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Identification of Contaminants Present in Rainwater Collected from Ground Pit and its Removal

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Abstract:

The need to use rainwater has become increasingly significant due to water scarcity, urbanization and rapid population growth, climate change, environmental sustainability, improved water quality, resilience and independence. Generally, rainwater is collected from rooftop which is not sufficient to meet the demand in water scarcity areas. In this research, the rainwater was collected from the pit dug on the open ground from two different locations. Odor, color, conductivity, total dissolved solids (TDS), turbidity, hardness, pH value and dissolved oxygen tests were conducted on the collected rainwater samples to identify the contaminants after settlement of suspended particles using plain sedimentation technique. Coagulation-flocculation, Mechanical filtration, Granular activated carbon and Powdered activated carbon filtration, Reverse Osmosis and jute rope method was used to treat the rainwater. Two methods i.e., chlorination and UV Irradiation were used to disinfect the treated rainwater. It was found that rainwater collected from two different locations have very low TDS at the time of collection and it goes on increasing with time when left undisturbed. In this research, comparison of different methods of treatment of rainwater was conducted considering quality, feasibility and cost effectiveness of the tests. Pros and cons of each method were analysed to determine the most suitable approach for treating rainwater in water-scarce areas. The study revealed that while reverse osmosis and activated carbon filtration achieved superior water quality, they were less cost-effective compared to simpler methods like the jute rope technique, which showed promise for rural and low-income settings. Chlorination proved highly effective in maintaining microbial safety, while UV irradiation offered a chemical-free alternative with minimal operational complexity. This comprehensive evaluation provides a roadmap for selecting appropriate rainwater treatment methods tailored to specific regional needs, balancing quality, cost, and feasibility to support sustainable water management practices.

Keywords: urbanization, feasibility, comprehensive, Coagulation, flocculation.

1. Introduction:

Water scarcity is a pressing global issue, intensified by rapid urbanization, population growth, climate change, and unsustainable water management practices. Over-extraction of groundwater, declining water tables, and uneven rainfall patterns have further compounded the problem, making it imperative to adopt sustainable water management solutions. Rainwater harvesting (RWH) has emerged as a promising alternative, offering an eco-friendly water source to address growing water demand. While rooftop rainwater collection is widely practiced, alternative methods such as ground pit collection offer significant potential for harvesting large quantities of water. However, the presence of contaminants in rainwater necessitates effective treatment strategies to ensure its safety and usability.

A growing body of research underscores the potential of RWH in mitigating water scarcity and promoting sustainable urban water management. For example, studies have evaluated the environmental trade-offs of city-wide RWH systems (Bagheri & Davani, 2024) and highlighted the integration of smart RWH approaches to alleviate hydric stress in megacities (Alvarez et al., 2024). Other studies have focused on the technical, environmental, and economic feasibility of RWH systems, including their impact on aquifer recharge (Jebamalar et al., 2023) and sustainable water management in semi-arid regions (Márquez et al., 2021). The use of advanced technologies such as GIS modeling (Abdullah et al., 2024) and machine learning techniques (Halder & Bose, 2024) has further refined the identification of suitable RWH zones and strategies.

Despite the potential of RWH, challenges related to water quality remain a critical concern. Contaminants such as heavy metals, bacteria, and organic pollutants have been identified in harvested rainwater from urban areas and highways (Marszałek et al., 2023), (Bouchali et al., 2024). Additionally, studies have demonstrated the effectiveness of advanced treatment methods, such as nanofiltration, in removing pollutants and meeting drinking water standards (Xiao et al., 2020). Furthermore, the application of innovative technologies like biofilm reactors for nutrient recycling (Böpple et al., 2024) and bioretention systems for urban runoff management (Zhang et al., 2019) shows promise for improving water quality. Research has also highlighted the need for microbiological surveillance and regulatory frameworks to ensure the safe use of harvested rainwater (Bouchali et al., 2024), (Carpio-Vallejo et al., 2024).

RWH systems also play a vital role in addressing region-specific challenges. For instance, studies have explored the use of RWH in arsenic-contaminated areas in Bangladesh (Abdullah et al., 2024) and fluoride-affected regions in Tanzania (Torello et al., 2024). Research in India has shown the potential of rooftop RWH systems in industrial complexes (Naik et al., 2024) and the feasibility of integrating wastewater reuse with RWH in urban areas (Huq et al., 2024). Studies have also addressed the optimization of RWH systems for stormwater control and economic performance (Ali et al., 2024) and the impacts of land use changes on RWH effectiveness (Salem et al., 2024).

This study builds on these insights by focusing on the rainwater collected from ground pits in Ludhiana and Sidhwa Bet, evaluating its quality, and identifying optimal treatment methods to improve its usability for human consumption. The findings aim to balance water quality, treatment cost, and feasibility to support sustainable water management practices, especially in water-scarce regions. By addressing the critical challenge of water quality in ground-pit-collected rainwater, this research contributes to the growing efforts to enhance the resilience and sustainability of urban and rural water systems worldwide.

2. Materials and Methods:

2.1 Rainwater Collection:

Rainwater samples were collected from ground pits in Ludhiana and Sidhwa Bet. The pits were located in open areas with minimal vegetation or industrial contamination as shown in figure-1.

