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Optimizing Water Reuse: Integrating Computer-Aided Greywater Treatment Systems with Decision Support Techniques for Enhanced Dissolved Oxygen and Turbidity Evaluation

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Abstract:

This paper presents a comprehensive approach to the design, implementation, and optimization of a robust, cost-effective, and sustainable Grey Water system. Through the utilization of advanced sensing technologies, the system meticulously monitors and analyzes a diverse array of water parameters, including Water Flow, Pressure, Temperature, Turbidity, Conductivity, and Dissolved Oxygen. Emphasizing the critical importance of optimized greywater management, the study integrates methodologies aimed at reducing Clean Water usage, thereby contributing to overall water conservation efforts.

Prior to system deployment, extensive simulation, modeling, and analysis were conducted to develop efficient and low-energy grey water treatment prototypes. A significant emphasis of this research lies in the integration of Decision Support Techniques tailored to evaluate key parameters such as Dissolved Oxygen and Turbidity. By leveraging advanced computational methodologies, the system enables real-time monitoring and informed decision-making, enhancing the overall efficiency and effectiveness of greywater treatment processes.

This research addresses pressing global challenges including climate change adaptation, food security, and environmental pollutant mitigation by exploring the vast potential of greywater reuse. While scrutinizing health and environmental perspectives, particular attention is given to the presence of microorganisms and xenobiotic organic compounds (XOCs) within greywater streams. Moreover, the study underscores the multifaceted benefits of greywater reuse, ranging from toilet flushing to irrigation, with the potential to significantly reduce household water consumption by up to 30%.

In response to the imperative to mitigate groundwater contamination risks, the research proposes innovative treatment strategies at the household level. By merging environmental consciousness with technological innovation, this work contributes to the optimization of water resources in a world increasingly challenged by water scarcity. The pivotal role of computer science in result analysis and decision support underscores the interdisciplinary nature of this endeavor, offering promising avenues for sustainable water management practices globally.

Keywords: Sustainable Water Management, Wastewater Treatment, Water Resource Optimization, Greywater (GW), Household-level Interception, GW Recycling, Decision Support

1. Introduction:

Greywater (GW) recycling emerges as a beacon of promise, driven by its significant availability and meager organic content. While GW constitutes up to 70% of the total consumed water, its organic fraction comprises a mere 30%, with nutrient content ranging from 9% to 20% [1]. These distinctive characteristics position GW as a compelling alternative to fresh water, particularly for non-potable applications, such as toilet flushing, car washing, and garden irrigation [2].

The global landscape of wastewater management presents an intriguing panorama. In North America, an estimated 85 cubic kilometers of wastewater are generated annually, of which 61 cubic kilometers undergo treatment. However, a mere 3.8% of this treated wastewater is reintroduced into the cycle through recycling. Europe exhibits a higher treatment rate of 71%, while in the Middle East and North Africa, approximately 22.3 cubic kilometers of wastewater are generated, with 51% undergoing treatment, primarily for irrigation. In stark contrast, Sub-Saharan Africa grapples with untreated wastewater due to limited data availability. Among regions, Australia stands out with comprehensive data, revealing that 19% of treated wastewater is repurposed, accounting for 4% of total water supply. In Asia, encompassing countries like China, India, Japan, Korea, and Vietnam, varying levels of data availability pertain to wastewater generation, treatment, and reuse. Notably, Asia's recycling rates remain relatively low, with only 32% of the generated wastewater undergoing treatment [2].

Treated GW has demonstrated its remarkable potential for diverse reuse applications on a global scale. Developing nations have leveraged the benefits of treated GW extensively, with a significant emphasis on its utilization for irrigation, thus underscoring its adaptability and profound significance. To provide a succinct insight into the range of treatment methodologies employed for GW reclamation, the subsequent table 1 offers a comprehensive overview.

Meters and Sensors: Meters and sensors are currently being intensively applied to regulate different activities of water distribution systems such as hydraulic pressure and flow, water quality, head losses, and water and energy consumptions. The major aim of water utilities is to convey water from one place to another effectively with a minimal compromise to its quality and quantity. Water quality monitoring inside the distribution or the network system helps in addressing problems and providing related operational management activities. An application of different water quality sensors provides verified information that leads to informed decisions related to the observed water quality change. An advanced water quality sensor measures the water pH, dissolved oxygen, temperature, turbidity, salinity, and conductivity.

Water Sensors and Early Warning System: It is essential to provide scientific and technical bases for improved water surveillance capable of global and rapid detection of pollutants from accidents or malevolence in order to protect surface waters. Effective water sensing and an early warning system is the key point of ensuring the water resources safety and sustainable use. When there is a sudden abnormal change in water quality, the on-site monitoring units can detect this abnormality and the system can present early warnings as soon as possible, determine the measures to be taken based on the conditions so implementation of these measures can be done promptly. An advanced system can even give precautions based on the change of sensing data before any serious accidents happen. This kind of programme can lead to substantive benefits, as their actual cost is very low compared to the economic and social impacts of hazards which are not detected early enough to undertake adequate actions.

Early warning is "the provision of timely and effective information, through identified institutions, that allows individuals exposed to hazard to take action to avoid or reduce their risk and prepare for effective response", and is the integration of four main elements (from International Strategy for Disaster Reduction, United Nations, 2006):

1. Risk knowledge: Risk assessment provides essential information to set priorities for mitigation and prevention strategies and designing early warning systems.
2. Monitoring and predicting: Systems with monitoring and predicting capabilities provide timely estimates of the potential risk faced by communities, economies and the environment.
3. Disseminating information: Communication systems are needed for transmitting the monitoring data and delivering warning messages to the potentially affected locations to alert local and regional governmental agencies. These messages need to be reliable, synthetic and simple for the authorities and public to understand.
4. Response: Coordination, good governance and appropriate action plans are a key point in effective early warning. Likewise, public awareness and education are critical aspects of disaster mitigation.

