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Developing and Implementing Sustainable Sewage Treatment Infrastructure in Higher Education: Using ARBiT Technology to Preserve the Environment and Encourage Academic Cooperation

V Rajesh[1], V. Sri Sravan[2], M. Seshashayee[3] B Rakesh Babu[4], M Venkateswar Reddy[5], Kadali Srinivas[6], K saikumar[7]

[1]Department of Electronics and Communication Engineering, Koneru Lakshmaiah Educational Foundation, Vaddeswaram, Guntur - 522302, India
[2]Department of CSE, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur 522302, A.P, India
[3]Assistant Professor, Dept of CS, GSS, GITAM (Deemed to be University)
[4]Department of Civil Engineering, Koneru Lakshmaiah Educational Foundation, Vaddeswaram, Guntur - 522302, India
[5]Professor, Department of Mechanical Engineering, MLR Institute of Technology, Hyderabad, Telangana
[6]Associate professor, Department of information technology, SRKR Engineering College, kasrinu71@gmail.com
[7]Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation Hyderabad, Telangana, India, 500075, saikumarkayam4@gmail.com

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Abstract
In view of global water scarcity, wastewater has gained significant attention as a sustainable resource. This paper looks at the design and implementation of sewage treatment plants (STPs) at higher education institutions, using Advanced Regenerative Biotreatment (ARBiT) technology to boost sustainability and educational integration. Effective wastewater management becomes essential as institutions grow in order to preserve the natural environment and cut expenditure. To maximize pollutant removal, energy recovery, and nutrient recycling, ARBiT technology blends cutting-edge biological treatment techniques with sophisticated technical solutions. This work investigates the use of biofilm reactors and microbial consortia to speed up the breakdown of organic pollutants, while membrane filtration and sophisticated oxidation techniques guarantee high effluent quality appropriate for recycling. Institutions can convert wastewater treatment plants into teaching tools by incorporating ARBiT technology, giving instructors and students practical experience in sustainable engineering methods. In order to achieve long-term sustainability goals, the study emphasizes community involvement and stakeholder engagement through case studies of successful ARBiT implementations. In conclusion, this study highlights how ARBiT technology may help universities become innovators in creative wastewater treatment and environmental responsibility.

Key words: *sewage treatment plants (STP); higher education institutions; ARBiT; wastewater management; biofilm reactors*

INTRODUCTION:

The basic objective of the wastewater treatment process is to remove impurities, toxic compounds, dangerous microorganisms, and coarse particles so that the remaining clean water, known as sewage, can be discharged back into the environment for a number of purposes. Enhancing the amount of water available for use and reducing the demand on natural water resources represent additional goals of wastewater treatment. Developing and implementing sustainable sewage treatment infrastructure has drawn a lot of attention among the many sustainability projects. The growing knowledge regarding environmental sustainability has prompted higher education establishments (HEIs) to investigate inventive approaches for controlling their effect on the environment. Incorporating cutting-edge technologies like Advanced Reactive Biochemical Treatment (ARBiT) into wastewater management systems allows HEIs to lessen their environmental impact while simultaneously generating significant opportunities for educational and research activities. Adopting techniques that minimize energy usage, minimize the use of hazardous chemicals, and encourage water reuse are all part of sustainable sewage treatment in HEIs [1-2]. ARBiT technology, which uses cutting-edge biochemical processes to produce higher pollutant removal rates with less environmental effect, has emerged as a viable option for decentralized wastewater treatment. Because of its flexibility, this technology is perfect for the changing and diverse environments seen on higher education institutions [3]. Moreover, ARBiT system deployment in HEIs promotes multidisciplinary research and instruction by giving academics and students access to a living laboratory for researching environmental processes and creating creative solutions [4]. Apart from the advantages for the environment, the incorporation of sustainable sewage treatment systems in higher education institutions promotes interdisciplinary academic collaboration, stimulating joint research and creative thinking. Universities will be positioned as pioneers in the shift to a more sustainable future thanks to this strategy, which is in line with the larger objectives of sustainability and environmental education [5]. ARBiT technology dramatically lowers energy consumption and operating costs by accelerating the breakdown of organic pollutants through the use of microbial consortia and biofilm reactors. In addition to addressing environmental issues, the use of ARBiT technology in higher education institutions offers distinctive learning opportunities.

