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# Mitigating Turbidity in the Mandroseza Basin: Potential of High-Flow Pump Integration with Flocculant-Assisted Decantation Pretreatment

**Andrianarivony Tiona[1], Robijaona Rahelivololoniaina Baholy[1,2]**
[1]Industrial, Agricultural and Food Process and Systems Engineering, Polytechnic High School of Antananarivo, University of Antananarivo, Antananarivo, Madagascar
[2]Laboratory for the Valorization of Natural Resources, Polytechnic High School of Antananarivo, Antananarivo, Madagascar
Email: andriationa@gmail.com, baholy.robijaona@univ-antananarivo.mg

**Abstract:**

*The increasing challenge of sediment-laden inflows to the Mandroseza Basin, the primary raw water source for Antananarivo, Madagascar, necessitates effective pretreatment strategies to safeguard water treatment plant efficiency. This study investigates the integration of a high-flow pumping system with flocculant-assisted decantation to mitigate seasonal turbidity spikes. Laboratory-scale static and dynamic sedimentation tests were conducted to evaluate the performance of aluminium sulfate, sodium silicate, cationic polyacrylamide (PAM), and polyethylene oxide (PEO). Results from jar tests indicated optimal dosage ranges for each flocculant, guiding subsequent dynamic settling experiments under simulated operational conditions. PAM, at 5-6 mg/kg, and PEO, at 17-18 mg/kg, consistently outperformed sodium silicate, demonstrating superior supernatant clarity (TSS of 46 mg/L and 35 mg/L, respectively) and enhanced sludge compaction. Flattening tests further confirmed the cohesive and dense nature of PAM and PEO-induced sludge. While sodium silicate offered moderate performance, its lower efficiency in fine particulate removal makes it less suitable for stringent clarity requirements. The findings suggest that integrating optimized PAM or PEO dosing with high-flow conveyance presents a promising, scalable solution for managing turbidity at the intake, reducing the load on downstream treatment processes and improving overall plant sustainability. Future research should focus on field validation and comprehensive cost-benefit analysis for large-scale implementation in urban water supply systems facing similar seasonal sedimentation challenges.*

**Keywords:**
*thickening, settling, flocculation, water treatment, Mandroseza Basin, dehydration, jar test*

## I. Introduction

Access to clean water in Antananarivo, Madagascar, is increasingly challenged by sediment-laden inflows into the Mandroseza Basin—an essential natural settling site and intake for the city's water supply. Particularly during the rainy season, heavy runoff carries high loads of suspended solids, resulting in sharp increases in turbidity. These turbidity spikes significantly reduce the efficiency of water treatment operations, accelerate equipment wear, increase sludge volumes, and raise operational costs. (Raharimalala et al., 2019)

Currently, the absence of an effective pretreatment system at the basin allows these high-solid-content flows to directly impact the intake, overwhelming conventional sedimentation systems. Traditional gravitational settling methods alone have proven inadequate to manage the fluctuating and intense turbidity levels characteristic of the basin during storm events. (Ralitera, 2021)

To address this issue, this research investigates a dual intervention strategy: the integration of high-flow pumping systems with flocculant-assisted decantation pretreatment. The goal is to reduce turbidity loads at the source—before water reaches downstream treatment stages—by promoting early-stage sedimentation. High-flow pumps facilitate rapid conveyance of water from the raw intake zone to designated settling units, minimizing sediment accumulation at the intake. Simultaneously, the strategic application of coagulants and flocculants enhances the agglomeration and settling of suspended particles, accelerating solid-liquid separation.

This study evaluates the feasibility of this approach through a series of static and dynamic sedimentation experiments, simulating both laboratory and real world hydraulic conditions. It aims to identify optimal flocculant types and dosages, assess the stability and compaction of flocs formed, and examine the operational implications of integrating such a system into existing infrastructure. The results offer a promising pathway toward sustainable turbidity management in regions where conventional sedimentation infrastructure is limited or absent.

This study aims to evaluate the integration of a high-flow pumping system with a flocculant-assisted pretreatment process to mitigate turbidity at the Mandroseza water intake. The investigation will identify the most effective flocculants through laboratory-scale jar tests and dynamic sedimentation trials, subsequently determining their optimal dosages for maximizing sedimentation rate and solid compaction. Finally, the performance of selected flocculants will be assessed under simulated operational (dynamic) conditions mimicking field applications. (Nabzar et al., 1988)

## II. Research Method

### 2.1 Materials

#### a. Mandroseza Raw Water Bassin

The inherent variability in raw water quality at the Lake Mandroseza intake, driven by seasonal hydrological fluctuations, negatively impacts the efficiency of downstream treatment processes. This variability leads to accelerated degradation of treatment infrastructure, increased volumes of sludge requiring management, and elevated operational expenditures. To enhance the reliability and maintain the productivity of the water treatment facility under these dynamic conditions, the implementation of flocculant-assisted sedimentation is proposed. This enhanced pretreatment strategy aims to improve the removal of suspended particulate matter, thereby buffering the system against the challenges posed by hydrological extremes.