The basic idea behind water sensing and early warning systems is that the earlier and more accurately short- and long-term potential risks associated with natural and human-induced hazards can be predicted, the more likely the disasters' impact on society, economies and the water environment can be mitigated and managed.

Table 1: Overview of Existing Greywater Treatment Technologies

Particulars	Salient Features
Grey Water Dam Design for Single and Multiple Household (Gravity Based System) [3]	• Designed inside a homestead shared by 5 households • Collection and discharge of grey water into a common tank • Conducted awareness programs for health, hygiene, and sanitation • Program for grey water disposal - 2000 L/D grey water treatment capacity • Aerobic breakdown of organic matter by passing air • Controlled supply to avoid overflow • Efficiency improvement with vertical pipes system • Hydraulic equation for seepage path determination
GW Recycling: Treatment Options and Application [4]	• Achieved 40% water savings and associated cost savings for 200 dwellings • Potential of decentralized GW treatment in high-density estates • Removal of over 90% of BOD5, COD, TSS, and ammonia • Effluent meeting WHO (2006) GW management requirements for BOD5 <10mg/L • Treated water discharged as surface water to storm drains
Constructed Wetland Treatment (US EPA, 2000) [5]	• Contaminant removal including BOD, suspended solids, heavy metals, and toxic substances • Utilized physical, chemical, and biological processes • Treatment rate depends on factors like surface loading rate and electron acceptor availability
Hybrid Treatment Process (Parjane & Sane, 2011) [6]	• Treatment plant with 180 lit/hr capacity (Lab-Based Model) • Four-stage treatment involving primary settling, aeration, agitation, and filtration • Organic load reduction of 83%, anions and cations adsorption of 46% and 49% respectively • Removal of traces of potassium, magnesium, and calcium
Filtration Characteristics for Domestic Wastewater Reclamation [7]	• Organic removal rates of TOC (95%), BOD (95%), TN (50%), TP (85%)
Monitoring of Indoor Plants for GW Reuse [8]	• Reductions in turbidity (18%), pH, suspended solids (28%), TOC (20%), TN, COD (25%
Lab-Based GW Treatment System [9]	• Highly effective turbidity (99%), pH, color (98%), COD (99%), suspended solids (99%) removal
Performance of GW Treatment [10]	• Significant reductions in hardness (60%), COD (91%), TDS (81%), TSS (90%), oil and grease (98%), nitrates (75%), nitrites (100%), cations (49%), and anions (46%)

The table presented above offers an exhaustive overview of various treatment methodologies employed for greywater reclamation, encompassing their distinguishing attributes and resultant outcomes.

2. Greywater Categorization and Generation: A Quantitative Insight

Greywater finds its classification based on source and pollutant load, with distinctions such as light greywater and dark greywater. Typically, greywater from bathrooms and washbasins exhibits a lower pollutant load, while greywater from laundry and kitchen sinks contains a relatively higher pollutant concentration.[11] A comprehensive tabulation in Table I.2 delves into the pertinent physical and chemical attributes characterizing greywater.

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Table 2: Physicochemical Characteristics of Greywater and Associated Concerns

Constituent	Reasons for Concern
Suspended solids	Can adsorb organic contaminants and heavy metals. - Shield microorganisms from disinfectants such as UV. - Excessive amounts can cause plugging in systems.
BOD, COD, TOC	Provide food to microorganisms leading to an increase in their numbers. - Food breakdown can lead to aesthetic problems (color and odor).
Nutrients (N, P)	Excessive discharge can lead to eutrophication in surface waters.
pH	Water pH affects disinfection, coagulation, metal solubility, as well as soil alkalinity.
Heavy metals (e.g., Cd, Zn, Ni, Hg)	Can accumulate in the environment and are toxic to flora and fauna.
EC/total dissolved solids (TDS)	Specific ions such as chloride, sodium, and boron are toxic to some plants. - When EC < 500 – no detrimental effects on plants. - When EC ¼ 500–1,000 – can affect sensitive plants. - When EC ¼ 1,000–2,000 – can affect many crops, and careful management practices should be followed. - When EC > 2,000 – can be used only for tolerant plants on permeable soils.
Residual chlorine	Excessive amounts of free residual chlorine (<0.05 mg/L) can be damaging to some sensitive crops (leaf burn). - Chlorination of water with high organic loads can form carcinogenic chloroforms or other halogenated organics.

Greywater composition exhibits marked variations depending on its source, with further nuances dictated by the locality in which it is generated. The confluence of diverse lifestyle choices, cultural customs, the installation of household products, and their chemical usage collectively shapes the distinct attributes of greywater.

The implications of infiltrating grey wastewater on soil pH and buffering capacity necessitate an understanding of the alkalinity, hardness, and pH of the infiltrating water. However, it is vital to recognize that the observed effects are significantly contingent upon the natural buffering capacity of the soil. The properties of the soil, including its capacity to adsorb pollutants, evolve as a direct consequence of infiltration. Furthermore, measurements of alkalinity and hardness, akin to turbidity and suspended solids, offer insights into the susceptibility of clogging within the system.[12] These parameters are chiefly influenced by the quality of the drinking water, with the impact of chemicals introduced during water usage generally exerting limited influence on these specific characteristics.