Figure-1: Collection of rainwater from Ground surface free from vegetation or industrial contamination

Samples were tested immediately after six hours of sedimentation and after six months of undisturbed storage. Parameters tested included odor, true color, electrical conductivity, TDS, turbidity, hardness, pH, biological oxygen demand (BOD), and chemical oxygen demand (COD). Treatment methods included coagulation-flocculation, mechanical filtration, granular and powdered activated carbon filtration, reverse osmosis, and the jute rope technique. Chlorination and UV irradiation were employed for disinfection. The efficiency of each method was evaluated in terms of water quality improvement.

2.2 Testing Parameters:

The following parameters were tested to evaluate water quality:

- Odor: Assessed through sensory evaluation.
- True Color (HU): Measured using a CR10 colorimeter.
- Electrical Conductivity (µS/cm): Determined using a conductivity meter.
- TDS (ppm): Measured using a TDS meter.
- Turbidity (NTU): Assessed with a turbidity meter.
- Hardness (ppm): Evaluated using test strips and titration methods.
- pH: Measured using a pH meter.
- BOD (mg/L) and COD (mg/L): Determined through standard laboratory methods.

2.3 Treatment Methods

1. **Coagulation-Flocculation**: Aluminum sulfate was used as a coagulant, followed by lime addition to enhance floc formation.

2. **Mechanical Filtration**: Rainwater was passed through filter paper with a pore size of 11 μm.

3. **Granular and Powdered Activated Carbon Filtration**: Used to remove organic contaminants and improve color.

4. **Reverse Osmosis (RO)**: Applied for comprehensive removal of dissolved solids, pathogens, and other contaminants.

5. **Jute Rope Technique**: A low-cost method utilizing jute ropes as a filtration medium to reduce turbidity and suspended solids.

2.4 Disinfection Methods:

1. Chlorination: Sodium hypochlorite was used to neutralize microbial contamination.
2. UV Irradiation: Applied for chemical-free disinfection using a UV lamp.

3. Results and Discussion

3.1 Initial Testing of Rainwater Samples

Testing results for collected rainwater samples are summarized in Table 1 below:

Table 1. Initial Rainwater Testing Results

Parameter	Tested for Ludhiana after 6 hours undisturbed	Tested for Ludhiana after 6 months undisturbed	Percentage Change (in %)	Tested for Sidhwa bet after 6 hours undisturbed	Tested for Sidhwa bet after 6 months undisturbed	Percentage Change (in %)
Odor	NIL	NIL	-	NIL	NIL	-
True Color (HU)	3.122	14.831	375.05	3.79	15.211	301.34
Electrical Conductivity (μs/cm)	33	101	206.06	29	106	265.52
TDS (ppm)	4	49	1125	3	61	1933.33
Turbidity (NTU)	58	5	-91.38	65	4	-93.85
Hardness (ppm)	0	0	0	0	0	0
pH (ppm)	5.5	6.5	18.18	6.0	6.5	8.33
BOD (mg/L)	0.6	1.0	66.67	0.0	0.0	0
COD (mg/L)	3.0	4.0	33.33	0.0	0.0	0

Results indicated that the true color and turbidity reduced after six months due to sedimentation but were still significant. Electrical conductivity and TDS increased over time, likely due to leaching of dissolved solids. The value of pH improved marginally with age, indicating stabilization. BOD and COD levels were higher in Ludhiana samples, reflecting organic contaminants.

3.2 Treatment Methods applied on Rainwater Samples

3.2.1 Coagulation: This method achieved moderate color improvement but required chemical reagents, increasing operational complexity and cost. The aluminum sulfate was used as coagulant in the coagulation process. About 60% turbidity reduction was noted with use of this method.

3.2.2 Mechanical Filtration: Mechanical filtration effectively reduced turbidity and suspended particles but was less effective in removing dissolved contaminants. The size of filter Paper used was 11 Micron having 125mm diameter.

3.2.3 Granular and Powdered Activated Carbon Filtration: Both granular and powdered activated carbon significantly improved color and reduced organic contaminants. Powdered activated carbon exhibited better performance but at higher operational costs.

3.2.4 Reverse Osmosis: Reverse osmosis delivered the best overall water quality by removing dissolved solids, organic contaminants, and pathogens. However, the method's high-cost limits its feasibility in rural areas. Reverse osmosis makes water acidic.

3.2.5 Jute Rope Technique: This cost-effective and simple method reduced turbidity and color moderately, making it suitable for low-income settings.

3.2.6 Flocculation: Lime is added to optimize flocculation or improve subsequent treatment processes. This can lead to a pH increase. Flocculation treatment can be used to obtain desirable pH value of water.

3.3 Disinfection Methods

Chlorination: Chlorination effectively neutralized microbial contamination and maintained residual disinfection capacity. However, chemical by-products were a concern. There is no use of chlorination as values of BOD and COD for tested rainwater for both locations come out very low.

UV Irradiation: UV irradiation offered a chemical-free disinfection method with minimal operational requirements but required consistent energy supply. There is no need to use this disinfection method for the collected samples as there is no pathogen found in water.

3.4 Testing of Rainwater Samples after treatment:

Rainwater collected from Ludhiana (6 hours) was tested after different treatments. The results shown in Table 2.

