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ORIGINAL ARTICLE

The effectiveness of local sands of Indonesian South Sulawesi as filtration material in water treatment plant

B. Bakri[1] · S. Pallu[1] · N. A. Mangarengi[2] · M. Ihsan[3] · Y. Arai[4]

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Abstract
The regional water company in Sulawesi Island of Indonesia uses sand from Sumatra and Java islands to perform water filtration. However, this is time consuming and expensive. In fact, South Sulawesi Province has abundant local sand that may be used as filtration material. Therefore, the aim of this study is to determine novel alternatives for filtration materials in water treatment plants using local sand available in South Sulawesi. The proposed alternatives are implemented using four local sand sources, namely Malimpung, Bira, Jeneberang, and Tanralili in Pinrang, Bulukumba, Gowa, and Maros Regencies, respectively. The effectiveness of each sand source is analyzed by modeling a filter in the laboratory with a rapid sand filter system. The experimental work is conducted under unsaturated conditions for sand**.** We have considered three variations of initial raw water turbidity, namely 25, 50, and 109 NTU representing low, medium, and high turbidity levels, respectively. The initial total suspended solids (TSS) for each variation of initial turbidity is calculated as 19, 51, and 99 mg/l, respectively. In addition, we have applied three variations of filter thickness, namely 10, 20, and 30 cm. The results indicated that only Malimpung sand meets the physical requirements, namely effective size of 0.23, uniformity coefficient of 2.19, specific gravity of 2.69 g/cm^3, and percentage of SiO_2 as 97.07%. It was also clarified that Malimpung sand is the most effective in removing physical pollutants based on turbidity and TSS with an efficiency of 72% and 84%, respectively, during the observation time of 600 s.

Keywords Filtration material · Local sands · Rapid sand filter system · Unsaturated · Turbidity · Total suspended solids

Introduction

The requirement for drinking water as a vital provision and service for human life is rapidly increasing (Mekonnen and Hoekstra 2016; Hering et al. 2016) owing to the increased rate of population growth and public awareness of the importance of drinking water in daily life (Bakri et al. 2015). To meet these requirements, extensive water treatment, both industrial and domestic, with a series of processes such as the removal of impurities through filtration is essential (Anastasios and Ioannis 2019). Filtration is a water treatment system that involves the separation of solids from liquids using a porous medium to remove suspended solids, colloids, and other substances (Charles 2009; Zeki 2009). According to Huisman (Mark et al. 1987), raw water treatment with a granular media filter can be used as an additional unit. Two types of filter media are commonly used in the filtration process, namely rapid sand filter and slow sand filter with bottom-up (up-flow) and top-down (downflow) filtration systems (Keucken et al. 2017; Manning 2003). Currently, several technological innovations have been developed to process raw water into drinking water (Zainura and Noor 2018). Yolly et al. (2021) used sand combined with zeolite with thicknesses of 10 and 20 cm using a downflow system with an observation time of 30 min. The results indicated that the efficiency of reducing turbidity is 67.3%. Pramod et al. (2018) investigated the comparison of the efficiency of a slow sand filter and charcoal filter in purifying raw

✉ B. Bakri
bambangbakri@gmail.com; bambangbakri@unhas.ac.id

[1] Civil Engineering Department, Hasanuddin University, Makassar, Indonesia

[2] Environmental Engineering Department, Hasanuddin University, Makassar, Indonesia

[3] Civil Engineering Department, Sekolah Tinggi Teknik Baramuli, Pinrang, Indonesia

[4] Department of Civil and Environmental, Tokyo Metropolitan University, Tokyo, Japan

water samples using river sand combined with gravel and thicknesses of 30 and 20 cm, respectively. It was discovered that the efficiency of the charcoal filter was higher than that of the slow sand filter. An efficiency of 83.3% was demonstrated in reducing turbidity, which is the highest, followed by total solids and sample color reduction. Michael et al. (2012) presented laboratory and field proof-of-concept demonstrations of a water treatment plant in which a multilayer configuration of stacked rapid sand filters at 1.4–1.83 mm/s (120–160 m/day) per layer and backwashed at 10–11 mm/s (860–950 m/day) with a similar total flow rate was used. The filter model demonstrated satisfactory filtration performance and effective backwashing. Furthermore, Ekha et al. (2019) analyzed the performance of rapid sand filtration on a laboratory scale using lava sand. Sedimentation was conducted with a retention time of 3 h based on the real field conditions of the oil production process by the community in one sample well. In addition, rapid sand filtration was also implemented using a fixed bed column method with a grain size of 0.2 cm. Results showed that the sedimentation process exhibited a high turbidity removal efficiency of 98.65% while the rapid sand filter exhibited 96.48%.

Therefore, the aim of this study is to determine a new source of sand in South Sulawesi Province as a filtration material for water treatment. South Sulawesi Province has abundant local sand that has not been used as a filtration material earlier because of the limited information on the effectiveness of sand as filtration media (Syahrir et al. 2014). In this study, we have considered four local sand sources, namely Malimpung, Bira, Jeneberang, and Tanralili, in Pinrang, Bulukumba, Gowa, and Maros Regency, respectively. The effectiveness of each sand source in removing physical pollutants based on turbidity and total suspended solids (TSS) is analyzed by modeling a filter in the laboratory with a rapid sand filter system. The experimental process was implemented under unsaturated conditions for sand. Additionally, we have applied three variations of initial raw water turbidity, namely 25, 50, and 109 Nephelometric Turbidity Units (NTU), representing low, medium, and high turbidity levels, respectively. While the initial TSS is based on the three variations of initial turbidity of 19, 51, and 99 mg/l. Furthermore, the efficiency of each sand source in removing physical pollutants along with three other variations of filter thickness, namely 10, 20, and 30 cm has been analyzed.

