Research Article

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Sediment accumulation in an 8 inch sewer pipe for a sample of various particles obtained from the streets of Karbala city, Iraq

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Abstract: This work investigates the intricate interplay between particle size and water flow velocity in connection to sedimentation within the sewage systems. The experimental design involves simulating the sedimentation process in a laboratory setup using an 8 inch unplasticized polyvinyl chloride pipe with a controlled slope. Three factors of flow and discharge velocity detailed in this work are particle size, velocity, and sedimentation rate, which are determined through calculations based on the Manning equation. For the numerical simulations, the software packages Fluent and Rocky were used. Sediment transportation under laminar flow conditions can be analyzed by means of numerical simulation. The size, shape, and velocity of the fluid in which the particles are suspended are only a few of the variables taken into consideration while assessing the drag force acting on the particles. The results show that the smaller particles escape the entry further because they are more movable within the conduit. Conversely, it is demonstrated that increased settling pressures near the entrance increase the probability of larger particle sizes settling. Higher water velocities have been found to have a favorable effect on the sediment mobility, which decreases the particle accumulation. This study presents practical methods to mitigate sedimentation in sewage systems, including increasing water flow rates and employing filtration methods to keep larger particles out of the system. This work adds a great deal to the body of information previously known on sedimentation behavior in these systems with its incisive finds that may boost the longevity and efficiency of sewage systems. More research is required to determine the value of the proposed treatments.

Keywords: Rocky software, particle deposition, sedimentation behavior, numerical simulation, particle size

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1 Introduction

Storm networks, like other components of urban infrastructure, are crucial to society's functioning. One of the main issues these networks deal with is pipe blockage from silt accumulation in sewage systems, which results in flooding during heavy rainy seasons. The purpose of this effort is to enhance storm network performance by applying a novel filter. A pipe network model was constructed to mirror the rain flow on a two-lane street [1]. Storm sewer systems in urban areas encounter numerous challenges, especially those that are aging and have exceeded their intended lifespan. Physically based models, such as Autodesk Storm and Sanitary Analysis (ASSA) and multiple nonlinear regression (MNLR), were utilized. Peak flooding occurs more often and is linked to rising rainfall output, which stresses how urgent it is to solve these problems [2]. The planning, design, and operation of projects involving the structure of water resources rely on models that visualize the relationship between intensity, duration, and frequency (IDF) curves and rainfall intensity. The purpose of this work is to calculate and estimate IDF curve equations for the city of Najaf in Iraq. Moreover, it searches for the distribution that produces the maximum rainfall intensity among the three frequently used in the industry. The relationship between rainfall intensity and various return periods is explained by IDF curves [3].

Runoff from rainfall is essential to many aspects of water resources management, including irrigation, flood control, and drainage system design. Deriving accurate hydrological models and building robust storm networks require a special understanding of precipitation patterns. The city of Karbala in Iraq has witnessed a huge population increase and the effects of climate change since 2003, so it is very important to study the rainfall rates in this city. Therefore, the purpose of this work is to study the maximum daily depth of rainfall in Karbala and use frequency analysis to predict its probability of occurrence in the future [4].

Precipitation-generated surface runoff is important for many aspects of managing and developing water resources, such as irrigation, scheduling, flooding control, irrigation design, and drainage networks. The purpose of the study is to determine how the surface runoff rate of Karbala desert soil is affected by the amount of precipitation and the slope of the soil [5]. Because anthropogenic influences including land use, drainage systems, and concrete structures change the direction of surface overland flow, modeling surface runoff in urban captures is difficult. The intricacy of modeling urban runoff presents challenges when creating urban drainage systems [6]. Over the last few decades, research has focused on protecting water resources, especially with regard to the consequences of pollution on natural water bodies found in metropolitan areas. This study uses storm water management model user's manual version 5.1 to analyze the major variations in total suspended solids (TSS) and biochemical oxygen demand characteristics in wastewater within sewer networks during wet seasons. For pollutant loading modeling, it makes use of 30 years' worth of temperature, rainfall, and sewage flow data from Karbala, Iraq (1980–2010) [7].

Urban planning and design are aided by the use of numerical models to evaluate sedimentation in urban environments using simulation approaches. The tracking of sediment particle movement is made easier by the integration of ANSYS Fluent and Rocky, which reveals important influences of particle size and speed on sedimentation patterns [8]. Hydraulic parameters, sediment content, and hydrodynamic variables are the main subjects of an assessment close to the Kufa Barrage. At ten cross-sections, silt concentrations and velocity are evaluated using Acoustic Doppler Current Profilers at different water depths. Depth-integrated sampling highlights light on the possibility of sediment transfer [9].

In order to create an empirical formula, field measurements in the upstream area require measuring hydraulic and fluid parameters as well as gathering sediment sample data. These equations ($R2 = 0.979$), which were obtained by means of statistical and dimensional studies, closely match the observed suspended sediment drainages [10]. Urban sinkholes are frequently caused by soil erosion, which is made worse by water passing through malfunctioning sewage systems. To anticipate the rates of erosion on sandy soil substrates, researchers have proposed using dimensional analysis and a dimensionless model [11]. Sediment transportation in sewer systems is a major engineering challenge, which means that models to forecast critical speed or shear stress for self-cleaning flow conditions in sewer pipelines must be developed [12]. Urban drain systems are often burdened by sediments from sewers. To find bed deposits, methods such as temperature monitoring and laboratory tests that replicate sewage temperature gradients are used [13]. Although gully pots allow stormwater to enter the system, removing silt can be costly and dangerous for the ecosystem. Understanding these dangers is helped by mineral analysis. Assessing the rates of sedimentation and mineral buildup is essential for upkeep and understanding the effects of metropolitan areas [14]. Localized scooting around piers is typically the cause of bridge collapse. This work uses artificial neural networks and genetic programming to anticipate exploration, integrating factors obtained from dimensional analysis [15]. Because of the difficulty in observing slurry transit within urban stormwater sewers, little study has been done in this area. Utilizing ANSYS Fluent computational fluid dynamics (CFD) software, forecasting technologies for soil slurry flow during rainstorm events are developed [16].