Table 2: Testing results of Rainwater collected from Ludhiana (6 hours) after treatment

Treatment Method	Turbidity (NTU)	TDS (ppm)	Color (HU)	BOD (mg/L)	COD (mg/L)	Electric Conductivity (µs/cm)	pH

Coagulation	23.2	3	1.56	0	2.4	14.7	5.15
Mechanical Filtration	29	4	2.18	0.5	2.7	32.3	5.5
Granular Activated Carbon	17.4	34	0.93	0	1.5	23.1	5.85
Powdered Activated Carbon	11.6	39	0.62	0	1.2	19.8	5.90
Reverse Osmosis	2.9	4	0.15	0	0	0.60	4.90
Jute Rope Technique	34.8	32	2.49	0.5	2.85	32.3	6.00

Rainwater collected from Ludhiana (6 months) was tested after different treatments. The results shown in Table 3.

Table 3: Testing results of Rainwater collected from Ludhiana (6 months) after treatment

Treatment Method	Turbidity (NTU)	TDS (ppm)	Color (HU)	BOD (mg/L)	COD (mg/L)	Electric Conductivity (µs/cm)	pH
Coagulation	2	44	7.41	0	2.8	30.9	6.4
Mechanical Filtration	2.5	48	10.38	0.6	3.6	95.9	6.5
Granular Activated Carbon	1.5	60	4.44	0	2	70.7	6.8
Powdered Activated Carbon	1	68	2.96	0	1.4	68.6	6.82
Reverse Osmosis	0.25	15	0.24	0	0	2.02	4.95
Jute Rope Technique	3	62	11.86	0.9	3.8	105.5	6.75

Rainwater collected from Sidhwa bet (6 hours) was tested after different treatments. The results shown in Table 4.

Table 4: Testing results of Rainwater collected from Sidhwa bet (6 hours) after treatment

Treatment Method	Turbidity (NTU)	TDS (ppm)	Color (HU)	BOD (mg/L)	COD (mg/L)	Electric Conductivity (µs/cm)	pH
Coagulation	26	3	1.895	0	0	26.1	5.70
Mechanical Filtration	32.5	3	2.653	0	0	27.5	6.0
Granular Activated Carbon	19.5	34	0.97	0	0	20.3	6.35
Powdered Activated Carbon	13	40	0.75	0	0	17.4	6.40
Reverse Osmosis	3.25	3	0.18	0	0	0.5	4.90
Jute Rope Technique	39	27	3.032	0	0	28.4	6.3

Water collected from Sidhwa bet (6 months) was tested after different treatments. The results shown in Table 5.

Table 5: Testing results of Rainwater collected from Sidhwa bet (6 months) after treatment

Treatment Method	Turbidity (NTU)	TDS (ppm)	Color (HU)	BOD (mg/L)	COD (mg/L)	Electric Conductivity (µs/cm)	pH
Coagulation	1.6	54	7.60	0	0	95.4	6.4
Mechanical Filtration	2	58	10.64	0	0	100.7	6.5
Granular Activated Carbon	1.2	80	4.56	0	0	84.2	6.88
Powdered Activated Carbon	0.8	92	3.04	0	0	93.6	6.9
Reverse Osmosis	0.2	20	0.36	0	0	2.1	4.95
Jute Rope Technique	2.4	75	12.16	0	0	109.8	6.75

Flocculation Process can be used to increase the pH of rainwater after above mentioned treatment as pH of rainwater is lesser even after treatments. Lime is easily available and cost-effective material which can be used as alkaline additives to increase pH of water.

4 Variation of test results with change in location of rainwater sample collection:

4.1 First Location - Ludhiana (30.902816N, 75.817858E)

The line charts shown in figure-2 to figure-6 illustrate the changes in key water quality parameters (Turbidity, TDS, Color, Conductivity, and pH) for Ludhiana after 6 hours and 6 months across different treatment methods.

4.1.1. Turbidity

Figure-2 shows the change in values of turbidity after different treatments applied on rainwater after 6 hours and 6 months of collection from Ludhiana city.

