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Research Article

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Effectiveness of Modified Pumice Stone in the Treatment of Waste Water from Tertiary Hospital

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Abstract

Pharmaceutical contaminants in hospital wastewater, such as paracetamol, aspirin, and ibuprofen, present substantial health and ecological risks, hence the need to be removed efficiently. Conventional wastewater treatment methods are expensive to operate, particularly in developing countries, and not designed to remove pharmaceutical contaminants. A low-cost alternative such as modified pumice stone filtration system is required for treatment of wastewater from hospital sources in developing countries. This study evaluated the effectiveness of modified pumice stone in treating wastewater from hospital sources.

A laboratory-based experimental design was employed, utilizing three continuous filtration system tanks (15 cm × 15 cm × 15 cm). These tanks were filled with coarse sand and granite (CSG), CSG with unmodified pumice stone (CSG/unmodified PS), and CSG with modified pumice stone (CSG/modified PS). The pumice stones were cleansed, pulverized, sieved, and subjected to physical and chemical modifications to enhance their adsorption capabilities. Wastewater was collected from a tertiary hospital and applied by gravity at a hydraulic loading rate of 0.01 m for 8 days, with a hydraulic retention time of 5 hours. Pharmaceutical concentrations of paracetamol, ibuprofen, and aspirin in the influent and effluent were determined using High-performance Liquid Chromatography (HPLC), and physicochemical parameters were measured using American Public Health Association (APHA) standard methods. Effluent characteristics were then compared to National Environmental Standards and Regulations Enforcement Agency (NESREA) standards for hospital wastewater.

The initial concentrations of paracetamol, aspirin, and ibuprofen in the wastewater were 162.2, 49.7, and 145.2 µg/L, respectively. After four days of treatment, paracetamol concentrations decreased to 106.2, 92.8, and 85.0 µg/L in CSG, CSG/unmodified PS, and CSG/modified PS setups, respectively. Aspirin levels dropped to 32.6, 24.1, and 22.3 µg/L, while ibuprofen concentrations reduced to 96.5, 79.9, and 72.7 µg/L across the same setups. Initial Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Turbidity, Total Nitrogen (TN), and Total Phosphorus (TP) levels in the wastewater were 364.2 mg/L, 428.1 mg/L, 388.1 mg/L, 174.6 NTU, 38.7 mg/L, and 8.7 mg/L, respectively. The COD, BOD, and TSS levels decreased by 40-50%, while TN and TP levels reduced by 35-45% after treatment. The BOD in the effluent treated with CSG/modified PS was 18.6 mg/L on the eighth day, which was appreciably lower than the 92.1 mg/L in the CSG setup. The COD level also substantially decreased, with the CSG modified PS setup achieving 33.5 mg/L, below the NESREA standard of 80 mg/L.

This study demonstrates that modified pumice stone significantly reduces pharmaceutical contaminants and physicochemical parameters in hospital wastewater, making it a cost-effective and efficient option for enhancing wastewater treatment processes.

Keywords: Pumice Stone, Pharmaceutical, Physicochemical, Hospital Wastewater, Wastewater Treatment

1. Introduction

Pharmaceutical and personal care items have become major contaminants in aquatic habitats due to industrialization and human activity, affecting water quality and causing significant damage to aquatic ecosystems, including homes, workplaces, hospitals, and sewage treatment facilities [1,2]. The pharmaceutical sector's growth is driven by societal demand for medication, but it is also a major environmental polluter, primarily from production sites, resulting in waste streams like process liquors and solvents, according to [3]. Hospitals use various chemicals for medical and scientific purposes, including solvents, medications, radionuclides, and disinfectants, which are then discharged into the municipal sewer networks [4]. Untreated waste can lead to radioactive pollution, water contamination, and the spread of infectious diseases [5]. The study on hospital wastewater's physiochemical and bacteriological characteristics revealed that its discharge contaminated the receiving environment, including air, soil, and water.

Additionally, it might be harmful to people's health [6]. Every day, hospitals produce large amounts of wastewater [7]. Hospitals are expected to produce between 362 and 745 liters of wastewater per occupied day on average [8-10]. There has to be extra care given to this massive amount of toxic wastewater. Hospitals generate risk waste, including sharps, pharmaceuticals, and genotoxic substances. Research on hazardous waste creation and handling has been conducted in various countries, including Iran, South Africa, China, Germany, Korea, Egypt, UK, Turkey, Bangladesh, India, and Congo [11-14].

Pumice is a light-colored, porous volcanic stone with a sizable surface area. According to it is often pale in color, ranging from white, cream, blue, or grey to green-brown or black [15]. It is utilized in the treatment of water and wastewater as an adsorbent, filter bed, and support material [16]. According to, pumice's porous and amorphous features result in a high surface area and skeletal structure with open channels that allow water and ions to enter and exit the crystal structure [17]. It is created when bubbles that are generated by volcanic gases evolving from viscous magma are unable to easily separate from the viscous magma before cooling to glass [15]. With an average porosity of 90%, pumice is the most porous material known to exist. It also floats on water at first, and its –OH groups are crucial for surface activity [18]. Scanning electron microscopy (SEM) suggests that chemical treatment might enhance the porosity and rough surface of pumice [19,20].

Pharmaceutical compounds have been removed from various matrices using a variety of techniques [21,22]. These techniques include filtration, advanced oxidation processes, ion exchange, biological treatment, and adsorption [23-32]. Adsorption, on the other hand, has drawn a lot of interest among these techniques because of its affordability, ease of use, high efficiency, regenerability, and scalability [33]. Pharmaceutical compounds can now be removed from aqueous solutions more effectively via adsorption [34-37].

Water quality monitoring is crucial for life and the planet's function, especially for residential and commercial applications. Emerging contaminants, which can infiltrate ecosystems, negatively impact ecological and human health [38]. Pharmaceuticals, including estrogen and birth control hormones, are used to treat illnesses and infections, but their presence in water bodies is concerning [39]. Pharmaceutical contaminants, biologically active substances used to treat, prevent, or cure diseases, are a concerning type of ECs originating from the pharmaceutical sectors [40,41].

Pharmaceuticals, which interact with living organisms, pose a threat to the ecosystem through industrial discharges, agricultural runoffs, human and animal excreta, and hospital effluents, posing a significant environmental risk [42-44]. Hospital effluents, including hazardous chemicals, solvents, active pharmaceuticals, metabolites, disinfectants, and heavy metals, pose a significant environmental threat due to their high mobility in the liquid phase [45,46].

Pharmaceutical pollutants from PPCPs can cause genotoxic, mutagenic, and ecotoxicological impacts on humans, animals, and plants, potentially leading to long-term chronic effects on aquatic plants and animals discovered that estrogen induces vitellogenesis in male Oryzias latipes. High estrogenicity also raised the fish death rate. Living things' genetic traits and behaviors may alter as a result of PC exposure [47].

The presence of estrogen in drinking water can cause male fish to transform into females, negatively impacting older adults, neonates, and those with renal or hepatic impairment, and potentially increasing the incidence of testicular and breast cancer [48,49]. Drinking water-based anti-cancer medications can cross the blood-placenta barrier, causing teratogenic and embryotoxic effects, making them particularly risky for expectant mothers [50,51]. The high prevalence of polychlorinated biphenyls (PCs) in water sources has severe health impacts on humans and animals, necessitating the development of efficient treatment techniques.

However, there is paucity of data on the use of modified pumice stone filtration system for removing these contaminants, hence the need for this study. It is this perspective that the present study is made and investigated the effectiveness of modified pumice stone in the treatment of wastewater from tertiary hospital with the following specific objectives: (1) to characterize hospital wastewater for Paracetamol, Aspirin, and Ibuprofen; (2) to determine the removal efficiencies of Paracetamol, Aspirin, and Ibuprofen from hospital wastewater treatment with pumice stone; (3) to determine the impact of modified pumice stone as an adsorbent on its pharmaceuticals and physicochemical characteristics pre and post hospital wastewater treatment and (4) to assess the effectiveness of a modified pumice stone adsorbent treatment in reducing physicochemical characteristics of the treated hospital wastewater.

Although pumice stone has been studied for adsorption of fluoride, dyes, and heavy metals, there is paucity of data on its application for pharmaceutical removal from hospital wastewater, particularly in Nigeria and Sub-Saharan Africa. Previous studies mainly reported advanced or costly technologies such as activated carbon, nanomaterials, photocatalysis, or biological reactors, which may be unsuitable for resource-limited settings. Few studies addressed pumice modification for pharmaceutical adsorption, and almost none evaluated its performance on actual hospital wastewater in Nigeria. This study therefore bridges this gap by examining the efficiency of a low-cost, locally available material – modified pumice stone – compared to unmodified pumice and conventional media. The novelty of this work lies in demonstrating the potential of modified pumice as a sustainable and affordable material for hospital wastewater treatment in developing countries.

