	0.06255	0.03345	0.01515
s13	0.1448	0.1203	0.10275	0.0906
s3	0.07335	0.06185	0.05545	0.04805

Table 11-sample volumetric and gravimetric water content

Sample	Gravimetric Water Content (%)	Volumetric Water Content (cm³/cm³)
s9	3.10	0.0434
s5	1.67	0.0267
s6	1.71	0.0325
s12	1.85	0.0333
s15	1.36	0.0241
s13	2.01	0.0361
s3	1.07	0.0198

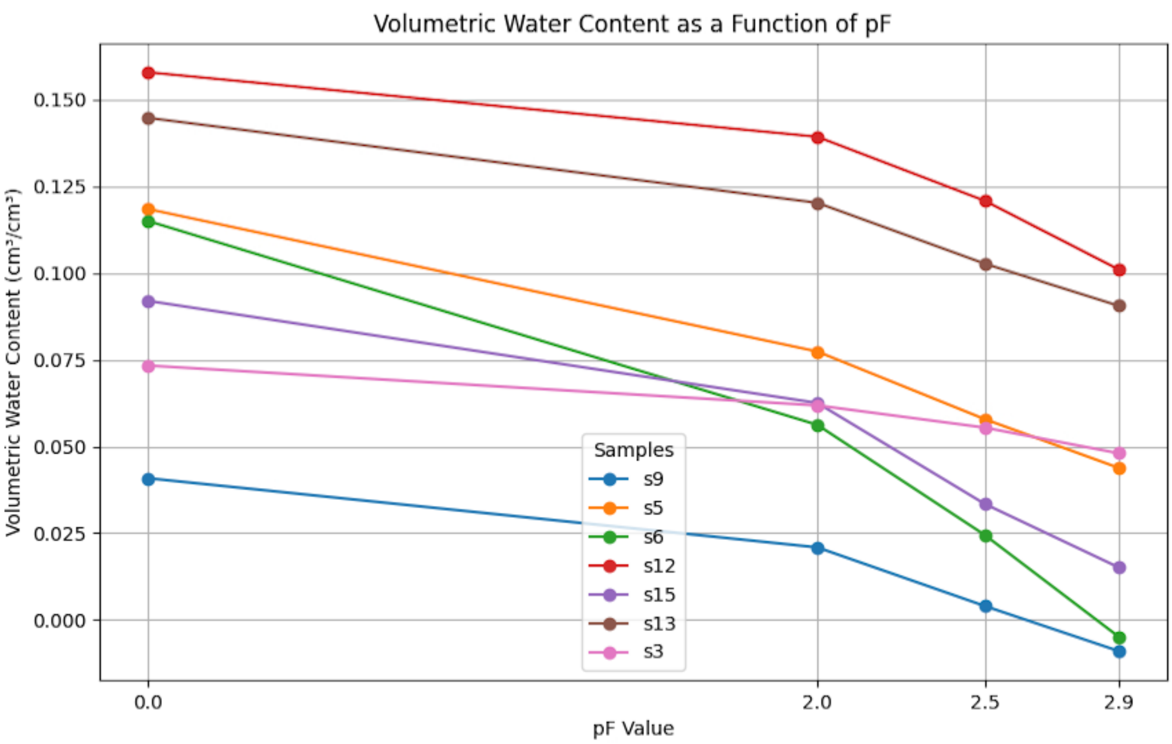

Fig 7- is showing the graph of volumetric water content in each pf

4-0 test intorduction

He **Suction Box Test** is a laboratory procedure designed to measure the water retention characteristics of soil, specifically its matric suction under controlled conditions. This test is essential for understanding the behavior of unsaturated soils, as it provides data for the soil-water retention curve (SWRC), which describes the relationship between soil water content

and suction pressure. The SWRC is critical for applications in geotechnical engineering, agriculture, and hydrology, particularly in unsaturated zone modeling and soil stability analysis.
The suction box test is used to assess the movement of water through soil pores and the soil's ability to retain moisture under varying suction pressures. This is particularly useful in applications where soil behavior under drought or drainage conditions is a concern.

IMPORTANCE AND APPLICATIONS

1. **Geotechnical Engineering:**
    a. Evaluates soil stability under unsaturated conditions.
    b. Determines properties such as shear strength and hydraulic conductivity in unsaturated soils.
2. **Agriculture:**
    a. Helps in understanding plant-available water and irrigation management.
3. **Environmental Engineering:**
    a. Used to design landfill liners and covers by analyzing soil-water movement.
4. **Hydrology:**
    a. Aids in modeling unsaturated flow for water table recharge and contaminant transport studies.

EQUIPMENT AND MATERIALS

1. **Suction Box:**
    a. A sealed chamber with a porous plate or membrane at the base that allows water flow but retains air under specific conditions.
    b. The plate must have a known air-entry value to apply suction accurately.
2. **Vacuum System:**
    a. Includes a vacuum pump or suction regulator capable of applying precise pressures ranging from 0 to 100 kPa, depending on the test requirements.
3. **Water Supply System:**
    a. A system to saturate the soil initially and maintain constant water conditions.
4. **Soil Sample Holder:**
    a. A mold or container that holds the soil sample in contact with the porous plate.
5. **Measurement Tools:**
    a. Precision balance for weighing the soil sample during the test.
    b. Pressure transducers to monitor suction applied.
6. **Soil Sample:**
    a. Soil of known properties (e.g., texture, density) prepared into uniform samples for testing.

TEST PROCEDURE

1. **Preparation of Soil Sample:**
    a. Compact the soil to a desired bulk density in a cylindrical mold.
    b. Ensure uniform initial saturation by submerging the sample in water until fully saturated.
2. **Setting up the Suction Box:**
    a. Place the saturated soil sample on the porous plate inside the suction box.
    b. Seal the suction box to prevent air leaks and ensure accurate pressure control.
3. **Applying Suction:**
    a. Connect the suction box to a vacuum pump or suction regulator.

b. Apply an initial suction pressure (e.g., 5 kPa) and allow the soil to reach equilibrium. This ensures that the soil water content stabilizes at the given suction level.
c. Measure the water content by recording the weight of the soil sample and subtracting the dry soil weight.

4. **Incremental Suction Adjustments:**
   a. Gradually increase the suction in increments (e.g., 5, 10, 20 kPa) and repeat measurements at each level.
   b. Equilibrium times may vary based on soil type and suction levels, typically taking hours or even days for fine-grained soils.
5. **Final Measurement:**
   a. Continue the process until the soil reaches the maximum suction level achievable by the equipment or the desired range (e.g., 50–100 kPa).

DATA ANALYSIS

1. **Soil-Water Retention Curve (SWRC):**
   a. The SWRC is plotted as suction pressure (*hh*h) on the x-axis against volumetric water content (*θ\theta*θ) or gravimetric water content on the y-axis.
   b. The curve typically shows an exponential decline, indicating that less water is retained as suction increases.
2. **Mathematical Modeling:**
   a. Models such as the van Genuchten or Brooks-Corey equations are used to fit the experimental data:
      i. **van Genuchten Model:** θ(h)=θr +(θs −θr)/(1+(αh)^n)^m
      ii. Where:
         1. θs : Saturated water content,
         2. θr : Residual water content,
         3. h: Matric suction,
         4. α,n,m: Empirical fitting parameters.
3. **Hydraulic Properties:**
   a. Derive unsaturated hydraulic conductivity and other key parameters for soil-water flow modeling.

KEY CONSIDERATIONS

1. **Soil Type:**
   a. Coarse-textured soils equilibrate faster than fine-textured soils due to differences in pore size and capillary forces.
2. **Equilibrium Time:**
   a. Ensure sufficient time for each suction increment to allow the soil to reach equilibrium.
3. **Porous Plate Properties:**
   a. The air-entry value of the porous plate should exceed the maximum suction applied.

ADVANTAGES

1. Provides precise control over suction pressure.
2. Produces detailed data on the soil's unsaturated hydraulic properties.
3. Laboratory-based, allowing for controlled and repeatable conditions.

LIMITATIONS

1. Time-consuming, particularly for soils with fine textures.
2. Limited range of suction pressures depending on the equipment used.
3. Requires specialized equipment and expertise for accurate results.

SUMMARY

The Suction Box Test is a critical method for determining the soil-water retention characteristics of unsaturated soils. By applying controlled suction and measuring the corresponding water content, this test provides the foundation for constructing the soil-water retention curve, a key tool in soil science and engineering. The insights gained from this test are instrumental in predicting soil behavior in real-world scenarios, such as drought, drainage, and structural stability under unsaturated conditions.