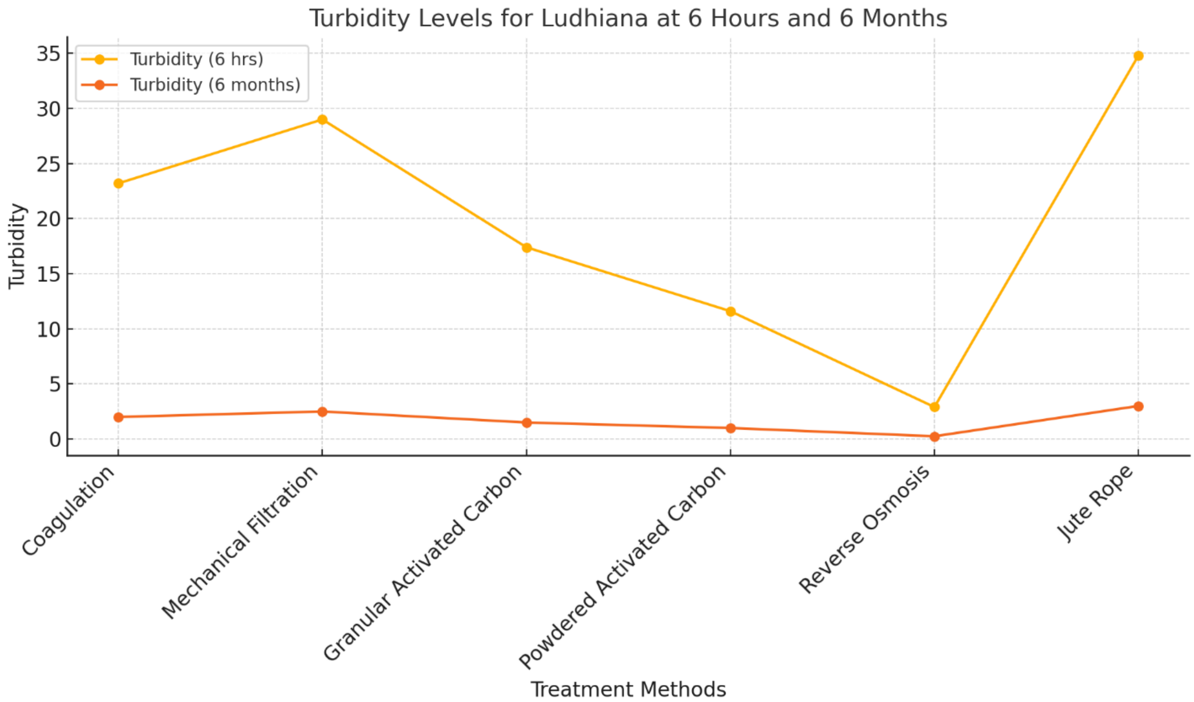

Figure-2 Line Chart showing Turbidity after different treatment

Turbidity significantly decreased after 6 months for all treatments due to natural sedimentation. Reverse osmosis consistently achieved the lowest turbidity levels. Powdered and granular activated carbon also performed well, showing significant reductions. The jute rope technique retained higher turbidity, highlighting its limited effectiveness. Hence, Reverse osmosis is the most effective treatment to reduce turbidity of water, but low-cost methods like coagulation and activated carbon can be viable alternatives.

4.1.2. Total Dissolved Solids (TDS)

Figure-3 shows the change in values of TDS after different treatments applied on rainwater after 6 hours and 6 months of collection from Ludhiana city.

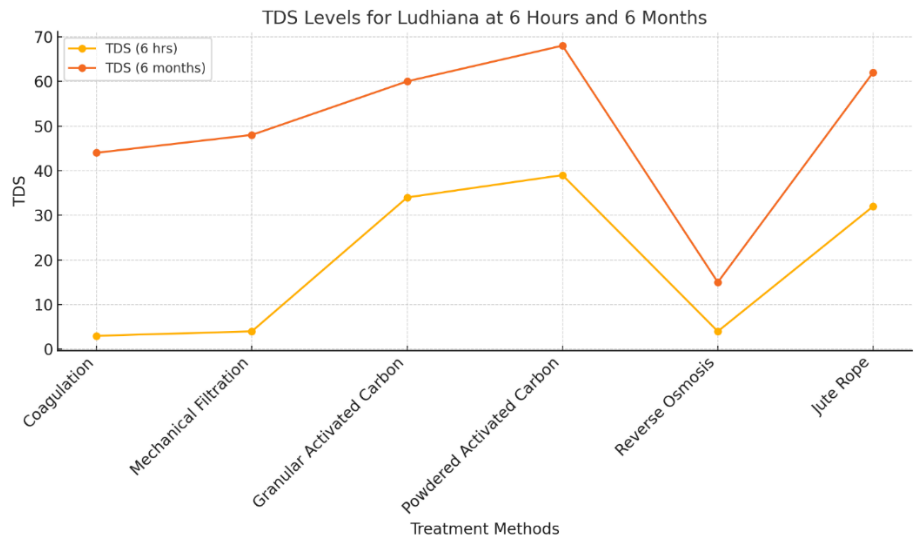

Figure-3 Line Chart showing TDS after different treatment

TDS increased significantly after 6 months for all treatments except reverse osmosis, indicating leaching of dissolved solids during storage. Reverse osmosis effectively reduce TDS levels, maintaining near-initial levels. Very low TDS makes water acidic. Reverse osmosis method is not useful for rainwater treatment as rainwater has very low TDS. Granular and powdered activated carbon slightly increases TDS.

4.1.3. Color

Figure-4 shows the change in color level after different treatments applied on rainwater after 6 hours and 6 months of collection from Ludhiana city.