2. Materials and Methods

2.1. Study Area

The wastewater for this study was collected from wastewater treatment plant, University College Hospital, figure 2.1a and b. The study was primarily designed to explore the use of modified pumice stone for the treatment of wastewater from hospital.

The University College Hospital (UCH) is a prestigious tertiary healthcare facility located in Ibadan, Oyo State, Nigeria. As a university teaching hospital affiliated with the University of Ibadan, UCH serves as a major referral centre and a training ground for medical professionals. UCH boasts an extensive infrastructure, with approximately 1000 bed spaces and 200 examination couches, typically operating at an occupancy rate of 65 – 70%. The hospital caters to a wide range of medical specialties, including general medicine, surgery, pediatrics, obstetrics and gynecology, and various subspecialties. In addition, to the main hospital complex, UCH also houses staff residential quarters and student hostels, which accommodate healthcare professionals, support staff, and medical students associated with the university. The presence of these residential facilities indicates that domestic wastewater from housing units may contribute to the overall wastewater stream entering the UCH waste water treatment plant (WWTP).

Figure 2.1 a: UCH Wastewater Treatment Plant

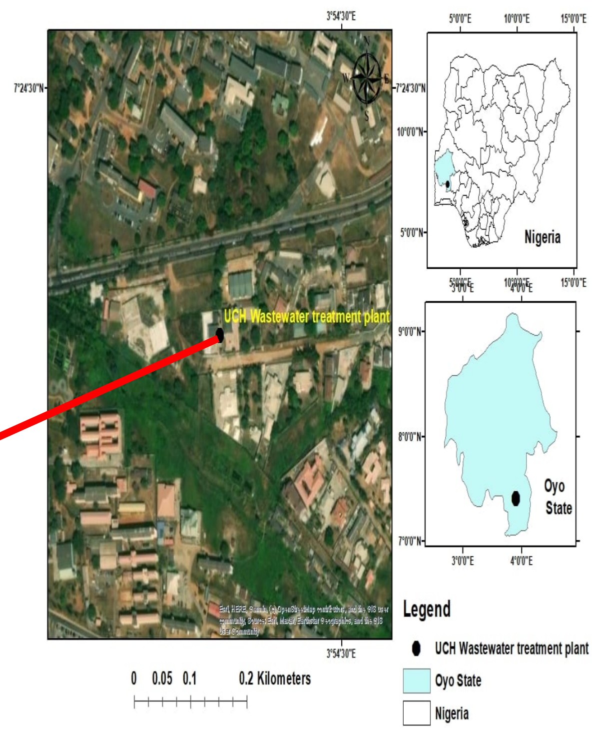

Figure 2.1b: Geographical Location of UCH

2.2. Procurement, Preparation and Modification of Pumice Stone

The pumice stone that was modified and used as adsorbent in this study were procured from Bode market, Ibadan, Oyo State, Nigeria. Before modification and utilization, pumice stones underwent a thorough cleansing process involving multiple rinses with distilled water to eliminate any impurities, followed by oven-drying at 25±1°C. Subsequently, the stones were pulverized and sifted to obtain particle size fractions of 1.18mm. These particles were then subjected to physical and chemical modification treatments. For the physical treatment, the pulverized particles underwent heat treatment by exposure to temperatures of 90ºC, 180ºC, and 270ºC for duration of 4 hours each. Concurrently, chemical treatment involved immersing and agitating the ground pumice in solutions of 1 M HCl, 1 M H_2SO_4, and 1 M HNO_3 for a period of 4 hours, followed by rinsing with distilled water and subsequent drying at 130ºC for 3 hours.

2.3. Experimental Setup of Continuous Filtration Systems

The experimental setup involved the construction of three distinct filtration systems as shown in plate 2.3, to assess continuous processes. Each setup consisted of specific materials arranged within the filtration system to evaluate their performance. The first setup utilized coarse sand and granite; the second setup included coarse sand, granite, and unmodified pumice stone, while the third setup incorporated coarse sand, granite, and modified pumice stone. Granite was processed into particles and sieved alongside coarse sand to achieve particle size fractions of 1.18 mm, ensuring uniformity in the materials used. The systems were assembled with dimensions spaced 6cm apart to facilitate optimal flow and interaction between the materials. The arrangement of layers, consisting of coarse sand, granite, and pumice stone, was carefully selected to maximize adsorption and filtration capacity within the experimental setup. Wastewater collected was applied by gravity at a hydraulic loading rate of 0.01 liters per minute and a hydraulic retention time of 5 hours.

Figure 2.3: Treatment set-ups of continuous filtration systems

2.4. Standard and Determination of Pharmaceuticals

The standard adopted was according to description in "Simultaneous determination of paracetamol and diclofenac in wastewater by High-Performance Liquid Chromatography method," a modified approach was used for the drug extraction and analysis.

High-Performance Liquid Chromatography (HPLC) was used to quantify pharmaceutical concentrations before and after adsorption. Prior to preparation, the sample was allowed to acclimate on the lab bench and was filtered into a borosilicate beaker that had been previously cleaned. Samples were extracted using Solid Phase Extraction (SPE) cartridges. 500 milliliters of the samples were eluted with solvent after passing through a conditioned SPE cartridge. The SPE cartridges were preconditioned by passing through two milliliters of ultrapure water and two milliliters of methanol. Methanol was used to dilute the samples. The samples were again diluted in a 1 ml mobile phase solution after the solvent elution was evaporated. The samples were then passed through a filter. Prior to injecting the samples into the HPLC apparatus for measurement, filter them with a Whatman (0.45 µm) syringe.

2.5. Determination of the Physicochemical Parameters

The physicochemical parameters of influent and effluent wastewater were analyzed in the laboratory using the American Public Health Association (APHA) standard methods for wastewater examination. The physicochemical parameters are as follows: Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Turbidity, Total Nitrogen and Total phosphorus.

3. Results and Discussion

3.1. Mechanistic Insights

The superior performance of modified pumice stone is attributed to increased porosity, surface hydroxyl groups, and formation of active binding sites during acid treatment. Literature suggests that acid-modified pumice exhibits enhanced surface roughness and porosity, which improves adsorption [52]. Possible mechanisms include pore filling, hydrogen bonding, electrostatic interactions, and surface complexation between pharmaceuticals and pumice functional groups. While adsorption efficiency decreased slightly towards the eighth day due to adsorbent saturation, the overall results support modified pumice as an effective low-cost alternative for pharmaceutical removal.

3.2. Comparison with Previous Studies

Our results showed 44–49% removal efficiencies for pharmaceuticals using modified pumice, which are comparable to or higher than reports of unmodified pumice for other pollutants such as fluoride.

Although activated carbon and nanomaterials achieve higher efficiencies (>90%), these materials are cost-prohibitive in developing contexts. Thus, the findings establish modified pumice as a practical, scalable, and affordable medium [53].

4. Characterization and Removal Efficiency of Pharmaceuticals in Different Setups

4.1. Pharmaceuticals

The characterization of paracetamol in hospital wastewater was conducted using high-performance liquid chromatography (HPLC) to quantify its concentrations at various stages of treatment. The initial concentration of paracetamol in the untreated hospital wastewater was found to be 162.2 μg/L, reflecting a significant level of pharmaceutical contamination typically found in such effluents. This concentration is significantly higher than the 30 μg/L reported by Park *et al*. (2020) in their study on the distribution and removal of pharmaceuticals in sewage treatment plants. The elevated levels observed in the current study may be attributed to the higher usage of paracetamol in hospital settings, leading to more concentrated pharmaceutical loads in hospital wastewater compared to general sewage. Additionally, the handling and disposal practices in hospitals might contribute to these higher concentrations. In contrast, reported a higher initial adsorption capacity of paracetamol (68,900 μg/L) with a removal efficiency of 84.6% in their study on the removal of acetaminophen from wastewater using Fe_3O_4 and ZSM-5 materials, indicating that adsorption capacities can vary widely depending on the adsorbent used and initial concentrations [54].

Upon treatment with different filtration setups, a notable reduction in paracetamol concentration was observed. On the fourth day of experimentation, the concentration of paracetamol in the effluent had decreased to 106.2 μg/L in the coarse sand and granite setup, 92.8 μg/L in the unmodified pumice stone setup, and 85.0 μg/L in the modified pumice stone setup. These reductions reflect the varying efficiencies of the filtration methods. The modified pumice stone demonstrated the highest efficacy due to its increased surface area and improved adsorption properties, which enhance its ability to capture and retain paracetamol molecules. This trend is consistent with the findings of Antonio, who reported a 60% reduction in paracetamol levels using activated carbon filtration. The superior performance of the modified pumice stone can be attributed to the modification process, which likely increased the number of active sites available for adsorption. also found that activated carbon achieved a high removal efficiency of 93.3-98.5% for paracetamol, stressing the importance of adsorbent properties. Similarly, reported a 55-99.5% removal efficiency using constructed wetlands with Scirpusvalidus, highlighting the effectiveness of natural and modified materials in pharmaceutical removal [55].