Table 3: Characteristics of Greywater from Various Countries and Sources

Parameters	Australia (Laundry)	Japan (Kitchen)	Korea (Kitchen + Shower)	India (Mixed)	Brazil (Mixed)	Turkey (Mixed)	Jordan (Mixed)
pH	9.3-10	X	X	7.3-8.1	X	7.1-7.2	6.35
EC (S/m)	190-1400	X	X	486-550	X	401-495	1830
Turbidity (NTU)	50-120	X	19-84.8	20.6-38.7	254	X	X
TSS (mg/L)	88-250	105	30-130	12-17.6	120	48-54	168
BOD (mg/L)	48-290	477	X	56-100	435	90-116	1056
COD (mg/L)	X	271	50-400	244-284	646	177-277	2568

***Note:** NTU - Nephelometric Turbidity Units; TSS - Total Suspended Solids; BOD - Biochemical Oxygen Demand; COD - Chemical Oxygen Demand.

It is important to note that the available data on greywater characterization is relatively limited. This can be attributed to the scarcity of comprehensive datasets and a broader implementation of greywater treatment and recycling technologies within real-world scenarios. Much of the existing research predominantly focuses on removing BOD and COD from wastewater, rather than preparing greywater for subsequent reuse. The presented data highlights the

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substantial variations in greywater characteristics among different countries and sources, which underscores the necessity for a more extensive and detailed exploration of greywater characteristics to facilitate effective and sustainable reuse strategies.

3. Materials and Methods: Sample Collection and Water Quality Assessment

In order to conduct a thorough assessment of water quality and achieve a comprehensive understanding of greywater in the specified region, a systematic sampling approach was implemented. Samples were meticulously gathered from various locations, including both households and apartment complexes. The initial phase of sampling focused particularly on the food court and hostel kitchen of UPES-Dehradun, India, with a duration of 4 days each month.

Each water source underwent a meticulous sampling process, where three grab samples were collected on the same day, with each acquisition spaced at two-hour intervals. These individual grab samples were subsequently combined to create a composite sample, ensuring an equal volume representation from each of the three grabs.

Onsite assessments were carried out to measure critical physico-chemical parameters, including pH, Total Dissolved Solids (TDS), and conductivity for each obtained sample. The analysis of additional physico-chemical parameters such as turbidity, nitrate, phosphorus, Chemical Oxygen Demand (COD), and Biochemical Oxygen Demand (BOD) was conducted at the UPES Water Research Laboratory. This systematic sampling and analysis strategy aimed to provide a comprehensive evaluation of water quality, laying the foundation for a holistic understanding of greywater dynamics in the region, with potential implications for computer science applications in environmental monitoring and data analysis.

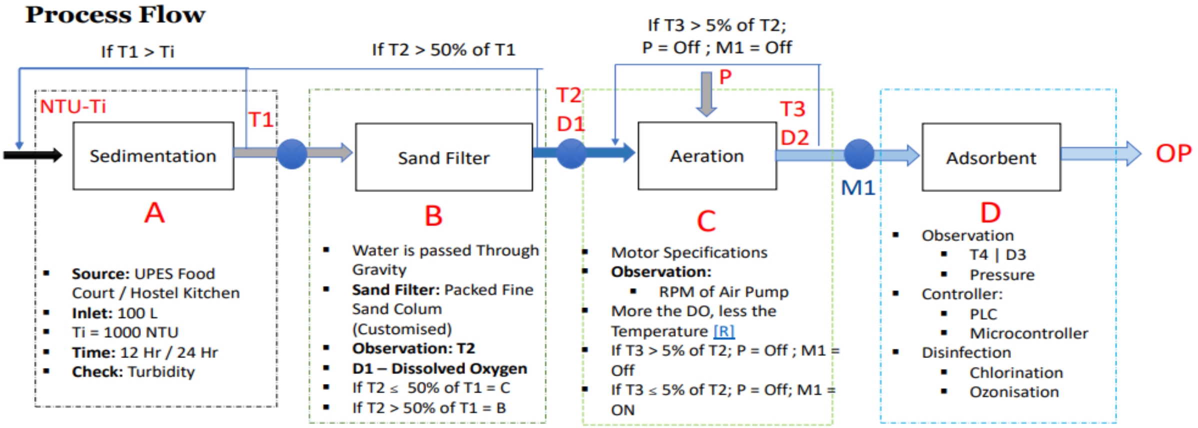

Figure 1: Process flow for Greywater treatment through hybrid water treatment technology

