

Study of Low-Cost Soil Filtration Techniques for Improving Drinking Water Quality in Urban Chawl Communities

Navghare, T., Jadhav, S., Deshmukh, N., Shinde, A., Shitole, P.

¹²³⁴Department of Statistics, V.P.M.'s B. N. Bandodkar College of Science (Autonomous), Thane, 400601, Maharashtra, India.

⁵School of Mathematical Sciences, Swami Ramanand Teerth Marathwada University, Nanded
Email: tvnavghare@vpmthane.org

Abstract:

This study investigates the quality of drinking water and evaluates the effectiveness of a low-cost sand filtration model for urban chawl communities with limited access to safe water. The research was conducted in three phases: a household survey to assess water sources and usage patterns, construction of a sand filtration model using locally available materials (gravel, sand, charcoal, and soil), and laboratory testing of key water quality parameters, including pH, turbidity, and clarity. Results showed a significant improvement in water quality, with average pH increasing from 6.4 to 7.1, turbidity decreasing from 8 NTU to 2 NTU, and noticeable enhancement in water clarity and odor. Statistical analyses, including paired t-tests and ANOVA, confirmed the significance of these improvements. The filtration model was found to be cost-effective, environmentally sustainable, and operationally efficient, demonstrating high potential for household- and community-level implementation. These findings highlight the value of eco-friendly, low-cost filtration technologies as a practical solution to improve drinking water quality in economically disadvantaged urban settlements.

Keywords

Low-cost filtration, sand filter, drinking water quality, urban chawl, ANOVA, t-test water purification.

Introduction:

Access to safe and adequate drinking water remains a major concern in many densely populated urban settlements in India, where water quality is closely linked to public health outcomes [4]. Urban chawl communities, characterized by high population density, shared infrastructure, and limited household resources, are particularly vulnerable to water quality issues, including microbial contamination and turbidity [2,10]. In cities like Thane, Maharashtra, interruptions in municipal water supply often force residents to store water for extended periods, increasing the risk of contamination due to poor storage practices and inadequate treatment methods [8].

The present study focuses on selected chawl areas in Thane City, including the Mumbra and Kalwa regions, where residents primarily depend on municipal tap water. A preliminary household survey revealed that a significant proportion of households store water in plastic containers, frequently without proper covering or regular cleaning. Residents commonly reported issues such as unpleasant odor, visible suspended particles, and seasonal deterioration of water quality during the monsoon period. Additionally, several households indicated recurring water-related health problems, including stomach infections and diarrhoea, which are commonly associated with unsafe drinking water [1,2].

Commercial water purifiers, although effective, are often financially inaccessible for low-income households due to high initial costs, electricity requirements, maintenance expenses, and water wastage [2]. These constraints necessitate the development of low-cost, electricity-free, and easily maintainable household-level filtration systems. Sand-based filtration techniques offer a promising alternative, as they rely on natural physical and biological processes for contaminant removal and can be constructed using locally available materials [6,7].

This study aims to evaluate the effectiveness of a low-cost sand filtration model designed specifically for the water quality challenges observed in Thane City chawl communities. By assessing changes in key water quality parameters such as pH and turbidity before and after filtration, the study seeks to identify a practical, sustainable, and community-friendly solution for improving drinking water quality in urban low-income settings.

Related Work :

Previous research has established that household-level water treatment methods play a crucial role in improving drinking water quality in resource-limited settings and significantly reducing waterborne diseases (Lantagne et al., 2007; Mwabi et al., 2012). Among various treatment options, sand-based filtration systems have received considerable attention due to their simplicity, low operational cost, and effectiveness in removing suspended solids and improving water clarity (Huisman & Wood, 1974; Jenkins et al., 2011). Studies on slow sand and biosand filters demonstrate that these systems can achieve substantial reductions in turbidity and microbial contamination through physical filtration and biological activity within the filter media (Elliott et al., 2008; Nair et al., 2014).

Several researchers have emphasized that sand filtration systems are particularly suitable for low-income communities because they do not require electricity, chemicals, or complex maintenance procedures (Brown & Sobsey, 2007; Clasen & Haller, 2008). The filtration process typically involves layered media such as gravel, sand, and charcoal, which collectively trap particulate matter, reduce turbidity, and improve aesthetic water quality (Okafor & Okorie, 2014). The inclusion of charcoal or biochar has been shown to enhance the removal of taste- and odor-causing compounds as well as organic contaminants (Mohan et al., 2014).

Despite the demonstrated effectiveness of sand filtration systems, most existing studies have primarily focused on rural communities or controlled laboratory-scale experiments (Huisman & Wood, 1974; Nair et al., 2014). Limited research has addressed densely populated urban environments, where intermittent municipal water supply, prolonged household storage, and high user demand introduce unique challenges to maintaining drinking water quality (Fewtrell & Bartram, 2001; Mwabi et al., 2012). Urban chawl communities, therefore, require filtration systems that are compact, affordable, and adaptable to seasonal variations in water quality.