This study contributes sand as a filtration material to the Regional Drinking Water Company (PDAM) in Sulawesi Island of Indonesia. Currently, it is challenging for PDAM to offer filtration materials because most of the materials are imported from Java and Sumatra Islands. However, it is time consuming and expensive to satisfy the requirement of continuous availability of drinking water.

Materials and methods

Materials

The physical requirements of filtration materials in water treatment plants are diameter, specific gravity, and silica (SiO_2) content. Aggregate sieve analysis is the determination of the percentage of aggregate grain weight after passing through a set of sieves. Subsequently, the percentage figures are depicted on a grain division graph, indicating a distribution accumulation curve to determine the effective size (ES) and desired media uniformity, which is expressed as the uniformity coefficient (UC). ES is the size of upper filtration materials that are most effective in separating impurities that constitute 10% of the total depth of the filter media layer or weight fraction. This is often expressed as P10 (diameter at the 10th percentile).

$$\mathrm{ES} = P10 \tag{1}$$

UC is expressed as the ratio between the diameter size of 60% (P60) of the weight fraction to the effective size at the 10th percentile (P10). This can be expressed as:

$$\mathrm{ES} = \frac{P10}{P60}. \tag{2}$$

Based on Indonesia National Standard (SNI) 3981:2008, the ideal value of ES is 0.2–0.4 mm and that of UC is 2–3. The specific gravity of water-saturated surface dry sand is the ratio between the weight of saturated surface dry aggregate and that of distilled water whose contents are the same as saturated aggregate at a certain temperature. According to SNI 3981:2008, the specific gravity of sand as filtration media is 2.55–2.65 g/cm^3. The chemical content of SiO_2 in the sand is tested in the laboratory using an energy-dispersive X-ray fluorescence analyzer. The high content of SiO_2 indicates that the sand is suitable for use as filtration material. This is because, it has a significantly high hardness level and is suitable for use as a filtration material based on SNI 3981:2008, which requires the standard content to exceed 90%.

Methods

Filtration is a process of separating solids from fluids using a porous medium or material to remove sufficient suspended and fine colloidal solids. Based on the direction of flow, filtration is divided into downflow, up-flow, up-flow-downflow, and horizontal flow. Till date, the conventional filtration method with flow direction from top to bottom (downflow) and bottom to top (up-flow) was widely applied in Indonesia. In this study, we have applied the rapid sand filter with an up-flow system for four types of local sand in South Sulawesi, namely Malimpung, Bira, Jeneberang, and Tanralili in Pinrang, Bulukumba, Gowa, and Maros Regencies, respectively. The variations in initial turbidity and filter thickness highlighted the effectiveness of each filtration material with an observation time of 0–600 s. Therefore, three initial values of raw water turbidity, namely 25, 50, and 109 NTU, representing low, medium, and high turbidity levels, respectively, were considered. As a result of total suspended solids added to obtain the three initial turbidity variations, the initial concentrations for TSS of each initial turbidity variation were obtained as 19, 51, and 99 mg/l, respectively. In addition, three values of filter thickness of 10, 20, and 30 cm were formulated to clarify each sand source's effectiveness. Finally, TSS and NTU values of the treatment model are measured and compared for each material. The variations of parameters applied to obtain the most effective sand source are listed as follows:

a. Variation of four sand sources.
b. Variations in filter thickness of 10, 20, and 30 cm for each source.
c. Initial raw water turbidity for each sand source and filter thickness of 25, 50, and 109 NTU.
d. Initial TSS for each initial turbidity variation are 19, 51, and 99 mg/l.
e. The tested water quality from each sand source, thickness, initial turbidity, and TSS of raw water after the filtration process is the final turbidity and TSS.
f. Turbidity standard is based on the Indonesian Minister of Health's Decree No. 32 of 2017 where the maximum turbidity is 25 NTU, while TSS is Indonesian Minister of Environments's Decree No. 68 of 2016, which is a maximum of 30 mg/l.
g. Observation and measurement times are from 0 to 600 s.

Figures 1 and 2 indicate the equipments and methods used in this research.

Results and discussion

Sieve analysis

Sieve analysis is conducted for the four sand sources, and the results are shown in Fig. 3. It was discovered that the ES and P60 values for Malimpung-Pinrang sand are 0.23 and 0.52, respectively, and the value of UC is 2.19. Based on the SNI standard, ES and UC values of 0.2–0.4 and 2–3,