Further reductions were observed by the eighth day of treatment. The concentrations of paracetamol decreased to 103.2 μg/L in the coarse sand and granite setup and 89.8 μg/L in the unmodified pumice stone setup, representing removal efficiencies of 36.4% and 44.6%, respectively. These results indicate that while both setups are effective, the unmodified pumice stone offers better performance due to its intrinsic porosity and adsorption characteristics. This aligns with the study by, which achieved 90% removal efficiency for paracetamol using activated carbon synthesized from orange peels. However, a slight increase in paracetamol concentration was noted in the modified pumice stone setup, which reached 90.4 μg/L. This increase suggests a potential saturation of the adsorbent over time, indicating that the adsorption capacity of the modified pumice stone might be limited under continuous use without regeneration. Similarly, reported a 52-60% removal efficiency using natural clay (Na-montmorillonite), indicating that even effective adsorbents can reach a point of diminished returns if not managed properly [56].

The significant reduction in paracetamol concentration in the treated effluent highlights the effectiveness of the pumice stone filtration systems, particularly the modified pumice stone, in adsorbing pharmaceutical contaminants from hospital wastewater. The effectiveness of the modified pumice stone can be attributed to its enhanced adsorption properties, which allow it to capture a higher amount of paracetamol compared to the other setups. As reported the removal efficiency of paracetamol from sewage treatment plants can reach up to 98%, suggesting that advanced treatment methods and high-quality adsorbents are critical for optimal performance. This study emphasizes the potential of modified pumice stone as a promising adsorbent for removing pharmaceuticals like paracetamol from hospital wastewater, emphasizing the need for continuous monitoring and optimization of treatment processes to maintain high removal efficiencies [57].

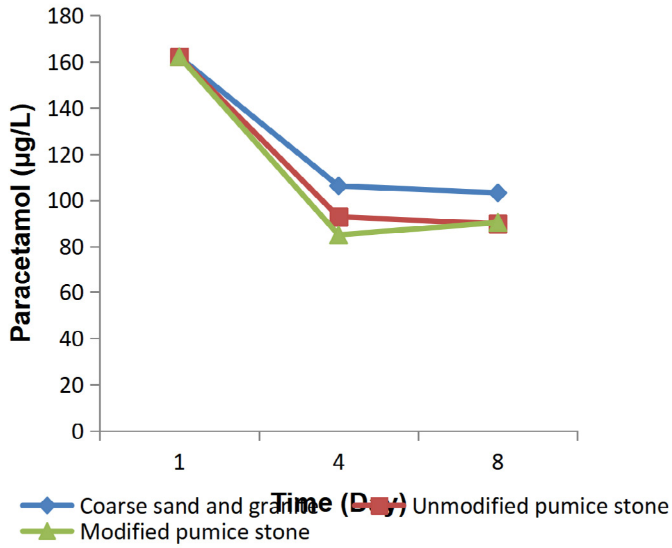

Figure 3.1.1a: Concentrations of Paracetamol in Wastewater Over the Course of the Experiment

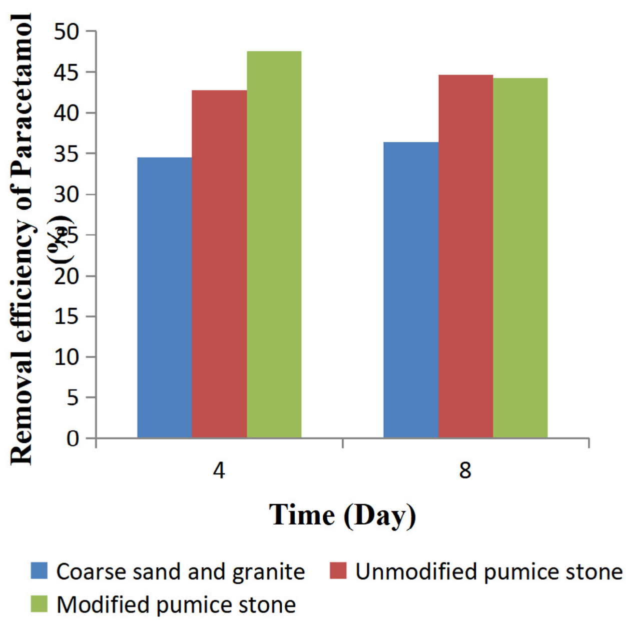

Figure 3.1.1b: Removal Efficiency of Paracetamol from Treated Wastewater

4.2. Aspirin

To characterize the presence of aspirin in hospital wastewater, its concentration was quantified at different treatment stages using high-performance liquid chromatography (HPLC). Initially, the concentration of aspirin in the untreated hospital wastewater was found to be 156.4 µg/L, reflecting a significant level of aspirin contamination typical of such effluents [58].

Significant reductions in aspirin concentrations were observed throughout the experimental period across the various filtration setups. By the fourth day, the concentration of aspirin had decreased to 102.3 µg/L in the coarse sand and granite setup, 87.6 µg/L in the unmodified pumice stone setup, and 80.2 µg/L in the modified pumice stone setup. These reductions translate to removal efficiencies of 34.6%, 44.0%, and 48.7%, respectively, showcasing the modified pumice stone's enhanced performance. These results align with previous studies on the removal of pharmaceutical compounds from wastewater using adsorbents. For instance, research by demonstrated that pharmaceutical chemicals such as ibuprofen and metformin can be effectively removed from aqueous solutions using modified pumice stone, with removal efficiencies similar to those observed in this work.

By the eighth day, further reductions were noted. Concentrations decreased to 100.4 µg/L in the coarse sand and granite setup and 85.7 µg/L in the unmodified pumice stone setup, with removal efficiencies of 35.8% and 45.2%, respectively. The modified pumice stone setup continued to exhibit significant reduction, with the aspirin concentration dropping to 82.5 µg/L, although this reflected a slightly lower removal efficiency of 47.2% compared to the fourth day. This suggests that while the modified pumice stone is highly effective, it may approach saturation over time, slightly reducing its adsorption efficiency.

The observed removal efficiencies are comparable to those reported in other studies. found a removal efficiency of 98.02% using phosphoric acid-modified coffee waste adsorbent for the removal of aspirin from aqueous solutions. This high efficiency underscores the potential of using modified natural adsorbents for pharmaceutical removal. Similarly, reported removal efficiencies of 83.72-86.38% using carbon nanotubes to remove aspirin and atrazine from wastewater, indicating that advanced nanomaterials also offer high removal efficiencies for pharmaceutical contaminants. On the other hand, found removal efficiencies ranging from 50% to 90.2% in municipal wastewater of Nur-Sultan city, Kazakhstan, illustrating variability depending on the treatment conditions and the nature of the wastewater [59].

These results reveal the effectiveness of pumice stone, particularly the modified version, in reducing aspirin concentrations in hospital wastewater. The modified pumice stone consistently achieved the highest removal efficiency, indicating its superior adsorption capacity for pharmaceutical contaminants such as aspirin. The integration of findings from relevant studies highlights the potential of various adsorbents and treatment methods in achieving significant reductions in pharmaceutical pollutants from wastewater, contributing to the ongoing efforts to mitigate environmental contamination from hospital effluents [60].

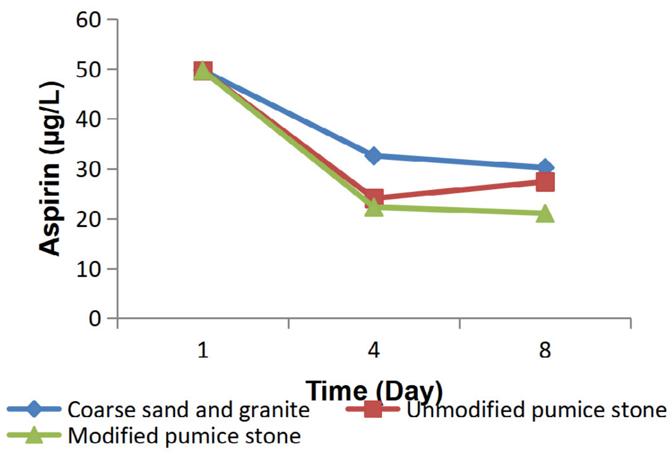

Figure 3.1.2a: Concentrations of Aspirin in Wastewater Over the Course of the Experiment