While SewerSedFoam simulates three sediment classes and tackles the effects of erosion and sediment deposition on flow velocity, the interFoam flow solver incorporates suspended sediment transport, bedload transfer, and deposited bed morphology [17]. Data on runoff, sediment movement, and mass balances in pipeline systems and gully pots are provided by a number of experiments [16]. Sewers carry comparable amounts of contaminants and sediments even with lower water usage, which may result in higher wastewater concentrations and perhaps excessive solids deposition. Stormwater ponds help improve the quality of water by facilitating the sedimentation of pollutants from runoff [18].

Real-time control (RTC) methods to optimize sewer operations have been investigated in response to the global sewage pollution challenge. Simplified models enable the quick adoption of RTC strategies, with a particular emphasis on TSS [19]. Although less water is used per person in economic co-operation and development nations, the same quantities of contaminants and solids are still transported, which might lead to an overabundance of solids deposit. Stormwater runoff introduces suspended materials into aquatic bodies, which adds pollution [20]. Optimizing stormwater pools requires an understanding of the sediment processes involved. To do this, a framework based on discrete phase modeling has been introduced, which allows for a full simulation of sediment movement.

2 Problem statement

The sedimentation of granular materials in sewer pipes is a common problem that can significantly influence the operation and reliability of urban sewer networks.

3 Material and mythology

3.1 Study area and components of laboratory experimental device

A pump equipped with a large 2,000 L water tank was used in the Karbala plant field to carefully monitor the sizes of transported sand grain while operating at a controlled velocity to ensure accurate control. An 8 inch pipe that connects to the water tank at the top enables easier water movement and has a sediment feeder at its beginning. In the Karbala plant field, a pump with a sizable 2,000 L water tank was utilized to precisely regulate the flow of sand particles while running at a regulated speed. A sediment feeder is located at the beginning of an 8 inch pipe that links to the water tank at the top, making water circulation simpler. As sediment passes through the unit's supplied sand particles, transmission controls are used to switch on and off the pump at a predefined flow rate. As seen in Figure 1, silt of varying sizes was continuously added to the flow throughout the first 15 min. The streets of Karbala were used to gather the particle size in order to determine the particle size that impacts sedimentation and examined through a sieve. As it traveled through the split at the top of the pipe, as indicated in Figure 1, the migration of the sediment to the pipe bed for each interval was likewise-monitored and recorded.

The process involves several stages, including sieve analysis, where samples are dried, and their dry weight is measured. Determining the number of particles in an 8-inch UPVC pipe with a 0.44 cm slope across a 6 m distance is the goal of this experiment (Figure 2).

Three main parameters that affect the particle stability were examined in this study, particle size, velocity, and the ratio of sedimentation rate to water flow. The Manning equation may be used to determine the flow and discharge velocity in a pipe with partial flow.

$$Q = \frac{1}{n} A R^{0.66} S^{0.5}. \tag{1}$$

Dimensional analysis must first evaluate the dimensions of each term in the supplied equation in order to discover the dimensions of velocity in order to get the velocity equation [21].

Q is the flow rate with dimensions of volume per time, represented as (L^3/T). A is the cross-sectional area with dimensions of area represented as (L^2). R is the hydraulic radius and S is the slope, which are dimensionless. Given that

$$Q = 1\frac{1}{n} A R^{0.66} S^{0.5}.$$

Now, let us assign dimensions to each term.

$Q = L^3/T$

$A = L^2$

Figure 1: The sand collection and sediment occurrence on the bed of the pipe.

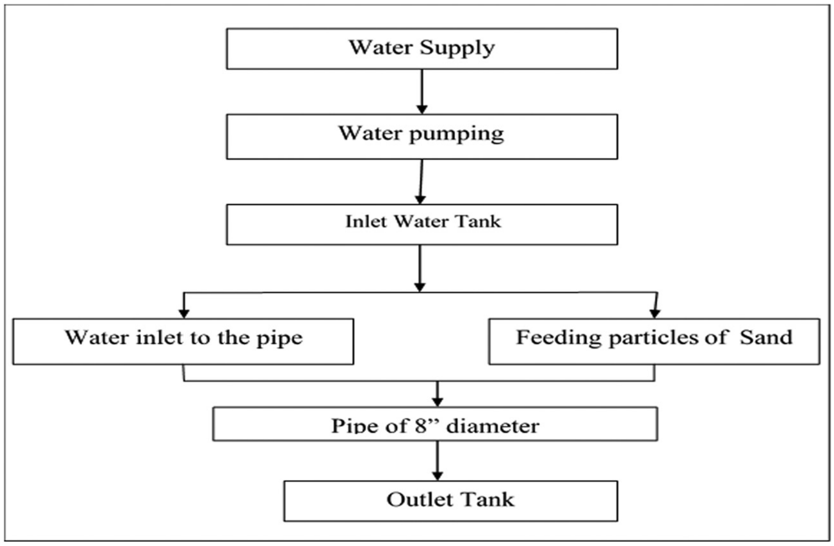


Figure 2: The procedure of the laboratory sediment analysis.

$R = L$ (dimensionless exponent does not change the dimensions)

$S = 1$ (dimensionless)

Now, equating the dimensions on both sides $\left[\frac{L^3}{T}\right] = \frac{1}{n}[L^2][L]^{0.66}$.

Let us denote the dimensions of velocity (V) as $\left[\frac{L}{T}\right]$.

Now, we equate dimensions $\left[\frac{L}{T}\right] = \frac{L^2}{n}[L]^{0.66}$.

Solving for $\left[\frac{L}{T}\right] = \left[\frac{L^2}{n}\right][L]^{0.66}$.

