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Start-Up Phase Performance of a Basic Water Purification System for Urban Surface Water Treatment

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Abstract

Background: The increasing degradation of urban surface water quality due to suspended solids, dissolved metals, and anthropogenic activities has driven the demand for simple, cost-effective, and sustainable water treatment technologies.
Methods: This study evaluated a Basic Water Purification System (BWPS) during its start-up phase, examining water quality changes associated with the stabilization of newly installed filtration media. Surface water from a retention pond was treated using a multi-media filtration system consisting of zeolite, silica sand, activated carbon, anthracite, manganese sand, and ion exchange resin across three configurations. Temperature, total dissolved solids (TDS), turbidity, color, pH, nitrate, nitrite, Fe, and Mn concentrations were assessed at three sampling points.
Results: TDS, turbidity, color, Fe, and Mn concentrations increased after filtration, resulting in negative removal efficiencies attributable to initial leaching from the newly installed media. However, TDS, Fe, and Mn concentrations consistently declined from the first to the third sampling point, indicating progressive media stabilization. Media 2 demonstrated the most consistent performance, maintaining a near-neutral pH range (6.3–7.2) and the lowest TDS levels, while Media 3 achieved the highest Fe removal efficiency (13.53%). Correlation analysis revealed strong positive relationships between TDS and dissolved metal concentrations, as well as between turbidity and color, confirming that these fluctuations were associated with media conditioning rather than inadequate treatment performance.
Conclusion: These findings confirm that the Basic Water Purification System (BWPS) is a promising low-cost, decentralized option for urban surface water treatment, provided that an adequate media conditioning period is implemented before full-scale operation.

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INTRODUCTION

The availability of sustainable clean water remains one of the major challenges in urban areas, particularly in regions characterized by high population density and significant anthropogenic pressures. Surface water sources such as rivers, lakes, reservoirs, and retention ponds are frequently utilized as alternative raw water sources; however, their quality tends to deteriorate due to urban runoff, domestic activities, sedimentation, and dissolved metal contamination (Matilainen et al., 2010; Olukowi et al., 2022; Shannon et al., 2008). Surface water is increasingly utilized as an alternative raw water source due to growing pressure on freshwater resources. However, urban surface water is often contaminated by suspended solids, dissolved metals, organic matter, and runoff-derived pollutants that require appropriate treatment before use (Hoslett et al., 2018; Olukowi et al., 2022). Engineered filtration systems incorporating zeolite-based media have demonstrated considerable potential for reducing dissolved metals and improving water quality in stormwater and surface water treatment applications (Kim & Ko, 2022). Granular filtration remains one of the most widely applied treatment technologies because of its simplicity, low operational cost, and effectiveness in improving water quality (Cescon & Jiang, 2020; Kim & Ko, 2022) . Consequently, surface water generally does not meet clean water quality standards without adequate treatment. Although these treatment options have been extensively studied under steady-state operation, including comparative evidence that multi-media configurations consistently outperform single-media filters once ripened (Kazemi Noredinvand et al., 2021; Ma et al., 2025), and although Indonesian surface waters such as urban rivers are increasingly documented to exceed water quality standards for TDS, nitrogen species, and metals (Pratama et al., 2020), the water-quality behavior of newly installed filtration media during the start-up phase, before the media reach equilibrium, remains comparatively underexplored, which constitutes the central gap this study addresses (Ma et al., 2025).

Conventional water treatment technologies, including large-scale water treatment plants and high-pressure membrane systems, have proven effective in improving water quality (Crini & Lichtfouse, 2019; Obayomi, 2024; Shannon et al., 2008). Nevertheless, these technologies often require high capital investment, complex operation, and substantial energy consumption, making them less suitable for small-scale applications, decentralized systems, or resource-limited areas. Recent developments in water treatment technologies emphasize the integration of physical filtration, adsorption, and hybrid treatment systems to improve treatment efficiency and sustainability (Obayomi et al., 2024). Therefore, the development of simple, efficient, and practical water treatment systems has become increasingly important to support sustainable urban water management.

Natural filtration media such as silica sand, zeolite, and activated carbon have been widely investigated as cost-effective and easy-to-operate alternatives for water treatment (Bhatnagar & Sillanpää, 2010; Shrivastava & Singh, 2022; Singh et al., 2018). Previous studies have demonstrated that these media effectively reduce turbidity, improve color, and remove undesirable odors from surface water. However, most existing studies have focused on single-stage filtration systems or system performance under stable operating conditions, with an emphasis on optimal removal efficiencies. The behavior of filtration media during the start-up period, particularly in newly installed systems, has received relatively limited attention (Ramsay et al., 2018; Shrivastava & Singh, 2022).