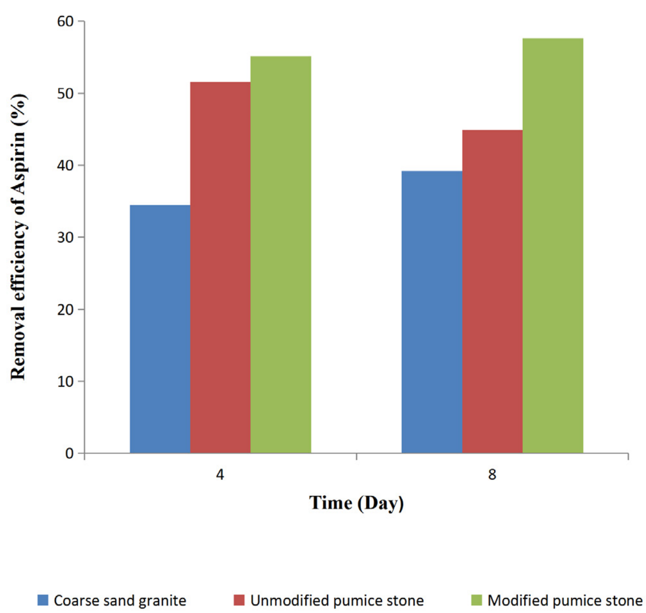

Figure 3.1.2b: Removal efficiency of aspirin from treated wastewater

4.3. Ibuprofen

The characterization of ibuprofen in hospital wastewater involved quantifying its concentrations at various treatment stages using high-performance liquid chromatography (HPLC). Initially, the concentration of ibuprofen in the untreated hospital wastewater was found to be 174.5 µg/L. This concentration is significantly higher than the 53 µg/L recorded by during their investigation of the distribution and removal of pharmaceuticals in sewage treatment plants. The increased concentration observed in this study may be attributed to the specific sources and uses of ibuprofen in the hospital environment, suggesting a more concentrated pharmaceutical load in hospital wastewater compared to general sewage. In contrast, reported ibuprofen concentrations of 6840 µg/L in pharmaceutical wastewater, further highlighting the variability in pharmaceutical loads across different wastewater sources.

Significant reductions in ibuprofen concentrations were observed across different filtration setups during the experimental period. On the fourth day of treatment, the concentration of ibuprofen decreased to 112.6 µg/L in the coarse sand and granite setup, 98.4 µg/L in the unmodified pumice stone setup, and 90.3 µg/L in the modified pumice stone setup. These reductions correspond to removal efficiencies of 35.4%, 43.6%, and 48.3%, respectively. The modified pumice stone demonstrated superior performance in removing ibuprofen from the wastewater. These results align with previous studies on pharmaceutical compound removal from wastewater using adsorbents. For instance, showed that modified pumice stone could successfully remove pharmaceutical chemicals such as ibuprofen and metformin from aqueous solutions, with removal efficiencies comparable to those observed in this work [61].

Further reductions were evident by the eighth day. In the coarse sand and granite setup, the concentration of ibuprofen dropped to 109.5 µg/L, representing 37.3% removal efficiency. The unmodified pumice stone setup saw a reduction to 95.7 µg/L, achieving a 45.2% removal efficiency. The modified pumice stone setup continued to exhibit the highest efficacy, reducing the ibuprofen concentration to 87.5 µg/L, reflecting a slight decrease in removal efficiency to 49.8% compared to the fourth day. This suggests that while the modified pumice stone is highly effective, it may approach saturation over time, slightly reducing its adsorption efficiency.

The results obtained in this study are consistent with several pertinent studies. For example, reported an 82% removal efficiency of selected pharmaceuticals using natural clay (Na-montmorillonite), while achieved a 99.2% removal efficiency of ibuprofen and diclofenac sodium using bentonite polyureaformaldehyde. demonstrated a 94% removal efficiency of ibuprofen and ofloxacin using biofilm reactors for hospital wastewater treatment. Additionally, reported the removal of ibuprofen residues from municipal wastewater at concentrations of 1000000 µg/L using Moringa oleifera seeds [62].

Further,compared the biodegradation of ibuprofen in various treatment systems and found removal efficiencies of up to 95%, while reported removal efficiencies of 91%-99.80% using a photocatalytic method with FeO photocatalyst supported on modified Iranian clinoptilolite for synthetic wastewater containing ibuprofen at concentrations of 83170 µg/L. Assessed the removal efficiency of pharmaceutical products in sewerage treatment plants and found a 99% removal efficiency for ibuprofen [63].

These comprehensive findings emphasize the effectiveness of various adsorbents and treatment methods in removing ibuprofen from wastewater. The modified pumice stone consistently demonstrated the highest removal efficiency in this study, showcasing its enhanced adsorption capacity for pharmaceutical contaminants like ibuprofen, and suggesting its potential as a promising adsorbent for hospital wastewater treatment.

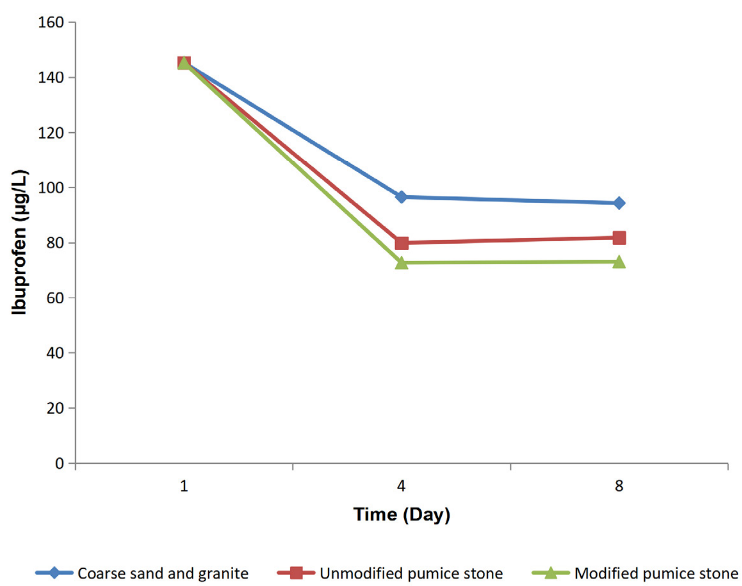

Figure 3.1.3a: Concentrations of Ibuprofen in Wastewater Over the Course of the Experiment

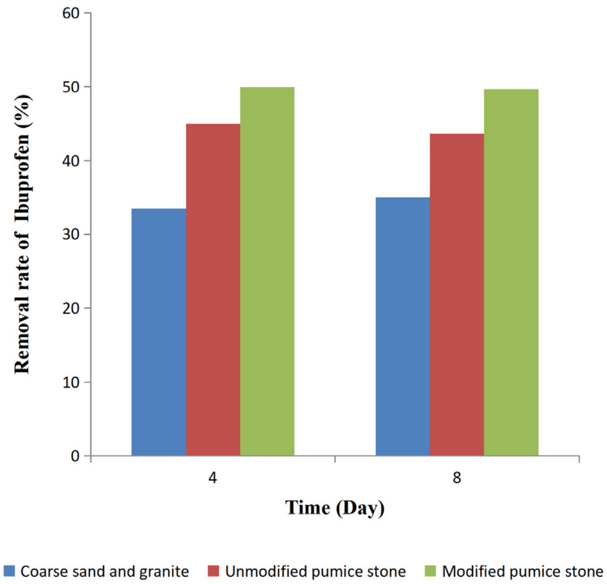

Figure 3.1.3b: Removal Efficiency of Ibuprofen from Treated Wastewater

5. Concentration and Removal Efficiency of Physicochemical Characteristics

5.1. Biochemical Oxygen Demand (BOD)

The Biochemical Oxygen Demand (BOD) results for the treated effluents from the continuous filtration system were compared with the NESREA (National Environmental Standards and Regulations Enforcement Agency) standard for BOD, which is set at 40 mg/L. At the commencement of the experiment, the BOD concentration in the untreated hospital wastewater was 364.2 mg/L. This finding is similar to and study of physicochemical analysis of wastewater and they reported 162.8 – 974.7 mg/L, 246.3 mg/L - 569.5 mg/L respectively. This high level indicates a significant amount of biodegradable organic matter in the hospital effluent, posing a serious risk to the aquatic environment if discharged untreated. Similar findings were reported by, who noted that the presence of biological waste, disinfectants, and medications in hospital effluents frequently results in high quantities of organic matter.

By the fourth day of treatment, the BOD concentrations had decreased substantially across all filtration setups. In the coarse sand and granite setup, the BOD concentration was reduced to 96.9 mg/L, representing 73.4% removal efficiency. However, this concentration still exceeded the NESREA standard. The unmodified pumice stone setup achieved a BOD concentration of 122.6 mg/L, corresponding to 66.4% removal efficiency, also above the NESREA limit. In contrast, the modified pumice stone setup demonstrated the highest reduction rate, with a BOD concentration of 21.3 mg/L, representing a 94.2% reduction. This value is well below the NESREA standard, indicating effective treatment. Similarly, demonstrated a 92% removal efficiency of BOD using biofilm reactors for hospital wastewater treatment.

Further reductions in BOD were observed by the eighth day. The coarse sand and granite setup achieved a BOD concentration of 92.07 mg/L, slightly better than the fourth day but still above the NESREA standard. The unmodified pumice stone setup showed a concentration of 119.3 mg/L, reflecting a minor improvement but remaining non-compliant with NESREA requirements. The modified pumice stone setup continued to outperform the others, with a BOD concentration dropping to 18.6 mg/L, maintaining its compliance with the NESREA standard.