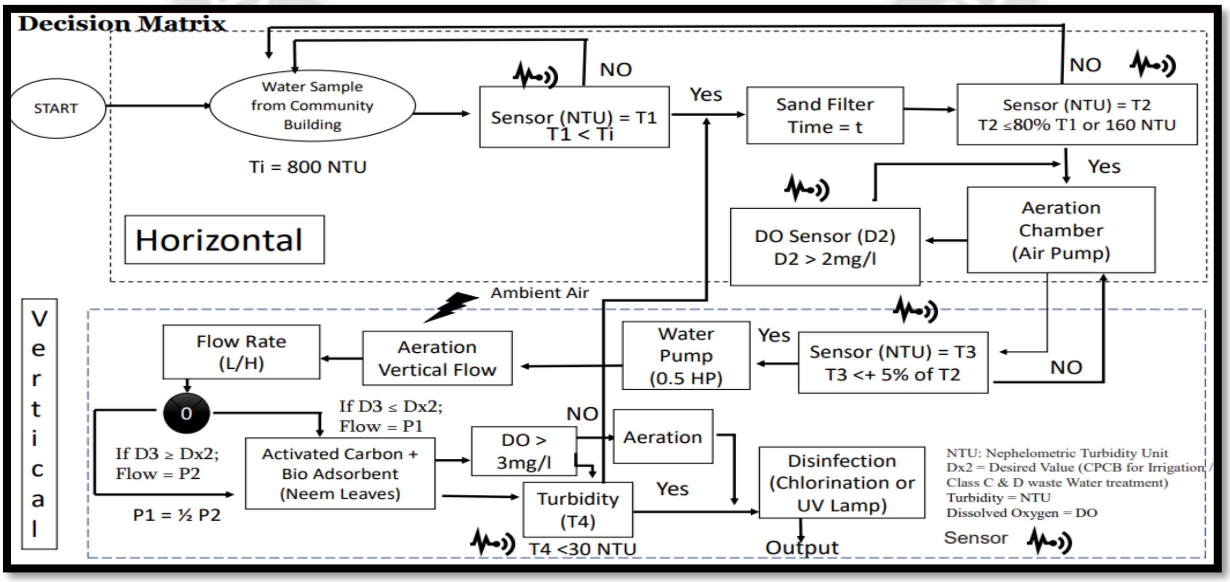

Figure 2: Decision Matrix support for treatment of water, and for the purpose of algorithm design.

The success of the entire system relies on every one of the four main elements listed above. For example, accurate warnings of hazards could not be made without accurate water-sensing data and effective risk assessment, while it will have no impact if the population is not prepared or if the alerts are received but not disseminated by the agencies receiving the messages.

Water which can be classified in three forms based on the Chemical, Physical and Bacteriological parameters namely clean water, grey water and dark water. Though, water treatment could be a promising alternative solution as water reuse is gaining a significant momentum. However, research shows opposite. Of 181 countries studied, only 55% have information on all three aspect, another 69 countries have data on one or two aspect and 57% countries does not have any information on any out of three aspect that includes waster generation, treatment and reuse. Water use has increased by three times since 1950. To meet out the world's water crises in the near future, water treatment and its reuse is necessity for all Water demand already exceed supplies in region with more that 40% of the world's population and in just 12 years as much as 60% of world's people may confront water scarcity. By understanding data available on waste water treatment done by various researchers and organization, only 70% of the generated waste water is treated by the high income countries, followed upper middle and lower income countries which treat 38% & 28% of the generated waste water respectively. The condition is even worse at nations with low income where only 8% of waste water go under any treatment. Clean water which remains to be of highest priority for the leaving with so much of little resource availability is not managed properly. About 70% of the world's fresh water is used for irrigation purpose that too increased upto 95% in some countries, the pressure on usage of clean water could be reduced by treating grey water. Grey water which can be defined as the waste water that includes water from baths, showers, kitchen, sinks is basically wash water, when managed and treated properly could be valuable resource for sectors like agricultural and horticultural.

Current Sensing Technology [13]:

1. Optical sensing technologies
2. UV-Vis spectrophotometry
3. Fibre optic sensors for real-time water quality monitoring
4. Electrochemical sensing technologies
5. Mass spectrometry for water micro-pollutants
6. Sensors based on sound and electromagnetic field interaction
7. Ultrasonic measurement
8. Electromagnetic waves sensor
9. Microwave sensing

To achieve adequate simultaneous detection of various water parameters, the current industry trend is to use a sensor array containing more than one type of sensor. Requirements include the need for robustness, reliability, energy efficiency, high sensitivity and selectivity and high accuracy; to be able to detect low level of traces with high confidence level and minimum sample preparation than before, to allow the detection of minute quantities of pollutants with high confidence and minimum sample preparation. It is usually required to map the spatial and temporal distribution of pollutants and locate them automatically. Distributed sensor networks can be used to achieve this purpose. However, an extra layer of control is needed to guarantee the seamless fusion of the sensor data. One major concern that hinders the sustainability of stationary water sensors, is the issue of bio-fouling. Accordingly, efforts in developing non-invasive techniques and mobile sensing methods, in addition to mitigation against bio-fouling issues need to be addressed.

Real-time monitoring of waste water quality provides a potential opportunity. However, associated with these techniques, are the needs for efficient powering and wireless connectivity that can resist channel impairments.

The advancement of microelectronics and microsystem devices brings great opportunities for improving water monitoring techniques and platforms. They usually come with advantages like low power consumption, small size, integrated control and data processing unit, wireless communication capabilities. For example, opto-chemical sensors or optodes are an attractive alternative to current electrochemical or electronic devices in terms of monitoring water, which is a suitable tool for the detection of a large number of chemical parameters. Optochemical sensors for parameters like oxygen, pH, carbon dioxide, and ammonia are reportedly available in the market or nearing the point of commercialization [14].

Most commonly measured water parameters and associated sensing technologies [3]

Parameter being measured	**Sensing technology**
Aluminium	Colorimetry; atomic absorption spectrometry
Antimony	Atomic absorption spectrometry

Ammonia	Colorimetric (manual; Nessler's reagent; automated; Berthelot reaction); ion selective electrode
Chlorine	Colorimetric; membrane electrode; polarographic membrane; 3-electrode voltametric method
Conductance	Conductivity cell; annular ring electrode; nickel electrode; titanium or noble metal electrode
Dissolved oxygen	Membrane electrode; 3-electrode voltametric method; optical sensor
Ions (Cl-, NO3-, NH4+)	Ion-selective electrodes
ORP	Potentiometric; platinum or noble metal electrode
pH	Titration with sodium hydroxide; proton selective glass bulb electrode, proton selective metal oxide; ion sensitive field effect transistor (ISFET)
Phosphates	Manual or automated colorimetry
Temperature	Thermistor
TOC	UV-persulfate digestion with near infrared detection or membrane conductometric detection of CO2
Turbidity	Optical sensor; nephelometric (light scattering) method

4. Analysis Of Greywater

To understand the water quality and to have a general overview of Greywater in the state, samples was collected from various locality, houses and apartments. In the phase, water samples from the Hostels and Residential areas were collected. From each source, three grab samples were collected on the same day in the interval of two hours. Composite sample was made by adding same volume of three grab samples. Onsite physico-chemical parameters like pH, TDS, and conductivity were measured for each sample collected. The remaining physico-chemical parameters such as turbidity, nitrate, phosphorus, COD and BOD were analyzed in the UPES Water Research Lab. The physico-chemical parameters were analyzed by different method which are given below, pH and conductivity were taken onsite during the sample collection by multimeter.