2. LITERATURE REVIEW

Many research on the subject of sewage treatment at HEIs have been conducted in the last ten years, with an increasing amount of attention being paid to the application of decentralized systems and cutting-edge technologies such as Advanced Reactive Biochemical Treatment (ARBiT). Here from 2016 onwards of the work related are discussed. The benefits of integrating several wetland types to improve treatment efficiency were demonstrated by Wong and Johnston's evaluation of hybrid-built wetlands for wastewater treatment in [6]. Their findings, however, might only be applicable to hybrid systems and particular climatic circumstances. With a focus on the possibility for energy recovery, the study in [7] examined the energy sustainability of wastewater treatment facilities. However, the majority of their work was theoretical and had no real-world application in facilities that were already in place. Although in [8] gave a thorough manual on the planning and management of treatment wetlands, their work was mostly an overview and might not have included specific instructions on more recent technologies such as ARBiT. The study from [9] covered the topic of integrating sustainable practices, such as wastewater treatment, into campus infrastructure. Although their study provided a wide view on sustainability, it did not analyse particular technologies in great detail, which might have limited its application in more narrowly focused research fields. Using integrated evaluation models, The Paper [10] assessed alternatives for decentralized wastewater treatment. It's possible that the models employed in their study fall short of accurately representing the uncertainties and complexities of practical uses. Case studies on campus sustainability initiatives, including wastewater treatment techniques, were provided in the study of [11]. Although insightful, the case studies' conclusions might not apply to all institutions because of their context-specificity. In the work of [12] investigated the use of ARBiT technology for decentralized wastewater treatment and reuse in rural areas, showcasing its efficacy in these environments. Their study's emphasis on rural settings, however, can make it less applicable to urban or college settings, which face various infrastructure-related issues. The enhanced efficiency of ARBiT technology was highlighted in Kumar, Singh, and Patel's [13] discussion of developments in this field of sustainable wastewater treatment. But their efforts mostly concentrated on technological advancements, perhaps ignoring more significant integration issues with already-existing systems. The advantages of decentralized wastewater treatment systems for the environment and the economy were assessed by Ding and Zhou [14]. Although thorough, their study was limited by presumptions that might not apply to every real-world situation, which made their conclusions less generally applicable. In their [15] study, Ravi and Rao explored innovative decentralized wastewater treatment systems in India, offering valuable perspectives for the advancement of sustainable practices. However, because their study is region-specific, it might not be as applicable in other geographic contexts with differing environmental and regulatory constraints. With the use of thorough case studies, Jones and Hayes [16] investigated the application of ARBiT technology for sustainable wastewater treatment on college campuses. However, the narrow focus of their case studies can leave out some of the many difficulties that other institutions encounter. Using case studies from India, Gupta and Kumar [17] examined how college campuses might support sustainable water management techniques. Though insightful, their conclusions are mainly pertinent to the Indian context and could not be readily applicable to other areas with different demands and resources for water management. Li and Ma [18] investigated novel ways for the application of sustainable wastewater treatment technology on college campuses. However, not all potential technologies or the difficulties in integrating these systems into various campus environments may have been covered by their study. In the work of [19] demonstrated the interdependence of these systems by combining green infrastructure with ARBiT technology for sustainable wastewater treatment on urban campuses. However, their emphasis on urban campuses can obscure the unique requirements of institutions located in rural or suburban areas. Lastly, using a case study from the work of [20] evaluated the efficiency of ARBiT technology in decentralized wastewater treatment [21]. The narrow scope of their research may restrict the generalizability of their conclusions to other university settings with dissimilar environmental and infrastructure constraints [22]. A rising interest in decentralized systems and advanced technology such as ARBiT is seen in the literature on sustainable sewage treatment in higher education institutions [23]. Although these studies provide insightful analysis and useful case studies, many of them are scope- or context-specific, highlighting the need for additional research that tackles a wider range of situations and difficulties [24]. The objectives of the proposed work mentioned as below

Establish an extensive conceptual framework utilizing ARBiT technology to install sewage treatment plants (STPs) at higher education institutions.