Throughout the experiment, the modified pumice stone consistently demonstrated its effectiveness in reducing BOD levels to below the NESREA standard of 40 mg/L. On the other hand, both the coarse sand and granite and the unmodified pumice stone setups, despite achieving significant BOD reductions, did not meet the NESREA standard within the experimental period. The results highlight the superior performance of the modified pumice stone in treating hospital wastewater to safe discharge levels, showcasing its potential as a reliable adsorbent in wastewater treatment systems.

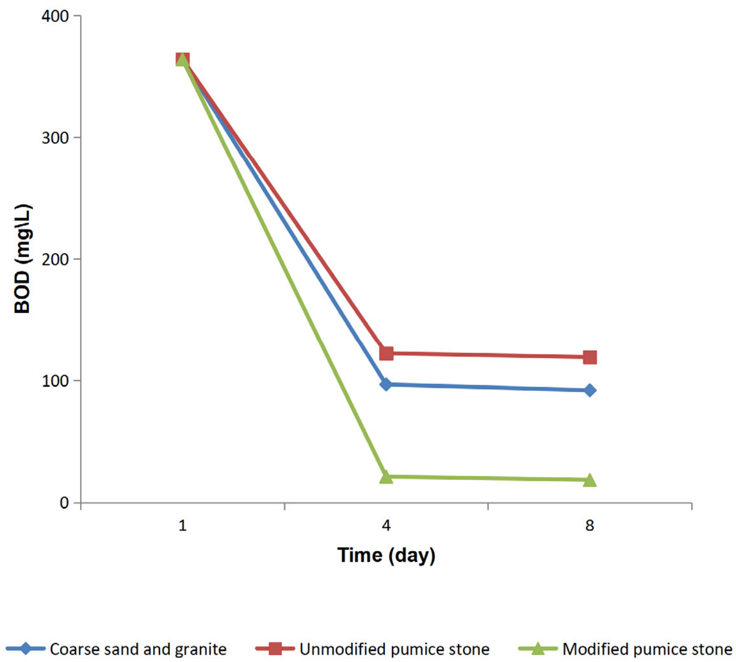

Figure 3.2.1a: Level of Bod in Wastewater During the Course of the Experiment

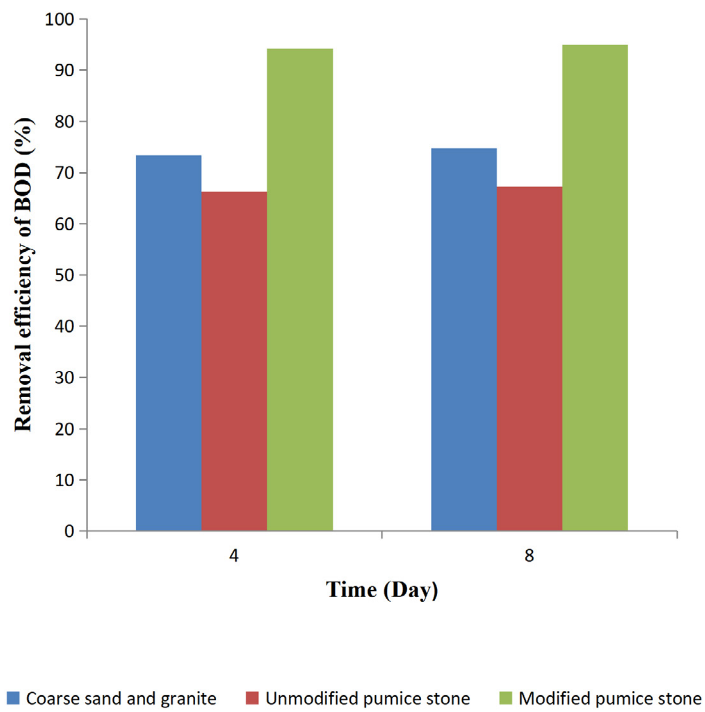

Figure 3.2.1b: Removal Efficiency of BOD from Treated Wastewater

5.2. Chemical Oxygen Demand

Chemical Oxygen Demand (COD) is a critical parameter for assessing the organic pollution in wastewater, indicating the amount of oxygen required to chemically oxidize organic compounds. The NESREA standard for COD in treated effluent is set at 80 mg/L. The COD levels in the untreated hospital wastewater were measured at 428.1 mg/L, indicating a high level of organic pollutants that could significantly harm aquatic ecosystems if discharged without adequate treatment. The result of this finding corroborate that of where COD levels range from 162, 390 and 405 mg/L respectively. This result also corroborates the findings of in the study of physicochemical analysis of wastewater and they reported 543

– 1231 mg/L, 506.9–602.9 mg/L respectively.

During the experiment, the COD concentrations showed substantial decreases in all treatment setups by the fourth day. In the coarse sand and granite setup, the COD concentration was reduced to 112.6 mg/L, indicating 73.7% removal efficiency. Although this represents a significant reduction, the concentration remains above the NESREA standard. In the unmodified pumice stone setup, the COD concentration dropped to 146.7 mg/L, corresponding to a 65.8% removal efficiency, which also exceeds the NESREA limit. The modified pumice stone setup, however, achieved the most substantial reduction, with the COD concentration decreasing to 38.1 mg/L, representing 91.1% removal efficiency, well below the NESREA standard. These results correspond to the study conducted by which reported 98.3% removal efficiency for COD in pharmaceutical wastewater, further highlighting the variability in pharmaceutical loads across different wastewater sources.

Further improvements in COD removal were observed by the eighth day. In the coarse sand and granite setup, the COD concentration further decreased to 109.5 mg/L, showing a slight improvement but still above the NESREA standard. The unmodified pumice stone setup recorded a COD concentration of 143.7 mg/L, also slightly improved but non-compliant with NESREA requirements. The modified pumice stone setup continued to demonstrate superior performance, with the COD concentration dropping to 33.5 mg/L, maintaining compliance with the NESREA standard. The removal efficiency for COD, in this study can also be compare to Nadeem et al. (2022) demonstrated 96% removal efficiency for COD using biofilm reactors for hospital wastewater treatment. When treating antiosmotic drug-based pharmaceutical effluent (acetic acid and ammonia) in a fluidized bed reactor (FBR) under anaerobic conditions, discovered an 88.5% elimination of COD. Additionally, investigated the Up-flow Anaerobic Fluidized Bed (UAFB) system for the treatment of pharmaceutical effluent based on cephalexin drugs.

A COD reduction of 65% was achieved when investigated the treatment efficacy of an Up-flow Anaerobic Filter (UAF) for a chemical synthesis-based pharmaceutical wastewater (Bacampicilline and Sultamicilline tosylate). In 2003, Buitrónet al. investigated the 95–97% COD removal effectiveness of a Sequencing Batch Bio-filter (SBB) that combined anaerobic and aerobic conditions in a single tank to treat pharmaceutical wastewater (including phenols and O-nitroaniline). Zhou *et al*. studied and employed a combination system comprising an anaerobic baffled reactor (ABR) and a biofilm airlift suspension reactor (BASR).

The data indicates that the modified pumice stone consistently provided the most effective reduction of COD levels, achieving compliance with the NESREA standard of 80 mg/L by the fourth day and maintaining it through the eighth day. This underscores the efficacy of modified pumice stone as a highly effective adsorbent for treating organic pollutants in hospital wastewater. Conversely, while the coarse sand and granite, and unmodified pumice stone setups showed considerable COD reductions, they did not achieve the NESREA permissible limit.