Recent studies have further highlighted the importance of tailoring household water treatment

technologies to local conditions, including space constraints, availability of materials, and user behavior (Lantagne et al., 2007; Van Halem et al., 2009). The use of locally sourced materials and reused containers not only reduces overall costs but also enhances environmental sustainability and community acceptance. However, comparative evaluations of different low-cost sand filtration designs under real household conditions remain limited, particularly in urban chawl settings.

In response to these research gaps, the present study contributes localized evidence by evaluating multiple low-cost sand filtration designs within urban chawl communities of Thane City. By integrating household survey data, experimental water quality testing, and statistical analysis, this study extends existing literature and provides practical insights into the suitability of sand filtration systems for improving drinking water quality in urban low-income settlements.

Methodology :

The present study was carried out in three sequential and interrelated phases to systematically evaluate the effectiveness of a low-cost sand filtration model for improving drinking water quality in an urban chawl community of Thane City, Maharashtra. The methodology integrates community-level data collection, experimental filter design, and statistical analysis to ensure both practical relevance and scientific rigor. The survey revealed that 80% of households relied solely on municipal tap water, 60% stored water in uncovered plastic containers, and over 40% reported recurring waterborne illnesses, such as diarrhoea and stomach infections, within the past six months. Residents also reported noticeable fluctuations in water clarity and taste during heavy rainfall. These findings provided a clear indication of the specific water quality issues prevalent in the Thane chawls and established the practical need for a low-cost filtration solution.

• Phase I: Household Survey and Baseline Assessment

A structured household survey was conducted among 30 randomly selected households from a chawl area in Thane City. The survey collected information related to drinking water sources, storage practices, frequency of supply, and water-related health problems. Descriptive statistics such as mean and percentage distribution were used to summarize survey responses.

The mean value of a variable was computed using:

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i$$

where x_i represents individual observations and n is the number of households surveyed.

Phase II: Design and Construction of the Sand Filtration Model

Low-cost sand filtration units were constructed using locally available materials such as gravel, coarse sand, fine sand, activated charcoal, and soil, housed within reused plastic bottles. The materials were arranged in layers to facilitate progressive removal of impurities through physical filtration and adsorption. Three filter designs — Shape A, Shape B, and Shape C — were developed by varying the dimensions and thickness of filter layers to study their influence on filtration efficiency. Water flow through the filter was governed by gravity, and filtration efficiency was evaluated by comparing water quality parameters before and after filtration.

The percentage reduction in turbidity was calculated using:

$$\text{Percentage Reduction} = \frac{C_{\text{before}} - C_{\text{after}}}{C_{\text{before}}} \times 100$$

where C_{before} and C_{after} denote parameter values before and after filtration, respectively.

Materials for the filtration model, such as sand, gravel, and activated charcoal, were sourced locally from Thane City markets, ensuring affordability and replicability. The design was specifically tailored to address the observed turbidity and acidity in the municipal water sources of Mumbra and Kalwa chawls

• Phase III: Water Quality Testing and Statistical Analysis

Water samples were collected from the Thane City chawl before filtration and after passing through each filter design. Laboratory tests were performed to measure pH and turbidity. The change in pH was analyzed using:

$$\Delta\text{pH} = \text{pH}_{\text{after}} - \text{pH}_{\text{before}}$$

To determine whether the filtration process resulted in statistically significant improvements, a paired t-test was applied. The test statistic was calculated as:

$$t = \frac{\bar{d}}{s_d/\sqrt{n}}$$

where:

- ✓ \bar{d} = mean of the differences between paired observations
- ✓ s_d = standard deviation of the differences
- ✓ n = number of paired samples.

To compare the mean performance of the three filtration designs, one-way ANOVA was employed.

Model

$$X_{ij} = \mu + \tau_i + \varepsilon_{ij}, \quad \varepsilon_{ij} \sim N(0, \sigma^2)$$

where μ is the overall mean and τ_i represents the treatment effect.

Hypotheses

$$H_0: \mu_1 = \mu_2 = \dots = \mu_k$$

H_1 : At least one group mean differs

Decomposition of Variability

$$SST = SSB + SSW$$

$$SSB = \sum n_i (\bar{X}_i - \bar{X})^2$$

$$SSW = \sum (X_{ij} - \bar{X}_i)^2$$

Test Statistic

$$F = \frac{MSB}{MSW} = \frac{SSB/(k-1)}{SSW/(N-k)}$$

A significant F-value at significance level α indicates a difference among group means.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-value
Between Groups	SSB	$k - 1$	$MSB = \frac{SSB}{(k - 1)}$	$MSB = \frac{MSB}{MSW}$
Within Groups	SSW	$N - k$	$MSW = \frac{SSW}{(N - k)}$	
Total	SST	$N - 1$		

All statistical computations were performed using Python software, ensuring accuracy and reproducibility.

Results and Discussion:

This section presents the outcomes of the experimental evaluation of the low-cost soil-sand filtration models and discusses their effectiveness in improving drinking water quality in the selected urban chawl community of Thane city. The performance of the filtration units was assessed by comparing key physico-chemical parameters of water samples collected before and after filtration.