Comparing with the dimension of velocity $[L/T]$

$$1 = \frac{[L]}{n}$$

So, $n = [L]$.

Thus, the velocity equation obtained from the dimensional analysis is

$$V = \frac{A}{n}R^{0.66}S^{0.5}.$$

As shown in Table 1, the Manning equation depicts two different pipe flow scenarios, one with a larger hydraulic diameter and the other with a smaller diameter. In order to evaluate how flow rates, particle sizes, and sedimentation rates affect the settling of particles inside the sewage line, tests were conducted in both scenarios. The results were achieved numerically under laminar flow conditions using ANSYS Fluent and Rocky software.

3.2 Numerical method

Rocky and ANSYS software were used to analyze the numerical data, with an emphasis on simulating the sedimentation in sewage lines. This made it easier to see how water and silt move through sewer lines and to determine if a programmer would work together. Deriving equations for granular systems is difficult since flow properties are dynamic and constantly changing. To guarantee precision and accuracy, constitutive relations related to phase interactions and particle material rheology must be established. The current methodology used in this work makes use of a continuum interpenetrating framework, which excludes incursion and does not include specific particle-level

Table 1: Flow characterization based on flow depth and hydraulic radius

Scenario	Flow depth (h) and diameter of pipe (D)	Hydraulic radius (R)	Flow characterization	Particle size (mm)
Less than half full flow	$h < D/2$ Small A compared to P	$R = A/P$ Flatter velocity profile	Subcritical, slower flow	d = 1.2, 1, 0.8, 0.6, and 0.4
More than half full flow	$h > D/2$ Significant A compared to P	$R = A/P$ Steeper velocity profile	Supercritical, faster flow	d = 1.2, 1, 0.8, 0.6, and 0.4

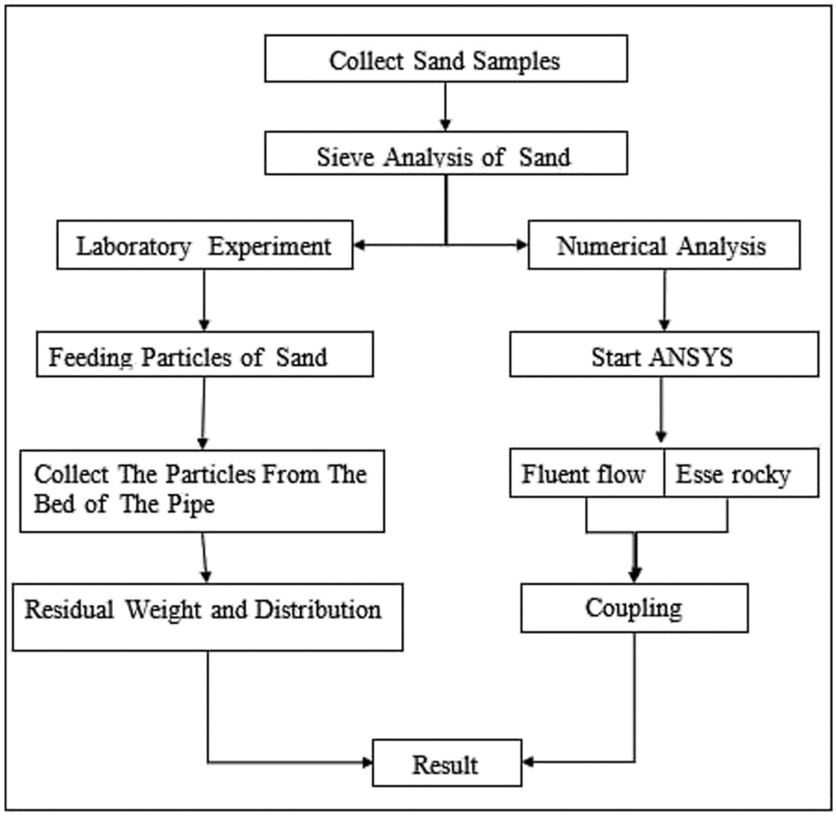


Figure 3: Illustrative diagram for the numerical analysis of sediment transport inside the pipe.

information. The addition of particle size distribution in the prescription process leads to an escalation in computing expenses. The integration of discrete particle methods with the finite volume method, known as discrete element method-computational fluid dynamics, presents a viable and efficient approach for simulating granular-fluid systems as shown in Figure 3.

3.3 Drag force

The drag force, commonly represented as F_D, and another component including all forces except drag, referred to as $F_{N\text{-}D}$, frequently constitute the resulting force arising from fluid interaction, denoted as F_{fp}. The effect of drag force on sediment transport can be observed in Equation (5) through its influence on the area of particles. In the subsequent manner

$$F_{f\to p} = F_D + F_{N-D}. \tag{2}$$

Authors can select the pressure gradient force (F_p), added (virtual) mass force (F_{VM}), and raise force (F_L) as some of the common non-drag forces. In order to prevent incursion, researchers may say it like this

$$F_{(f\to p)} = F_D + F_P + F_L + F_{VM} + F_{Others}. \tag{3}$$

Depending on the flow conditions, the majority of these forces can be ignored and only the drag and pressure gradient forces need to be considered, such as in cases where the specific mass difference between the fluid and molecules is high ($\rho p \gg \rho f$) [22].

$$F_{f\to p} = F_D + F_{\nabla P}. \tag{4}$$

Unless otherwise indicated, the drag coefficient C_D is used to determine the drag force, F_D, that affects the particles.

$$F_D = C_{D\rho f}\acute{A}|u - v_p|(u - v_p). \tag{5}$$

In fluid dynamics, variables such as the relative velocity between the particle and fluid ($u - v_p$) and the projected area of the particle in the direction of the flow (Á) influence the drag force experienced by a particle traveling through a fluid. The Rocky package includes a number of drag correlations that account for differences in particle