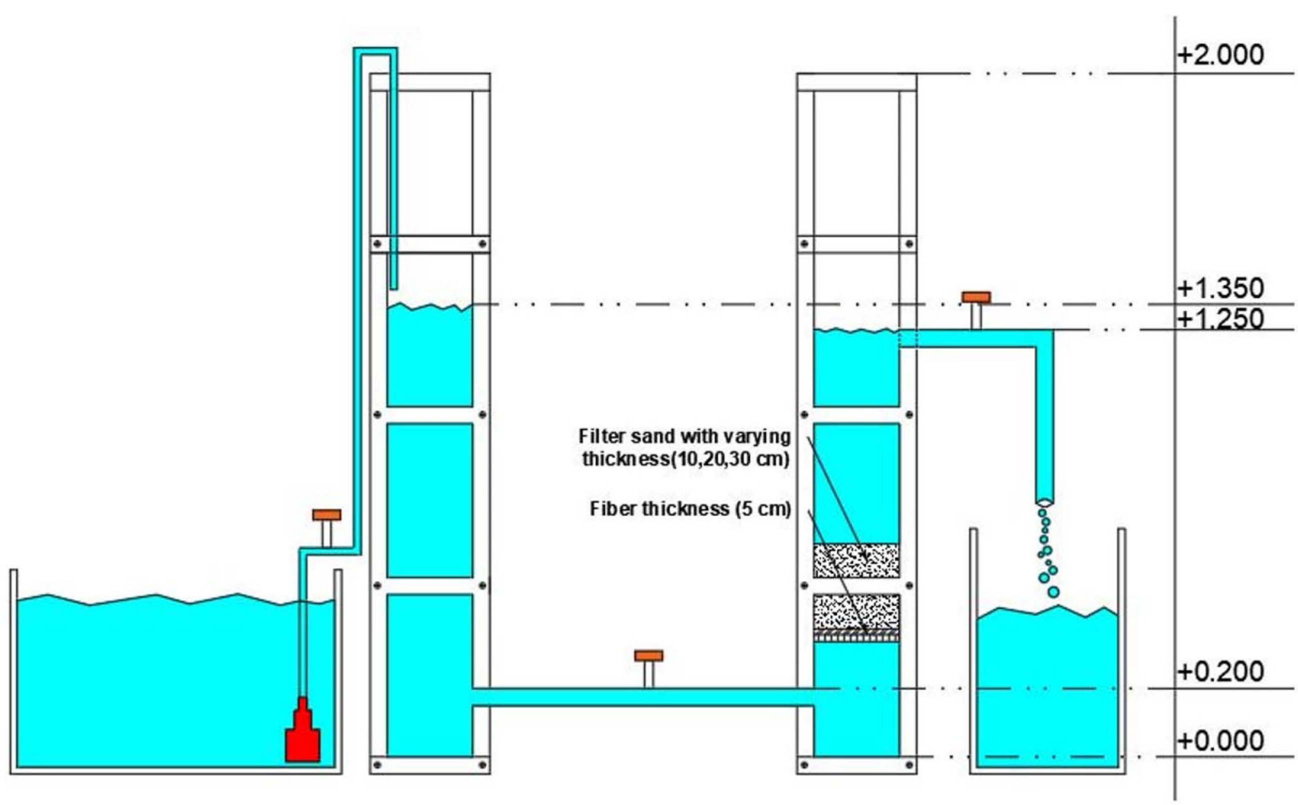

Fig. 1 The simulation equipment of the filtration process

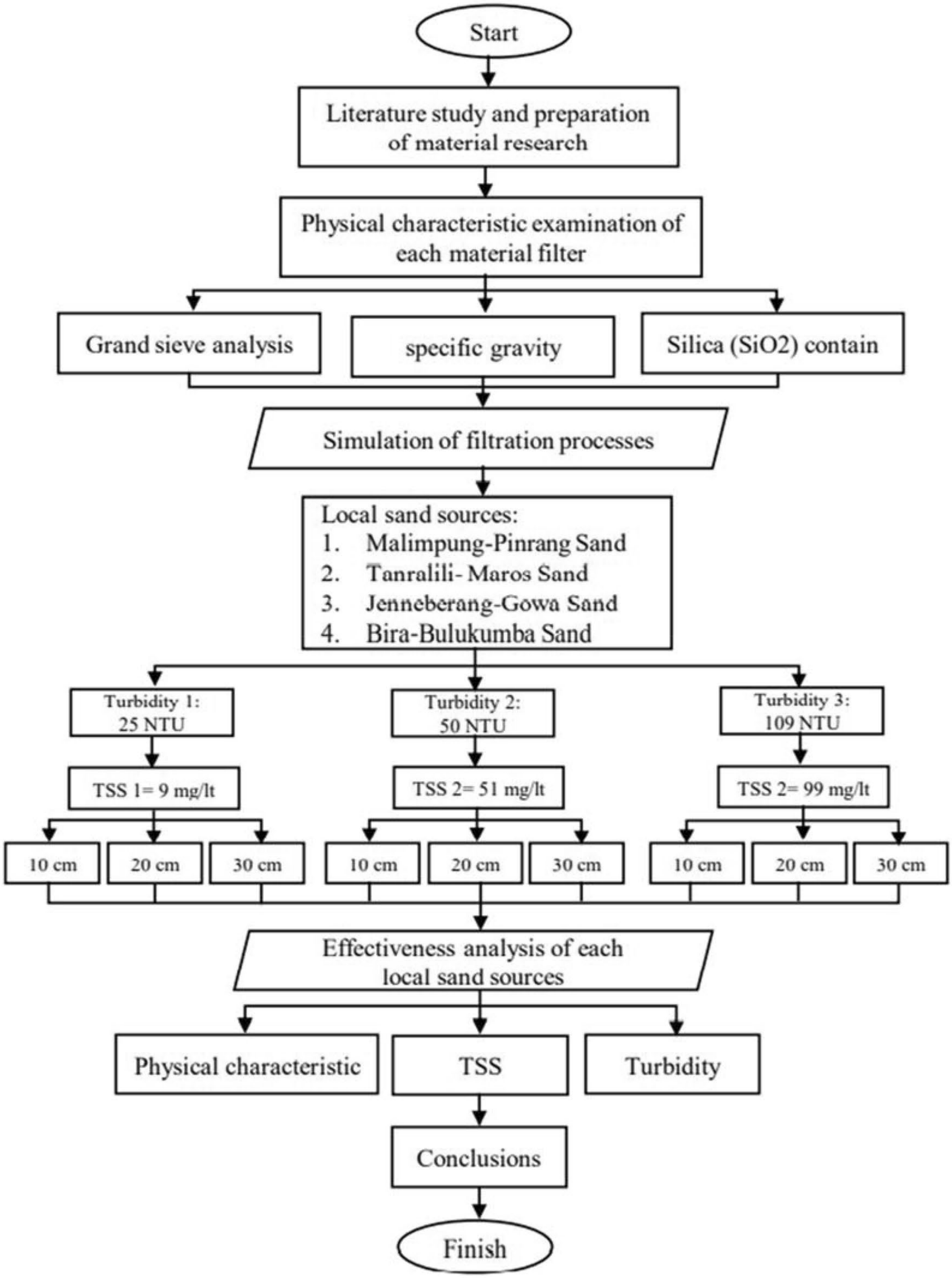

Fig. 2 Research methods

respectively, for Malimpung-Pinrang sand satisfy the criteria for use as filteration material. Similarly, for Bira-Bulukumba sand, the ES and P60 values are 0.25 and 0.57, respectively, with a UC value of 2.25, which satisfies the criteria for use as filtration material. However, the ES, P60, and UC values for Jenneberang-Gowa sand did not satisfy the criteria for use as filtration material because the ES and P60 values are 0.16 and 0.66, respectively, with a UC value of 4.17.

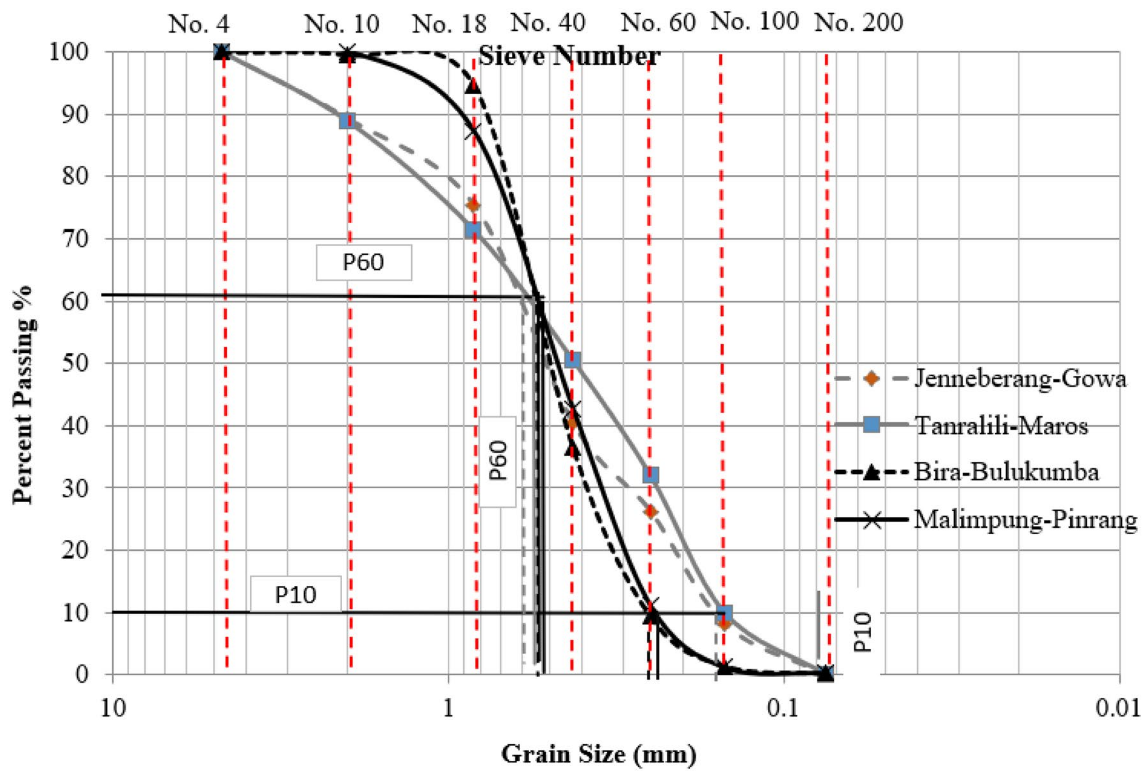

Fig. 3 Sieve analysis results

Similarly, the values of ES and P60 for Tanralili-Maros sand are 0.15 and 0.51, respectively, with a UC value of 3.43, thus indicating that the sand did not satisfy the criteria for use as filteration material.

Specific gravity results

The specific gravity of Malimpung-Pinrang and Bira-Bulukumba sands were 2.69 and 2.5 g/cm^3, respectively; therefore, both types of sand satisfy the criteria for use as filtration material. The specific gravity of Jenneberang-Gowa and Maros sands are 2.43 and 2.53 g/cm^3, respectively. This indicated that the two types of sand do not satisfy the criteria for use as filtration material.