4.1. Total Dissolved Solid (TDS)

TDS was analyzed by gravimetric method. For this, the weight of empty beaker (W_1) was taken first. After that, the 50 ml water was filtered by 0.2 micron filter and pour in the beaker and kept in the oven on 180°C upto dryness of beaker. After beaker removed from the oven, the beaker was allowed to reach the room temperature by keeping in desiccator. The weight of beaker plus dissolved solids (W_2) was taken. The correct value of TDS was calculated by using the formula.

4.2. Chemical Oxygen Demand (COD)

COD analysis was carried out by open reflux method. 20 mL sample taken in COD flask. Mercuric sulfate (pinch of) was added in the COD flask. 10 mL 0.25N potassium dichromate solution and 30 mL concentrated sulfuric acid were added in the COD flask. The sample was refluxed for 2 hours at 150^0C. After cooling, the digested sample was titrated against 0.1N ferrous ammonium sulfate solution. The exact value of COD was calculated by using formula.

4.3. Turbidity

Turbidity of samples was analyzed on turbidity meter. Firstly, the standard solution was run on the meter. Then the turbidity of each sample was taken.

4.4. Nitrate

Nitrate analysis was carried out by UV/Vis spectrophotometric method. For this, the standard stock solution of nitrate was made by dissolving known amount of sodium nitrate in the 1000 mL distilled water. From this stock solution of nitrate, five standard solution of different concentration were made by diluting in distilled water. 1 mL 1N hydrochloric acid was added in 50 mL standard solution and the absorbance was taken on UV/Vis spectrophotometer at 220 nm and 275 nm. The calibration curve was plotted between concentration and absorbance. The absorbance of sample was taken at the same wavelength. For determining the concentration of nitrate in the sample, the calibration curve was used.

4.5. Phosphorus

Phosphorus analysis was carried out by UV/Vis spectrophotometric method. For this, the standard stock solution of phosphorus was made by dissolving known amount of sodium phosphate in the 1000 mL distilled water. From this stock solution of phosphorus, known volume of solution taken in 50 mL volumetric flask. To this 10 mL VM reagent was added and after 10 minutes, the absorbance was taken on UV/Vis spectrophotometer at 420 nm. The calibration curve was plotted between concentration and absorbance. The absorbance of sample was taken at the same wavelength. For determining the concentration of phosphorus in the sample, the calibration curve was used.

4.6. Biochemical Oxygen Demand (BOD)

BOD was carried out by wrinkle method (5 day). Distilled water was aerated for 12 hours and the incubated for 12 hours at 20^0C. When the temperature of distilled water reached to room temperature, added calcium chloride, ferric chloride, magnesium sulfate and phosphate buffer solution

1mL per liter of distilled water. The water was mixed properly and filled one BOD bottle for blank. Then seed was added in the distilled water in the concentration of 2 mL per liter. Again the water was mixed properly and filled one bottle for seed blank. Then the calculated amount of sample was taken in volumetric flask and diluted it with the distilled water. Two BOD bottles were filled for sample, one for zero day and one for fifth day. Zero-day sample was analyzed for the DO on the same day by adding manganese sulfate, alkali azide and sulphuric acid and immediately titrate against sodium thiosulfate using starch as indicator. Fifth day sample was kept in BOD incubator for five days at 20^0C. Fifth day sample was also analyzed for the DO. By applying the formula, the result of 5-day BOD was calculated.

5. Result and Analysis:

The table 4 presents the analysis of various parameters over four consecutive days. Each parameter is measured using specific units, and the values are expressed in either absolute terms or as a percentage change from the baseline.

1. Electrical Conductivity (µS/cm): This parameter measures the ability of water to conduct electrical current, which is influenced by dissolved ions. The values are reported both in absolute terms (µS/cm) and as percentage changes from Day-1.
2. TDS (mg/l): Total Dissolved Solids (TDS) represent the concentration of dissolved solids in water, including minerals, salts, and organic matter. Similar to electrical conductivity, values are provided in both absolute terms (mg/l) and as percentage changes from Day-1.
3. pH: pH indicates the acidity or alkalinity of water. It is a measure of the concentration of hydrogen ions in the water. The values in the table represent the pH levels observed on each day.
4. Turbidity (NTU): Turbidity measures the clarity of water by quantifying the amount of suspended particles present. The values are reported in Nephelometric Turbidity Units (NTU), with percentage changes from Day-1.
5. Nitrate (mg/l): Nitrate concentration in water is crucial as excessive levels can be harmful to human health and the environment. The values are presented in milligrams per liter (mg/l), along with percentage changes from Day-1.
6. Phosphorous (mg/l): Phosphorous is an essential nutrient for plant growth but can cause water quality issues when present in excess. The values are reported in mg/l, with percentage changes from Day-1.
7. BOD (mg/l): Biological Oxygen Demand (BOD) measures the amount of dissolved oxygen consumed by microorganisms during the decomposition of organic matter in water. The values are expressed in mg/l, with percentage changes from Day-1.
8. COD (mg/l): Chemical Oxygen Demand (COD) is another indicator of water quality, representing the amount of oxygen required to oxidize organic and inorganic matter in water. Values are provided in mg/l, with percentage changes from Day-1.