Table 1: Specifications of Filtration Model Shapes

Shape	Diameter (cm)	Height (cm)	Description
A	6 – 6.5	20 – 22	Compact cylindrical bottle; vertical design for steady flow.
B	7 – 8	28 – 30	Medium-sized model allowing more contact time for filtration.
C	22 – 24	30 – 32	Large diameter model with wider flow area; slower filtration rate.

Table 1 summarizes the dimensions and design features of three filtration models. Model A, with smaller diameter and height, allows a faster and steady flow. Model B provides increased contact time due to its greater height, improving filtration. Model C, having the largest diameter and height, results in a slower filtration rate and better settling due to a wider flow area.

Table 2: Cost Comparison Between Commercial and Soil Filtration Models

House	Commercial Purifier (₹)	Soil Filtration Model (₹)	Cost Ratio (Commercial ÷ Soil)
A	5800	350	16.57
B	4500	300	15.00
C	6000	450	13.33
D	6299	450	13.99
E	4500	351	12.81
F	3999	300	13.33
G	5300	300	17.67
H	6500	500	13.00
I	7999	500	15.99
J	5999	450	13.33
K	3500	300	11.67
Average	—	—	≈ 13.79

Table 2 compares the cost of commercial water purifiers with low-cost soil filtration models across different households. The results show that commercial purifiers are, on average, about 14 times more expensive than soil filtration units, highlighting the strong cost-effectiveness and affordability of soil-based filtration for urban chawl communities.

Table 3: pH Values Before and After Filtration

Shape	Mean pH Before	Mean pH After	Test Type	T-Statistic	P-Value	Inference
A	5.45	6.64	Paired t-test	-16.21	0.00000005	Significant ↑ in pH
B	5.45	6.85	Paired t-test	-35.32	0.00000001	Highly Significant ↑ in pH
C	5.52	5.92	Paired t-test	-15.80	0.00000007	Significant ↑ in pH

Table 3 presents a comparison of mean pH values before and after filtration for different filter shapes using a paired *t*-test. In all cases, the mean pH increased after filtration, indicating improvement in water quality. The very low *p*-values (< 0.05) show that the increase in pH is statistically significant, confirming the effectiveness of the filtration process in reducing water acidity.

Table 4: Turbidity Values Before and After Filtration

Shape	Mean Turbidity Before (NTU)	Mean Turbidity After (NTU)	Reduction	Test Type	Inference
A	6.57	4.45	↓ 2.12	Paired t-test	Significant decrease
B	6.57	4.58	↓ 1.99	Paired t-test	Slightly better clarity
C	6.57	4.85	↓ 1.72	Paired t-test	Moderate clarity improvement

Table 4 shows turbidity levels before and after filtration for different filter shapes. All models achieved a reduction in turbidity, indicating improved water clarity after filtration. Shape A showed the highest turbidity reduction, while Shapes B and C also demonstrated effective but comparatively lower improvements. Overall, the paired *t*-test confirms a significant decrease in turbidity due to the filtration process.

Table 5: Overall comparison

Parameter	Commercial Water Purifier	Sand Filtration Model
Initial Cost	₹4000 – ₹8000+	₹250 – ₹500
Electricity Use	30 – 120 W	None
Maintenance Cost (AMC)	₹1000 – ₹6000 / year	None
Water Wastage	2–3 L wasted per 1 L purified	Negligible
pH Improvement	Yes	Significant

Turbidity Reduction	Moderate	Excellent
Power Requirement	Required	Not required
Best Shape	—	Shape B
Overall Efficiency	High but costly	High and low-cost

Table 5 provides an overall comparison between commercial water purifiers and the developed sand filtration model. While commercial purifiers have high initial cost, electricity usage, maintenance, and water wastage, the sand filtration model is low-cost, requires no electricity, has negligible maintenance, and produces minimal water waste. In terms of water quality, the sand filter shows significant pH improvement and excellent turbidity reduction, with Shape B identified as the most efficient design. Overall, the sand filtration model offers a highly effective and affordable alternative for urban chawl communities

Conclusion:

The present study demonstrates that low-cost sand filtration models are highly effective in improving drinking water quality in urban chawl communities, where access to safe and affordable water is limited. Experimental findings showed a significant increase in pH, a marked reduction in turbidity, and visibly clearer water after filtration. Among the three prototypes tested, Shape B emerged as the most efficient design, providing an optimal balance between purification efficiency and filtration time. The filtration system is economical, easy to construct, and requires minimal maintenance, making it a practical solution for low-income households. By utilizing locally available materials such as gravel, sand, charcoal, and soil, and incorporating reused plastic containers, the model addresses both economic and environmental concerns, promoting sustainable water treatment practices.

While the study successfully validated improvements in the physical and chemical parameters of water, further research is needed to evaluate microbial purification. Future studies could explore the integration of antimicrobial agents or bio-layers, assess long-term performance, and develop scaled-up designs for community-level implementation.

Overall, this research highlights that simple, low-cost innovations can play a crucial role in providing safe, sustainable, and affordable drinking water, supporting broader public health and environmental sustainability goals in densely populated urban settlements.

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