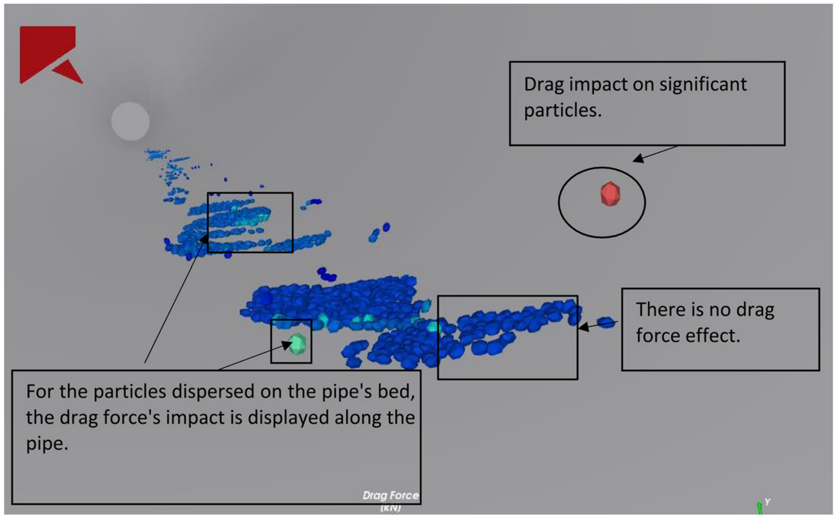


Figure 4: The drag force effect on the particle.

shape (spherical and non-spherical) and particle concentration (divide or dense flows) [22]. The idea of the relative particle Reynolds number, Rep, which is based on the relative vellications of the particle and the fluid, is used in these communications. Figure 4 explains the effect of the drag force. Using the appropriate drag correlation depending on the flow conditions and particle characteristics is made possible by the Rocky package.

$$R_{e_p} = \frac{p_{F|V_p - u|\mathrm{d}p}}{\mu}. \tag{6}$$

The size, shape, and fluid characteristics of the particle as well as the fluid's velocity through the pipe all affect how much drag a particle experiences in a sewage system. A typical way to describe the drag force acting on a particle in a liquid is to use the drag equation, which is given as

$$F_{\mathrm{drag}} = 0.5\rho v^2 C_\mathrm{d} A, \tag{7}$$

There are other factors to take into account when calculating the drag force a particle experiences in a sewage tube. This consists of the following parameters are F_{drag} represents the drag force; ρf denotes the fluid density; indicates the fluid velocity relative to the particle; and C_d is the particle's drag coefficient. Additionally, A represents the particle's projected area perpendicular to the flow direction. In this case, the flow rate of water is 0.49 m/s for an 8-inch pipe size, and this information can be used to calculate the particle's velocity. It is important to note that a particle's size and shape influence its projected area and drag coefficient.

Most of the small particles in waste water are either irregularly shaped or spherical, and that in turn determines their bulk drag force by means of its Reynolds number. This gives one an insight into how fluid regimes may be distributed around and even within individual particles. Therefore, you require additional details about the specific situation and characteristics of the carriages to properly calculate the drag force – such as the Reynolds number, elasticity at this flow, as well as the size and shape of each individual particle.

This includes information on Reynolds number (method for fluid), fluid density, and particle size and shape. These extensive data allow for the accurate calculation of the drag force that the particle experiences.

3.4 Particle mass and particle count

The water flow was mixed with particles of sizes 1.2, 1, 0.8, 0.6, and 0.4 mm at a rate of 17.3 g/min. By carefully tracking each particle as it passed through the pipe, the total number of particles that passed through it was precisely calculated using Rocky software. Notably the term "particle out count" refers to the particles that were forced out of the pipe by the water flow, whereas the term "particle count" refers to the particles that are still inside the pipe as either surface residents or being transported.

Particle mass refers to the amount of particles that are added to a stream of water as it flows. More specifically, particle out mass indicates the particles leaving the pipeline's outflow, while particle in mass indicates the particles that have settled inside the pipeline. Figure 5, which displays the particle count at the input and outflow of the diesel beseeching, provides pipe. Figure 5 provides insights