The application of chemical flocculants to enhance sedimentation offers a proactive approach to optimizing solid-liquid separation prior to conventional treatment stages. This strategy has the potential to mitigate the adverse effects of both low-flow periods, which can concentrate dissolved and particulate matter, and high-flow events characterized by elevated turbidity. By promoting the rapid aggregation and settling of suspended solids, flocculant-assisted decantation can reduce the loading on subsequent filtration and disinfection processes, leading to more stable, efficient, and cost-effective water purification.

The adoption of this enhanced pretreatment methodology aligns with principles of sustainable water resource management by aiming to minimize the generation of treatment residuals and optimize the overall efficiency of the water purification process. By proactively addressing the challenges posed by raw water variability, the long-term reliability and environmental sustainability of the drinking water supply for Antananarivo can be significantly improved.

**b. Raw Water Chemistry Contents**

Understanding the baseline chemical composition of the raw water source is fundamental to effective water treatment strategy development. Table 1 presents the concentrations of selected elements, determined via ICP-OES, in water samples collected from four distinct points within the Lake Mandroseza intake. This preliminary chemical characterization provides essential context for assessing potential water quality challenges and informing the selection and optimization of appropriate treatment technologies to ensure the provision of safe drinking water for Antananarivo.

**Table 1 .** ICP-OES results for selected elements in water samples (mg/L)

| Element | Point 1 | Point 2 | Point 3 | Point 4 |
|---|---|---|---|---|
| Aluminium (Al) | <0.05 | <0.05 | <0.05 | <0.05 |
| Arsenic (As) | <0.1 | <0.1 | <0.1 | <0.1 |
| Beryllium (Bi) | <0.1 | <0.1 | <0.1 | <0.1 |
| Calcium (Ca) | 7.15 | 7.65 | 7.21 | 7.55 |
| Cadmium (Cd) | <0.03 | <0.03 | <0.03 | <0.03 |
| Cobalt (Co) | <0.05 | <0.05 | <0.05 | <0.05 |
| Chromium (Cr) | 0.069 | 0.068 | 0.059 | 0.064 |
| Copper (Cu) | <0.05 | <0.05 | <0.05 | <0.05 |
| Iron (Fe) | 0.27 | 0.32 | 0.25 | 0.32 |
| Potassium (K) | 2.39 | 2.32 | 2.12 | 2.41 |
| Magnesium (Mg) | 4.72 | 4.78 | 4.63 | 4.79 |
| Manganese (Mn) | 0.029 | 0.024 | 0.030 | 0.021 |
| Sodium (Na) | 9.9 | 9.6 | 9.1 | 8.6 |
| Nickel (Ni) | <0.05 | <0.05 | <0.05 | <0.05 |
| Lead (Pb) | <0.2 | <0.2 | <0.2 | <0.2 |
| Sulfur (S) | 2.5 | 2.3 | 2.8 | 2.2 |
| Silicon (Si) | 2.4 | 2.62 | 2.18 | 2.63 |
| Chloride ($Cl^-$) | 8.31 | 8.65 | 8.38 | 8.56 |

The ICP-OES analysis of raw water samples from four points in Lake Mandroseza (Table 1) reveals generally low concentrations of potentially toxic heavy metals, with aluminum, arsenic, beryllium, cadmium, cobalt, copper, nickel, and lead consistently below the detection limits specified. The dominant cations are calcium (ranging from 7.15 to 7.65 mg/L), magnesium (4.63 to 4.79 mg/L), sodium (8.6 to 9.9 mg/L), and potassium (2.12 to 2.41 mg/L), indicating moderate hardness. Iron concentrations (0.25 to 0.32 mg/L) suggest a potential need for oxidation and removal during treatment. Silicon levels (2.18 to 2.63 mg/L) are typical for surface waters, while sulfur (2.2 to 2.8 mg/L) and chloride (8.31 to 8.65 mg/L) are present at relatively low concentrations. Chromium was detected at low levels (0.059 to 0.069 mg/L) across all sampling points. Manganese concentrations (0.021 to 0.030 mg/L) are also relatively low. These baseline values provide a crucial chemical context for evaluating the efficacy of subsequent water treatment processes.

The ICP-OES analysis confirms that the raw water in the Mandroseza Basin is free of hazardous heavy metals and suitable for general treatment applications. However, moderate concentrations of magnesium and silicon—elements that significantly influence floc formation—suggest a potential for sedimentation challenges. Magnesium can enhance floc formation through precipitation as $Mg(OH)_2$, while elevated silicon, particularly in colloidal form, may interfere with settling dynamics by stabilizing particles in suspension. An excess of colloidal silica may necessitate additional coagulant dosing to achieve desired sedimentation performance. (Clark et *al*., 1990)

These findings highlight the importance of tailored coagulant and flocculant selection to optimize water clarification, especially under the variable conditions characteristic of the Mandroseza Basin. Subsequent flocculation tests were thus informed by the observed ionic composition, particularly the $Ca^{2+}/Mg^{2+}/Si^{4+}$ balance, which can affect both floc stability and sludge characteristics (Ray & Hogg, 1987).