4.1. UNDERSTANDING THE DATA

- **W water (Initial Water Content):** This column represents the initial amount of water in the soil sample before any changes in moisture levels due to drainage or suction.
- **Gr (Columns 1 to 5):** These columns show the weight of the soil samples at different moisture levels, with reductions over time or after applying different levels of suction. Negative values indicate a loss of water from the sample, likely due to suction forces or evaporation.

4.2. KEY OBSERVATIONS

- **Sample s9 (13 cm depth):**
  - Initial water content was 4.085 grams.
  - Over time, the weight decreased, showing a net loss of water, with final readings showing a decrease to -1.36 grams. This suggests a significant loss of moisture, likely due to high suction forces in the soil, leading to water being drawn out of the sample.
- **Sample s12 (22 cm depth):**
  - This sample had the highest initial water content at 15.795 grams.
  - The water content gradually decreased, but even at the last reading, the sample retained 9.795 grams, indicating that this soil has a high capacity for water retention under these conditions.
- **Sample s6 (14 cm depth):**
  - The initial water content was 11.505 grams.
  - Like s9, this sample showed a decrease in water content, with final negative values indicating that more water was lost than the initial water content, suggesting very high suction or desiccation levels.
- **Sample s13 (30 cm depth):**
  - Initial water content was 14.48 grams.
  - This sample also retained a significant amount of water, with 8.635 grams still present at the final reading, showing that deeper soils can have a substantial capacity for water retention.

4.3. ANALYSIS OF WATER RETENTION AND SUCTION LEVELS

- **Water Retention**:
  - **Samples s12 and s13** demonstrate the highest water retention capacity, which aligns with their higher initial water content. This suggests that these soils, being deeper, are better at retaining moisture.

- **Samples s9 and s6** show the most significant water loss, indicating higher susceptibility to suction forces drawing moisture out of the soil.

- **Suction Forces**:
  - The negative values seen in **Samples s9 and s6** reflect strong suction forces or evaporation effects, highlighting the porous nature of these soils.
  - In contrast, the stability in **Samples s12 and s13** indicates that these soils have a more robust structure capable of retaining moisture even under stress.
- **Water Retention Section: Revised Calculations with Formulas**
- The following calculations are based on the provided data for soil samples s9, s5, s6, s12, s15, s13, and s3. Each calculation follows the necessary formulas for dry bulk density, total porosity, and volumetric water content.
- The following formulas are used in the calculations:
- 1. Dry Bulk Density (ρ_b): **$\rho_b = M_d / V_s$**
  Where:
  M_d = Dry soil weight (g)
  V_s = Soil volume (cm^3)
- 2. Total Porosity (φ): **$\varphi = 1 - (\rho_b / \rho_p)$**
  Where:
  ρ_b = Dry bulk density (g/cm^3)
  ρ_p = Particle density (assumed as 2.65 g/cm^3 for sand)
- 3. Volumetric Water Content (θ) at pF 2: **$\theta = (M_d - M_{pf2}) / V_s$**
  Where:
  M_d = Dry soil weight (g)
  M_{pf2} = Soil weight at pF 2 (g)
  V_s = Soil volume (cm^3)

  Sample s9
- Dry weight (M_d) = 146.335 g
- Weight at pF 2 (M_{pf2}) = 144.34 g
- Water retained at pF 2 ($M_d - M_{pf2}$) = 1.995 g
- Volumetric Water Content (θ) = 0.014 cm^3/cm^3
- Sample s5
- Dry weight (M_d) = 166.78 g
- Weight at pF 2 (M_{pf2}) = 162.67 g
- Water retained at pF 2 ($M_d - M_{pf2}$) = 4.110 g
- Volumetric Water Content (θ) = 0.025 cm^3/cm^3

  Sample s6
- Dry weight (M_d) = 199.125 g
- Weight at pF 2 (M_{pf2}) = 193.245 g
- Water retained at pF 2 ($M_d - M_{pf2}$) = 5.880 g
- Volumetric Water Content (θ) = 0.030 cm^3/cm^3

  Sample s12
- Dry weight (M_d) = 185.185 g
- Weight at pF 2 (M_{pf2}) = 183.325 g
- Water retained at pF 2 ($M_d - M_{pf2}$) = 1.860 g
- Volumetric Water Content (θ) = 0.010 cm^3/cm^3

  Sample s15
- Dry weight (M_d) = 180.32 g
- Weight at pF 2 (M_{pf2}) = 177.375 g
- Water retained at pF 2 ($M_d - M_{pf2}$) = 2.945 g
- Volumetric Water Content (θ) = 0.016 cm^3/cm^3

Sample s13

- Dry weight (M_d) = 104.46 g
- Weight at pF 2 (M_pf2) = 102.01 g
- Water retained at pF 2 (M_d - M_pf2) = 2.450 g
- Volumetric Water Content (θ) = 0.023 cm^3/cm^3

Sample s3

- Dry weight (M_d) = 188.125 g
- Weight at pF 2 (M_pf2) = 186.975 g
- Water retained at pF 2 (M_d - M_pf2) = 1.150 g
- Volumetric Water Content (θ) = 0.006 cm^3/cm^3

4.4. ANALYSIS OF WATER RETENTION AND SUCTION LEVELS

- **Water Retention:**
  - Samples s12 and s13 demonstrated the highest water retention capacity, which correlates with their higher initial water contents and minimal negative losses. This indicates that these soils, likely being deeper, are less prone to drying out and can hold water more effectively.
  - Samples s9 and s6 showed the most significant water loss, likely due to their higher susceptibility to suction, leading to water being drawn out of the soil.
- **Suction Forces:**
  - The negative values in samples s9 and s6 indicate the presence of strong suction forces or evaporation effects. This suggests that these soils are either highly porous, allowing water to be pulled out quickly, or they are in environments where water loss through evaporation is significant.
  - The other samples, particularly s12 and s13, show more stable water content, suggesting that the suction forces are either weaker or that these soils have a more robust structure, retaining water more effectively even under stress.

4.5. IMPLICATIONS FOR SOIL MANAGEMENT AND AGRICULTURAL PRACTICES

- **Soil Types and Water Management:**
  - Soils like s12 and s13 that retain water well are beneficial for agricultural practices where consistent moisture levels are critical. These soils can sustain plant growth without frequent irrigation, making them ideal for crops that require steady water supply.
  - On the other hand, soils like s9 and s6, which lose water rapidly, may require more frequent irrigation or the use of soil amendments to improve water retention. In such soils, understanding the depth at which water is lost is crucial for effective water management.
- **Flooding Risk:**
  - Soils that retain more water could potentially contribute to flooding if they are not managed properly, especially if they are in low-lying areas or regions with a high water table. Understanding the balance between retention and drainage is critical in flood-prone areas like Kærby.
  - For soils with high suction and water loss, such as s9 and s6, the risk of waterlogging may be lower, but they could still contribute to surface runoff if water is applied faster than it can be absorbed, particularly in heavy rainfall scenarios.

4.6. CONCLUSION

The analysis of the soil-water retention data underscores the critical role of soil moisture dynamics in influencing both agricultural productivity and flood management. The observed differences across soil types and depths reveal distinct hydrological behaviors, with implications for water management strategies in urban and agricultural settings.

Soils with **high water retention**, such as **s12 and s13**, provide significant advantages for agriculture by ensuring consistent moisture availability for crops. However, these soils also pose a higher risk of waterlogging and surface flooding, especially during heavy rainfall events. Proper drainage systems and controlled irrigation practices are essential to balance their benefits with the potential risks.

Conversely, soils like **s9 and s6**, which exhibit **lower water retention**, are more prone to drying out quickly, necessitating interventions to enhance their moisture-holding capacity. This may include the addition of organic matter, mulching, or other soil amendments to improve structure and prevent excessive water loss. These strategies are particularly crucial for supporting sustainable plant growth, reducing irrigation demands, and conserving water resources.

These insights are directly applicable to regions like **Kærby**, where managing soil moisture is critical for mitigating flooding risks while maintaining agricultural productivity. By tailoring water management practices to the specific characteristics of each soil type, stakeholders can achieve a balance between flood prevention and sustainable land use.

Furthermore, understanding soil-water retention across depths enables better decision-making for deep-rooted crops and informs hydrological models used in urban planning. For instance, incorporating this data into urban stormwater systems can enhance infiltration and reduce surface runoff during extreme weather events.

In conclusion, the findings from this study emphasize the importance of soil-specific and depth-specific strategies in achieving optimal water management. By addressing the unique needs of different soil types, this research provides a foundation for sustainable practices that safeguard both urban and agricultural systems against the challenges posed by climate change and increasing water demands.