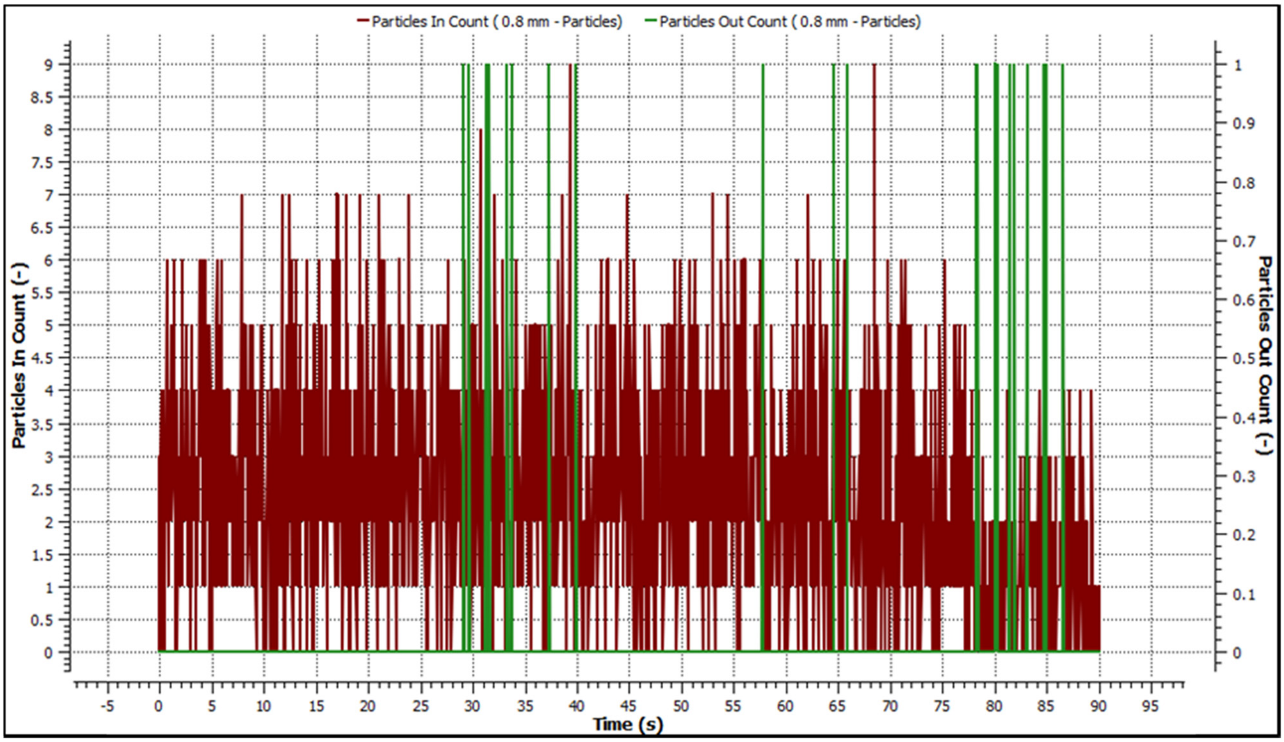


Figure 5: Illustrates the particle in count and particle out count.

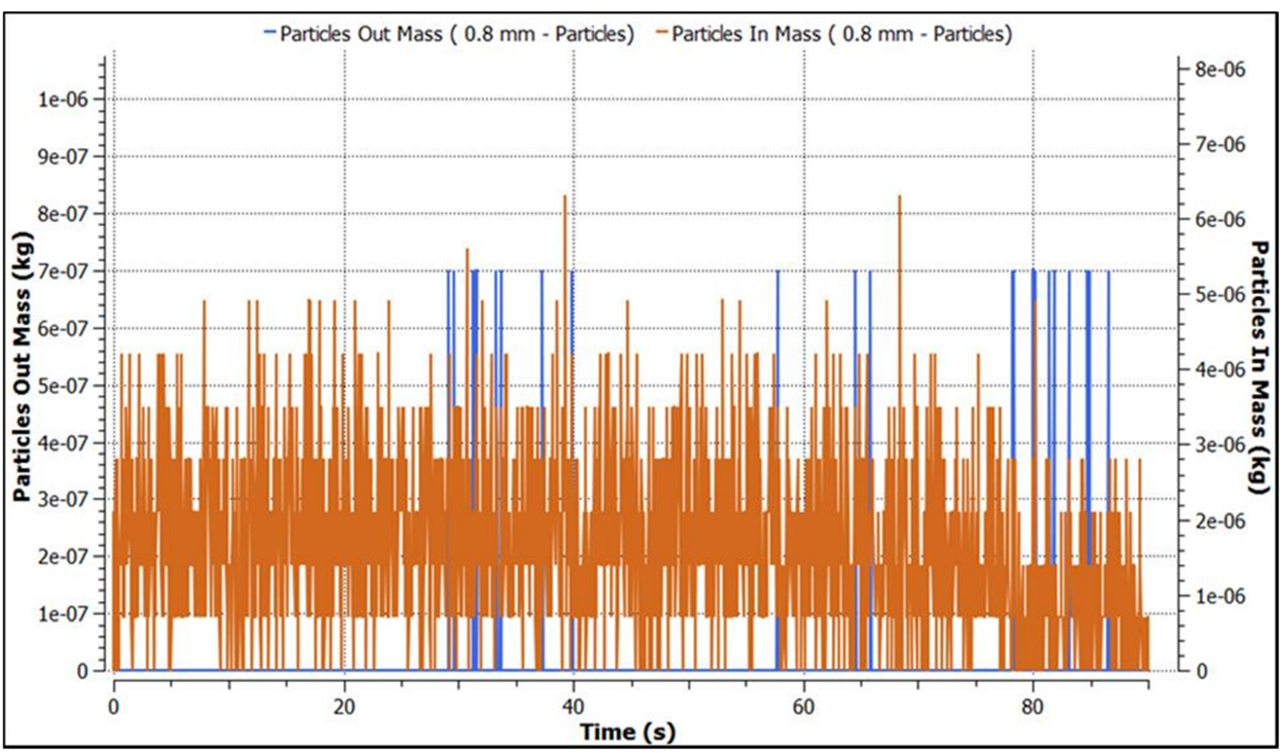


Figure 6: Illustrates the particle in mass and particle out mass.