Zeolite possesses adsorption and ion-exchange properties that enable the removal of dissolved metals and nitrogen compounds from water (Maikano et al., 2026; Wang & Peng, 2010). Activated carbon functions as an adsorbent for organic compounds and odor-causing substances through surface adsorption mechanisms (Ali, 2012; Maikano et al., 2026). Manganese sand is commonly used to remove dissolved metals through oxidation and filtration processes (Cescon & Jiang, 2020; Maikano et al., 2026; Ramsay et al., 2018). Although the effectiveness of natural filtration media has been widely reported, most studies have primarily evaluated system performance under steady-state conditions.

This study specifically investigates water quality changes during the initial operation of a Basic Water Purification System (BWPS), when filtration media are still adapting to the raw water. During this start-up period, temporary changes may occur due to the release of fine particles and dissolved ions from newly installed filtration media, affecting parameters such as total dissolved solids (TDS), turbidity, iron (Fe), and manganese (Mn). In addition, the study proposes a small-scale water treatment system that can be directly implemented at water sources or user locations without relying on centralized treatment facilities.

Although the effectiveness of multi-media filtration systems has been widely reported, most studies have focused on steady-state operating conditions after the filtration media have reached equilibrium. Limited information is available regarding water quality fluctuations during the start-up phase, particularly for decentralized treatment systems utilizing newly installed natural filtration media. Consequently, the influence of media stabilization and initial leaching on treatment performance remains insufficiently understood. Previous studies have demonstrated that the start-up period plays an important role in determining filtration performance, particularly for systems designed to remove dissolved manganese. Media stabilization and filter ripening are necessary before optimal treatment efficiency can be achieved (Jiang et al., 2023).

The novelty of this study lies in evaluating the performance of a Basic Water Purification System (BWPS) during the initial operational phase. Specifically, the study investigates the transient changes in physical and chemical water quality parameters resulting from interactions between raw water and newly installed filtration media. Furthermore, the study explores the applicability of BWPS as a decentralized water treatment technology supporting sustainable urban water management.

Therefore, this study aims to evaluate the performance of BWPS in improving surface water quality based on physical and chemical parameters and to identify the initial operational characteristics of the system as a basis for the development and optimization of decentralized water treatment technologies. The findings are expected to provide both scientific and practical contributions to the development of simple, realistic, and sustainable water treatment systems.

METHOD

Study Area and Raw Water Source

Surface water samples were collected from a retention pond located within the Institut Teknologi PLN (ITPLN) campus, West Jakarta, Indonesia. The retention pond receives stormwater runoff and surface drainage from surrounding urban areas characterized by domestic and commercial activities. The study location is illustrated in Figures 1 and 2.

Figure 1. Study Case Location

Figure 2. Retention Pond at PLN Institute of Technology

Basic Water Purification System Design and Configuration

The BWPS consisted of two treatment stages. The first stage functioned as a sedimentation chamber for removing coarse suspended solids. The filtration media employed in this system as illustrated in figure 3.

Figure 3. Filtration Media

Each filtration column was constructed using a transparent acrylic cylinder with a diameter of 4 inches and a height of 1.0 m. The filtration media employed in this study, namely manganese sand, anthracite, and ion exchange resin, are widely used in water treatment processes owing to their ability to improve water quality across a range of parameters. Manganese sand plays an important role in oxidizing and removing iron and manganese ions (Putra et al., 2026; Suharto, 2020). The Basic Water Purification System (BWPS) was designed as a simplified water treatment unit employing a two-stage configuration housed within transparent cylindrical acrylic pipes. Each pipe has an inner diameter of 4 inches and a height of 1.0 m, with an effective operational capacity of approximately 8 liters per unit. The first stage functions as a collection and preliminary sedimentation tank, intended to reduce coarse suspended particles and sediment prior to the water being directed into the filtration stage. The second stage constitutes the primary filtration unit, which integrates multiple filtration media within a single column to enhance overall contaminant removal performance.

The combination of zeolite, silica sand, and activated carbon has been widely recognized as an effective multi-layer filtration approach, as each medium contributes distinct and complementary removal mechanisms. Silica sand serves as the primary physical barrier, effectively retaining suspended solids and coarse particulates through mechanical straining. Zeolite, owing to its high cation exchange capacity and microporous structure, selectively captures fine particles and specific ionic contaminants. Activated carbon further enhances treatment performance by adsorbing organic compounds, thereby reducing undesirable odor, color, and taste from the treated water (Matilainen et al., 2010; Propolsky & Romanovski, 2025). To address the removal of heavy metals and dissolved substances, anthracite, manganese sand, and ion exchange resin are incorporated into the filtration system, leveraging their respective capacity for oxidation, catalytic filtration, adsorption, and ion-exchange processes (Propolsky & Romanovski, 2025).