5.1. UNDERSTANDING CAPILLARY RISE IN SOIL

- Capillary rise in soil is a fundamental process that significantly influences soil-water interactions, directly impacting **plant water availability**, **soil stability**, and **agricultural productivity**. This upward movement of water through the soil pores occurs due to the combined effects of **adhesion, cohesion, and surface tension**. Capillary rise plays a crucial role in determining water distribution within the soil profile, particularly in regions where irrigation is limited or during periods of low rainfall. Understanding this phenomenon is essential for optimizing soil and water management practices in both agricultural and urban settings.

5.2. MECHANISM OF CAPILLARY RISE

- The mechanism of capillary rise relies on the balance between two key forces:
- **Adhesion**: The attraction between water molecules and soil particles.
- **Cohesion**: The attraction between water molecules themselves.
- When soil pores are small, these forces can overcome gravitational pull, allowing water to move upward from saturated zones to drier areas above. The height to which water rises depends on several interrelated factors:
- **Soil Texture**:
  - Finer soils, such as **clay**, have smaller pores that support a **higher capillary rise** due to the greater surface area for adhesion.

    - Coarser soils, like **sand**, have larger pores that limit the height of capillary rise.

- **Soil Structure**:
    - **Well-structured soils** with stable aggregates and interconnected pores enhance capillary rise by providing continuous pathways for water movement.
    - In contrast, compacted or poorly aggregated soils restrict water movement, reducing capillary action.
- **Water Properties**:
    - The **surface tension of water**, influenced by temperature and dissolved substances, plays a critical role. Higher surface tension results in greater capillary rise.
- **Pore Size Distribution**:
    - Soils with a uniform distribution of pore sizes allow for efficient capillary action, while those with irregular pore sizes may disrupt upward water movement.

5.3. EFFECTS OF CAPILLARY RISE ON SOIL PROPERTIES

- The impact of capillary rise extends beyond water movement and influences several key soil properties:
- **Water Availability**:
    - Capillary rise ensures the redistribution of water from deeper layers to the root zone, providing plants with an additional water source during dry periods. This process is especially beneficial in arid and semi-arid regions where rainfall is sporadic.
- **Soil Salinity**:
    - In areas with saline groundwater, capillary rise can transport dissolved salts to the soil surface, causing **salinization**. This phenomenon poses a significant challenge for agriculture, as high salt concentrations can reduce crop yields and degrade soil health. Effective management practices, such as **leaching** or **salt-tolerant crops**, are often required in such areas.
- **Soil Structure and Compaction**:
    - Continuous capillary rise can influence soil compaction and aeration. Water moving through small pores can cause fine particles to settle, reducing pore space and increasing bulk density. This, in turn, can limit root growth and microbial activity.
- **Nutrient Redistribution**:
    - Capillary rise can also carry nutrients from deeper soil layers to the root zone, improving nutrient availability for plants. However, if nutrient-rich water evaporates at the surface, it may lead to **surface crusting** and nutrient loss.

5.4. PRACTICAL IMPLICATIONS OF CAPILLARY RISE

- **Agricultural Management**:
    - Understanding capillary rise is essential for designing **irrigation systems** that optimize water use efficiency. For example, capillary action can reduce irrigation frequency by ensuring that water from deeper soil layers is available to plants.
    - In saline soils, managing capillary rise through controlled water tables can help mitigate the effects of salinization.
- **Urban Applications**:

- In urban settings, capillary rise can affect **foundation stability** by introducing moisture into subsoil layers. Engineering solutions, such as sub-surface drainage systems, are often necessary to counteract this effect.

- **Environmental Management**:
  - By promoting upward water movement, capillary rise can contribute to the recharge of shallow groundwater and the maintenance of wetland ecosystems. However, excessive capillary rise may also lead to waterlogging in poorly drained soils.

- **CONCLUSION**

Capillary rise is a vital process that governs water movement and distribution in soils, influencing plant growth, soil stability, and agricultural sustainability. While it provides essential benefits such as enhancing water availability, it also presents challenges like soil salinization and compaction. Understanding the mechanisms and effects of capillary rise is critical for developing effective strategies to manage soil and water resources in diverse environments, from agricultural fields to urban landscapes. This knowledge supports efforts to optimize irrigation, mitigate salinity, and ensure long-term soil health and productivity.

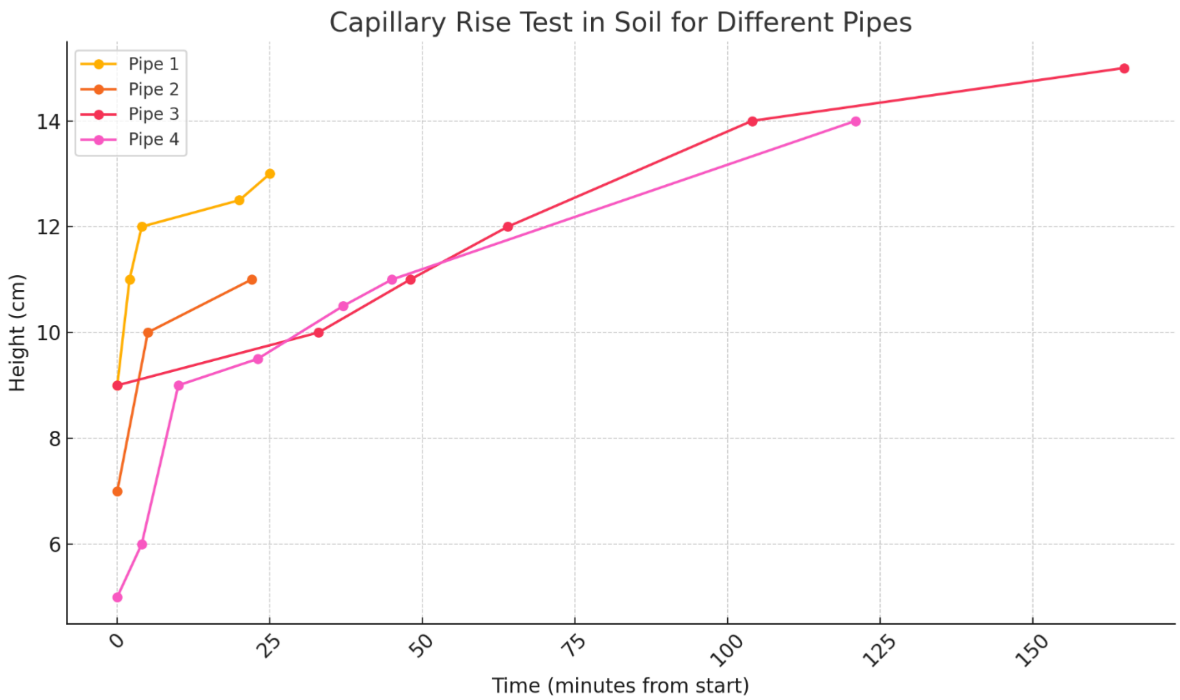

Fig 8- showing the water height during the time of test

5.5. ANALYZING CAPILLARY RISE RESULTS

The capillary rise results provided can be analyzed to understand how different soil and pipe conditions influence water movement in the soil. Below are the results and the interpretation:

PIPE 1 (WEIGHT: 2.894 KG)

- **Initial Observation (11:38 AM):** 9 cm
- **Final Observation (12:03 PM):** 13 cm
- **Total Rise:** 4 cm over 25 minutes

This pipe shows a moderate capillary rise. The relatively steady increase suggests a consistent soil structure, likely with medium-sized pores, facilitating the gradual movement of water.

PIPE 2 (WEIGHT: 2.8558 KG)

- **Initial Observation (11:38 AM):** 7 cm
- **Final Observation (12:00 PM):** 11 cm
- **Total Rise:** 4 cm over 22 minutes

Pipe 2 demonstrates a similar rise to Pipe 1, though it starts at a lower initial height. This could indicate slightly coarser soil particles or less compacted soil compared to Pipe 1.

PIPE 3 (WEIGHT: 2.2008 KG)

- **Initial Observation (11:39 AM):** 9 cm
- **Final Observation (14:24 PM):** 15 cm
- **Total Rise:** 6 cm over 2 hours and 45 minutes

Pipe 3 shows a slower and more prolonged capillary rise. The extended time suggests that the soil in Pipe 3 has larger pores, possibly indicating a sandier texture, which allows for a slower movement of water.

PIPE 4 (WEIGHT: 2.1968 KG)

- **Initial Observation (11:49 AM):** 5 cm
- **Final Observation (13:50 PM):** 14 cm
- **Total Rise:** 9 cm over 2 hours and 1 minute

Pipe 4 has the most substantial rise among the samples, indicating very fine soil particles, such as clay, that have the highest capillary action due to their small pore sizes.