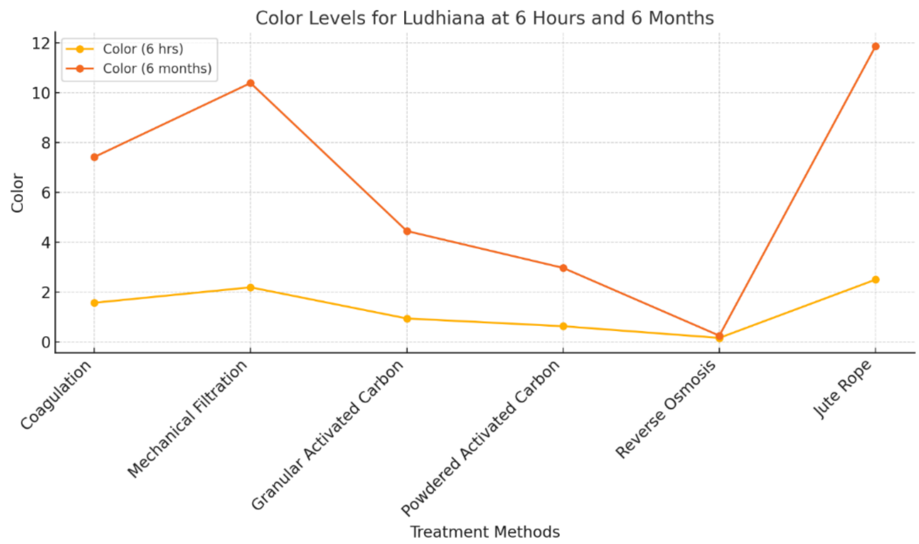

Figure-4 Line Chart showing color level of rainwater after different treatment

Color values were higher after 6 months due to organic decomposition or soil leaching. Powdered activated carbon showed the best performance in color removal, followed by granular activated carbon.

Coagulation and jute rope techniques were less effective, especially after prolonged storage. Activated carbon filtration is the preferred choice for improving color, particularly for long-term storage.

4.1.4. Conductivity

Figure-5 shows the conductivity after different treatments applied on rainwater after 6 hours and 6 months of collection from Ludhiana city.

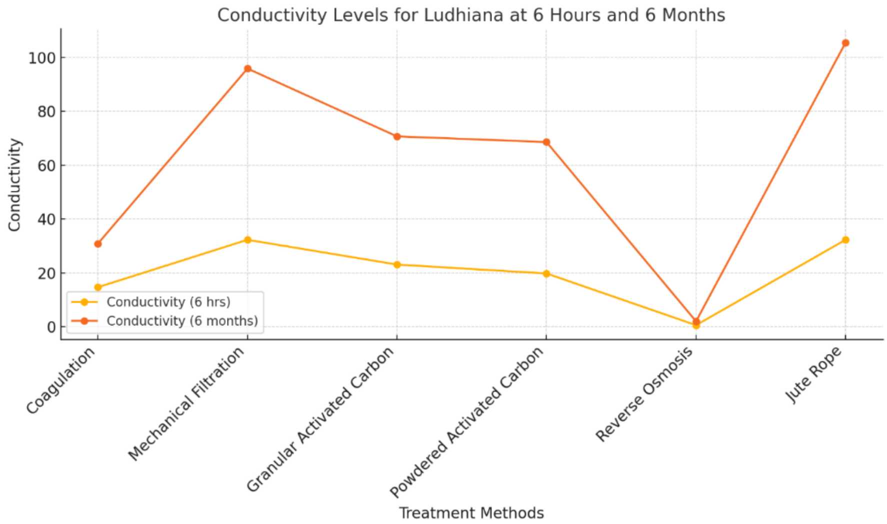

Figure-5 Line Chart showing conductivity of rainwater after different treatment

Conductivity mirrored TDS trends, increasing after 6 months due to dissolved mineral content. Reverse osmosis dramatically reduced conductivity, while other methods had limited impact. Reverse osmosis is indispensable for areas with high conductivity issues, while simpler methods are inadequate.

5. pH

Figure-6 shows the conductivity after different treatments applied on rainwater after 6 hours and 6 months of collection from Ludhiana city.

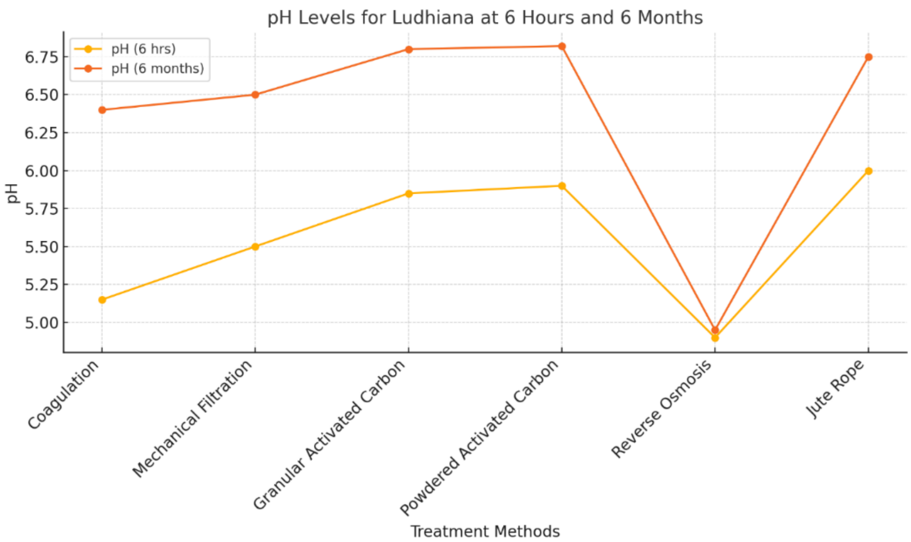

Figure-6 Line Chart showing pH value of rainwater after different treatment

pH values generally improved over 6 months, stabilizing closer to neutral. Coagulation increased pH significantly due to lime addition, making it effective for acidic rainwater. Reverse osmosis slightly reduced pH, requiring post-treatment adjustments in some cases. Coagulation can serve as a low-cost pH stabilizer.