The Basic Water Purification System (BWPS) was designed as a decentralized water treatment unit utilizing a multi-media filtration configuration consisting of zeolite, manganese sand, ion exchange resin, and silica sand. Surface water collected from the retention pond was subjected to laboratory analysis before being treated through the BWPS filtration unit. The treated water was subsequently evaluated for potential non-potable applications. The overall research framework and BWPS configuration are presented in Figure 4.

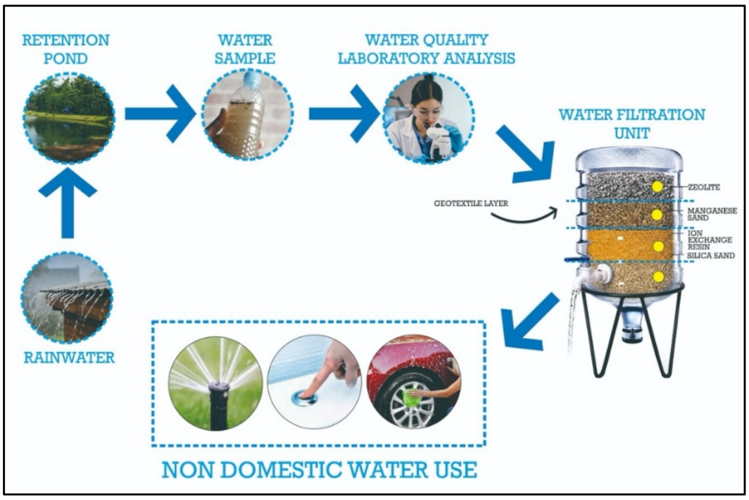

Figure 4. Research framework and configuration of the Basic Water Purification System (BWPS) for urban surface water treatment and non-potable water applications

Parameters and Water Quality Analysis

Water quality analysis was conducted on samples collected before and after the filtration process. The parameters analyzed encompassed the following:

1) Physical parameters: temperature, total dissolved solids (TDS), turbidity, color, and odor;
2) Chemical parameters: pH, nitrate, nitrite, dissolved iron (Fe), and dissolved manganese (Mn).

All water quality testing was performed at an accredited laboratory. The analytical results were compared against the clean water quality standards stipulated in the Regulation of the Minister of Health of the Republic of Indonesia Number 2 of 2023.

Removal Efficiency Analysis

Removal efficiency is commonly used to evaluate the performance of water treatment systems in reducing contaminant concentrations. The parameter indicates the percentage reduction of a specific water quality constituent after treatment compared with its initial concentration. A higher removal efficiency reflects better treatment performance, whereas a negative removal efficiency indicates that the concentration of the parameter increased after treatment.

The removal efficiency was calculated using Equation (1):

$$\eta = \frac{C_0 - C_t}{C_0} x100$$

Where:
η = removal efficiency (%)
C_0 = concentration before filtration
C_t = concentration after filtration

A positive value indicates successful contaminant removal, while a negative value indicates an increase in concentration after treatment. In filtration systems, negative removal efficiencies may occur during the start-up phase due to the release of fine particles, dissolved ions, or residual compounds from newly installed filter media. This phenomenon is commonly referred to as initial leaching and generally decreases as the filtration media become stabilized through continued operation. In this study, removal efficiency was calculated for each physical and chemical parameter to evaluate the treatment performance of the Basic Water Purification System (BWPS) and to identify the influence of media stabilization during the initial operational phase.

The BWPS was operated under a continuous gravity-fed flow at an average filtration flow rate of 2 L/min, corresponding to a hydraulic loading rate of approximately 6.3 m^3/m^2·h based on the 4-inch (0.081 m^2) cross-sectional area of the acrylic column. Each of the three media configurations was operated continuously for approximately 6 hours of start-up filtration time, during which effluent samples were withdrawn at three sequential sampling intervals (T1, T2, and T3), spaced approximately 2 hours apart, to capture the progressive stabilization of the filtration media. All physical and chemical parameters were measured in duplicate at each sampling point, and the reported values represent the mean of the two replicate measurements to reduce analytical variability.

RESULTS AND DISCUSSION

Water Sample

Water samples were collected from three sampling locations with varying levels of water quality. Analysis was conducted on water samples prior to filtration and on effluent water following treatment through three variations of filtration media configurations, as illustrated in Figure 5. In this study, T1, T2, and T3 refer to three sequential temporal sampling points collected from the effluent of each media configuration during a single continuous filtration run (approximately 2 hours apart, as described above), rather than three distinct spatial locations. This temporal sampling scheme was designed specifically to capture the progressive stabilization trend of the filtration media during the start-up phase.