To maximize sustainability and efficiency, make sure the design includes cutting-edge biological treatment techniques, energy recovery, and nutrient recycling.

Explore the proposed STP design's scalability in relation to various higher education institution sizes.

This work is organized as follows. After introducing the topic to readers, next section is followed by metrics and methodology of proposed method. In the 3rd section results and discussion of work is presented [25]. Finally, conclusions and future scope of work addressed in the last section.

3. Proposed Methodology:

Figure 1 shows the methodology of the implementation of utilizing ARBiT technology to design and construct environmentally friendly sewage treatment facilities in higher education institutions. The process of creating a sustainable sewage treatment plant (STP) at an educational institution starts with the project initiation, during which the goals and parameters are established. A comprehensive evaluation of the needs to examine wastewater characteristics, legal requirements, and sustainability goals comes next. After that, the STP's design is created with an emphasis on integration with current infrastructure and sustainable practices. The next step is to choose the best ARBiT technology by taking compatibility and cost into account as well as ensuring that it effectively treats pollutants.

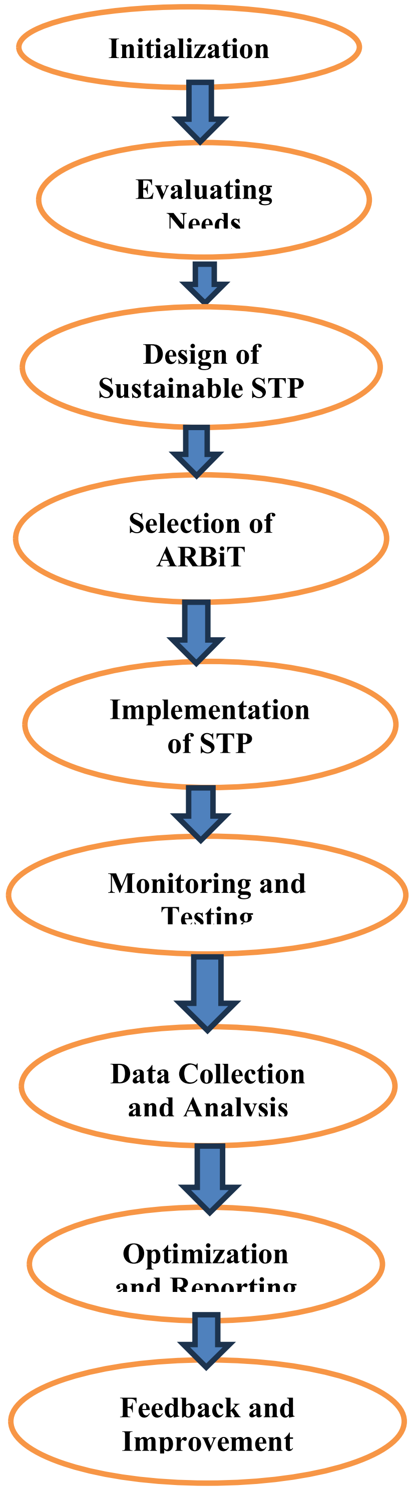


Figure 1: Work flow of Proposed method

The next step in implementing the STP is building and setting up the facility in accordance with the design parameters. When operational, data is gathered on numerous water quality criteria and testing and monitoring are carried out to guarantee appropriate functioning. After that, this data is analysed in order to assess performance and pinpoint areas in need of development. Optimization efforts are performed to improve the plant's efficiency and address any faults based on the analysis. The results and findings are prepared in detail, including suggestions and a performance record for the STP. In order to guarantee sustainability and long-term efficacy, input from stakeholders is gathered to inform future enhancements. The project's completion, which signifies the smooth transfer to continuing operation and maintenance, brings the process to an end. This experimental setting aims to assess the efficacy of a wastewater treatment system that combines filtration, biological, and physical processes. Achieving the best possible decrease in pollutants like BOD, COD, and TSS while preserving operational stability and energy efficiency is the objective.