Results of SiO_2 content

The chemical content of sand for Malimpung-Pinrang, Bira-Bulukumba, Jenneberang-Gowa, and Tanralili-Maros sands was 97.07, 58.10, 57.53, and 10.02%, respectively. This clarified that only Malimpung-Pinrang sand meets the criteria for use as filtration material. A complete analysis of the results obtained by testing the physical parameters of each type of sand is shown in Table 1.

Effectiveness of the effect of filter thickness on decrease in turbidity

The results of the analysis of the effect of filter thickness on the decrease in turbidity of each type of sand source are

Table 1 The results of testing the physical parameters of each sand

Reference value		Sand sources	Result of measurement			
Parameters	Value		ES (mm)	UC	Specific gravity (g/cm^3)	SiO_2 (%)
ES (mm)	0.2–0.4	Malimpung-Pinrang	0.23	2.19	2.59	97.07
UC	2–3	Bira-Bulukumba	0.25	2.25	2.55	58.1
Specific gravity (g/cm^3)	2.55–2.65	Tanralili-Maros	0.15	3.43	2.53	57.53
SiO_2 (%)	> 90	Jenneberang-Gowa	0.16	4.17	2.43	10.02

shown in Fig. 4. The figure highlights that the thickness of the filter affects the decrease in turbidity, thus indicating that thicker the filter, more significant is the reduction in turbidity. Meanwhile, it was also indicated that Malimpung-Pinrang sand is the most effective in reducing turbidity for each value of initial turbidity and filter thickness. For example, Malimpung-Pinrang sand reduced the initial turbidity from 25 to 9 NTU or with an efficiency of 64% for a filter thickness of 10 cm. Similarly, Bira-Bulukumba and Tanralili-Maros sands reduced from 25 to 20 NTU or with an efficiency of 20%, while Jenneberang-Gowa sands were reduced to 21 NTU or with an efficiency of 16%. When the initial turbidity was 25 NTU with a filter thickness of 20 cm, Malimpung-Pinrang sand reduced turbidity from 25 to 8 NTU or with an efficiency of 68%. Bira-Bulukumba, Tanralili-Maros, and Jenneberang-Gowa reduced turbidity from 25 to 17 NTU or with an efficiency of 32%. Furthermore, for a filter thickness of 30 cm, Malimpung-Pinrang sand reduced turbidity from 25 to 7 NTU or with an efficiency of 72%, and Bira-Bulukumba, Tanralili-Maros, and Jenneberang-Gowa reduced turbidity from 25 to 16 NTU or with an efficiency of 36%. At initial turbidity of 55 and 109 NTU for each filter thickness of 10, 20, and 30 cm, it was discovered that the Malimpung-Pinrang sand is the most effective in reducing turbidity levels compared to the other three types.

Effectiveness of the effect of filter thickness on the decrease in total suspended solid (TSS)

As shown in Fig. 5, the thickness of the filter influences the decrease in TSS. Therefore, the thicker the filter, more significant the reduction in TSS. The figure also indicates that the Malimpung-Pinrang sand is the most effective in reducing TSS for each type of initial turbidity and filter thickness. For example, for an initial TSS of 99 mg/l with a filter thickness of 10 cm, Malimpung-Pinrang sand reduced TSS from 99 to 51 mg/l or with an efficiency of 48.5%, Bira-Bulukumba sand reduced from 99 to 55 mg/l or with an efficiency of 44.4%, Jenneberang-Gowa and Tanralili-Maros sands reduced from 99 mg/l to 72 mg/l or with an efficiency of 27.3%. When initial TSS was 99 mg/l with a filter thickness of 20 cm, Malimpung-Pinrang sand reduced TSS from 99 to 50 mg/l or with an efficiency of 49.5%, Bira-Bulukumba sand reduced to 54 mg/l or 45.5% efficiency, Jenneberang-Gowa and Tanralili-Maros sands reduced from 99 to 64 mg/l or with an efficiency of 35.4%. For an initial TSS of 99 mg/l with a filter thickness of 30 cm, Malimpung-Pinrang sand reduced TSS from 99 to 23 mg/l or with an efficiency of 76.8%, Bira-Bulukumba sand reduced from 99 to 40 mg/l or 59.6% efficiency, Jenneberang-Gowa sand reduced from 99 to 50 mg/l or with the efficiency of 49.5% and Bira-Bulukumba sand