Capillary Rise (hc):

- **Pipe 1:** 13 cm
- **Pipe 2:** 11 cm
- **Pipe 3:** 15 cm
- **Pipe 4:** 14 cm

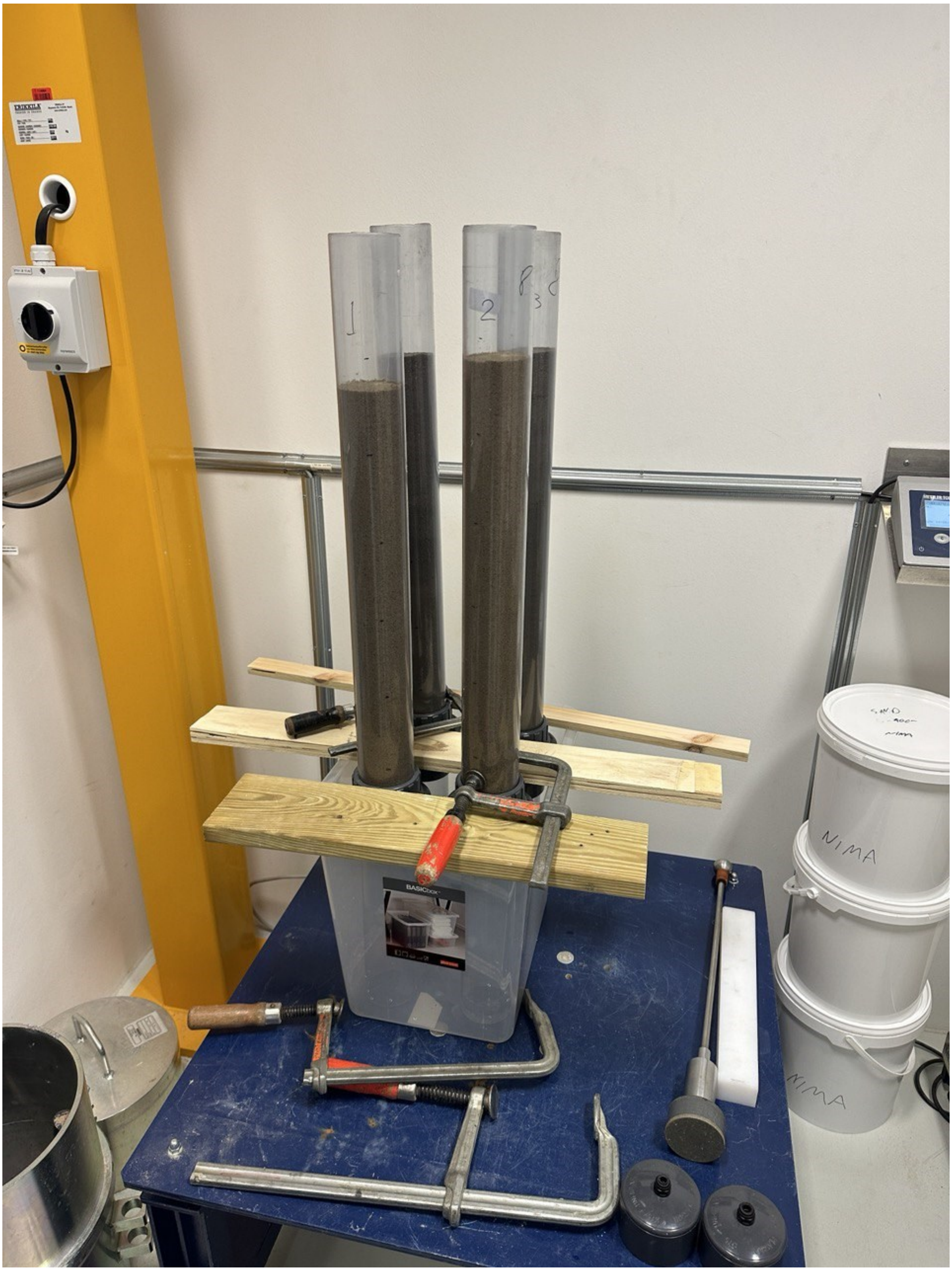

Fig 9- test procedure

Fig 10-test stabilizing

Fig 11-water height

5.6. SUMMARY OF CAPILLARY RISE BEHAVIOR

The capillary rise data from the four pipes illustrate how soil texture and structure can significantly influence water movement within the soil. Pipes 3 and 4, which have lower weights, demonstrate greater capillary rise over time. This suggests finer soil particles and a more compact structure in these pipes, leading to higher water retention and movement.

Conversely, Pipes 1 and 2, with higher weights, show less rise, indicative of coarser soils with larger pores, leading to quicker water drainage and less capillary action.
The higher capillary rise in **Pipes 3 and 4** suggests that these soils have finer particles and a more compact structure, allowing for greater capillary action. These soils are more likely to retain moisture at the surface, which could pose a risk of waterlogging during wet periods.

5.7. IMPLICATIONS OF CAPILLARY RISE ON SOIL MANAGEMENT

Understanding the capillary rise in different soil types is essential for effective soil management. For agricultural purposes:

- **Irrigation management**: Knowledge of capillary rise can help in designing irrigation schedules that maximize water availability to crops while minimizing losses.
- **Salinity control**: In saline environments, managing capillary rise is crucial to prevent the accumulation of salts in the root zone.
- **Soil health**: Maintaining optimal soil structure through practices like organic matter addition and reduced tillage can enhance capillary action, improving water availability and soil fertility.

6. FIELD INVESTIGATION USING A DOUBLE-RING INFILTROMETER

6.1. INTRODUCTION TO WATER INFILTRATION CAPACITY AND SATURATED HYDRAULIC CONDUCTIVITY

The infiltration capacity of soil is a critical parameter in hydrological studies and agricultural planning. It defines the maximum rate at which soil can absorb water. The saturated hydraulic conductivity (K_sat) is closely related, representing the ease with which water moves through saturated soil. These parameters are essential for understanding how water interacts with soil, influencing irrigation practices, drainage design, and overall soil management.
The Double-Ring Infiltrometer is a standard tool for field investigation of water infiltration capacity and K_sat. It provides a reliable means of quantifying how quickly water infiltrates the soil under controlled conditions, reducing the impact of lateral water movement.

6.2. UNDERSTANDING THE DOUBLE-RING INFILTROMETER TEST

The **Double-Ring Infiltrometer (DRI) Test** is a widely recognized method for measuring the infiltration rate of water into soil in a field setting. Infiltration is the process by which water enters the soil surface, moving through the soil matrix under gravity and capillary forces. This test is fundamental in soil science, hydrology, agriculture, and environmental engineering for assessing water movement, evaluating soil permeability, and determining the saturated hydraulic conductivity (*Ksat*) of soils.
The technique employs two concentric rings—an inner and an outer ring—to control the direction of water movement. By minimizing lateral flow, the test ensures a predominantly vertical water movement from the inner ring, providing a more accurate measure of infiltration rates. It is widely used in research and practice to inform irrigation system design, predict runoff potential, estimate groundwater recharge, and evaluate soil management practices.

IMPORTANCE AND APPLICATIONS

1. **Agriculture:** Helps in designing efficient irrigation systems and assessing soil's ability to absorb and retain water.
2. **Hydrology:** Aids in understanding water recharge rates for aquifers and estimating surface runoff potential during storms.
3. **Soil Science:** Provides data on soil texture and structure, which influence infiltration.

4. **Environmental Engineering:** Assists in assessing land suitability for projects such as septic tank installations and stormwater management.

EQUIPMENT AND MATERIALS

1. **Double Rings:**
    a. **Inner Ring:**
        i. Diameter: Commonly 30–60 cm (12–24 inches).
        ii. Height: 20–40 cm.
    b. **Outer Ring:**
        i. Diameter: Typically 1.5 to 2 times the diameter of the inner ring (e.g., 60–120 cm or 24–48 inches).
        ii. Height: 20–40 cm.
    c. The rings are generally constructed from durable materials like stainless steel or heavy-duty PVC to maintain shape during insertion.
2. **Driving Equipment:**
    a. **Driving Tool:** A wooden plank or a hammer with a protective layer to avoid damaging the rings.
    b. Some setups use a specialized driver with evenly distributed pressure to avoid uneven soil penetration.
3. **Water Source:**
    a. A controlled water source (e.g., tank, hose, or bucket) with a steady supply to maintain a constant head in the rings.
4. **Measurement Tools:**
    a. **Ruler or Float Gauge:** To measure water level changes.
    b. **Stopwatch:** To record time intervals.
    c. Optional automated data loggers for precision measurements in advanced setups.
5. **Other Materials:**
    a. Shovels and soil preparation tools to clear the test area.
    b. Containers to collect water for volume measurements.