**c. Suspended Solids Particle Size Distribution**

Figure 1 illustrates the particle size distribution of suspended solids within the raw water source, as determined by wet sieving analysis. This granulometric characterization provides critical insights into the nature of the particulate load, which has direct implications for the selection and optimization of appropriate pretreatment technologies in the water treatment process. Understanding the distribution of particle sizes, particularly the proportion of finer fractions, is essential for predicting sedimentation behavior and designing effective coagulation and flocculation strategies to enhance solid-liquid separation.

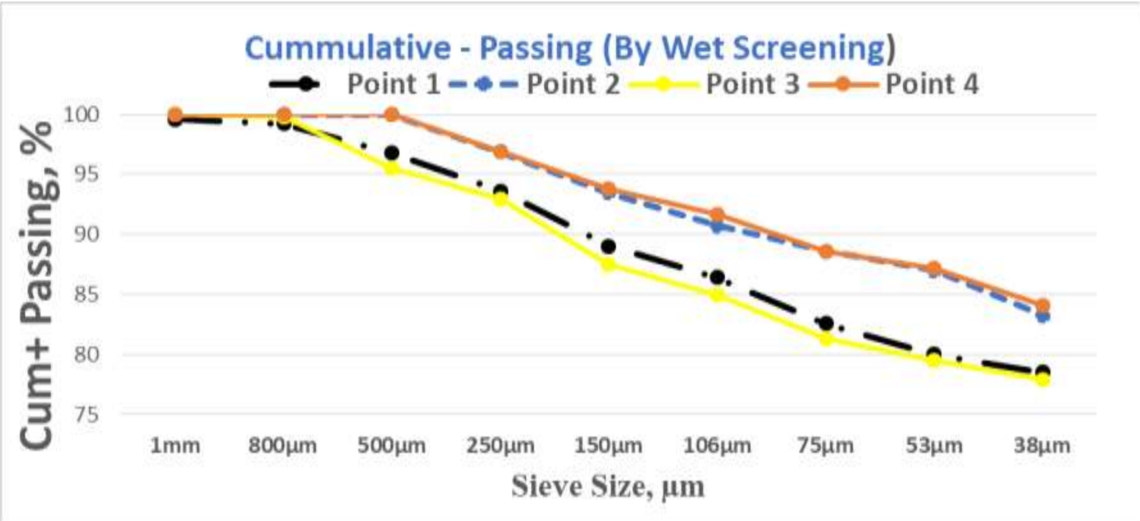


**Figure 1.** Particles size distribution by wet screening

The particle size distribution analysis, depicted in Figure 1, reveals that a substantial proportion of the suspended particulate matter in the raw water source exhibits a hydrodynamic diameter below 250 µm. Specifically, the cumulative passing percentage indicates that over 80% of the particles at sampling points 1 and 2, and approximately 75% at points 3 and 4, fall within this size range. Furthermore, a significant fraction, ranging from 30% to 50% across the sampling points, comprises particles smaller than 106 µm. This prevalence of fine particulate matter underscores the potential challenges for efficient gravity sedimentation and highlights the necessity for enhanced coagulation and flocculation strategies to effectively destabilize and aggregate these smaller particles for subsequent removal during water treatment. The observed variability in the sub-106 µm fraction across sampling locations suggests potential spatial heterogeneity in the source water characteristics, which may necessitate adaptive treatment approaches.

**Table 2.** Fine Fraction Analysis by Camera Granulometry (Below 38 μm)

| **Quantile Size (D)** | **Point 1 (μm/%)** | **Point 2 (μm/%)** | **Point 3 (μm/%)** | **Point 4 (μm/%)** |
|---|---|---|---|---|
| D90 | 32 / 70.67 | 30 / 74.93 | 32 / 70.09 | 30 / 75.65 |
| D80 | 30 / 62.82 | 25 / 66.60 | 31 / 62.30 | 26 / 67.24 |
| D70 | 25 / 54.96 | 22 / 58.28 | 28 / 54.52 | 23 / 58.84 |
| D60 | 21 / 47.11 | 18 / 49.95 | 24 / 46.73 | 20 / 50.43 |
| D50 | 19 / 39.26 | 15 / 41.63 | 20 / 38.94 | 16 / 42.03 |
| D40 | 17 / 31.41 | 14 / 33.30 | 18 / 31.15 | 13 / 33.62 |
| D30 | 14 / 23.56 | 10 / 24.98 | 15 / 23.36 | 10 / 25.22 |
| D20 | 9 / 15.70 | 8 / 16.65 | 10 / 15.58 | 8 / 16.81 |
| D10 | 8 / 7.85 | 6 / 8.33 | 7 / 7.79 | 6 / 8.41 |