Figure 5. Water Sampling

Water Quality Testing

Following sample collection, the water samples were submitted to an accredited water testing laboratory for quality analysis prior to the filtration process. The designated laboratory was the Environmental Laboratory at the Faculty of Landscape Architecture and Environmental Technology. The results of the water quality testing conducted on March 2, 2026, are presented in Table 1.

Table 1. Water Quality Analysis Results of the Retention Pond Prior to Filtration

No.	Parameter	Unit	Before Filtration			Media 1 (Zeolite + Silica Sand + Activated Carbon)			Media 2 (+ Anthracite + Manganese Sand)			Media 3 (+ Ion Exchange Resin)			Quality Standard (PerMenKes 2/2023)
			T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	
1	Temperature	°C	25,6	25,6	25,6	25,6	25,6	25,6	25,6	25,6	25,6	25,6	25,6	25,6	Dev. ±3°C
2	Total Dissolved Solids (TDS)	mg/L	181	183	183	**2161**	**1962**	**1834**	963	634	395	**2312**	**2100**	**1760**	1,000 mg/L
3	Turbidity	NTU	14,49	18,95	17,62	**278**	20,7	8,82	**167**	**143**	**110**	**258**	11,42	5,02	25 NTU
4	Color	Pt-Co	57,96	75,8	70,48	**612**	**82,8**	35,28	**668**	**572**	**440**	**1032**	45,68	20,08	50 Pt-Co
5	Odor	-	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless	Odorless
6	pH	-	6,8	7,3	7,5	**3,2**	**3,2**	**3,3**	6,3	6,8	7,2	**3,5**	**3,4**	**3,5**	6.5 – 8.5
7	Nitrate (as $NO3^-$, dissolved)	mg/L	0,12	0,13	0,12	0,15	0,09	0,05	0,12	0,05	0,04	0,13	0,2	0,04	10 mg/L

No.	Parameter	Unit	Before Filtration			Media 1 (Zeolite + Silica Sand + Activated Carbon)			Media 2 (+ Anthracite + Manganese Sand)			Media 3 (+ Ion Exchange Resin)			Quality Standard (PerMenKes 2/2023)
			T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	
8	Nitrite (as NO2⁻, dissolved)	mg/L	0,02	0,01	0,01	0,12	0,02	<0.01	0,06	0,04	0,03	0,1	0,17	<0.01	1 mg/L
9	Chromium VI (Cr^{6+}, dissolved)	mg/L	N/T	N/T	N/T	N/T	N/T	N/T	N/T	N/T	N/T	N/T	N/T	N/T	0.05 mg/L
10	Iron (Fe, dissolved)	mg/L	1,29	1,72	0,02	**3,17**	1,78	0,62	**1,76**	**1,48**	0,95	**1,59**	0,78	0,25	1 mg/L
11	Manganese (Mn, dissolved)	mg/L	0,61	0,59	<0.01	**8,1**	**2,15**	**1,19**	**5,23**	**3,81**	**1,4**	**6,82**	**1,74**	**0,67**	0.4 mg/L

Water Quality Before Filtration

Prior to filtration, water samples were collected from three sampling points (T1, T2, and T3) with varying baseline water quality conditions. The pre-filtration analysis revealed that several parameters already exceeded the clean water quality standards stipulated in the Regulation of the Minister of Health of the Republic of Indonesia Number 2 of 2023 (PerMenKes No. 2/2023). The average temperature across all sampling points was 25.6°C, which remained within the permissible deviation range. The average TDS concentration was 182.3 mg/L, which is below the 1,000 mg/L threshold; however, turbidity averaged 17.02 NTU and color averaged 68.08 Pt-Co, with the latter already exceeding the standard limit of 50 Pt-Co. The average pH of 7.2 was within the acceptable range of 6.5–8.5. Iron (Fe) concentration averaged 1.01 mg/L, marginally exceeding the 1 mg/L limit, while manganese (Mn) averaged 0.40 mg/L, at the boundary of the 0.4 mg/L standard. Nitrate and nitrite concentrations remained well within permissible limits at 0.12 mg/L and 0.01 mg/L, respectively. Odor was absent across all sampling points.

Water Quality After Filtration

Physical Parameters

Temperature. Water temperature remained constant at 25.6°C throughout all sampling points, both before and after filtration. This indicates that the filtration process had no effect on the thermal characteristics of the water.