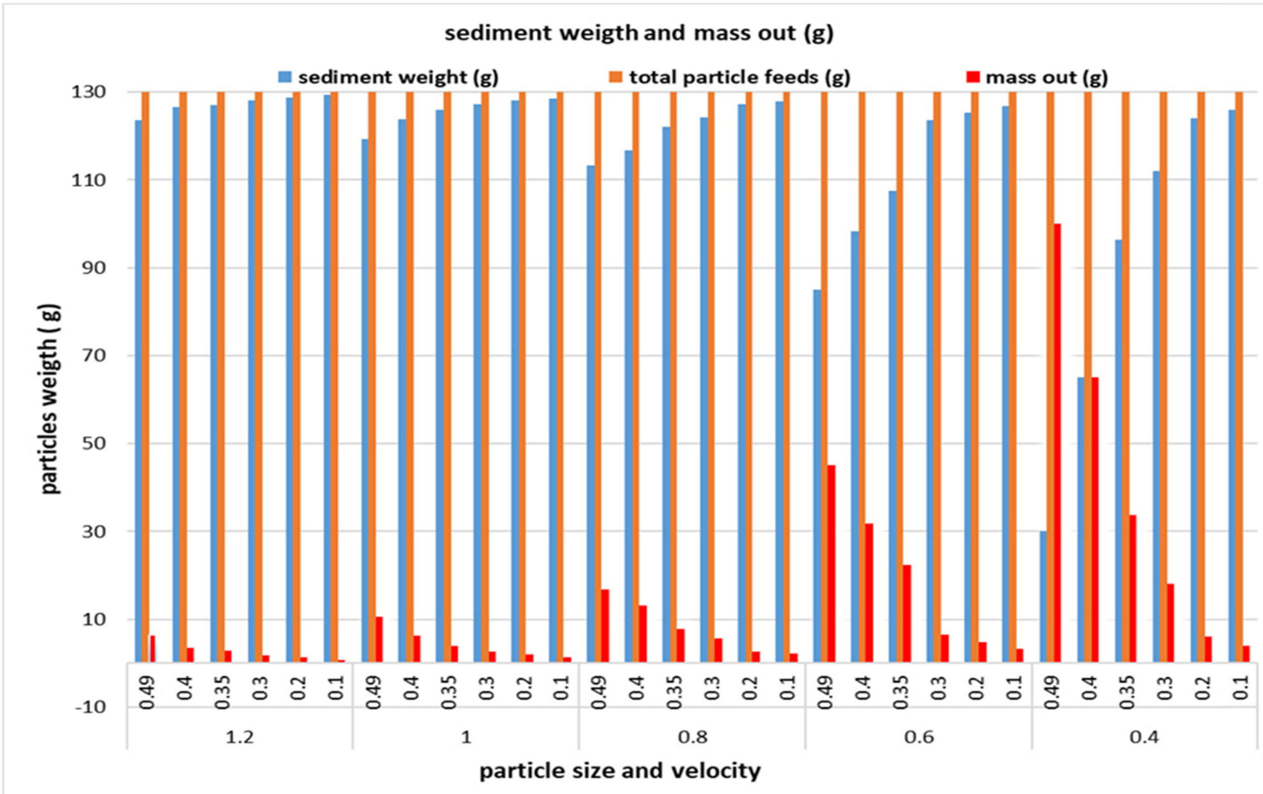


Figure 7: Relationship between flow velocity and sediment transport.

into the behavior of particles as they enter and exit the pipe, showing the number of particles counted at the inlet compared to those counted at the exit. Subtracting the total particle injection count from the particle count at the output yields the quantity of sedimentation within the pipe. After the software ran for 30 s, it was discovered that some of the injected particles, specifically those with a size of 0.8%, came out of the pipe through the outlet. The green curve represents the second time point, indicating when the particle size departs from the pipe, while the departure is shown in red.

Figure 6 displays the information about mass-inflow and mass-outflow. It shows the total mass of particles injected over a 120-s period. As shown by the blue curve, the masses of the particles recorded at the same time as the number of particles exiting the pipe were also measured at 29 seconds The numerical study explores various models to determine how they affect the movement of silt. According to the study, sediments with varying sizes respond differently to a given water flow velocity. The sediment weight in pipe can be calculated using Equation (8).

$$\text{THE SEDIMENT WEIGHT} = \text{MASS IN} - \text{MASS OUT}. \tag{8}$$

As seen in Figure 7, the 1 mm sized particles, on the other hand, were scattered over a greater distance down the pipe but remained inside it. This indicates that there was no mass outflow. As a result, the total weight introduced into the water flow is equal to the total weight of sedimentation inside the pipe. Moreover, as Figure 8 illustrates, the sedimentation region moved farther away from the pipe's starting point as compared to the dispersion of particles sized at 1.2, 1, 0.8, 1, and 1.2 mm, respectively. This is according to the examination of sediment sizes. For example, when 0.4 mm sized silt was sporadic distributed throughout the pipe, a sizable amount of weight came out of the pipe.

4 Results

4.1 Experiential result

4.1.1 Effect of water velocity and particle size on sediment weight

Equation (8), which illustrates the particle-mass-inflow and mass-outflow in a sewer pipe, can be understood by applying the concept of mass conservation. It is possible to discretize the

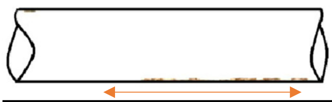
Particle size in (mm)	Sediment distribution along the bed of pipe at velocity 0.49 m/s	
1.2mm	 Max.X-Coordinate =2.850m	
1 mm	 Max.X -Coordinate =4.86m	
0.8 mm	 Max.X-Coordinat= 5.986m	
0.6 mm	 Max.X-Coordinate=5.99 m	
0.4 mm	 Max.X-Coordinate 6 m	

Figure 8: Depicts the sediment transport within a pipe and the sediment settled on the pipe's bed at a velocity of 0.49 m/s. *D* represents the particle size and *d* represents the particle distribution on the bed.

time domain and solve equations iteratively through empirical analysis. To calculate the mass of particles leaving the system, extract the mass entering from an accumulator. With a total particle feed rate of 130 g/s, Figure 7 shows sediment weights for a range of particle sizes (1.2, 1, 0.8, 0.6, and 0.4 mm) at various velocities (0.1, 0.2, 0.3, .35, 0.4, and 0.49 m/s). According to the findings shown in Figure 8, sediment weight falls for each particle size as velocity rises. For example, the sediment weight for 1.2 mm particles is 129.3 g at a velocity of 0.1 m/s and drops to 123.5 g at a velocity of 0.49 m/s.

Figure 8 shows that this trend holds true for other particle sizes as well. Similarly, with 0.4 mm particle size, the weight of the sediment drops as the velocity increases, going from 126 g at 0.1 m/s to 30 g at 0.49 m/s. Particles of varying sizes appear to be sediment along the pipe bed at a constant velocity of 0.49 m/s, as seen in Figure 8. The range of particle sizes is 1.2–0.4 mm. The results show that 1.2 mm particles indicate deposition within that range when they settle between the 50 and 120 cm locations along the pipe from the input. On the other hand, 0.4 mm particles do not show signs of sedimentation inside the pipe, indicating that the water flow drag force is responsible for their passage through and out of the exit.