4.2 Second Location - Sidhwa Bet (30.9324069N, 75.4883806E)

The line charts shown in figure-7 to figure-11 compare the performance of various treatment methods for rainwater (Turbidity, TDS, Color, Conductivity, and pH) collected at Sidhwa Bet over two durations i.e. after 6 hours and 6 months of storage. Detailed analysis for each parameter is discussed as:

4.2.1. Turbidity

Figure-7 shows the change in values of turbidity after different treatments applied on rainwater after 6 hours and 6 months of collection from the region Sidhwa Bet.

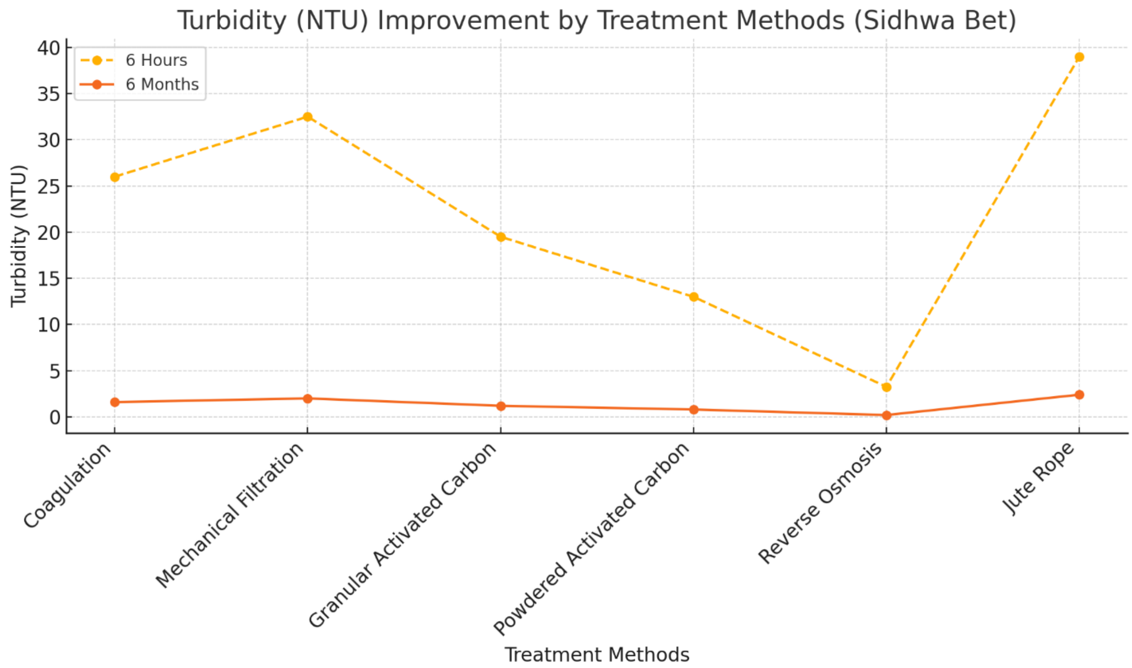

Figure-7 Turbidity of rainwater after different treatments for Sidhwa Bet region

Turbidity levels were highest for the jute rope method and lowest for reverse osmosis for age of 6 hours. Granular and powdered activated carbon also showed significant reductions of turbidity. Turbidity decreased for all methods for age 6 months, with reverse osmosis again being the most effective, achieving almost negligible turbidity. Long storage helps with natural sedimentation, but reverse osmosis or carbon filtration ensures superior results.

4.2.2. TDS (Total Dissolved Solids)

Figure-8 shows the change in TDS after different treatments applied on rainwater after 6 hours and 6 months of collection from the region Sidhwa Bet.