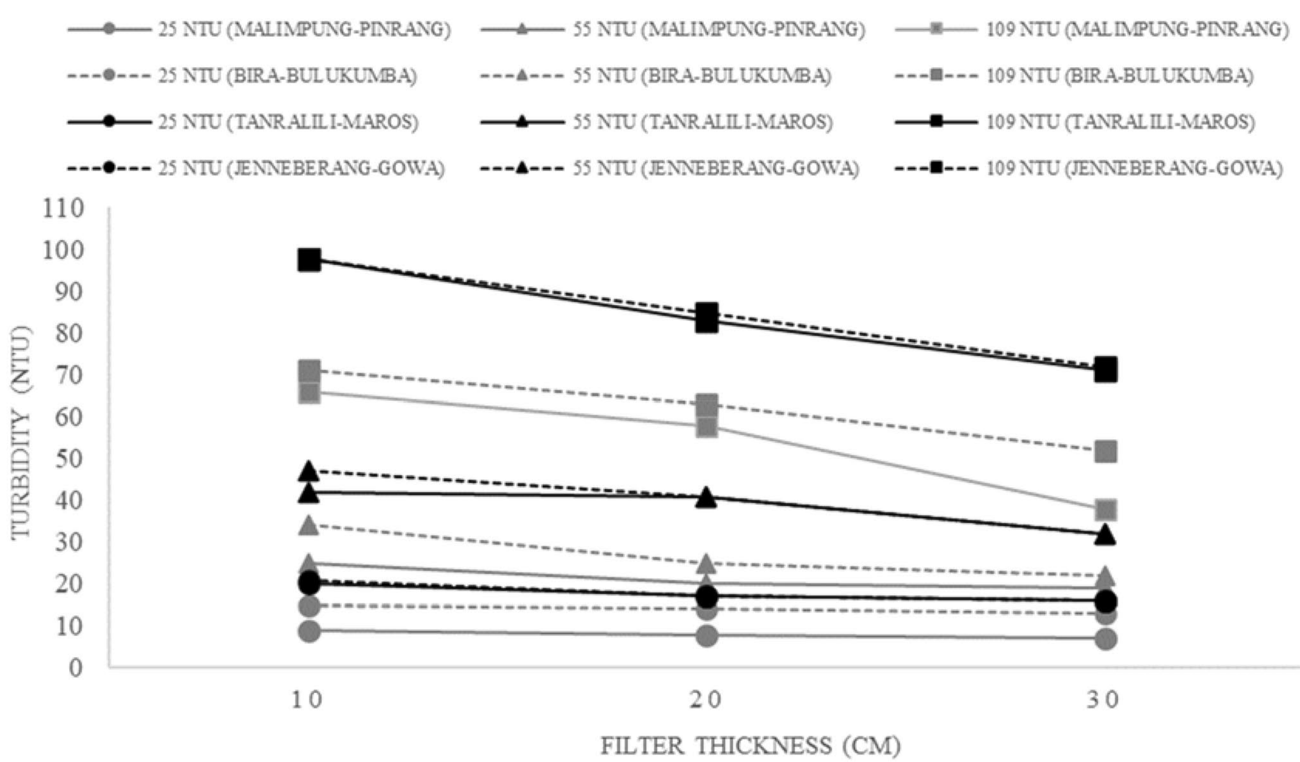

Fig. 4 Effect of filter thickness on the decrease in turbidity of Malimpung-Pinrang Sand, Bira-Bulukmba Sand, Jenneberang-Gowa Sand and Maros Sand

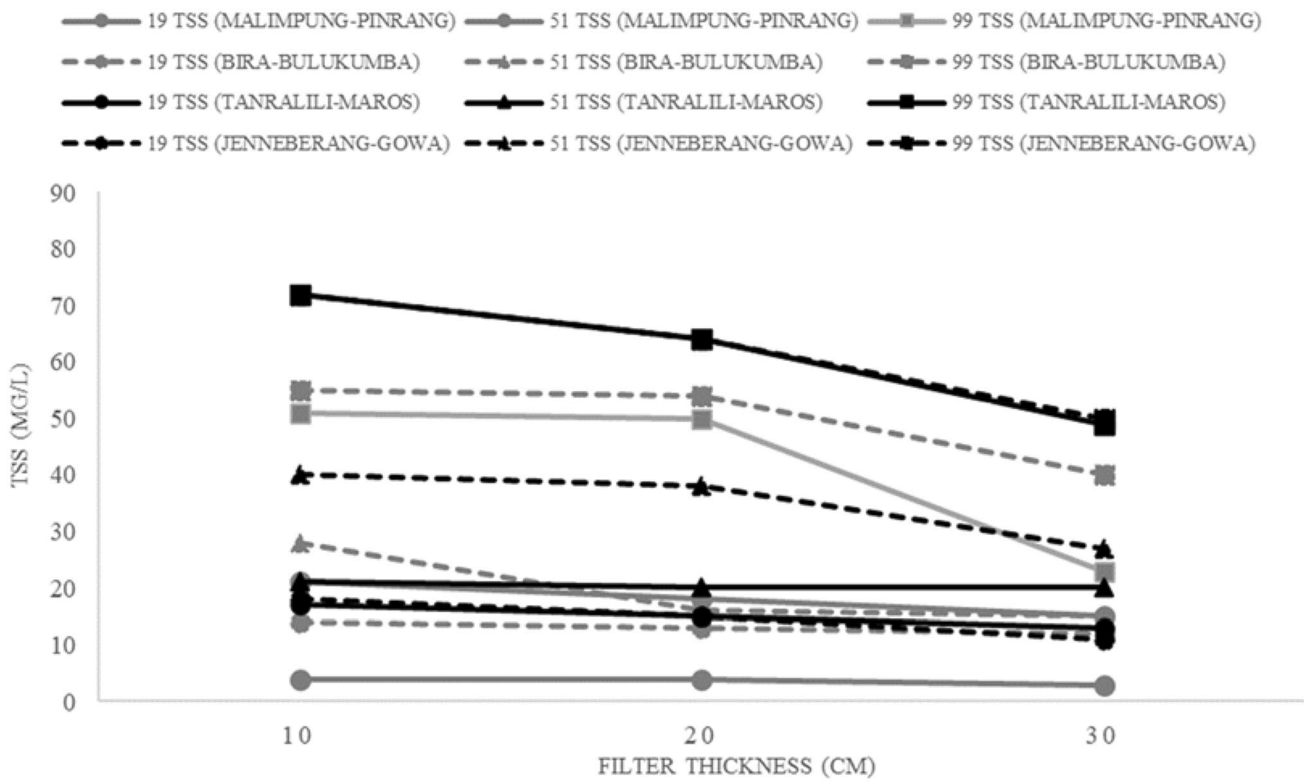

Fig. 5 Effect of filter thickness on TSS reduction

reduced TSS from 99 mg/l to 64 mg/l or with an efficiency of 35.4%. Similarly, initial TSS of 19 and 51 mg/l for each filter thickness of 10, 20, and 30 cm showed that the Malimpung-Pinrang sand was the most effective in reducing the TSS level.