Total Dissolved Solids (TDS). TDS concentrations increased significantly in all filtration configurations. Prior to filtration, TDS values ranged from 181 to 183 mg/L. After filtration, the concentrations increased to 1,834–2,161 mg/L in Media 1, 395–963 mg/L in Media 2, and 1,760–2,312 mg/L in Media 3. Among the three configurations, Media 2 produced the lowest TDS values and remained closest to the drinking water standard of 1,000 mg/L. The increase in TDS is likely associated with the release of dissolved minerals and ions from the zeolite, manganese sand, and ion exchange resin during the initial stabilization period.

Turbidity. A similar trend was observed for turbidity. Although turbidity values increased during the early stage of operation, a gradual decrease was recorded from T1 to T3 in all media configurations. Media 2 produced turbidity values ranging from 110 to 167 NTU, while Media 1 and Media 3 exhibited higher values at the initial observation point. Despite still exceeding the regulatory limit of 25 NTU, the consistent decline suggests that the release of fine particles from the filtration media decreased as the system continued to operate.

Color. Color values followed a pattern similar to turbidity. The raw water color ranged from 57.96 to 75.80 Pt-Co and increased after filtration, particularly at T1. The highest color value was recorded in Media 3 (1,032 Pt-Co), while the lowest value was observed in Media 3 at T3 (20.08 Pt-Co), which met the water quality standard of 50 Pt-Co. The strong relationship between color and turbidity indicates that the increase in color was mainly caused by suspended particles and colloidal materials released from the new filtration media.

Odor. No changes were observed in odor characteristics. All samples remained odorless before and after filtration, indicating that the filtration process did not negatively affect the aesthetic quality of the water. Odor was evaluated qualitatively by trained laboratory personnel using a simple organoleptic (sniff) test, in accordance with the qualitative odor assessment approach adopted for clean water quality testing under PerMenKes No. 2/2023.

Chemical Parameters

pH. The pH results showed clear differences among the media configurations. Media 1 and Media 3 produced acidic conditions, with pH values ranging from 3.2 to 3.5, which did not comply with the clean water quality standard. In contrast, Media 2 maintained pH values between 6.3 and 7.2 and was the only configuration capable of producing water within or close to the acceptable pH range. This finding suggests that the addition of anthracite and manganese sand contributed to better chemical stability during filtration.

The strongly acidic effluent produced by Media 1 and Media 3 is attributable to the freshly installed ion exchange resin, which is manufactured and supplied in the hydrogen (H^+) form. During the initial service cycles, this resin exchanges H^+ ions for cations present in the raw water, releasing hydrogen ions into the treated water and lowering its pH until the readily exchangeable H^+ sites are progressively depleted (Arias-Paic et al., 2016; Propolsky & Romanovski, 2025; Tang et al., 2026). Because Media 2 additionally incorporated anthracite and manganese sand ahead of the ion exchange resin, the combined oxidative and catalytic filtration action of these media likely buffered part of this effect, resulting in the near-neutral effluent pH observed for this configuration. As the ion exchange resin approaches its operating equilibrium, the magnitude of hydrogen-ion release is expected to decline, and effluent pH should progressively stabilize toward neutral values with continued operation.

Nitrate (NO_3^-). Nitrate concentrations remained low in all configurations and were well below the regulatory limit of 10 mg/L. Post-filtration concentrations ranged from 0.04 to 0.20 mg/L, indicating that nitrate was not a major concern in the treated water.

Nitrite (NO_2^-). Nitrite concentrations remained far below the standard limit of 1 mg/L. Although slight increases were observed in some sampling points, the concentrations were still very low and did not significantly affect overall water quality.

Iron (Fe). For dissolved iron (Fe), the initial concentrations ranged from 0.02 to 1.72 mg/L. Following filtration, Fe concentrations increased at T1 in most configurations, indicating the release of iron from the filtration media during the start-up phase. However, concentrations gradually decreased at T2 and T3. Media 3 produced the best result, achieving a final Fe concentration of 0.25 mg/L at T3, which was below the regulatory limit of 1 mg/L.

Manganese (Mn). Manganese showed the most pronounced increase among all parameters. Initial concentrations ranged from <0.01 to 0.61 mg/L, while post-filtration concentrations reached as high as 8.10 mg/L in Media 1 and 6.82 mg/L in Media 3. This substantial increase indicates that the manganese sand was still undergoing an initial leaching process. Nevertheless, all configurations exhibited a consistent decline from T1 to T3, suggesting that the filtration media were gradually approaching stable operating conditions.