Table 4: Characteristics of Greywater

Parameters	**Day-1**	**Day-2**	**Day-3**	**Day-4**
Electrical Conductivity (µS/cm)	2042 (28.45%)	1732 (29.98%)	2310 (30.32%)	2045 (34.89%)
TDS (mg/l)	1750 (23.65%)	1460 (27.65%)	1920 (27.68%)	1735 (23.84%)
pH	8.4	7.4	9	8.5
Turbidity (NTU)	42 (60.23%)	34 (58.67%)	44 (61.89%)	41 (65.45%)
Nitrate (mg/l)	8 (18.44%)	7.5 (23.47%)	11 (23.48%)	9 (27.45%)
Phosphorous (mg/l)	0.75 (12.45%)	0.8 (8.34%)	1.0 (10.46%)	0.9 (8.44%)
BOD (mg/l)	185 (60.52%)	150 (56.89%)	237 (60.39%)	263 (55.35%)
COD (mg/l)	575 (55.63%)	540 (52.94%)	775 (67.43%)	890 (65.69%)

These parameters are essential for assessing the quality of water and monitoring changes over time. The presented data allows for the evaluation of trends and identification of any deviations from baseline conditions, which can inform appropriate interventions or remediation measures.

Table 5: Output characteristics of treated Greywater

Parameters	Day - 1	Day - 2	Day - 3	Day - 4
Electrical Conductivity (µS/cm)				
Initial concentration of composite sample	2042	1732	2310	2045
Concentration after primary treatment	1461 (28.45%)	1213 (29.98%)	1610 (30.32%)	1331 (34.89%)
Concentration after secondary treatment	927 (36.58%)	893 (26.38%)	1230 (23.59%)	1018 (23.56%)
Concentration after tertiary treatment	245 (73.53%)	282 (68.36%)	388 (68.44%)	332 (67.34%)
TDS (mg/l)				
Initial concentration of composite sample	1750	1460	1920	1735
Concentration after primary treatment	1336 (23.65%)	1056 (27.65%)	1389 (27.68%)	1321 (23.84%)
Concentration after secondary treatment	1082 (18.99%)	821 (22.26%)	1122 (19.23%)	1063 (19.53%)
Concentration after tertiary treatment	394 (63.59%)	210 (74.37%)	288 (74.35%)	278 (73.85%)
pH				
Initial concentration of composite sample	8.4	7.4	9	8.5
Concentration after primary treatment	8.2	7.5	8.6	8.6
Concentration after secondary treatment	8.1	7.3	8.2	8.3
Concentration after tertiary treatment	8	7.2	8.1	8.1
Turbidity (NTU)				
Initial concentration of composite sample	42	34	44	41
Concentration after primary treatment	16.7 (60.23%)	14.05 (58.67%)	16.8 (61.89%)	14.2 (65.45%)
Concentration after secondary treatment	12.1 (27.32%)	10.7 (23.57%)	12.8 (23.63%)	10.1 (28.94%)
Concentration after tertiary treatment	11.0 (9.42%)	9.72 (9.46%)	11.1 (13.59%)	9.11 (9.54%)
Nitrate (mg/l)				
Initial concentration of composite sample	8	7.5	11	9
Concentration after primary treatment	6.52 (18.44%)	5.74 (23.47%)	8.42 (23.48%)	6.53 (27.45%)
Concentration after secondary treatment	3.56 (45.37%)	3.24 (43.47%)	5.09 (39.49%)	3.50 (46.39%)
Concentration after tertiary treatment	2.78 (19.54%)	2.64 (18.72%)	3.80 (25.34%)	2.82 (19.34%)
Phosphorous (mg/l)				
Initial concentration of composite sample	0.75	0.8	1	0.9
Concentration after primary treatment	0.66 (12.45%)	0.73 (8.34%)	0.90 (10.46%)	0.82 (8.44%)
Concentration after secondary treatment	0.53 (19.34%)	0.60 (18.39%)	0.66 (26.48%)	0.62 (24.35%)
Concentration after tertiary treatment	0.41 (22.48%)	0.45 (24.56%)	0.53 (19.59%)	0.47 (24.44%)
BOD (mg/l)				
Initial concentration of composite sample	185	150	237	263
Concentration after primary treatment	73.0 (60.52%)	64.7 (56.89%)	93.9 (60.39%)	117 (55.35%)
Concentration after secondary treatment	18.8 (74.27%)	17.7 (72.62%)	20.2 (78.45%)	22.9 (80.52%)
Concentration after tertiary treatment	8.28 (55.92%)	6.84 (61.39%)	8.28 (59.05%)	10.2 (55.31%)

COD (mg/l)				
Initial concentration of composite sample	575	540	775	890
Concentration after primary treatment	255 (55.63%)	254 (52.94%)	252 (67.43%)	305 (65.69%)
Concentration after secondary treatment	75.8 (70.28%)	83.0 (67.35%)	87.6 (65.29%)	79.9 (73.84%)
Concentration after tertiary treatment	34.9 (53.92%)	36.9 (55.49%)	45.0 (48.62%)	48.7 (38.98%)

The presented tables 5 provide a detailed analysis of various water quality parameters across multiple days and treatment stages. The parameters examined include Electrical Conductivity (µS/cm), Total Dissolved Solids (TDS) in mg/l, pH, Turbidity (NTU), Nitrate (mg/l), Phosphorus (mg/l), Biochemical Oxygen Demand (BOD) in mg/l, and Chemical Oxygen Demand (COD) in mg/l. The data is organized by day (Day 1 to Day 4) and treatment stage (Initial, Primary, Secondary, and Tertiary).