The predominance of particulate matter with hydrodynamic diameters below 50 μm, and a significant sub-fraction even finer than 20 μm, signifies a substantial influence of colloidal and fine clay-sized particles within the Mandroseza Basin's suspended sediment load. This finely dispersed nature of the particulate matter poses a considerable challenge to efficient gravity-driven sedimentation processes, thereby underscoring the imperative for the implementation of flocculant-assisted decantation as an enhanced pretreatment strategy to facilitate particle aggregation and removal. (Biggs et *al.*, 2000). Notably:

- D50 values range between 15–20 μm across all sites.
- D90 values indicate that 70–75% of particles are below 30–32 μm.
- A high proportion of ultrafine solids necessitates chemical pre-treatment to optimize settling kinetics.

### 2.2 Methods

#### a. Accelerate Settling with Flocculants Agents

The selection of appropriate flocculant agents is a critical determinant of efficiency in enhanced sedimentation processes for water treatment. These substances facilitate the aggregation of colloidal and fine suspended particles into larger, more readily settleable flocs through various physicochemical mechanisms. Table 3 provides a representative selection of flocculants within the global classification, detailing their category, origin, ionic charge characteristics, and primary mode of action in promoting particle destabilization and agglomeration. This overview underscores the diverse range of chemical tools available for optimizing solid-liquid separation in water treatment applications.

**Table 3.** Sample of Flocculants within Global Classification

| **Flocculant** | **Category** | **Origin** | **Ionic Charge** | **Mode of Action** |
|---|---|---|---|---|
| Aluminium Sulfate ($Al_2(SO_4)_3$) | Inorganic Salt | Mineral-based | Cationic | Charge neutralization; forms $Al(OH)_3$ to enmesh particles |
| Sodium Silicate ($Na_2SiO_3$) | Inorganic Polymer | Mineral-derived | Anionic/ neutral | Bridging and gel-forming; supports coagulation as an aid |
| Polyacrylamide (PAM) | Synthetic Organic Polymer | Petrochemical | Cationic | Long-chain bridging; highly efficient at low concentrations |

| | | | | |
|---|---|---|---|---|
| Polyethylene Oxide (PEO) | Synthetic Organic Polymer | Petrochemical | Non-ionic | Bridging via hydrogen bonding; excellent for fine particles |
| Guar Gum | Natural Organic Polymer | Plant-based (natural) | Non-ionic | Viscosity enhancement; weak particle interaction |

Table 3 presents a selection of flocculants categorized by their chemical nature and origin. Aluminium sulfate, an inorganic salt of mineral origin, acts through cationic charge neutralization and the formation of aluminum hydroxide precipitates that enmesh particles. Sodium silicate, an inorganic polymer derived from minerals, facilitates bridging and gel formation, often as a coagulation aid. Synthetic organic polymers, including cationic polyacrylamide (PAM) and non-ionic polyethylene oxide (PEO), exhibit high efficiency through long-chain bridging, with PEO particularly effective for fine particles. Guar gum, a natural non-ionic polymer of plant origin, primarily enhances viscosity, exhibiting weaker particle interaction. This diversity in flocculant characteristics allows for tailored application based on specific water matrix properties and treatment objectives.

**b. Rationale for Flocculant Selection**

The selection of specific flocculants for this study was strategically determined based on their inherent compatibility with the physicochemical characteristics of the Mandroseza Basin's water matrix, the prevailing sub-250 μm particle size distribution, and the operational requirements dictated by a high-flow water treatment scenario:

1. Aluminium sulfate (alum), a widely recognized and extensively studied inorganic coagulant, was chosen as a benchmark due to its established efficacy in reducing turbidity and promoting the formation of dense, readily settleable flocs, particularly under conditions of moderate water hardness (Mpofu et *al*., 2004).
2. Sodium silicate was included in the experimental design for its potential dual functionality as a coagulation aid and a floc-strengthening agent. Given the analytical detection of dissolved silica and magnesium within the source water, it was hypothesized that sodium silicate could positively influence floc architecture and enhance settling behavior under specific operational parameters.
3. Cationic polyacrylamide (PAM), a synthetic organic polymer characterized by its high molecular weight and significant bridging capacity, was selected for its suitability in capturing the fine colloidal particles that constitute a dominant fraction (<38 μm) of the suspended solids in the Mandroseza samples. Its performance evaluation is critical for assessing its compatibility with high-throughput decantation systems intended for the treatment facility (Mpofu et *al*., 2004).
4. Polyethylene oxide (PEO), a non-ionic synthetic organic polymer, was chosen for its reported efficiency at low dosage rates and its unique flocculation mechanism predicated on hydrogen bonding interactions. PEO was evaluated as a potentially more environmentally benign alternative to conventional synthetic polymers, particularly in water matrices exhibiting low ionic strength (Quast et *al*., 2015)

## III. Result and Discussion

### 3.1 Jar Settling Test

To identify the most effective flocculant agent for enhanced turbidity removal, a series of jar sedimentation tests were conducted. These preliminary experiments provided initial indications regarding the optimal dosage ranges for each tested flocculant, offering a basis for subsequent, more refined optimization trials.