TEST PROCEDURE

1. **Site Preparation:**
    a. Select a flat, undisturbed site representative of the study area. Avoid areas with significant slope, large rocks, or vegetation.
    b. Clear the surface of debris and organic matter but avoid disturbing the soil structure.
2. **Installing the Rings:**
    a. Place the rings concentrically on the soil surface, with the inner ring at the center.
    b. Drive the rings vertically into the soil using a hammer or driving tool. The insertion depth should be 5–10 cm to prevent water leakage at the edges.
    c. Ensure both rings are level to maintain uniform water head.
3. **Adding Water:**
    a. Fill both rings with water simultaneously to maintain a constant depth (e.g., 2–5 cm head of water).
    b. Begin with an initial high-volume application to saturate the soil, reducing variability from air pockets or dry soil layers.
4. **Infiltration Measurement:**

a. Maintain the water head in both rings, especially the outer ring, to prevent lateral water movement from the inner ring.
b. Measure the drop in water level in the inner ring over time, typically at intervals of 1–5 minutes for rapid infiltration or 10–30 minutes for slower rates.
c. Record measurements until a steady-state infiltration rate is achieved (water level drops uniformly over multiple intervals).

DATA ANALYSIS

1. **Infiltration Rate (*II*I):**
    a. Calculate the infiltration rate using: $I=\Delta V/(A \cdot \Delta t)$
    b. Where:
        i. ΔV: Volume of water infiltrated (cm³),
        ii. A: Cross-sectional area of the inner ring ($\pi r2$) (cm²),
        iii. Δt: Time interval (seconds or minutes).
2. **Saturated Hydraulic Conductivity (*Ksat*):**
    a. Derived using empirical or theoretical models, such as the Green-Ampt or Philip infiltration models. These equations incorporate soil properties, initial saturation, and steady-state infiltration rates.

FACTORS AFFECTING RESULTS

- **Soil Type and Structure:** Sandy soils exhibit faster infiltration compared to clayey soils due to larger pore spaces.
- **Initial Moisture Content:** Dry soils have higher initial infiltration rates due to capillary action.
- **Compaction:** Compacted soils reduce infiltration rates by decreasing pore space.
- **Vegetation Cover:** Can either enhance or impede infiltration based on root activity and organic matter.

ADVANTAGES

- Simple and cost-effective for field measurements.
- Provides direct, site-specific data for soil infiltration and permeability.
- Minimizes lateral flow through the outer ring, enhancing accuracy.

LIMITATIONS

- Requires large volumes of water, which may not be feasible in remote or arid regions.
- Time-intensive, especially for soils with low permeability.
- Results are site-specific and may not represent the larger area due to soil heterogeneity.

SUMMARY

The Double-Ring Infiltrometer Test is an essential tool for quantifying soil infiltration characteristics in situ. By controlling the movement of water through the soil, this test provides valuable insights into water-soil interactions, which are critical for agricultural planning, hydrological modeling, and environmental assessments. Proper preparation, execution, and analysis are key to obtaining accurate and meaningful results.

6.3. SATURATED HYDRAULIC CONDUCTIVITY (K_SAT)

K_sat is a measure of a soil's ability to transmit water when fully saturated. It depends on the soil's texture, structure, and porosity. Coarse-textured soils (e.g., sandy soils) typically have high K_sat values due to larger pore spaces, while fine-textured soils (e.g., clay) have lower K_sat due to smaller pores that restrict water flow.

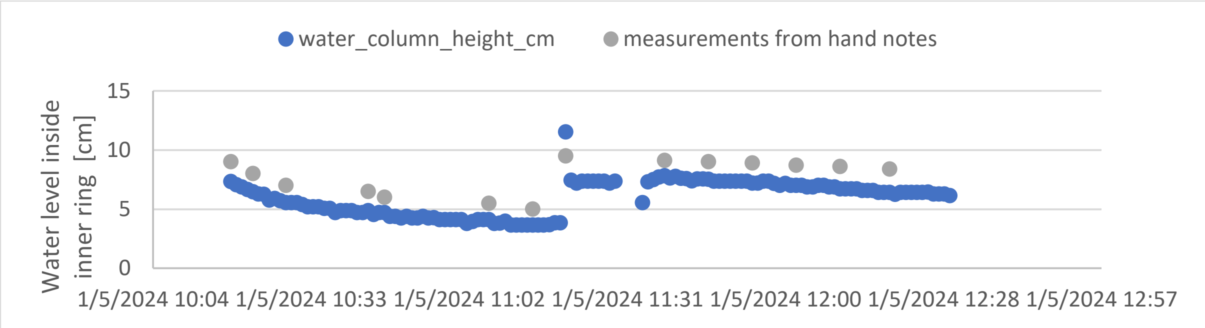

Fig 12- the difference of visual measurments and sensore measurments

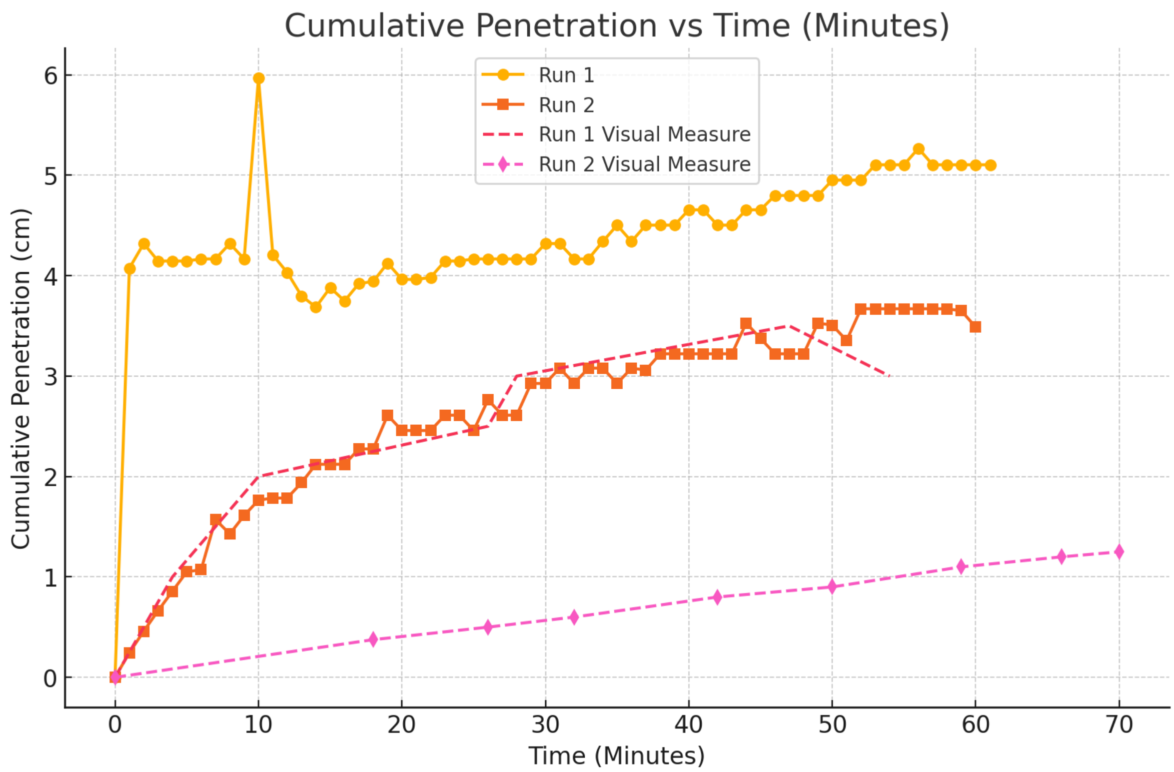

Fig 13- cumulative penetration in time

6.4. FIELD INVESTIGATION RESULTS: RUN 1 AND RUN 2

RUN 1: INITIAL CONDITIONS

In Run 1, the Double-Ring Infiltrometer test was conducted under standard field conditions, with the soil likely being at its natural moisture content. The infiltration rate observed would provide a baseline understanding of the soil's capacity to absorb water. Typically, in such a test, the infiltration rate decreases over time as the soil becomes saturated, eventually reaching a steady-state infiltration rate.

RUN 2: POSSIBLE EFFECTS OF CAPILLARY WATER TABLE

During Run 2, there is a possible indication of the influence of a capillary water table on the infiltration process. The capillary rise refers to the movement of water from the water table upward into the unsaturated zone due to capillary forces. If the water table is close to the surface, capillary rise can significantly affect the infiltration rate.

- **Increased Infiltration Rate:** If the capillary water table is close to the surface, the soil may already be partially saturated, leading to a higher initial infiltration rate. This occurs because the soil pores are filled more quickly, with less air to displace.
- **Steady-State Infiltration:** As the soil approaches saturation, the capillary action from the water table can lead to a more stable infiltration rate, potentially masking the typical decline observed in soils farther from the water table.
- **Hydraulic Conductivity:** The presence of a capillary water table might also result in higher K_sat values in Run 2 compared to Run 1, especially if the soil's structure facilitates upward water movement.