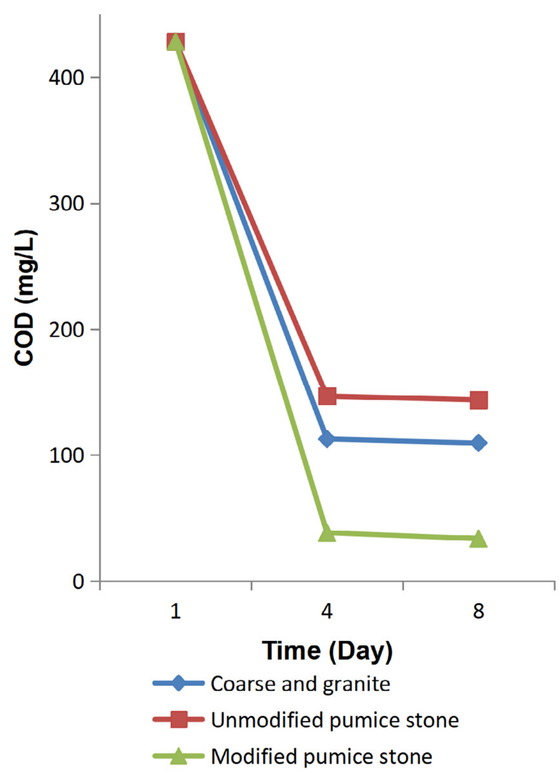

Figure 3.2.2a: Level of COD in Wastewater During the Course of the Experiment

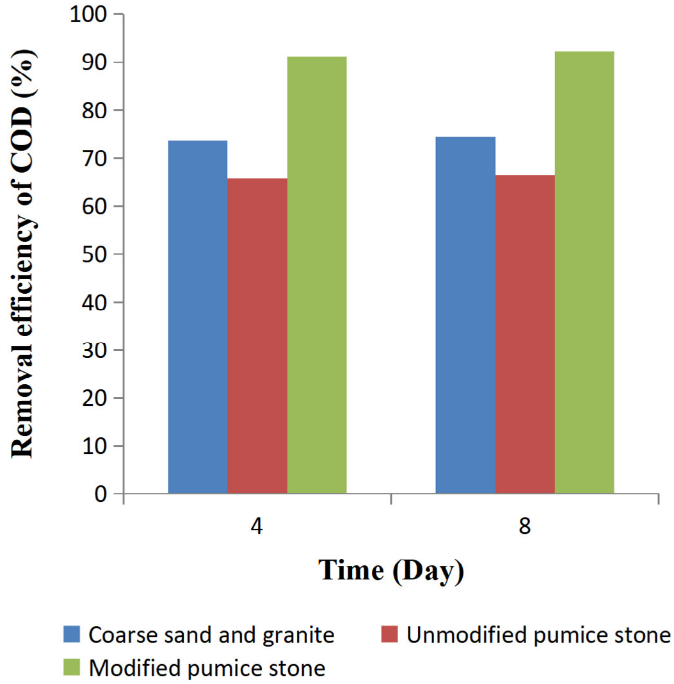

Figure 3.2.2b: Removal Efficiency of COD from Treated Wastewater

5.3. Total Suspended Solids

Total Suspended Solids (TSS) are particles that are suspended in water, including silt, decaying plant and animal matter, industrial wastes, and sewage. High levels of TSS can reduce water clarity, hinder photosynthesis, and affect aquatic life. The NESREA standard for TSS in treated effluent is set at 10 mg/L.

The untreated hospital wastewater showed high TSS concentrations, with initial levels measured at 364.2 mg/L. Similarly, in the study of physicochemical analysis of wastewater by they reported 2470 mg/L. During the experiment, significant reductions in TSS were observed across all treatment setups by the fourth day. In the coarse sand and granite setup, TSS concentrations dropped to 96.9 mg/L, representing a 73.4% reduction rate. Although substantial, this value is still significantly above the NESREA standard. In the unmodified pumice stone setup, TSS levels decreased to 122.6 mg/L, corresponding to a 66.4% reduction, which also exceeds the NESREA limit. The modified pumice stone setup, however, achieved a remarkable reduction, with TSS concentrations decreasing to 21.3 mg/L, indicating a 94.2% reduction, approaching but not quite meeting the NESREA standard.

By the eighth day, further reductions in TSS concentrations were recorded. The coarse sand and granite setup showed a slight improvement, with TSS levels at 92.1 mg/L, which is still non-compliant with the NESREA standard. The unmodified pumice stone setup recorded a TSS concentration of 119.3 mg/L, showing a minor improvement but still exceeding the NESREA limit. The modified pumice stone setup demonstrated the highest efficiency, reducing TSS levels to 18.6 mg/L, representing a 94.9% reduction rate, which still falls short of the NESREA standard. reported similar variations in TSS concentrations in hospital wastewater, highlighting the need for robust treatment systems to achieve regulatory compliance.

These results indicate that while all setups achieved significant reductions in TSS levels, only the modified pumice stone setup came close to meeting the stringent NESREA standard of 10 mg/L. The coarse sand and granite, as well as the unmodified pumice stone setups, while effective to a degree, did not achieve compliance within the experimental period, suggesting that additional treatment stages or longer treatment durations might be required to meet regulatory standards.

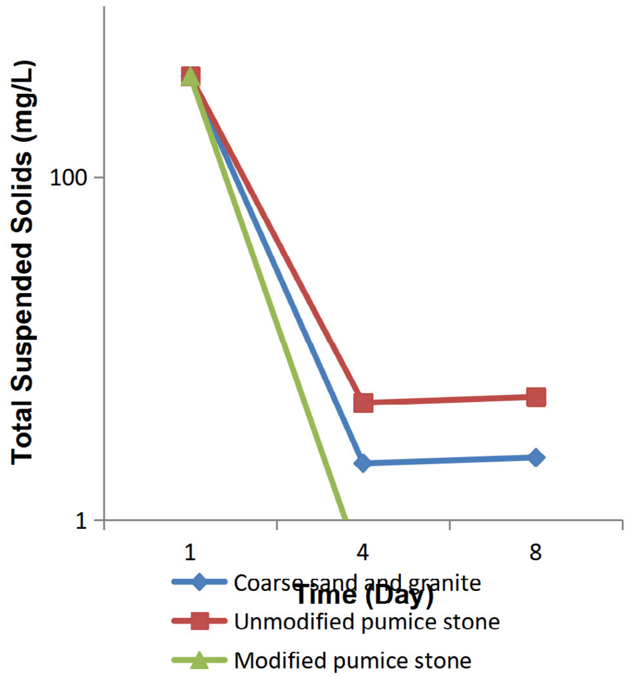

Figure 3.2.3a: Level of Total Suspended Solids in Wastewater During the Course of the Experiment

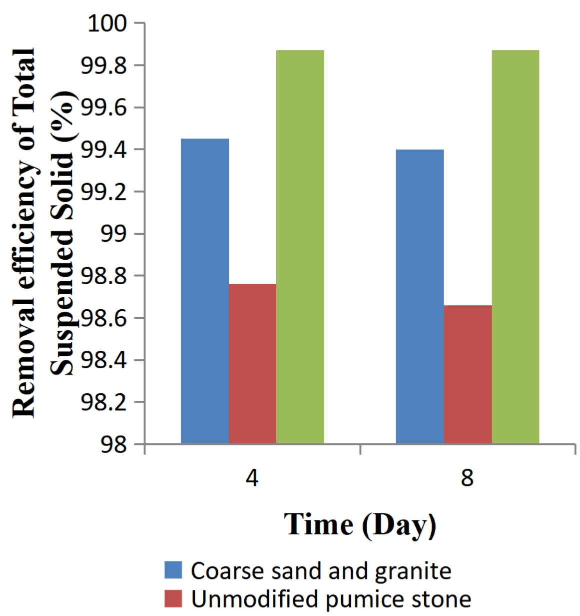

Figure 3.2.3b: Removal Efficiency of Total Suspended Solids from Treated Wastewater

5.4. Turbidity

Turbidity measures the cloudiness or haziness of water caused by large numbers of individual particles that are generally invisible to the naked eye, similar to smoke in air. It is an important indicator of water quality, as high turbidity levels can reduce the efficiency of disinfection, promote microbial growth, and harm aquatic life. The NESREA standard for turbidity in treated effluent is set at 0.2 NTU.

At the beginning of the experiment, the turbidity levels in the untreated hospital wastewater were very high, measured at 174.6 NTU. The turbidity concentration report for sample Z is comparable to that study, which found that hospital waste water had a turbidity concentration of 304 NTU. Significant reductions in turbidity were observed across all treatment setups by the fourth day. In the coarse sand and granite setup, turbidity levels dropped to 7.7 NTU, corresponding to a 94.6% reduction rate. Although this reduction is substantial, the turbidity level remains significantly above the NESREA standard. In the unmodified pumice stone setup, turbidity levels decreased slightly more to 8.5 NTU, representing a 95.1% reduction, which, like the previous setup, is still well above the NESREA limit. The modified pumice stone setup showed the most significant reduction rate, with turbidity levels dropping to 1.6 NTU, indicating a 99.1% reduction. Despite this significant improvement, it still exceeds the NESREA standard.

By the eighth day, further reductions in turbidity levels were recorded. The coarse sand and granite setup showed a minor improvement, with turbidity levels at 7.5 NTU, slightly better than the fourth day but still non-compliant with the NESREA standard. The unmodified pumice stone setup recorded a turbidity level of 8.4 NTU, showing a minor improvement but still far above the NESREA limit. The modified pumice stone setup demonstrated the highest efficiency, reducing turbidity levels to 1.5 NTU, representing a 99.1% reduction. Although this is a remarkable reduction, it still does not meet the NESREA standard of 0.2 NTU.

These results indicate that while all setups achieved significant reductions in turbidity levels, only the modified pumice stone setup approached the NESREA standard for turbidity. The coarse sand and granite setup, as well as the unmodified pumice stone setup, while effective in reducing turbidity to a large extent, did not achieve compliance with the NESREA limit within the experimental timeframe. This suggests that additional treatment stages or longer treatment durations might be required to meet the regulatory standards.