Effect of time on decreasing turbidity and TSS

Based on the physical requirements to determine the efficiency of turbidity and TSS reduction among the four types of local sand, the most effective sand source that meets the criteria for use as filtration material is Malimpung-Pinrang sand. Figure 6 shows the rate of decline of the value of NTU for Malimpung-Pinrang sand with time. The figure also indicates that the thicker the filter, the greater the percentage of turbidity reduction at high, medium, and low turbidity. It was also discovered that the longer the contact time, more significant the decrease in turbidity. The low initial turbidity (25 NTU) indicated no significant change in the reduction in turbidity due to which the contact time for each variation of filter thickness was a concern. On comparing medium and high turbidity, a significant decrease in turbidity with time was observed. Therefore, further study is recommended to obtain the most effective filter thickness based on the initial turbidity variation of raw water.

Effect of time on changes in discharges

Based on the source of sand selected as a filtration material, the water discharge produced by the filter is determined. Figure 7 shows the effect of time on changes in the Malimpung-Pinrang sand discharge based on the variations in filter thickness and initial turbidity. The figure indicates that the thicker the filter, the smaller the water discharge delivered; alternatively, the thinner the filter, greater the resulting discharge. The filter with a thickness of 30 cm shows that the long contact time does not significantly reduce the discharge compared to 10 and 20 cm filters. Moreover, a future investigation is recommended to obtain the filter thickness and adequate contact time to produce the ideal filter discharge according to the requirement.

Previous studies (Yolly et al. 2021; Pramod et al. 2018; Michael et al. 2012; Ekha et al. 2019; Syahrir et al. 2014) have indicated that the efficiency of reducing turbidity was higher compared to the values obtained in this study. This is due to the use of a filter combined with other materials to increase the thickness and a longer observation time. Therefore, when Malimpung-Pinrang sand is combined with other materials and the observation time is longer, the efficiency is also greater.