6.5. IMPLICATIONS OF CAPILLARY WATER TABLE ON INFILTRATION MEASUREMENTS

The presence of a capillary water table can complicate the interpretation of infiltration tests. If the water table is near the surface, the measured infiltration rate might not accurately reflect the soil's natural ability to absorb rainwater or irrigation water. Instead, the rate could be artificially enhanced by the capillary movement of water from below.
In agricultural settings, understanding this interaction is vital. Overestimating the infiltration capacity due to capillary effects could lead to inappropriate irrigation practices, where water application rates exceed what the soil can handle under natural conditions, leading to runoff and erosion.

6.6. CALCULATION OF INFILTRATION RATE AND K_SAT

1. **Infiltration Rate (I):**

- Measured as the volume of water infiltrated per unit area per unit time (e.g., cm/hr).
- $I = \frac{\Delta h}{\Delta t} \times \text{Area of the ring}$
- Where Δh is the change in water level and Δt is the time interval.

2. **Saturated Hydraulic Conductivity (K_sat):**
   - Estimated using the steady-state infiltration rate when the soil is fully saturated.
   - Can be calculated using empirical relationships such as the Green-Ampt model or Darcy's law, depending on the data available.

Table 12- calcuilating the Ksat

Run	Datalogger Ksat (cm/hour)	Visual Inspection Ksat (cm/hour)
Run 1	4.0	4.0
Run 2	1.0	1.0

6.7. DISCUSSION AND INTERPRETATION OF RESULTS

The results from Runs 1 and 2 should be carefully compared to understand the effect of the capillary water table. A significantly different infiltration rate or K_sat value in Run 2 could suggest that the water table's influence is substantial.

- **Run 1 Analysis:**
  - Likely provides a true representation of the soil's infiltration capacity under natural field conditions.
  - The infiltration curve should show a typical decline, stabilizing at a steady-state rate that reflects K_sat.
- **Run 2 Analysis:**
  - The possible influence of the capillary water table might be evident in a higher initial infiltration rate and a different steady-state value.

- This run may reflect conditions that could be encountered during periods of high groundwater levels or after significant rainfall when the water table rises.

These results highlight a significant reduction in the infiltration rate between **Run 1** and **Run 2**, likely due to the influence of the capillary water table. The higher saturation levels observed in **Run 2** suggest that the capillary action brought water closer to the surface, reducing the soil's ability to absorb additional water.

6.8. CONCLUSION

The Double-Ring Infiltrometer test is a powerful tool for assessing soil infiltration capacity and saturated hydraulic conductivity. However, the presence of a capillary water table during such tests can significantly affect the results, leading to higher infiltration rates that do not necessarily represent typical field conditions.

Understanding these effects is crucial for accurate interpretation of the data, particularly in areas with shallow water tables or in regions where irrigation practices could lead to periodic water table rise. The insights gained from comparing Runs 1 and 2 will help in making informed decisions about soil management, irrigation planning, and drainage design, ensuring sustainable use of soil and water resources.

FINAL CONCLUSION: HYDROLOGICAL INVESTIGATION OF KÆRBY, AALBORG

The hydrological investigation of Kærby, Aalborg, was aimed at understanding the key water-related processes that influence the area's flood risk, soil behavior, and agricultural potential. By focusing on soil texture, water retention, capillary rise, and infiltration rates, this study provides a comprehensive view of the hydrological dynamics at play in the region. The findings contribute valuable insights into flood management, soil conservation, and sustainable land use practices in urban and agricultural settings.

1. SOIL TEXTURE AND ITS ROLE IN WATER MOVEMENT

Soil texture plays a pivotal role in determining water infiltration, retention, and movement within the soil profile. The study found that the soil in Kærby is predominantly composed of sandy and gravelly materials, particularly in the subsoil, with finer particles such as silt and clay present in smaller proportions. These textural differences lead to significant variations in how water interacts with the soil.

- **Coarse-Grained Soils (Sandy/Gravelly)**: The coarse-grained soils exhibit high permeability, allowing water to move through the soil quickly. This characteristic is advantageous in preventing waterlogging and improving drainage. However, the low water retention in these soils presents a challenge for maintaining moisture levels, especially during dry periods. The rapid drainage also increases the risk of surface runoff during heavy rainfall events.
- **Fine-Grained Soils (Silt/Clay)**: The finer particles, although less common in the overall soil profile, play a crucial role in water retention. These soils exhibit low permeability, which slows down water movement but increases the soil's capacity to retain moisture. This property is particularly important for maintaining soil fertility and supporting plant growth, especially in agricultural areas.

The balance between these two soil types affects the hydrological behavior of Kærby. Areas with a higher proportion of fine particles are likely to experience slower drainage, increasing the risk of waterlogging and contributing to higher flood risks during extreme weather events. Conversely, areas dominated by coarse-grained soils are more prone to surface runoff due to their rapid drainage capabilities.

2. WATER RETENTION AND SUCTION LEVELS

The analysis of water retention across different soil samples revealed a diverse range of moisture-holding capacities. Samples taken from deeper soil layers, such as **s12** and **s13**, demonstrated higher water retention capacity, which aligns with the presence of finer particles in these soils. These deeper layers are more capable of holding water, making them less prone to drying out during dry periods.

In contrast, shallower soils, such as **s9** and **s6**, exhibited higher water loss, particularly under suction forces. The rapid loss of moisture in these soils suggests that they are more porous, allowing water to be drawn out easily. This characteristic poses challenges for agricultural practices, as these soils may require more frequent irrigation to maintain adequate moisture levels for crops.

The suction levels in the soil samples highlight the importance of understanding the interplay between soil texture, water retention, and suction forces. Soils that lose water rapidly under suction are more vulnerable to drying out, while soils that retain moisture more effectively are better suited for long-term agricultural use.

3. CAPILLARY RISE AND ITS IMPLICATIONS

Capillary rise is a key factor in the movement of water within the soil profile, particularly in areas with shallow water tables. The capillary action observed in the study varied significantly across the soil samples, with **Pipes 3 and 4** demonstrating the highest capillary rise. These soils, likely composed of finer particles, exhibited greater capillary action due to their small pore sizes, allowing water to move upward more effectively.

- **High Capillary Rise**: Soils with high capillary rise can maintain moisture in the root zone, supporting plant growth even during periods of low rainfall. However, this characteristic also increases the risk of waterlogging, especially in areas with high water tables. In Kærby, where the water table is relatively close to the surface, capillary rise could exacerbate flooding risks by bringing water to the surface, saturating the soil, and reducing its ability to absorb additional rainfall.
- **Low Capillary Rise**: In contrast, soils with lower capillary rise, such as those observed in **Pipes 1 and 2**, are less prone to water movement from deeper layers. These soils are more likely to dry out during drought conditions but are less susceptible to waterlogging. The lower capillary action reduces the risk of salt buildup on the soil surface, making these soils more suitable for long-term agricultural use in areas with saline groundwater.

The differences in capillary rise across the soil samples provide valuable insights into the potential for both water retention and waterlogging in Kærby. Soils with high capillary rise may require careful management to prevent flooding, while soils with low capillary action may need more frequent irrigation to support agricultural productivity.

4. INFILTRATION RATES AND SATURATED HYDRAULIC CONDUCTIVITY (KSAT)

The infiltration rates measured during the **Double-Ring Infiltrometer Test** offer important insights into how water moves through the soil in Kærby. The test revealed a significant decrease in infiltration rates between **Run 1** and **Run 2**, with the **Ksat** values dropping from 4.0 cm/hour in **Run 1** to 1.0 cm/hour in **Run 2**. This reduction suggests that the soil became saturated during the second run, likely due to the influence of a capillary water table.

- **Run 1 (Baseline Conditions)**: The initial infiltration rate observed in **Run 1** reflects the soil's natural ability to absorb water under field conditions. The relatively high infiltration rate indicates that the soil is well-drained, allowing water to move through the profile quickly. This finding is consistent with the presence of coarse-grained soils, which facilitate rapid water movement.
- **Run 2 (Influence of Capillary Water Table)**: The lower infiltration rate observed in **Run 2** suggests that the capillary water table was closer to the surface, reducing the soil's ability to absorb additional water. The presence of a capillary water table can

lead to higher initial infiltration rates as the soil becomes partially saturated, but as the soil approaches full saturation, the infiltration rate stabilizes at a lower value.

The significant difference between the infiltration rates in **Run 1** and **Run 2** highlights the importance of accounting for capillary water tables in hydrological assessments. In areas where the water table is close to the surface, the soil may become saturated more quickly, increasing the risk of surface runoff and flooding during heavy rainfall events.