Rapid sand filters conditioned with manganese-oxide coatings typically require an initial ripening or conditioning period, during which loosely bound manganese oxide fines are progressively washed from the media surface until effluent manganese concentrations stabilize (Jiang, 2023). Quantitatively, full-scale rapid sand filters treating manganese-bearing water have been reported to require on the order of 17–25 weeks of continuous operation before stable manganese removal is achieved, although targeted inoculation with biologically active media can substantially shorten this period (Haukelidsaeter et al., 2025). Based on the declining trend observed from T1 to T3 in this study, a conditioning period on the order of several operating days to weeks, accompanied by periodic backwashing, would likely be required before manganese leaching subsides to within the regulatory limit. In practice, this leaching effect can be mitigated by pre-washing or pre-conditioning the manganese sand with clean water prior to installation, and by discarding or recirculating the initial filtrate rather than routing it directly to end use. Consequently, the BWPS should not be used for any application, including non-potable purposes, until effluent manganese and iron concentrations have been confirmed by testing to remain consistently below the regulatory limits of 0.4 mg/L and 1 mg/L, respectively, across at least three consecutive sampling events.

Discussion

The preceding subsections reported the observed water quality data and removal efficiencies objectively.

Media Performance Evaluation

Based on the overall results, Media 2 (Zeolite + Silica Sand + Activated Carbon + Anthracite + Manganese Sand) demonstrated the most stable performance among the three configurations. This media combination produced lower TDS, turbidity, color, Fe, and Mn concentrations compared with Media 1 and Media 3, while also maintaining pH values near neutral conditions. In contrast, Media 1 and Media 3 exhibited higher levels of dissolved ions and fine particles, as reflected by the elevated TDS, color, and dissolved metal concentrations.

Overall, the findings indicate that the BWPS has considerable potential as a small-scale surface water treatment system. However, the filtration media require a conditioning or flushing period before optimum performance can be achieved. The consistent reduction observed in most parameters from T1 to T3 suggests that treated water quality will continue to improve as the filtration media become fully stabilized during long-term operation.

Removal Efficiency

Table 2 presents the removal efficiency of each filtration media configuration in improving the quality of retention pond water. In general, most parameters exhibited negative removal efficiencies, indicating that the concentrations measured after filtration were higher than those observed in the raw water. However, these results do not necessarily indicate poor performance of the BWPS. Instead, they reflect the condition of newly installed filtration media that were still undergoing adaptation and stabilization processes during the initial stage of operation.

Table 2. Removal Efficiency (%) of the Basic Water Purification System (BWPS) Based on Average Values Across Three Sampling Points

No.	Parameter	Unit	Before Filtration (Average)	Media 1 (Avg After)	Efficiency M1 (%)	Media 2 (Avg After)	Efficiency M2 (%)	Media 3 (Avg After)	Efficiency M3 (%)	Quality Standard (PerMenKes 2/2023)
1	Total Dissolved Solids (TDS)	mg/L	182,333	1985,667	**-989,03**	664	**-264,17**	2057,333	**-1028,34**	1,000 mg/L
2	Turbidity	NTU	17,02	102,507	**-502,27**	140	**-722,56**	91,48	**-437,49**	25 NTU
3	Color	Pt-Co	68,08	243,36	**-257,46**	560	**-722,56**	365,92	**-437,49**	50 Pt-Co
4	pH	-	7,2	3,233	**55,09**	6,767	**6,02**	3,467	**51,85**	6.5 – 8.5
5	Nitrate (as $NO3^-$)	mg/L	0,123	0,097	**21,62**	0,07	**43,24**	0,123	0	10 mg/L
6	Nitrite (as $NO2^-$)	mg/L	0,013	0,048	**-262,5**	0,043	**-225**	0,092	**-587,5**	1 mg/L
7	Iron (Fe, dissolved)	mg/L	1,01	1,857	**-83,83**	1,397	**-38,28**	0,873	**13,53**	1 mg/L
8	Manganese (Mn, dissolved)	mg/L	0,402	3,813	**-849,38**	3,48	**-766,39**	3,077	**-665,98**	0.4 mg/L