4.2 Numerical result

4.2.1 Particle in mass and particle out mass

Particle mass input, particle mass output, and sedimentation inside the network of sewer pipes must all be taken into account in the domain of sewer system-sediment-transport simulations. Particle feeding and its dependence on velocity are demonstrated in Figure 9, where the effect of water drags forces on particle masses leaving the conduit and settling at its bed is highlighted.

Numerous numerical investigations have been conducted on this phenomenon, especially with regard to equation (5). Drag force effects on particle size are responsible for the total sedimentation seen at particle sizes of 1.2

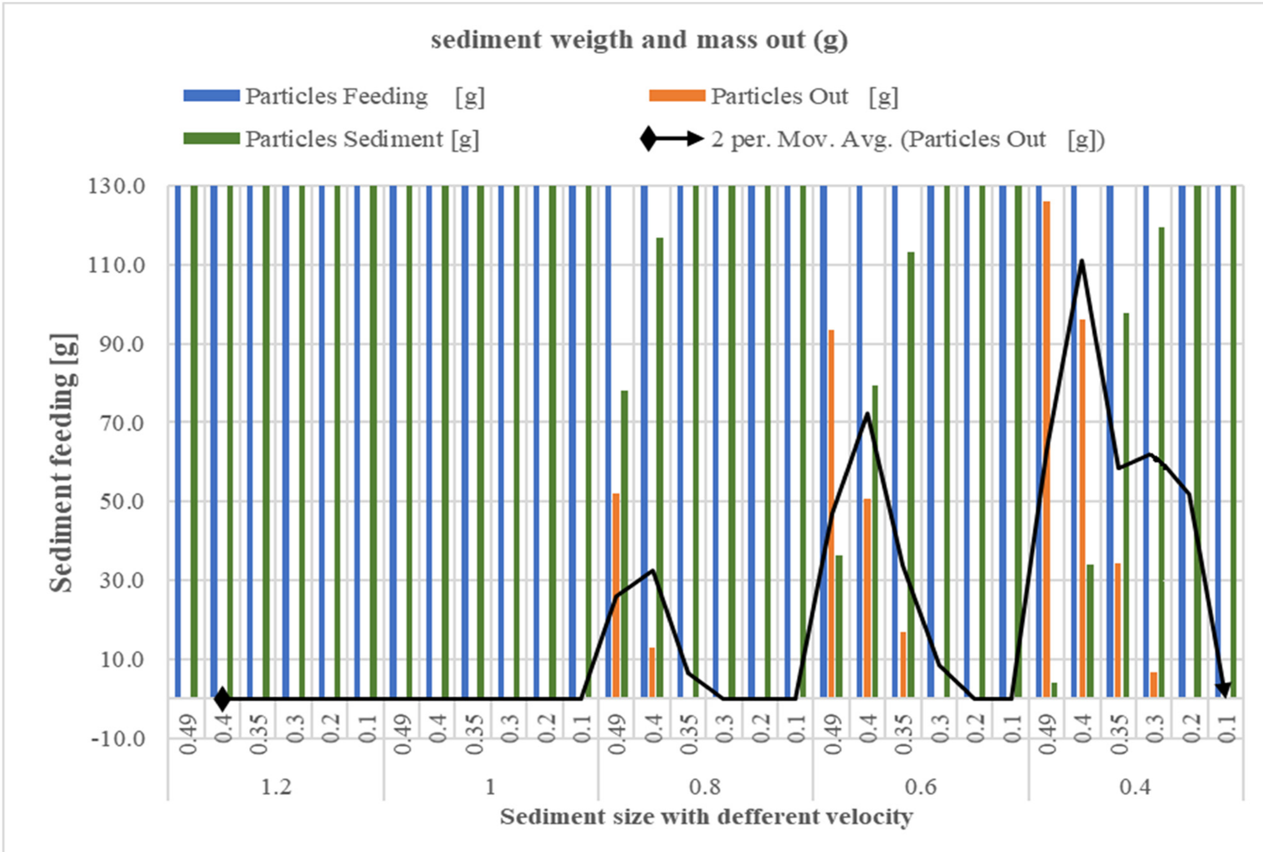


Figure 9: Sediment weight in the pipe at different velocities and particle size of 0.4 mm.

and 1 mm within the pipe, showing the clear impact of sediment size on sedimentation. The wandering particles result from an increase in drag force due to their size as they settle against the bed of the pipe. Additionally, Figure 9 shows how particles of different sizes (0.8 mm, 0.6 mm, and 0.4 mm) behave differently, with varying sediment masses exiting the pipe depending on their size. Figure 10 further illustrates this phenomenon by comparing the behaviors of the smallest and largest particle sizes.

The impact of the sediment phenomenon is more evident when particle sizes of 1.2 and 0.4 mm are taken into account, as Figure 10 illustrates. The figure shows that at different vellications, sediments with a size of 1.2 mm were consistently deposited on the pipe's bed. On the other hand, as shown by Figure 10, the majority of the sediment mass for particles with a size of 0.4 mm remained suspended in the pipe flow, with just small amounts settling on the pipe's bottom.