5. FLOOD RISK AND WATER MANAGEMENT IN KÆRBY

The combination of high water retention in some soils, high capillary rise, and reduced infiltration rates due to the capillary water table presents a complex flood risk scenario for Kærby. The study's findings indicate that areas with fine-grained soils and high capillary action are at a greater risk of flooding, particularly during periods of heavy rainfall or when the water table rises.

- **Flood Risk**: Soils with high water retention and capillary rise are more prone to becoming saturated, increasing the likelihood of surface runoff and flooding. The reduced infiltration rates observed in **Run 2** suggest that the soil's capacity to absorb additional water is limited, particularly when the capillary water table is near the surface. This finding underscores the need for effective drainage systems in Kærby to manage excess water during storm events.
- **Water Management**: The study's findings also have important implications for water management in Kærby. In areas where soils retain water effectively, it may be necessary to implement measures to prevent waterlogging, such as improving drainage or using soil amendments to enhance permeability. In contrast, areas with rapid drainage and low water retention may require more frequent irrigation to support agricultural productivity, particularly during dry periods.

6. IMPLICATIONS FOR AGRICULTURAL PRACTICES

The study's findings have significant implications for agricultural practices in Kærby. Soils with high water retention, such as those observed in **Samples s12 and s13**, offer advantages for crop growth by maintaining consistent moisture levels. However, these soils also pose a risk of waterlogging, particularly during wet periods. Effective soil management practices, such as the use of organic matter to improve soil structure, may help mitigate this risk by enhancing water infiltration and reducing the potential for saturation.

Conversely, soils with lower water retention, such as **Samples s9 and s6**, may require more frequent irrigation to maintain adequate moisture levels for crops. These soils are less prone to waterlogging but may struggle to retain sufficient water during dry periods. Agricultural practices in these areas should focus on optimizing irrigation schedules and using soil amendments to improve water-holding capacity.

7. CONCLUSION

The **hydrological investigation of Kærby, Aalborg**, has provided a comprehensive understanding of soil behavior, water dynamics, and their implications for urban flooding and sustainable land management. By integrating various methods, including the Double-Ring Infiltrometer Test and Suction Box Test, the study has explored the critical factors influencing water infiltration, retention, and capillary rise, offering valuable insights for both practical applications and future research.

KEY FINDINGS AND IMPLICATIONS

1. **Soil Texture and Permeability**:
   a. The analysis revealed a predominance of coarse-grained soils in the subsoil layer, facilitating rapid water movement and high infiltration rates under normal conditions. However, this characteristic also increases the risk of surface runoff during heavy rainfall events, highlighting the need for improved drainage systems in flood-prone areas.
   b. Fine-grained soils in localized areas exhibit higher water retention but lower permeability, making them susceptible to waterlogging, particularly in urban settings where natural drainage is often limited by impermeable surfaces.
2. **Water Retention and Suction Characteristics**:
   a. The Suction Box Test demonstrated significant variability in water retention across different soil depths, with deeper layers retaining more water due to finer particles and higher organic content. These findings underscore the importance of understanding soil-water interactions when designing irrigation systems or assessing drought resilience.
   b. The soil-water retention curve (SWRC) provided crucial data for modeling unsaturated flow and estimating hydraulic conductivity, which is essential for both agricultural planning and urban flood risk assessments.
3. **Capillary Rise and its Effects**:
   a. The study highlighted the critical role of capillary rise in redistributing water within the soil profile. Soils with finer textures exhibited higher capillary action, which could either benefit plant growth by maintaining moisture in the root zone or exacerbate flooding by bringing groundwater closer to the surface in areas with shallow water tables.
   b. Managing capillary rise is especially crucial in areas with saline groundwater, where upward water movement can lead to salt accumulation at the surface, posing a threat to soil health and agricultural productivity.
4. **Infiltration Rates and Saturated Hydraulic Conductivity (K_sat)**:
   a. The Double-Ring Infiltrometer Test provided detailed insights into the infiltration dynamics of Kærby soils. High infiltration rates observed in baseline conditions (Run 1) reflect the potential for effective water absorption during moderate rainfall. However, the reduced rates in Run 2, influenced by the capillary water table, indicate the limitations of soil absorption under saturated conditions.
   b. The comparison between runs highlights the complexity of soil-water interactions and the need to consider external factors such as the water table when interpreting field data.

PRACTICAL APPLICATIONS

The findings of this study have several practical implications for urban planning, agriculture, and environmental management:

- **Flood Management**: Understanding the infiltration and retention characteristics of Kærby soils can inform the design of effective drainage systems and flood mitigation strategies, reducing the risk of surface runoff and waterlogging during extreme rainfall events.
- **Irrigation Planning**: The study's insights into soil-water retention and capillary dynamics are invaluable for optimizing irrigation schedules, ensuring efficient water use while preventing overwatering and potential flooding.
- **Soil Conservation**: Managing soil salinity and maintaining optimal moisture levels are essential for preserving soil health and supporting sustainable agriculture, particularly in regions with shallow water tables or saline groundwater.
- **Urban Development**: By integrating these hydrological insights into urban planning, policymakers can design resilient infrastructures, such as permeable pavements and green roofs, that promote infiltration and reduce flood risks.

BROADER IMPACTS

This research contributes to the growing body of knowledge on hydrological processes in urban and peri-urban environments. By addressing key challenges such as urban flooding, water management, and soil sustainability, the study provides a robust framework for developing adaptive strategies to cope with the impacts of climate change and increasing urbanization. The findings are particularly relevant for cities like Aalborg, where the interplay between natural and built environments necessitates a nuanced understanding of water-soil dynamics.

The findings of this study align with similar hydrological investigations conducted in other urban settings, such as Copenhagen and Berlin, which also face increased flooding risks due to climate change and urbanization. However, Kærby's unique combination of coarse-grained and fine-grained soils presents a dual challenge of managing both rapid runoff and potential waterlogging. This duality offers a valuable case study for cities with diverse soil textures and varying hydrological responses, underscoring the need for tailored flood management strategies.

FUTURE DIRECTIONS

While the study has provided valuable insights, several areas warrant further investigation:

- **Long-Term Monitoring**: Future research could focus on monitoring seasonal variations in soil-water dynamics to capture the long-term impacts of climate variability and land use changes.
- **Soil Amendments**: Investigating the effects of organic or mineral amendments on soil infiltration and retention properties could help improve water management practices.
- **Model Integration**: Incorporating the findings into predictive hydrological models could enhance the accuracy of flood risk assessments and inform decision-making at a broader scale.

As climate change continues to intensify the frequency and severity of rainfall events, the insights provided by this study are particularly timely. The observed soil behaviors under varying saturation levels emphasize the need for proactive soil management to prevent urban flooding and sustain agricultural productivity. Policymakers should consider integrating climate adaptation strategies, such as enhancing soil organic matter and maintaining vegetation cover, to mitigate the impacts of extreme weather events on urban and agricultural systems.

The economic implications of these findings are substantial. Investing in sustainable soil and water management practices can significantly reduce the long-term costs associated with flood damage to infrastructure, transportation, and properties in Kærby. Additionally, improving soil retention capacities can enhance agricultural yields, contributing to food security and local economic stability. Cost-benefit analyses should be conducted to prioritize interventions that provide the greatest return on investment for both urban and agricultural stakeholders.

FINAL REMARKS

This study underscores the importance of detailed hydrological investigations in understanding the complex interactions between soil, water, and environmental factors. The methodologies and findings presented here serve as a foundation for informed decision-making, fostering resilience and sustainability in urban and agricultural systems alike. As cities like Aalborg continue to grapple with the challenges posed by climate change and urbanization, integrating these insights into planning and policy will be key to ensuring a sustainable and water-secure future.

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APPENDIX: SOIL DATA CALCULATIONS AND FORMULAS

A.1 Gravimetric Water Content Calculations

Gravimetric water content represents the amount of water held in the soil based on its weight and is calculated using the following formula:

Gravimetric Water Content (%) = (Weight after pF2 (g) - Dry Weight (g)) / Dry Weight (g) × 100

The table below shows the gravimetric water content for each sample:

Sample	Weight after pF2 (g)	Dry Weight (g)	Gravimetric Water Content (%)
s9	144.34	140.00	3.10
s5	162.67	160.00	1.67
s6	193.245	190.00	1.71
s12	183.325	180.00	1.85
s15	177.375	175.00	1.36
s13	102.01	100.00	2.01
s3	186.975	185.00	1.07

A.2 Volumetric Water Content Calculations

Volumetric water content measures the volume of water in the soil and is expressed as:

Volumetric Water Content (θ) = (Weight after pF2 (g) - Dry Weight (g)) / Soil Volume (cm^3)

The calculated volumetric water content for each sample is shown in the table below:

Sample	Weight after pF2 (g)	Dry Weight (g)	Volumetric Water Content (cm^3/cm^3)
s9	144.34	140.00	0.0434
s5	162.67	160.00	0.0267
s6	193.245	190.00	0.0325
s12	183.325	180.00	0.0333
s15	177.375	175.00	0.0241
s13	102.01	100.00	0.0361
s3	186.975	185.00	0.0198

A.3 Saturated Hydraulic Conductivity (Ksat) Calculations

Saturated hydraulic conductivity (Ksat) is the soil's ability to transmit water when fully saturated. In this study, the Double-Ring Infiltrometer method was used to estimate Ksat in cm/hour.