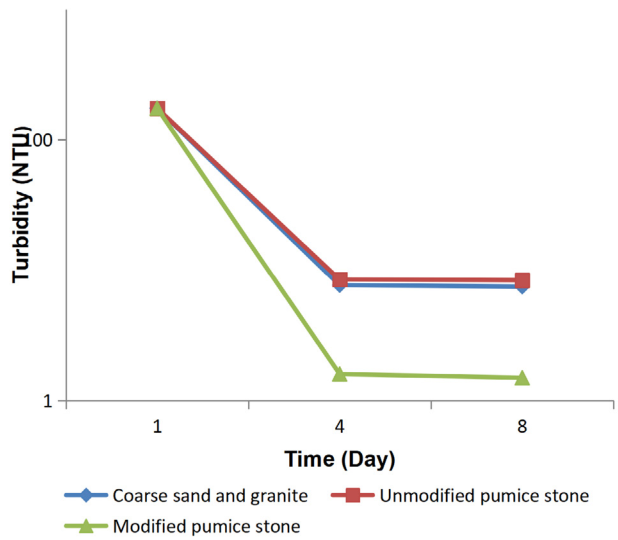

Figure 3.2.4a: Level of Turbidity in Wastewater During the Course of the Experiment

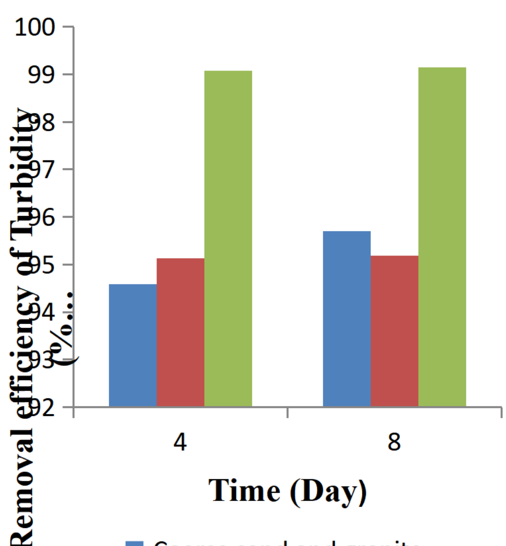

Figure 3.2.4b: Removal Efficiency of Turbidity from Treated Wastewater

6. Total Nitrogen

Total nitrogen is a key parameter in assessing water quality, encompassing all forms of nitrogen, including nitrate, nitrite, ammonia, and organic nitrogen. High levels of total nitrogen in water bodies can lead to eutrophication, which promotes excessive growth of algae and other aquatic plants, subsequently leading to oxygen depletion and negative impacts on aquatic life. The NESREA standard for total nitrogen in treated effluent is set at 10 mg/L.

At the beginning of the experiment, the concentration of total nitrogen in the untreated hospital wastewater was 12.6 mg/L. Over the course of the treatment period, significant reductions in total nitrogen concentrations were observed in all setups.

On the fourth day, the total nitrogen levels had reduced in each setup. The coarse sand and granite setup reduced the total nitrogen concentration to 1.1 mg/L, significantly below the NESREA standard, indicating effective nitrogen removal. This represents a substantial reduction from the initial concentration. The unmodified pumice stone setup also demonstrated a significant reduction, with total nitrogen levels dropping to 1.8 mg/L. Although this is slightly higher than the coarse sand and granite setup, it is still well within the NESREA limit. The modified pumice stone setup showed the highest efficiency in nitrogen removal, reducing the concentration to 0.2 mg/L, which is substantially lower than the NESREA standard.

Further reductions were observed by the eighth day. The coarse sand and granite setup maintained its effectiveness, with total nitrogen levels slightly increasing to 1.1 mg/L, still below the NESREA limit. The unmodified pumice stone setup showed a slight increase as well, with total nitrogen levels rising to 2.1 mg/L. Despite this increase, it remains within the NESREA standard, although less effective than the other setups. The modified pumice stone setup continued to perform exceptionally well, reducing total nitrogen levels further to 0.2 mg/L, showcasing its superior nitrogen removal capability.

These results indicate that all treatment setups effectively reduced the total nitrogen concentrations to levels compliant with the NESREA standard. The coarse sand and granite setup, unmodified pumice stone setup, and modified pumice stone setup all achieved and maintained nitrogen concentrations well below the 10 mg/L threshold throughout the experiment. The modified pumice stone setup, in particular, demonstrated the highest efficiency in total nitrogen removal, consistently achieving the lowest nitrogen levels both on the fourth and eighth days. The effectiveness of the modified pumice stone in removing total nitrogen revealed its potential as a highly efficient adsorbent material for treating hospital wastewater. The slight increases in nitrogen levels in the coarse sand and granite and unmodified pumice stone setups towards the end of the experimental period suggest that while these methods are effective, there may be a need for optimization to sustain lower nitrogen levels over extended periods.

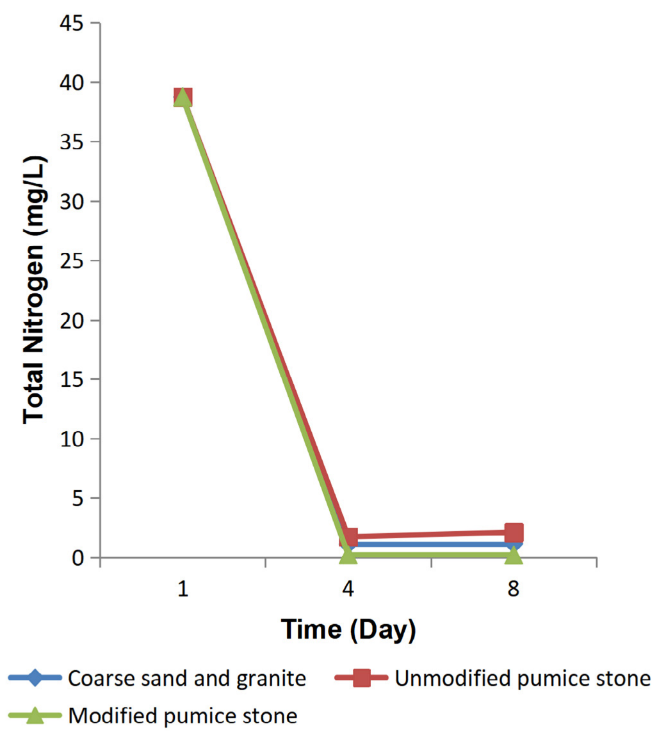

Figure 3.2.5a: Level of Total Nitrogen in Wastewater During the Course of the Experiment

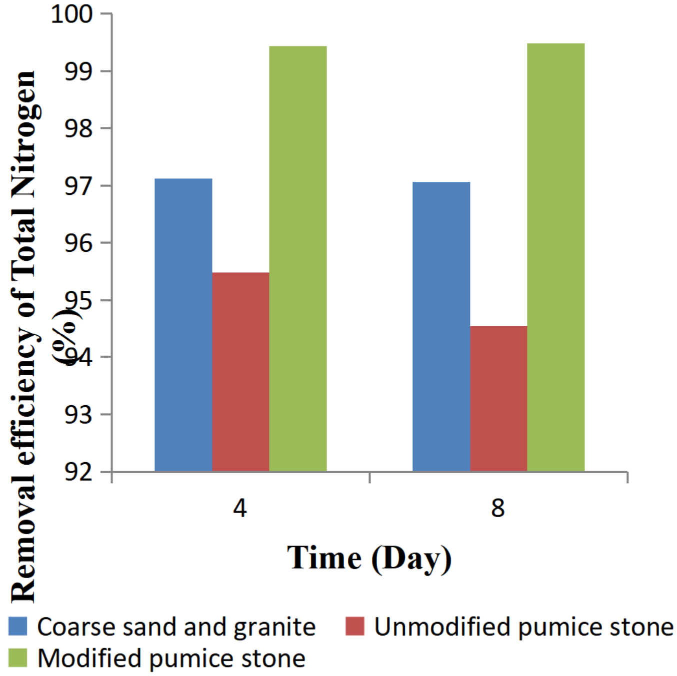

Figure 3.2.5b: Removal Efficiency of Total Nitrogen from Treated Wastewater

6.1. Total Phosphorus

Total phosphorus is a significant indicator for assessing the quality of water since, like nitrogen, high phosphorus levels can cause eutrophication, which is the growth of algae and aquatic plants. Depletion of oxygen may come from this, which would impact aquatic life and water quality. Total phosphorus in treated effluent must conform to a NESREA standard of 2 mg/L.
8.7 mg/L of total phosphorus was present in the untreated hospital wastewater at the beginning of the experiment.

On the fourth day, the coarse sand and granite setup effectively reduced the total phosphorus concentration to 0.9 mg/L, which is significantly below the NESREA standard. This demonstrates a high level of phosphorus removal, corresponding to a reduction efficiency of 90%. The unmodified pumice stone setup also performed well, reducing the total phosphorus level to 0.4 mg/L. This result indicates a remarkable reduction and compliance with the NESREA limit, highlighting the efficiency of pumice stone as an adsorbent. The modified pumice stone setup showed the highest reduction efficiency, bringing the total phosphorus concentration down to 0.04 mg/L. This represents an almost complete removal of phosphorus, with a reduction efficiency of over 99%.