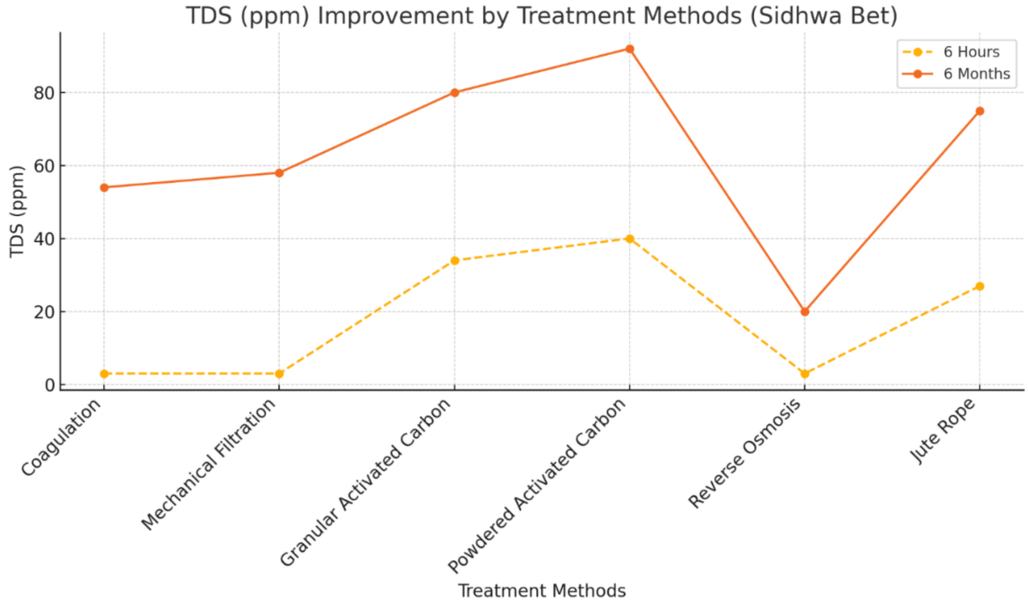

Figure-8 TDS of rainwater after different treatments for Sidhwa Bet region

TDS levels remained low across most methods for age of 6 hours, except for activated carbon, which retained some dissolved solids. TDS increased significantly after storage as we can see it for 6 months age in chart, particularly for granular and powdered activated carbon. Reverse osmosis remained the best performer. Storage of rainwater introduces additional dissolved solids.

4.2.3. Color

Figure-9 shows the change in color level after different treatments applied on rainwater after 6 hours and 6 months of collection from the region Sidhwa Bet.

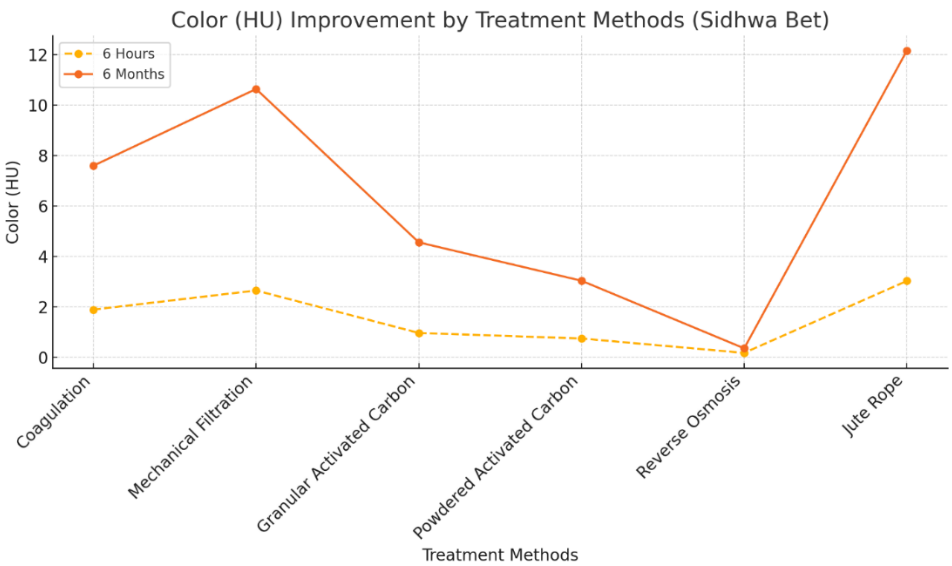

Figure-9 Color Level of rainwater after different treatments for Sidhwa Bet region

Powdered activated carbon and reverse osmosis showed excellent performance for reducing color level. Color levels increased after storage, particularly for untreated methods like jute rope and coagulation.

4.2.4. Conductivity

Figure-10 shows values of Electric Conductivity after different treatments applied on rainwater after 6 hours and 6 months of collection from the region Sidhwa Bet.

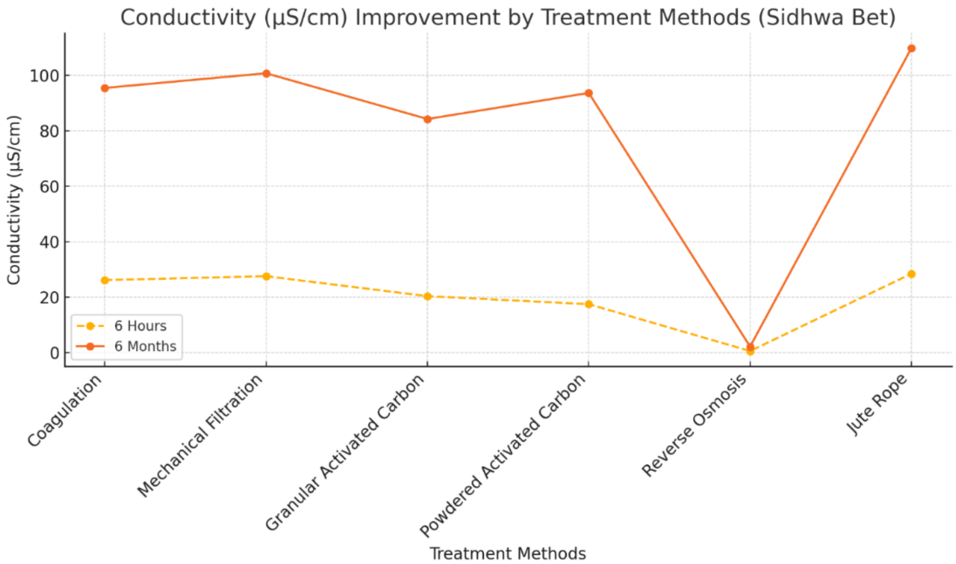

Figure-10 Conductivity of rainwater after different treatments for Sidhwa Bet region

Conductivity values were moderate, with reverse osmosis showing the lowest levels. Conductivity increased significantly with age of water storage indicating leaching of minerals during storage. Reverse osmosis effectively minimizes conductivity, crucial for high-quality water standards.