The Ksat values are calculated based on field observations for two runs. The table below summarizes these values.

Run	Datalogger Ksat (cm/hour)	Visual Inspection Ksat (cm/hour)
Run 1	4.0	4.0
Run 2	1.0	1.0

The significant reduction in Ksat between Run 1 and Run 2 indicates the influence of the capillary water table, which can reduce infiltration rates when the soil becomes saturated.

Additional analysis and calculations can be included here, expanding on the methodologies and results used for soil testing. This section will help elaborate on specific case studies or additional data points observed during field testing.

Formula Examples:

For bulk density calculations:

$\rho_b = M_d / V_s$

Where:

M_d = Dry soil weight (g)

V_s = Soil volume (cm^3)

Additional analysis and calculations can be included here, expanding on the methodologies and results used for soil testing. This section will help elaborate on specific case studies or additional data points observed during field testing.
Formula Examples:
For bulk density calculations:
$\rho_b = M_d / V_s$
Where:
M_d = Dry soil weight (g)
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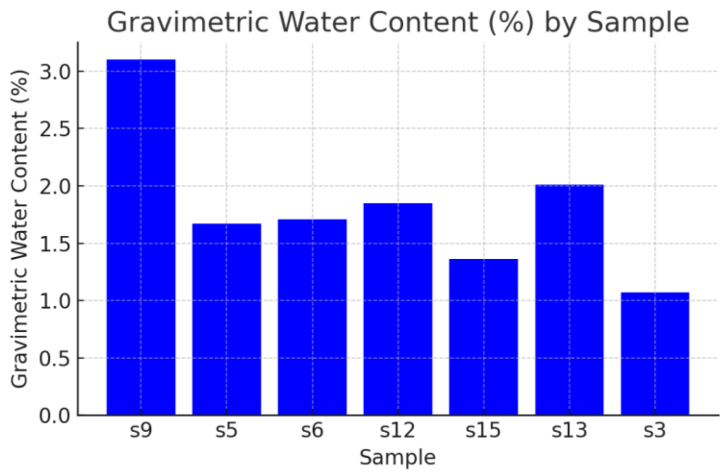
Formula Examples:
For bulk density calculations:
$\rho_b = M_d / V_s$
Where:
M_d = Dry soil weight (g)
V_s = Soil volume (cm^3)

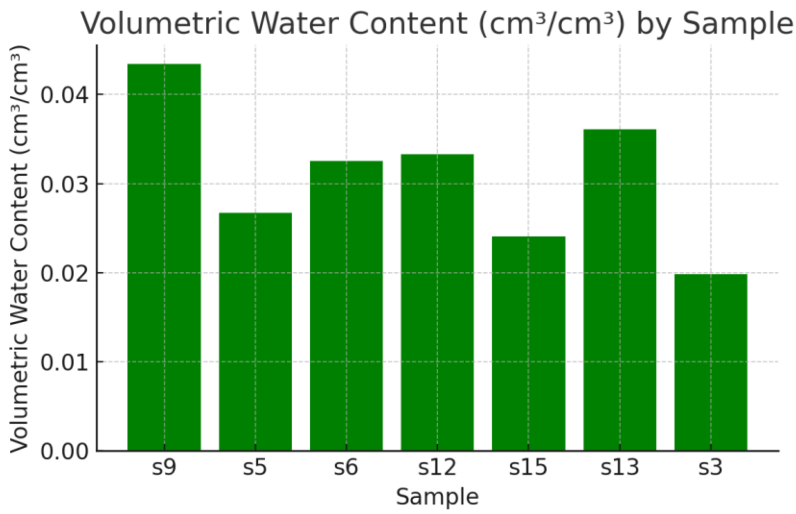
A.4 Gravimetric Water Content Graph

The following graph represents the Gravimetric Water Content (%) for each sample:



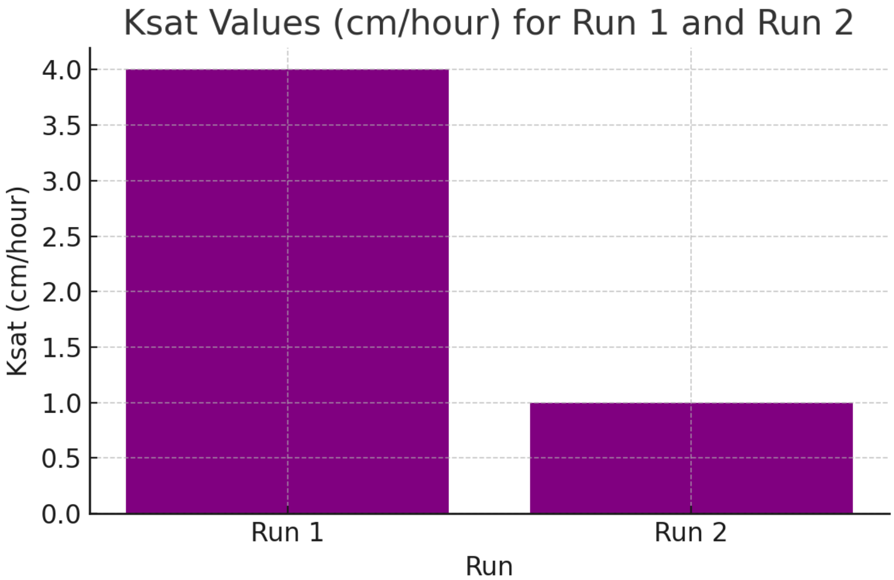
A.5 Volumetric Water Content Graph

The following graph represents the Volumetric Water Content (cm^3/cm^3) for each sample:



A.6 Ksat Values Graph

The following graph shows the Ksat (Saturated Hydraulic Conductivity) values for Run 1 and Run 2:



A.7 Field Test Observations: Double-Ring Infiltrometer

The Double-Ring Infiltrometer is used to measure the infiltration rate of soil, which provides key information about the soil's ability to absorb water.

During Run 1, the soil was at its natural moisture content, and the infiltration rate gradually stabilized as the soil became saturated. Run 2 showed the possible influence of a capillary water table, which might have artificially increased the infiltration rate due to capillary action from the water table.

The data from these tests provides valuable insights for flood risk assessments, irrigation planning, and soil management.

A.8 Saturated Hydraulic Conductivity (Ksat) and Capillary Rise

Saturated Hydraulic Conductivity (Ksat) represents the soil's ability to transmit water when fully saturated. In this study, the Ksat values varied between Run 1 and Run 2, with the second run showing a reduced rate due to saturation effects.

The data also indicates the significant role of capillary rise in soil water movement, especially in finer soils with higher water retention capacities.

A.9 Flood Risk Assessment in Kærby

Based on the infiltration data and capillary rise measurements, it is clear that certain soils in Kærby are at higher risk for waterlogging and flooding, especially during periods of high rainfall or when the water table is near the surface. Effective water management strategies are necessary to mitigate these risks.

This analysis underscores the importance of understanding soil texture, water retention, and infiltration capacity in planning flood prevention measures and urban infrastructure improvements.

A.10 Soil Behavior and Hydrological Implications

The soil samples in this study demonstrated varying capacities for water retention and infiltration. Soils with higher proportions of fine particles, such as clay, exhibited greater water retention and capillary rise but lower infiltration rates, making them more prone to flooding.

Understanding these properties is essential for soil management practices, particularly in agricultural regions where consistent water supply is needed for crops.

A.11 Additional Analysis

Further exploration of soil characteristics and water movement dynamics will enhance our understanding of water management in Kærby. This section will cover more advanced soil analysis techniques.

Key methods include soil pore space analysis, permeability testing, and advanced modeling of water movement in saturated soils.

Understanding how water moves through different soil types will aid in developing more accurate predictions for flood risk management and irrigation practices in Kærby.

A.12 Additional Analysis

Further exploration of soil characteristics and water movement dynamics will enhance our understanding of water management in Kærby. This section will cover more advanced soil analysis techniques.

Key methods include soil pore space analysis, permeability testing, and advanced modeling of water movement in saturated soils.

Understanding how water moves through different soil types will aid in developing more accurate predictions for flood risk management and irrigation practices in Kærby.