1. Electrical Conductivity (µS/cm): The electrical conductivity values are measured in microsiemens per centimeter (µS/cm). The initial concentration of the composite sample is presented for each day, followed by concentrations after primary, secondary, and tertiary treatments. The values in parentheses represent the percentage decrease compared to the initial concentration.
2. Total Dissolved Solids (TDS) in mg/l: TDS values are measured in milligrams per liter (mg/l). Similar to electrical conductivity, the initial concentration is given for each day, along with concentrations after each treatment stage and the percentage decrease.
3. pH: The pH values represent the acidity or alkalinity of the water. Initial pH values are provided for each day, followed by values after primary, secondary, and tertiary treatments.
4. Turbidity (NTU): Turbidity, measured in nephelometric turbidity units (NTU), indicates the cloudiness or haziness of the water. Initial concentrations and those after each treatment stage are presented, along with the percentage decrease.
5. Nitrate (mg/l): Nitrate concentrations are given in milligrams per liter (mg/l). The initial concentration, concentrations after each treatment stage, and the percentage decrease are provided.
6. Phosphorus (mg/l): Phosphorus concentrations are measured in milligrams per liter (mg/l). Initial concentrations and those after each treatment stage, along with the percentage decrease, are presented.
7. Biochemical Oxygen Demand (BOD) in mg/l: BOD values indicate the amount of dissolved oxygen needed by aerobic biological organisms in a body of water. Initial concentrations, concentrations after each treatment stage, and the percentage decrease are given.
8. Chemical Oxygen Demand (COD) in mg/l: COD values represent the amount of oxygen required to chemically oxidize pollutants in water. Initial concentrations, concentrations after each treatment stage, and the percentage decrease are provided.

The analysis reveals the impact of each treatment stage on the specified water parameters, demonstrating the effectiveness of the treatment process in reducing the concentrations of various contaminants. The presented data forms a comprehensive and technical overview, essential for understanding the water treatment outcomes and ensuring compliance with water quality standards.

Table 6: Overall Performance of Greywater Treatment Over Four Consecutive Days

Parameters	Inlet Concentration (Day)	Outlet Concentration	Percentage Decrease
Electrical Conductivity (µS/cm)			
Day 1	2042	245	87.99
Day 2	1732	282	83.69
Day 3	2310	388	83.2
Day 4	2045	332	83.75
TDS (mg/l)			
Day 1	1750	394	77.48
Day 2	1460	210	85.58

Day 3	1920	288	85.02
Day 4	1735	278	83.97
pH			
Day 1	8.4	8	-
Day 2	7.4	7.2	-
Day 3	9	8.1	-
Day 4	8.5	8.1	-
Turbidity (NTU)			
Day 1	42	11	73.82
Day 2	34	9.72	71.4
Day 3	44	11.1	74.85
Day 4	41	9.11	77.79
Nitrate (mg/l)			
Day 1	8	2.87	64.15
Day 2	7.5	2.64	64.84
Day 3	11	3.8	65.43
Day 4	9	2.82	68.63
Phosphorous (mg/l)			
Day 1	0.75	0.41	45.26
Day 2	0.8	0.45	43.57
Day 3	1	0.53	47.07
Day 4	0.9	0.47	47.66
BOD (mg/l)			
Day 1	185	8.28	95.52
Day 2	150	6.84	95.44
Day 3	237	8.28	96.5
Day 4	263	10.2	96.11
COD (mg/l)			
Day 1	575	34.9	93.92
Day 2	540	36.9	93.16
Day 3	775	45	94.19
Day 4	890	48.7	94.52

The tables 6 outline the results of a water treatment process, presenting various parameters' values at the inlet (initial) and outlet (after treatment) concentrations over a span of four days. The key parameters measured include Electrical Conductivity, Total Dissolved Solids (TDS), pH, Turbidity, Nitrate concentration, Phosphorous concentration, Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD). The percentage decrease in concentration from the inlet to the outlet is also calculated.

1. Electrical Conductivity (µS/cm): The inlet concentration on Day 1 was 2042 µS/cm, reduced to 245 µS/cm at the outlet, resulting in a 87.99% decrease. Similar trends were observed on Days 2, 3, and 4, with consistent substantial percentage decreases.
2. TDS (mg/l): The inlet TDS concentration on Day 1 was 1750 mg/l, reduced to 394 mg/l at the outlet, with a 77.48% decrease. Days 2, 3, and 4 show consistent and significant percentage decreases in TDS.
3. pH: Inlet pH values fluctuated around neutral, with minimal variations between the inlet and outlet concentrations on all four days.
4. Turbidity (NTU): Turbidity exhibited a notable reduction, with percentage decreases ranging from 71.4% to 77.79% across the four days.

5. Nitrate (mg/l): Inlet nitrate concentrations on Day 1 were 8 mg/l, decreased to 2.87 mg/l at the outlet, resulting in a 64.15% decrease. Days 2, 3, and 4 demonstrated consistent percentage decreases in nitrate concentration.
6. Phosphorous (mg/l): Inlet phosphorous concentrations experienced percentage decreases ranging from 43.57% to 47.66% over the four days.
7. BOD (mg/l): Biochemical Oxygen Demand showed substantial percentage decreases, ranging from 95.44% to 96.5%, indicating effective treatment.
8. COD (mg/l): Chemical Oxygen Demand exhibited considerable percentage decreases, ranging from 93.16% to 94.52% over the four days.