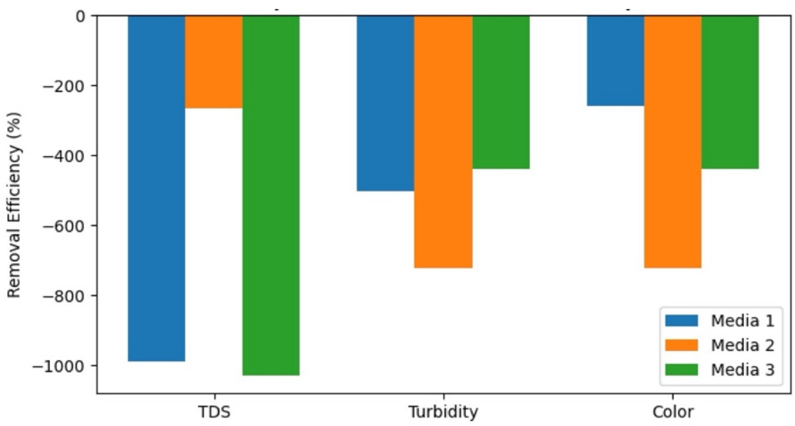

Figure 6. Physical Parameters Removal Efficiency

Figure 6 illustrates the removal efficiency of physical water quality parameters, including TDS, turbidity, and color, for the three BWPS media configurations. All parameters exhibited negative removal efficiencies, indicating that the concentrations measured after filtration were higher than those in the raw water. This behavior is attributed to the initial leaching phenomenon commonly observed in newly installed filtration media. Among the tested configurations, Media 2 showed the best performance in controlling TDS increase, whereas Media 3 exhibited the lowest turbidity increase. Media 1 produced the most favorable result for color. The negative efficiencies observed in all physical parameters suggest that the filtration media were still undergoing stabilization and conditioning processes during the start-up phase. Consequently, the increases in TDS, turbidity, and color should be interpreted as temporary effects associated with media adaptation rather than poor filtration performance.

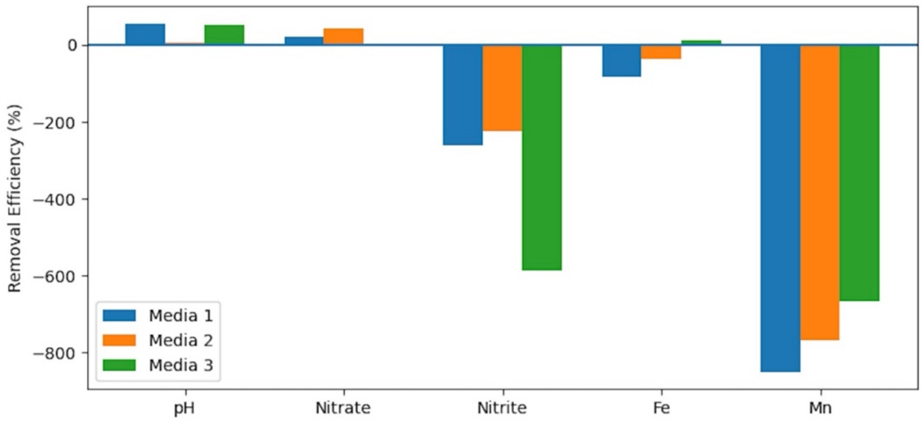

Figure 7. Chemical Parameters Removal Efficiency

Figure 7 presents the removal efficiency of chemical water quality parameters for the three BWPS media configurations. Positive removal efficiencies were observed for pH and nitrate, indicating improvements in water quality after filtration. Media 2 achieved the highest nitrate removal efficiency (43.24%) and maintained pH values closest to the drinking water quality standard. In contrast, nitrite and manganese exhibited negative removal efficiencies across all configurations, reflecting the influence of initial media stabilization and leaching processes. Iron removal was only achieved by Media 3, which attained a positive removal efficiency of 13.53% and reduced Fe concentrations below the regulatory limit. The substantial increase in manganese concentration confirms the occurrence of initial leaching from newly installed manganese sand. Overall, the results indicate that the BWPS was still operating within its start-up phase, during which media conditioning significantly influenced the observed water quality responses.

Comparison with Previous Studies

The best-performing iron removal efficiency obtained in this study (13.53% by Media 3) is considerably lower than the removal efficiencies typically reported for dual- and multi-media systems operating under steady-state conditions, such as the zeolite–mortar dual-media filter of Kim and Ko (2022), which achieved substantially higher and more consistent heavy-metal removal once the media had stabilized. Similarly, the negative manganese removal efficiencies observed here during start-up are consistent with the fast-ripening behavior reported for rapid sand filters treating manganese-bearing surface water, where effluent manganese concentrations only fall below regulatory limits after the filter media develop a mature manganese-oxide coating (Jiang, 2023). This similarity supports the interpretation that the negative removal efficiencies recorded in the present study reflect a transient conditioning phase rather than an inherent limitation of the BWPS media selection, and is further corroborated by recent reviews of iron and manganese removal media, which consistently identify a start-up conditioning period as a prerequisite for reliable performance (Propolsky & Romanovski, 2025).