**Table 4.** Results Static Jar Test

| **Flocculant** | **Tested Dosages** (mg/kg) | **Optimal Dosage** (mg/kg) | **Observations** |
|---|---|---|---|
| Aluminium Sulfate ($Al_2(SO_4)_3$) | 10 – 90 | 30 | Effective at higher doses. Fast settling starts around 30 mg/kg. Overdosing slightly flattens results. |
| Sodium Silicate ($Na_2SiO_3$) | 10 – 90 | 10 | Good clarity at low doses. Higher doses slow final interface drop due to floc overgrowth. |
| Polyacrylamide (PAM) | 10 – 90 | **≤10** | Very fast settling at low doses. Overdosing causes oversized flocs and slower separation. |
| Polyethylene Oxide (PEO) | 10 – 90 | [10 ; 20] | Clear and stable supernatant. Broad effective range between 10–20 mg/kg. |
| Guar Gum | 10 – 90 | 40 | Ineffective; no improvement over control. Rejected due to poor performance. |

The static jar test results (Table 4) provide initial insights into flocculant performance across a dosage range of 10 to 90 mg/kg.

1. Aluminium sulfate exhibited effective turbidity removal at higher dosages, with optimal settling observed around 30 mg/kg; overdosing led to minimal further improvement.
2. Sodium silicate achieved good clarity at a low dosage of 10 mg/kg, while higher concentrations resulted in slower settling due to floc overgrowth.
3. Cationic polyacrylamide (PAM) demonstrated very rapid settling at dosages ≤10 mg/kg, with oversized flocs and reduced separation efficiency at higher concentrations.
4. Polyethylene oxide (PEO) yielded clear and stable supernatant within a broader effective range of 10–20 mg/kg.
5. Guar gum proved ineffective across the tested range and was subsequently rejected. These preliminary findings informed the selection of optimal dosage ranges for subsequent dynamic sedimentation trials.

### 3.2 Mechanized Static Settling Test

A controlled experimental series was conducted to ascertain the optimal dosage regimens for selected flocculant and coagulant agents – specifically polyacrylamides, polyethylene oxide (PEO), and sodium silicate – in the context of water treatment. Utilizing a motorized static jar test apparatus, six 1-liter beakers were employed per experimental run: one serving as a control (without chemical addition) and five subjected to varying flocculant dosages spanning a defined concentration range. Prior to chemical addition, the raw water was homogenized to ensure uniformity across replicates. Following manual dissolution of the treatment agents, the beakers underwent a standardized two-phase mixing protocol: an initial rapid dispersion phase of 2 minutes at 30 revolutions per minute (rpm), followed by a slow mixing phase at 5 rpm for a duration sufficient to promote flocculation. Subsequently, the suspensions were allowed to settle under quiescent conditions for 60 minutes. The efficacy of flocculant treatment was evaluated based on qualitative assessments of supernatant clarity and quantitative measurements of floc size, floc compaction, and the temporal evolution of the sludge-supernatant interface height. Final settled solids concentrations were calculated based on the stabilized interface level and the initial suspended solids concentration, with floc stability and compaction characteristics meticulously monitored throughout the sedimentation period.

**Figure 2.** Mechanized jar settling test illustration

Table 5 presents the results of dosage optimization experiments conducted for three selected flocculant agents: sodium silicate ($Na_2SiO_3$), polyacrylamide (PAM), and polyethylene oxide (PEO). For each flocculant, a series of dosages (mg/kg) was tested to determine the optimal concentration yielding the most effective solid-liquid separation after a 60-minute settling period. The optimal dosage for each agent is reported alongside the corresponding interface height (mm) and the resulting settled solid concentration (%). These data provide a quantitative basis for comparing the performance of different flocculants and selecting the most suitable option for enhancing sedimentation in the water treatment process.

**Table 5.** Results with dosage series

| Flocculant agent | Dosages (mg/kg) | | Optimal Dosage at 60 min | |
|---|---|---|---|---|
| | Tested | Optimal | Interface | Solid (%) |
| $Na_2SiO_3$ | 6 – 8 – 10 – 12 – 14 | 12.0 | 185 | **29** |
| PAM | 6 – 8 – 10 – 12 – 14 | 6.0 | 140 | **38** |
| PEO | 10 - 12.5 – 15 - 17.5 - 20 | 17.5 | 160 | **35** |

The dosage optimization trials (Table 5) revealed distinct performance characteristics for each flocculant after 60 minutes of settling.