Overall, the results suggest that the water treatment process effectively reduced the concentrations of various parameters, reflecting positive outcomes in terms of water quality improvement. The consistent trends across the parameters indicate the stability and reliability of the treatment process over the observation period.

Table 7: Comparative analysis of Overall performance

Parameters	Percentage Decrease Day 1	Percentage Decrease Day 2	Percentage Decrease Day 3	Percentage Decrease Day 4
Electrical Conductivity (µS/cm)	87.99	83.69	83.20	83.75
TDS (mg/l)	77.48	85.58	85.02	83.97
pH	-	-	-	-
Turbidity (NTU)	73.82	71.40	74.85	77.79
Nitrate (mg/l)	64.15	64.84	65.43	68.63
Phosphorous (mg/l)	45.26	43.57	47.07	47.66
BOD (mg/l)	95.52	95.44	96.50	96.11
COD (mg/l)	93.92	93.16	94.19	94.52

6. Conclusion:

The comparative analysis presented in Table 7 illustrates the performance assessment of greywater recycling over a four-day period. This research endeavors to underscore the viability of greywater (GW) recycling as a sustainable alternative water source, particularly due to its low organic content. Figure 1 and Figure 2, helps on Optimizing Water Reuse of Decision Support Techniques for Enhanced Dissolved Oxygen and Turbidity Evaluation.

Our investigation focuses on a comprehensive evaluation of the treated greywater, aiming to showcase its potential as an environmentally friendly water reuse strategy. Table 7 provides a comparative overview of the performance assessment conducted each day, highlighting the effectiveness of the treatment methods employed.

The findings reveal significant improvements across various crucial parameters following treatment. Specifically, there is a notable decrease in electrical conductivity, total dissolved solids (TDS), turbidity, nitrates, phosphorous, biological oxygen demand (BOD), and chemical oxygen demand (COD) over the four-day period. These positive outcomes signify the efficacy of the implemented techniques in enhancing the quality of recycled greywater.

Overall, the results underscore the promising potential of greywater recycling as a sustainable solution for water resource management, emphasizing its role in mitigating water scarcity and promoting environmental conservation.

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Reference:

1. K. Kujawa-Roeleveld and G. Zeeman, “Anaerobic treatment in decentralised and source-separation-based sanitation concepts,” Rev Environ Sci

Biotechnol, vol. 5, pp. 115–139, 2006.

2. M. M. Karpiscak, R. G. Brittain, and K. E. Foster, “DESERT HOUSE: A DEMONSTRATION/EXPERIMENT IN EFFICIENT DOMESTIC WATER AND ENERGY USE 1,” JAWRA Journal of the American Water Resources Association, vol. 30, no. 2, pp. 329–334, 1994.
3. P. H. Gleick, “Global freshwater resources: soft-path solutions for the 21st century,” Science (1979), vol. 302, no. 5650, pp. 1524–1528, 2003.
4. A. T. Tiruneh, “A grey water dam design for the treatment and reuse of grey water from single and multiple households,” J Water Resour Prot, vol. 6, no. 14, p. 1259, 2014.
5. M. Pidou, F. A. Memon, T. Stephenson, B. Jefferson, and P. Jeffrey, “Greywater recycling: treatment options and applications,” in Proceedings of the Institution of Civil Engineers-Engineering Sustainability, Thomas Telford Ltd, 2007, pp. 119–131.
6. M. Halalsheh et al., “Grey water characteristics and treatment options for rural areas in Jordan,” Bioresour Technol, vol. 99, no. 14, pp. 6635–6641, 2008.
7. S. B. Parjane and M. G. Sane, “Performance of grey water treatment plant by economical way for Indian rural development.,” Int J Chemtech Res, vol. 3, no. 4, pp. 1808–1815, 2011.
8. Balasubramanian, S., Raparthi, M., Dodda, S. B., Maruthi, S., Kumar, N., & Dongari, S. (2023). AI-Enabled Mental Health Assessment and Intervention: Bridging Gaps in Access and Quality of Care. PowerTech Journal, 47(3), 81. https://doi.org/10.52783/pst.159
9. G. T. Seo, B. H. Moon, Y. M. Park, and S. H. Kim, “Filtration characteristics of immersed coarse pore filters in an activated sludge system for domestic wastewater reclamation,” Water Science and technology, vol. 55, no. 1–2, pp. 51–58, 2007.
10. M. Gual, A. Moià, and J. G. March, “Monitoring of an indoor pilot plant for osmosis rejection and greywater reuse to flush toilets in a hotel,” Desalination, vol. 219, no. 1–3, pp. 81–88, 2008.
11. J. Kim, I. Song, H. Oh, J. Jong, J. Park, and Y. Choung, “A laboratory-scale graywater treatment system based on a membrane filtration and oxidation process—characteristics of graywater from a residential complex,” Desalination, vol. 238, no. 1–3, pp. 347–357, 2009.
12. E. Marinelli et al., “Water-energy-food-climate Nexus in an integrated peri-urban wastewater treatment and reuse system: From theory to practice,” Sustainability, vol. 13, no. 19, p. 10952, 2021.
13. W. Zhang et al., “Technologies for pollutant removal and resource recovery from blackwater: a review,” Front Environ Sci Eng, vol. 17, no. 7, p. 83, 2023.
14. ITU-T L.1500 Series – Requirements for water sensing and early warning systems ; Environment And ICTs, Climate Change, E-Waste, Energy Efficiency; Construction, Installation and Protection of Cables and Other Elements of Outside Plant
15. Li, Fangyue, Knut Wichmann, and Ralf Otterpohl. "Review of the technological approaches for grey water treatment and reuses." Science of the total environment 407.11 (2009): 3439-3449.