5 Discussion

The data show that there is a strong relationship between the size of the sediment particles and the process of sedimentation in pipes. In fluid flow, smaller molecules move more easily and can cover greater distances before settling. On the other hand, due to the drag force, which is related to the exposed surface, larger particles have a tendency to settle closer to the intake side. Smaller particles can travel more quickly because the drag force is less strong. This factor reduces the surface exposed to liquid, thus increasing drag force and accelerating stability. The velocity of water and sedimentation are interdependent. Refilling with sediment can be analyzed based on how the fluid force decreases at slower velocities, which shortens the sediment's kinetic distance. High water velocity plays a crucial role in flushing sediment out of the pipe, highlighting the importance of proximity parameters alongside high water

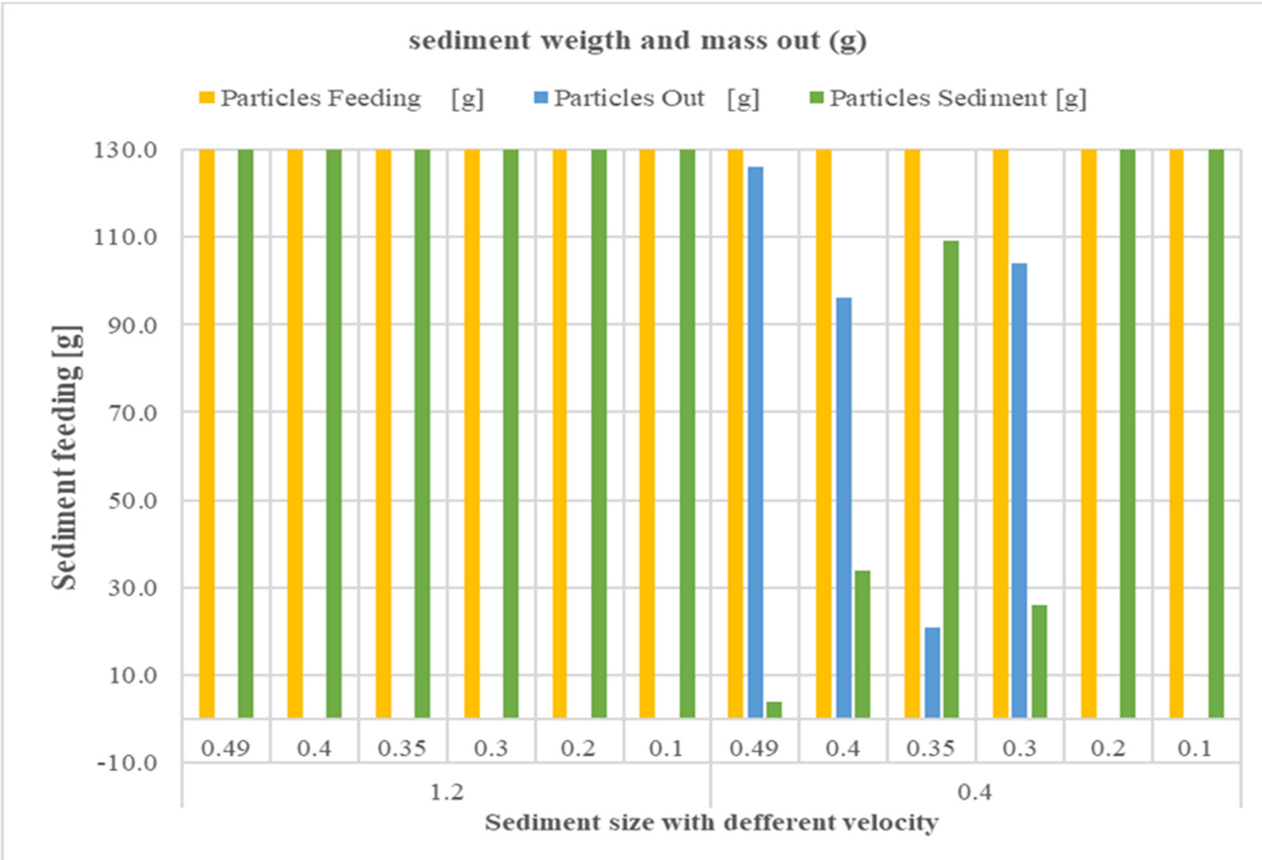


Figure 10: Shows the weight of sediments and mass out accumulated for particle sizes of 1.2 and 0.4 mm.

velocity. The sediment distribution seemed to go along the *x*-coordinate from 0 to 148.1 cm at 1.2 mm particle size for 0.49 cm/s. There may be variations to a particle with an impact based on the flow dynamics leading to an increased sediment buildup.

6 Conclusion

1. From the research, it is proven that particle size and water velocity have effects on sediment behaviors. In the first case, particle size influenced the diffusion of settled particles along the base of the pipe, which is evident from the differences in the *x*-coordinates that the particles reached before settling. Additionally, water velocity affected the quantity of sediment and the distribution points on the pipe's bed.
2. Since fine particles settled slower than larger particles, especially at low sedimentation velocities, the maximum settling locations of finer particles are decreasing. Hence, as the research points out, smaller particles attain lower maximum positions at a given deposition velocity. This notion further supported the fact that this interpretation was indeed upheld by the statement that the results of the numerical analysis agreed with the theoretical concerns.
3. This study tests the effect of sediment dispersion in reducing the pipe efficiency as the particle size decreases. Its findings show that, with a fine particle of 0.6–0.4 *d* dimension, a relative efficiency ratio has an increased detrimental impact. The values and results described in this article might provide new critical information in the physics of sedimentation of particles and its aspects and variables of that in a sewer.
4. A rising torque power due to a higher water flow velocity triggers posts to settle further apart; the phenomenon is most pronounced for large particles.
5. The article reports that "the study showed that when high water flow rates are maintained, several suspensions can be reduced, resulting in a clear sewer system and continuous flow of water."
6. There are two ways to reduce bottlenecks in sewage lines due to the accumulation of silt which are
   a. Increasing water velocity positively impacts sediment transport, facilitating the deposition of particles at

greater distances along the x-coordinate, especially in sewer networks with reduced diameters.

b. Installing filters within the sewage network is another method to mitigate silt accumulation and prevent larger particles from entering the system.

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Conflict of interest: Authors state no conflict of interest.

Data availability statement: Most datasets generated and analyzed in this study are in this submitted manuscript. The other datasets are available on reasonable request from the corresponding author with the attached information.

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