1. Sodium silicate achieved optimal sedimentation at 12 mg/kg, resulting in an interface height of 185 mm and a settled solid concentration of 29%.
2. Cationic polyacrylamide (PAM) demonstrated superior settling, reaching an interface height of 140 mm and the highest solid concentration of 38% at a lower optimal dosage of 6 mg/kg.
3. Polyethylene oxide (PEO) exhibited optimal performance at 17.5 mg/kg, yielding an interface height of 160 mm and a settled solid concentration of 35%.

These quantitative results highlight the varying efficacy and optimal concentration requirements for each flocculant in promoting solid-liquid separation. As a next step, dynamic settling tests will be conducted to evaluate the floc stability and performance under flow conditions, simulating the operational environment for better real-world applicability.

### 3.3 Dynamic Settling Tests

To evaluate the performance of selected flocculants under flow conditions, dynamic settling tests were conducted using a closed-loop pilot system. The setup consisted of an integrated system of dosing pumps, connecting pipes, a mixing chamber, and a conical-bottom settling cylinder. Prior to testing, all components were assembled and thoroughly rinsed with clean water to eliminate residual contaminants (Metallurgist 911, 2025).

Each flocculant—Sodium Silicate ($Na_2SiO_3$ at 12 mg/kg), Polyacrylamide (PAM at 6 mg/kg), and Polyethylene Oxide (PEO at 17.5 mg/kg)—was prepared at a concentration of 0.25 g/L. Calibration of the dosing pumps ensured precise reagent delivery, while the main feed pump was set to provide a constant flow rate of 47 mL/min into the system. Raw water was initially homogenized using an immersion mixer to simulate continuous intake conditions.

As the system was activated, the main feed pump directed water into the inline mixer, where flocculants were injected at calibrated rates. The mixed suspension then flowed by gravity into a 200 mL conical settling chamber. Clear water (supernatant) overflowed continuously and was collected for clarity analysis, while settled sludge accumulated at the bottom. After 60 minutes, the compacted sludge was extracted and collected for density measurements.

The performance of each flocculant was assessed based on three parameters:
1. Clarity of the recovered supernatant
2. Density and compaction of the settled sludge
3. Visual assessment of floc stability and sediment interface

**Table 6.** Dynamic settling tests results

| **Flocculant** | **Dosage (mg/kg)** | **Supernatant Clarity *(score /40)*** | **Sludge Density (g/mL)** | **Solid Concentration (%)** | **Compacted Sludge Volume (mL)** | **TSS mg/L** |
|---|---|---|---|---|---|---|
| **$Na_2SiO_3$** | 10 | 32 | 1.3025 | 36 | 492.5 | 73 |
| | 12 | 32 | 1.3031 | 36 | 486 | 72 |
| | 14 | 33 | 1.3055 | 36 | 473 | 63 |
| | 16 | 33 | 1.3102 | 37 | 460 | 51 |
| **PAM** | 4 | 38 | 1.3409 | 40 | 427.5 | 52 |
| | 5 | 39 | 1.3472 | 41 | 414.5 | 46 |
| | 6 | 39 | 1.3461 | 40 | 421 | 56 |
| | 7 | 38 | 1.3359 | 39 | 427.5 | 62 |
| **PEO** | 16 | 38 | 1.3225 | 38 | 453.5 | 73 |
| | 17 | 39 | 1.3231 | 38 | 440.5 | 56 |
| | 18 | 39 | 1.3287 | 39 | 440.5 | **35** |
| | 19 | 39 | 1.3146 | 37 | 453.5 | 41 |

Dynamic settling tests, simulating operational flow conditions, corroborated the efficacy of PAM and PEO as robust flocculants.

Specifically, PAM at an optimal dosage of 5 mg/kg yielded the highest settled solid concentration (41%), superior supernatant clarity (39/40), and the smallest compacted sludge volume (414.5 mL), indicating excellent floc strength and settling characteristics (Lee et *al.*, 2014). While slight overdosing of PAM resulted in a marginal performance decrease, it remained within acceptable limits.

PEO demonstrated consistently high supernatant clarity (38-39/40) and stable settled solid concentrations (37-39%) across its tested optimal range (17-18 mg/kg), with compacted sludge volumes between 440 and 453.5 mL, confirming its suitability and operational flexibility under dynamic conditions.

Sodium silicate, while providing acceptable performance, exhibited lower efficiency in both sludge compaction (maximum 37%) and supernatant clarity (32-33/40) compared to the polymers, although it remains a viable, lower-cost inorganic alternative, particularly in contexts with limited access to synthetic polymers.

Overall, these dynamic test results reinforce the static jar test findings, identifying PAM (5-6 mg/kg) and PEO (17-18 mg/kg) as the most promising flocculant candidates for integration into a high-flow pretreatment system at the Mandroseza Basin.