5. pH

Figure-11 shows values of pH after different treatments applied on rainwater after 6 hours and 6 months of collection from the region Sidhwa Bet.

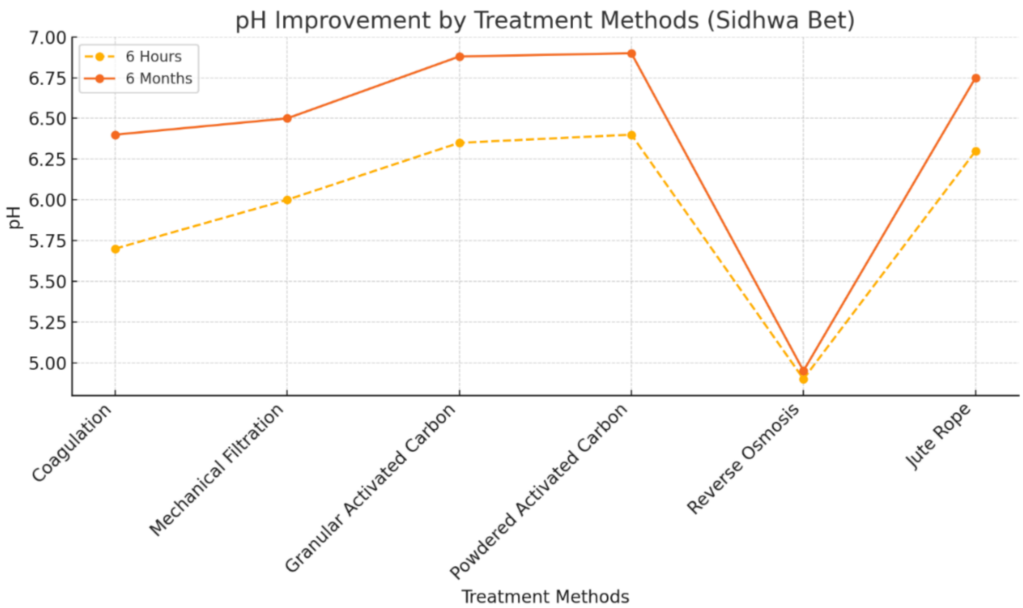

Figure-11 pH of rainwater after different treatments for Sidhwa Bet region

pH levels were slightly acidic with coagulation. Activated carbon methods showing slight improvements. pH value increased over time, approaching neutrality for most methods. Reverse osmosis maintained the lowest pH making water acidic which is not suitable for drinking. For pH-sensitive applications, lime addition post-treatment can help achieve optimal levels.

5. Conclusion

5.1 Turbidity:

Reverse osmosis consistently achieved the lowest turbidity across all locations and durations, indicating superior filtration capability. Turbidity significantly decreased after 6 months for all treatments due to natural sedimentation. Powdered and granular activated carbon also performed well, showing significant reductions. The jute rope technique retained higher turbidity, highlighting its limited effectiveness. The jute rope technique was the least effective but still showed moderate improvement, making it viable for low-cost solutions in rural areas. Reverse osmosis is the most effective, but low-cost methods like coagulation and activated carbon can be viable alternatives. Powdered activated carbon and granular activated carbon also showed significant reductions, with effectiveness varying slightly by initial water quality.

5.2 Total Dissolved Solids:

Reverse osmosis excelled, nearly eliminating TDS, demonstrating its capacity for removing dissolved salts and impurities. But in case of rainwater treatment, TDS required to be increased as rainwater has very low TDS value. Therefore, it is not suitable method for treating rainwater. Mechanical filtration and the jute rope technique had minimal impact on TDS of rainwater. Rainwater from Sidhwa Bet generally had higher turbidity and TDS than Ludhiana, likely due to local environmental factors and soil type. Longer durations (6 months) resulted in increased TDS levels across both locations, possibly due to leaching of minerals from the pit.

5.3 Color

Color values were higher after 6 months due to organic decomposition or soil leaching. Powdered activated carbon showed the best performance in color removal, followed by granular activated carbon. Coagulation and jute rope techniques were less effective, especially after prolonged storage. Activated carbon filtration is the preferred choice for improving color, particularly for long-term storage.

5.4 Conductivity

Conductivity mirrored TDS trends, increasing after 6 months due to dissolved mineral content. Reverse osmosis dramatically reduced conductivity, while other methods had limited impact.

5.5 pH

pH values generally improved over 6 months, stabilizing closer to neutral. Lime addition can increase pH significantly, making it effective for acidic rainwater. Reverse osmosis reduces pH, making it unsuitable for drinking.

5.6 Odor and Taste

Rainwater collected from both locations are absent from odor and taste.

5.7 Hardness

Rainwater was tested for presence of hardness. Results show that rainwater collected was a soft in nature. Passage of time or leaching of minerals upto age 6 months does not show significant effect on hardness of water. Water collected from both locations having no hardness.

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