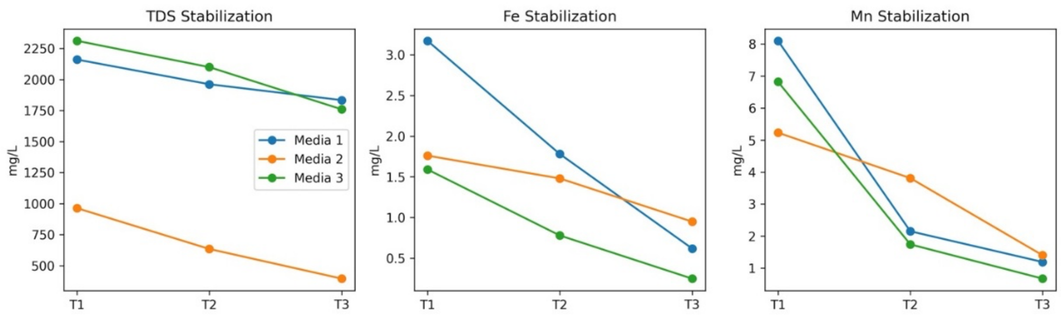

Figure 8. Comparison of TDS, Fe, and Mn stabilization trends for the three BWPS media configurations during the start-up phase.

Figure 8 compares the stabilization behavior of the three BWPS media configurations during the start-up phase. All configurations exhibited decreasing trends in TDS, Fe, and Mn concentrations from T1 to T3, indicating progressive stabilization of the filtration media. Media 2 consistently produced the lowest TDS concentrations, while Media 3 achieved the lowest final Fe and Mn concentrations. These results suggest that the elevated concentrations observed immediately after filtration were primarily caused by initial leaching from newly installed media. As the operating time increased, the release of dissolved ions and fine particles gradually decreased, resulting in improved treated water quality and more stable system performance.

Correlation Analysis

Correlation analysis showed strong positive relationships between TDS and dissolved metals (Fe and Mn), as well as between turbidity and color. The similar trends observed among these parameters indicate that the temporary increase in water quality constituents during the start-up phase was mainly caused by the release of dissolved ions and fine particles from newly installed filtration media. As the media stabilized, all parameters exhibited decreasing trends, confirming the occurrence of initial leaching during the early stage of BWPS operation.

Table 3. Correlation Between Water Quality Parameters During the BWPS Start-Up Phase

Parameters	Relationship	Interpretation
TDS – Fe	Positive	Release of dissolved iron contributes to TDS increase
TDS – Mn	Positive	Release of manganese contributes to TDS increase
Turbidity – Color	Positive	Suspended particles increase apparent color
Fe – Mn	Positive	Both parameters are influenced by media stabilization
TDS – Turbidity	Moderate	Dissolved ions and fine particles are released simultaneously

CONCLUSION

This study evaluated the performance of a Basic Water Purification System (BWPS) during its initial operational phase for improving urban surface water quality. The findings indicate that filtration performance was strongly influenced by media stabilization, resulting in temporary increases in several physical and chemical parameters due to the initial leaching of fine particles, dissolved minerals, and residual compounds from newly installed media. Consequently, negative removal efficiencies were observed for TDS, turbidity, color, manganese (Mn), and nitrite during the start-up period. Nevertheless, Media 2 demonstrated the most stable overall performance by maintaining pH within the acceptable range, producing the lowest TDS concentrations, and achieving the highest nitrate removal efficiency (43.24%), while Media 3 provided the best iron (Fe) removal efficiency (13.53%). The progressive reductions in TDS, Fe, and Mn concentrations from T1 to T3 further confirm that the observed deterioration in water quality was temporary and reflected the natural conditioning process of the filtration media rather than system failure.

The main contribution of this study is the characterization of BWPS performance during the start-up phase, a stage that has received limited attention in previous research, which has predominantly focused on stabilized operating conditions. These findings emphasize that media stabilization and initial leaching should be considered when evaluating decentralized water treatment technologies and highlight the necessity of implementing an appropriate pre-conditioning or flushing period before routine operation. With adequate conditioning, BWPS shows considerable potential as a simple, low-cost, and sustainable technology for decentralized urban surface water treatment. Future studies should determine the optimal conditioning duration through longer monitoring periods, investigate the effectiveness of pre-washing filtration media to minimize initial leaching, and evaluate the long-term treatment performance of BWPS under steady-state operating conditions.

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AUTHOR CONTRIBUTION STATEMENT

Endah Lestari conceived and designed the study, developed the methodology, coordinated the research, analyzed the data, secured funding, and prepared the original manuscript. Dede Rohmat contributed to the research design, methodology development, data interpretation, and manuscript refinement. Wati Asriningsih Pranoto contributed to the methodology, data analysis, validation of the findings, and manuscript preparation. Muhammad Sofyan contributed to data collection, laboratory coordination, data visualization, and manuscript preparation. Arief Suardi Nur Chairat contributed to data collection, data curation, visualization, and validation of the research results. All authors read and approved the final version of the manuscript and agree to be accountable for the accuracy and integrity of the work.

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