### 3.4 Total Suspended Solids (TSS) Analysis of the Liquid Phase

To quantitatively validate the observed supernatant clarity and establish a key performance indicator for each flocculant under simulated operational conditions, a Total Suspended Solids (TSS) analysis was performed on the treated water following the dynamic settling tests. This analytical step provides a precise measure of the residual particulate matter concentration in the supernatant, complementing the qualitative visual assessments and offering a robust metric for evaluating flocculant efficacy in solid-liquid separation. (Biggs & Lant, 2000 ; Nabzar et *al*., 1988)

The TSS analysis was performed in accordance with ISO 11923:1997 (*Water quality — Determination of suspended solids by filtration through glass fibre filters*) and is consistent with Standard Methods 2540 D as recommended by the APHA/AWWA/WEF. The procedure involved:

1. Filtration of a known volume of the supernatant through a 5 cm diameter polished glass fiber filter, supported on a pre-cleaned and pre-weighed evaporation dish.
2. The dish with the retained solids was dried in an oven at 60 °C for 6 hours to remove all moisture.
3. After cooling in a desiccator, the dish was reweighed, and the difference in mass was used to calculate the TSS. (Garcia Martinez & Osornio, 2017)

This standard analytical method, widely adopted in environmental water quality assessments, ensures both the repeatability and inter-comparability of results across experimental trials.

The quantitative determination of Total Suspended Solids (TSS) in the treated water effluent following dynamic settling provides critical insights into the residual particulate load. While floc characteristics such as compaction and the clarity of the settling interface are key indicators of sedimentation efficiency, TSS analysis directly quantifies the concentration of remaining suspended particles in the clarified supernatant. This measurement is essential for evaluating the real-world performance of each flocculant in effectively reducing turbidity and consequently minimizing the particulate loading on subsequent downstream filtration processe (Shulei et *al*., 2021)

Polyethylene oxide (PEO), at an optimized dosage of 18 mg/kg, yielded the lowest residual Total Suspended Solids (TSS) concentration of 35 mg/L, signifying exceptional removal of fine particulate matter at this specific concentration. Notably, while all tested PEO dosages resulted in comparable compacted sludge volumes and high supernatant clarity scores (38-39), a significant reduction in TSS was only observed within this optimal range, underscoring that visual clarity assessments alone may not fully reflect the efficiency of fine particle removal.

Polyacrylamide (PAM), particularly at a dosage of 5 mg/kg, achieved a TSS concentration of 46 mg/L while concurrently maintaining excellent sludge density and minimal sludge volume. The flocs formed under PAM treatment exhibited both high compactness and stability, demonstrating efficient removal of colloidal particles. These findings confirm the utility of PAM in systems where both effluent clarity and operational compactness of the generated sludge are critical performance parameters.

In contrast, sodium silicate, despite producing reasonable sludge compaction values and moderate supernatant clarity (32-33), consistently resulted in the highest residual TSS concentrations, ranging from 73 mg/L down to 51 mg/L across the tested dosages. This trend suggests that while sodium silicate is effective in promoting floc formation and the settling of larger, visible solids, its efficacy in capturing finer colloidal particles, which remain suspended in the supernatant, is comparatively limited.

In summary:

1. Polyethylene oxide (PEO) demonstrates optimal performance in achieving both high supernatant clarity and minimal residual Total Suspended Solids (TSS) when applied at a dosage closely regulated around 18 mg/kg.
2. Polyacrylamide (PAM) exhibits robust and consistent efficacy, particularly within the dosage range of 5–6 mg/kg, effectively combining low TSS values, rapid floc formation kinetics, and high sludge compaction characteristics.
3. Sodium silicate ($Na_2SiO_3$), while capable of facilitating the settling of suspended solids, demonstrates a comparatively lower efficiency in polishing the liquid phase, rendering it a less suitable option in scenarios where stringent post-treatment clarity requirements are paramount.

This comprehensive analysis underscores the critical importance of incorporating quantitative liquid phase metrics, such as Total Suspended Solids (TSS) concentration, alongside qualitative visual assessments and physical parameters of the formed sludge, to achieve a holistic and accurate evaluation of flocculant performance in water treatment applications.

### 3.5 Visual Analysis of Compacted Sludge: Flattening Test

To gain further insight into the physical characteristics of the settled sludge, specifically its compaction and internal cohesive strength, a flattening test was implemented. This method assesses the spreading behavior of the sludge under gravitational forces on a planar surface, providing an indirect indication of its dewaterability potential and stickiness propertie (Nasser & James, 2006).

Following each dynamic settling test, a 50 mL aliquot of the consolidated sludge was carefully extracted using a syringe to maintain its structural integrity. This representative sample was then gently transferred to the center of a clean, dry, circular glass plate with a standardized diameter of 12 cm.