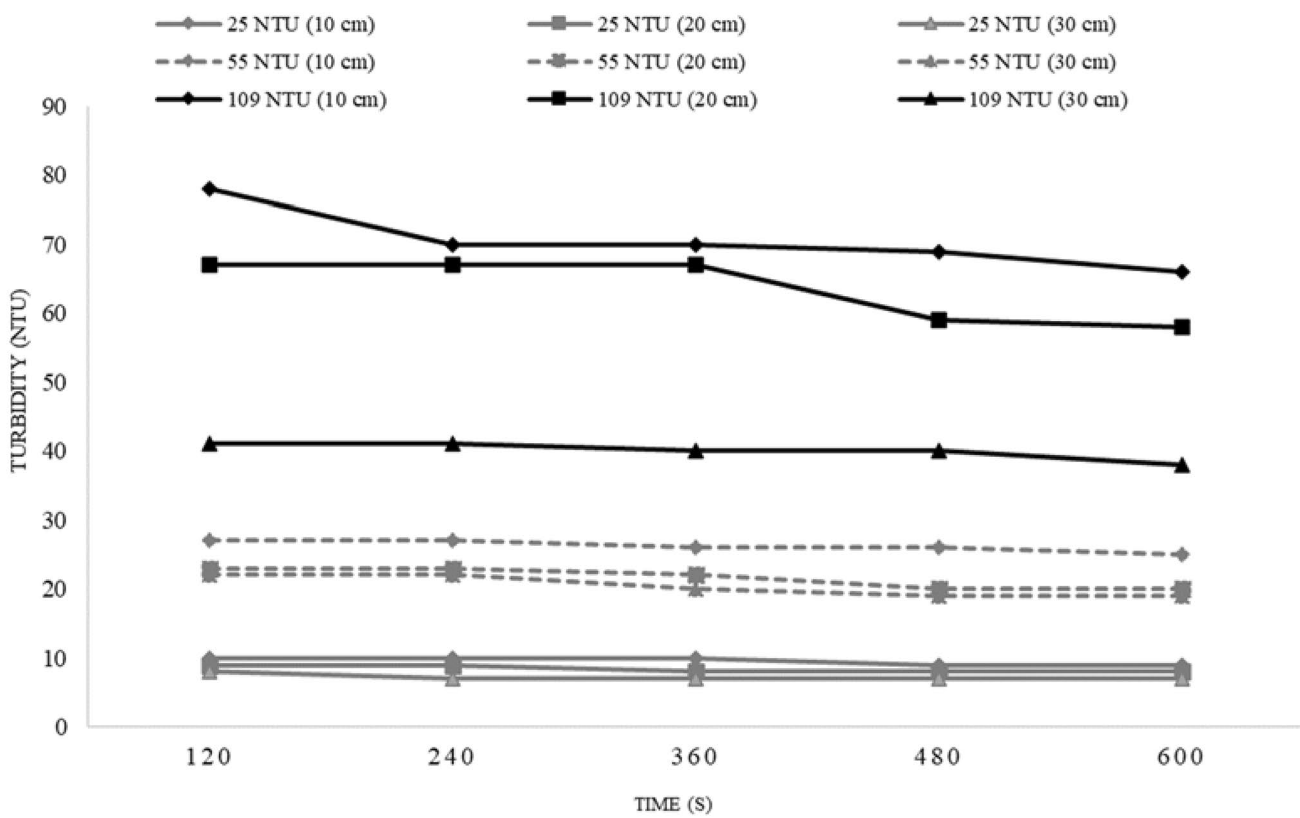

Fig. 6 The effect of time on the decrease in the NTU of Malimpung-Pinrang sand

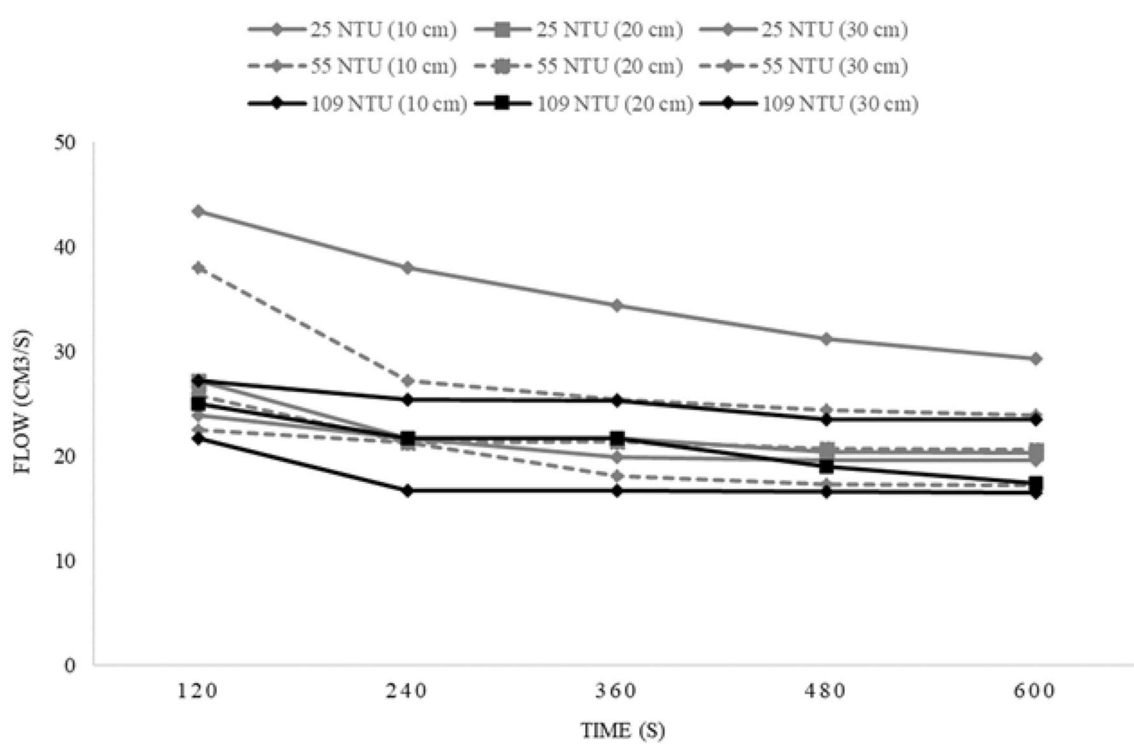

Fig. 7 The effect of time on changes of discharge in the Malimpung-Pinrang sand

Conclusion

In this study, we proposed a novel alternative to the filtration material by considering the local sand sources in South Sulawesi. We considered four sand sources and implemented sieve analysis to determine the most effective sand source for use as filtration material. Results indicated that Malimpung-Pinrang sand was the most effective in removing physical pollutants based on turbidity and TSS among the four local sand sources in South Sulawesi Province. It satisfies the physical requirements, namely ES of 0.23, UC of 2.19, specific gravity of 2.69 g/cm^3, and SiO_2 of 97.07% with the highest percentage of turbidity and TSS reduction. At a contact time of 600 s with initial turbidity of 25 NTU and TSS of 19 mg/l for filter thicknesses of 10, 20, and 30 cm, the percentage decrease in turbidity was 64, 68, and 72%, respectively, while TSS reduced by 79, 79, and 84%, respectively. When the initial turbidity was 55 NTU and TSS value was 51 mg/l with a filter thickness of 10, 20, and 30 cm, the percentage decrease in turbidity was 54.5, 61.8, and 65.4%, while TSS reduced by 58.8, 64.7, and 70.6%, respectively. At initial turbidity of 109 NTU and TSS of 99 mg/l with filter thicknesses of 10, 20, and 30 cm, the percentage decrease in turbidity was 39.4, 46.8, and 65.1%, while TSS reduced by 48.5, 49.5, and 76.8%, respectively.

We identified that the longer the contact time, the greater the decrease in turbidity and TSS for each variation of filter thickness. This is inversely proportional to the discharge; that is, a thicker filter produces a smaller discharge. Additionally, further investigation is recommended to obtain the most effective filter thickness from Malimpung-Pinrang Sand based on variations in initial turbidity, filter thickness, and effectiveness compared to filtration materials that have been used in water treatment. The combination of Malimpung-Pinrang sand with other materials and a longer observation time may increase the effectiveness of reducing physical pollutants based on turbidity and TSS.

Data availability statement The datasets generated during and/or analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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