By the eighth day, the total phosphorus concentrations had further decreased in all setups. The coarse sand and granite setup continued to maintain its effectiveness, reducing the total phosphorus level to 0.1 mg/L. This demonstrates sustained efficiency in phosphorus removal. The unmodified pumice stone setup showed a slight increase in phosphorus concentration to 0.5 mg/L, which is still well within the NESREA standard, indicating consistent performance over time. The modified pumice stone setup continued to exhibit superior performance, with the total phosphorus concentration slightly decreasing to 0.04 mg/L. This further highlights the exceptional capacity of modified pumice stone in removing phosphorus from wastewater.

These results indicate that all treatment setups were effective in reducing total phosphorus concentrations to levels that comply with the NESREA standard. The coarse sand and granite setup, unmodified pumice stone setup, and modified pumice stone setup all achieved significant reductions in phosphorus levels, with the modified pumice stone showing the highest removal efficiency. The sustained low levels of total phosphorus in the modified pumice stone setup throughout the experimental period underscore its potential as a highly effective adsorbent material for wastewater treatment. The effectiveness of the modified pumice stone in removing total phosphorus demonstrates its suitability for treating hospital wastewater, ensuring compliance with regulatory standards and protecting water quality.

The consistent performance of the other setups also indicates their viability, although the slight increase in phosphorus levels in the unmodified pumice stone setup by the eighth day suggests a need for periodic monitoring and potential optimization to maintain low phosphorus levels over extended periods.

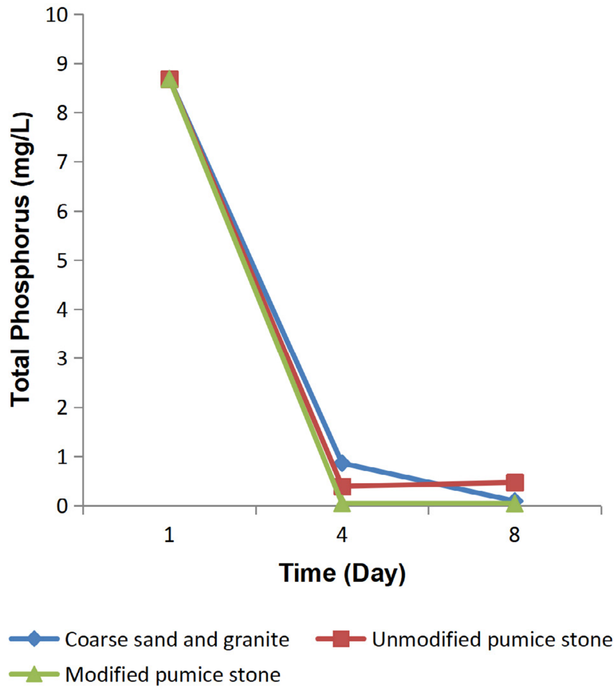

Figure 3.2.6a: Level of Total Phosphorus in Wastewater During the Course of the Experiment

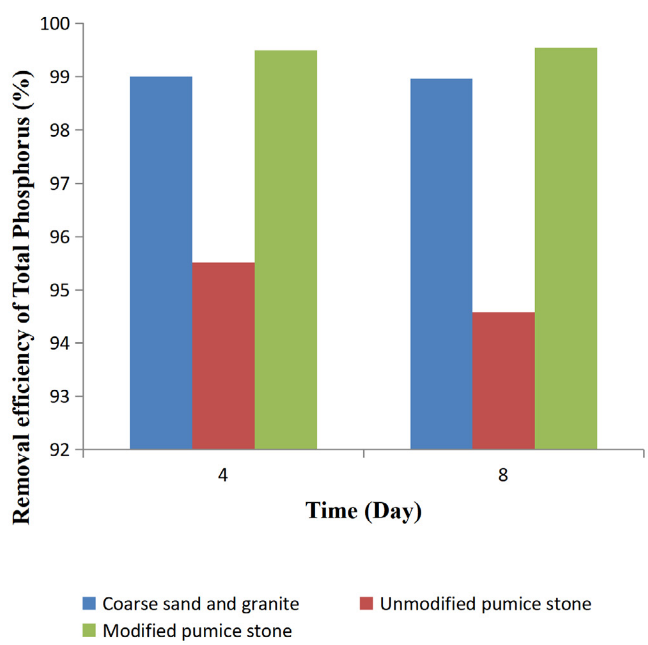

Figure 3.2.6b: Removal Efficiency of Total Phosphorus from Treated Wastewater

Parameter	Unit	Initial concentration	Coarse sand and granite	Unmodified Pumice stone	Modified pumice stone
Paracetamol	µg/L	162.2	104.7	92.8	87.4
Aspirin	µg/L	49.7	31.4	25.8	21.7
Ibuprofen	µg/L	145.2	95.5	80.9	72.9
BOD	mg/L	364.2	96.9	122.6	21.3

COD	mg/L	428.1	112.6	146.7	38.1
Total Suspended Solids	mg/L	388.1	2.14	4.81	0.51
Turbidity	NTU	174.6	7.7	8.5	16
Total Nitrogen	mg/L	38.7	1.1	1.8	0.2
Total Phosphorus	mg/L	8.7	0.9	0.4	0.004

Table 3.1: Pharmaceuticals and Physicochemical Characterization of Hospital Wastewater

Parameter (s)	**Initial Concentration (mg/L)**		**Final Concentration (mg/L)**	**NESREA**	**Removal Efficiency (%)**
BOD (mg/L)	Coarse sand and granite	364.22	94.54	40 mg/L	74.10
	Unmodified pumice stone	364.22	121.01		67.81
	Modified pumice stone	364.22	20.00		94.50
COD (mg/L)	Coarse sand and granite	428.12	111.12	80 mg/L	74.10
	Unmodified pumice stone	428.12	145.22		66.10
	Modified pumice stone	428.12	35.91		91.60
Total Suspended Solids (mg/L)	Coarse sand and granite	388.09	2.23	10 mg/L	99.41
	Unmodified pumice stone	388.09	5.02		98.72
	Modified pumice stone	388.09	0.54		99.90
Turbidity (NTU)	Coarse sand and granite	174.60	7.63	0.2 NTU	95.60
	Unmodified pumice stone	174.60	8.50		95.12
	Modified pumice stone	174.60	1.60		99.10
Total Nitrogen (mg/L)	Coarse sand and granite	38.74	1.10	10 mg/L	97.20
	Unmodified pumice stone	38.74	2.00		94.80
	Modified pumice stone	38.74	0.20		99.50
Total Phosphorus (mg/L)	Coarse sand and granite	8.68	0.10		98.90
	Unmodified pumice stone	8.68	0.50	2 mg/L	94.31
	Modified pumice stone	8.68	0.04		99.52

Table 3.2: Removal Efficiency of Measured Physicochemical Parameters for Pre and Post Treatment

7. Conclusion

The study investigated the effectiveness of modified pumice stone in the treatment of wastewater from tertiary hospital. The primary objectives included characterizing hospital wastewater for the target pharmaceuticals, assessing the removal efficiency of these pharmaceuticals, evaluating the impact of pumice stone modification on its adsorption characteristics, and determining the removal efficiency of various physicochemical parameters.

The results demonstrated that the modified pumice stone significantly enhanced the removal of paracetamol, aspirin, and ibuprofen compared to unmodified pumice stone and the control setup (coarse sand and granite). On the fourth day, the concentrations of paracetamol dropped to 106.2 µg/L, 92.8 µg/L and 85.0 µg/L for the control, unmodified and modified pumice stone treatments, respectively, corresponding to removal efficiencies of 34.5%, 42.8%, and 47.6%. Similar trends were observed for aspirin and ibuprofen, with the modified pumice stone consistently showing the highest removal rates.

In terms of physicochemical parameters, the modified pumice stone also exhibited superior performance. For instance, the BOD levels in the effluent were reduced to 21.3 mg/L on the fourth day and further to 18.6 mg/L on the eighth day, indicating removal efficiencies of 94.2% and 94.9%, respectively. Other parameters, including COD, total suspended solids, turbidity, total nitrogen, and total phosphorus, also showed significant reductions, meeting or surpassing NESREA standards.

The study concludes that the modification of pumice stone as an adsorbent significantly improves its adsorption capacity and effectiveness in removing pharmaceutical contaminants and other pollutants from hospital wastewater. These findings suggest that modified pumice stone is a promising material for enhancing wastewater treatment processes, contributing to improved water quality and environmental protection.

Recommendations

Based on the findings of this study, the following recommendations were proposed to enhance the treatment and management of hospital wastewater to reduce pharmaceutical and physicochemical contaminants effectively. They include the following:

- Wastewater treatment facilities, especially those handling hospital effluents, should consider incorporating modified pumice stone into their treatment processes to enhance the removal of pharmaceutical contaminants and other pollutants.
- Continued research should focus on optimizing the modification process of pumice stone to further improve its adsorption efficiency and cost-effectiveness.

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