The deposited sludge sample was allowed to spread naturally under ambient temperature conditions for a duration of one hour, without any external disturbance. Subsequent to this settling period, the final diameter of the flattened sludge mass was precisely measured using a digital caliper.

The principle of the test is simple:

1. A larger spread suggests lower cohesiveness or compaction, possibly indicating weaker floc structure or excess water content.

2. A smaller spread indicates a denser, stickier sludge that retains its shape, pointing to better compaction and stronger floc integrity (Najar et al., 2023).

This visual test supplements the quantitative data (e.g., compaction volume, TSS, density) by offering insight into the physical handling characteristics of the sludge, which are critical for downstream treatment operations like thickening, drying, or disposal.

The flattening test provides a straightforward visual measure of sludge cohesiveness and compaction: the smaller the final spread diameter, the denser and more cohesive the sludge cake. Here are the observed diameters after one hour on a 12 cm plate:

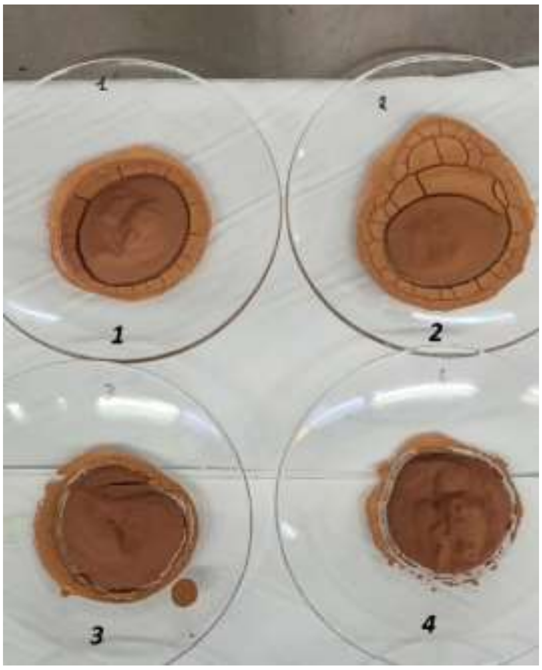


**Figure 3.** Illustration of one hour Flattening Test

1. PAM (6.0 cm) produced the smallest spread**,** indicating the strongest floc cohesion and best compaction**.** This correlates with its high sludge density and low TSS, making it ideal for dewatering and transport.
2. PEO (6.3 cm) also formed very cohesive cakes, slightly less so than PAM but still substantially more compact than the control. This reinforces its excellent performance in both static and dynamic tests.
3. $Na_2SiO_3$ (6.6 cm) yielded moderately compact sludge, consistent with its intermediate compaction volume and TSS results.
4. The untreated slurry (8.0 cm) spread the most, reflecting minimal cohesion and the poorest dewaterability.

This visual test, alongside the quantitative metrics (compaction volume, density, TSS), provides a comprehensive picture of each flocculant's sludge management characteristics.s

## IV. Conclusion

This investigation substantiates the efficacy of integrating high-discharge pumping systems with flocculant-assisted decantation as a robust pretreatment strategy for managing turbidity challenges within the Mandroseza Basin. Controlled laboratory experiments, encompassing both static and dynamic settling tests, consistently demonstrated the superior performance of cationic polyacrylamides (PAM) and polyethylene oxide (PEO) relative to other tested flocculants, as evidenced by enhanced supernatant clarity and improved solid compaction characteristics. Notably, PAM exhibited exceptional performance across a range of experimental conditions, yielding cohesive flocs with the highest degree of compaction and the minimal spread diameter observed in flattening tests.

Polyethylene oxide (PEO), characterized by its wider effective dosage range and consistent performance across varying flow regimes, presents a compelling option for enhanced operational flexibility in water treatment applications. While sodium silicate demonstrated a lower efficiency in the removal of finer particulate matter, it remains a potentially viable, cost-effective inorganic alternative in contexts where access to synthetic polymer-based flocculants is limited.

By proactively addressing both the chemical and hydraulic complexities associated with turbidity management at the water intake level, the proposed integrated system offers a scalable and adaptable solution for mitigating the impacts of storm-induced sedimentation events. The strategic implementation of optimized flocculant dosing in conjunction with high-flow conveyance infrastructure has the potential to significantly reduce the sediment loading on downstream water treatment processes, thereby enhancing overall plant efficiency and extending the operational lifespan of critical equipment.

Future research endeavors should prioritize long-term field validation studies and the seamless integration of this pretreatment strategy into existing water treatment infrastructure. Furthermore, a comprehensive cost-benefit analysis for large-scale implementation is warranted to fully assess the economic and environmental sustainability of this approach. The findings derived from this study provide a robust scientific basis for advancing turbidity mitigation strategies in urban water supply systems that are susceptible to seasonal sedimentation challenges.

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