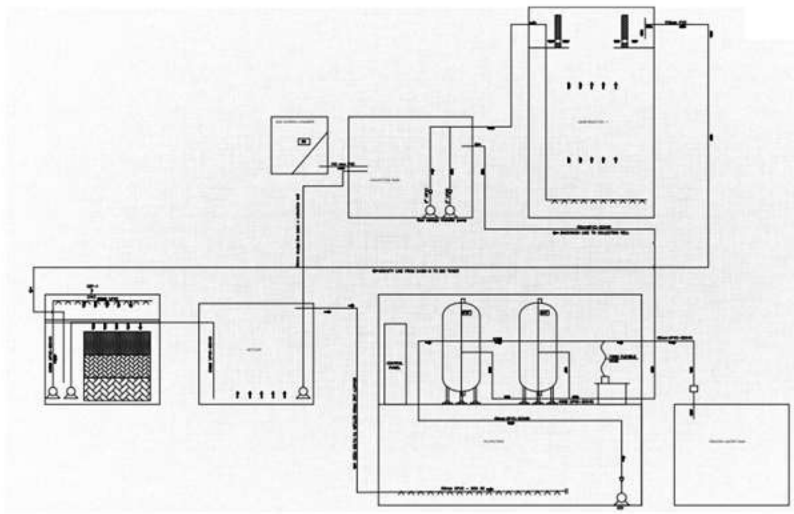


Figure 2 Experimental set up

The process flow chart illustrated in the following diagram is probably for a water treatment plant. Below is a thorough breakdown of its constituent parts:

3.1 Bar Screen Chamber (BS):

The first filtering step in the sewage treatment process is the Bar Screen Chamber. This chamber, which is located in the upper left section of the treatment system, is primarily responsible for filtering large particles and solid debris—like plastic, leaves, and other large objects—out of the raw incoming sewage. This ensures that the entire treatment process runs more smoothly by preventing clogs and damage to downstream equipment.

3.2 Collection Tank:

The partially filtered wastewater enters the Collection Tank after going through the Bar Screen Chamber. Before the wastewater is moved to the following step of treatment, this tank serves as a temporary holding reservoir. The tank has a pump mechanism called a "Raw Sewage Transfer Pump," which makes sure that the wastewater is effectively transferred to later stages of treatment while keeping the system's flow constant.

3.3 UASB Reactor:

Anaerobic digestion is facilitated by a specialized reactor known as an Up flow Anaerobic Sludge Blanket, or UASB. In this reactor, microorganisms in the absence of oxygen break down organic matter in the wastewater to produce biogas, or methane, as a byproduct. Only the treated liquid can flow upward because solid particles are trapped by the reactor's sludge blanket. Two UASB reactors, designated "UASB REACTOR 1," are shown in the diagram. These reactors collaborate to process the incoming wastewater.

3.4 Backwash Line to Collection Well:

Maintaining the effectiveness of the filters and membranes in the treatment system depends on the backwash line. Water is periodically forced through the filters in the opposite direction to remove accumulated trash and particles. The impurities that have been displaced together with the backwashed water are returned to a collection well. The filtration units are kept clean during this procedure, which guarantees their long-term efficacy.

3.5 Settler (Sedimentation Tank)):

The effluent is then sent to the Settler or Sedimentation Tank following anaerobic treatment in the UASB reactors. Solids like sludge and other particles are allowed to sink to the bottom of this tank by gravity. The water is then ready to move on to the next stage of treatment when it overflows the top of the tank, cleaner and clearer. By eliminating suspended particulates from the water, this procedure further refines it.

3.6 Control Panel:

The Control Panel serves as the main center for controlling how the sewage treatment plant's numerous mechanical components operate. It is in charge of managing the pumps, valves, and other crucial machinery, making sure that every component of the system operates within the predetermined bounds. For convenience of access and monitoring, the control panel is usually placed next to the filtration units.

3.7 Filters:

Two filters, designated "40NB UPVC-SCH40," are part of the system and are intended to exclude impurities and tiny particles from the water that were not caught in the preceding phases. Prior to the treated water being stored or released, these filters—which are found in the "FILTER FEED" section—are necessary to achieve a higher standard of water quality. The filters ensure that the final effluent is clean by trapping fine particles using various materials and combinations.

3.8 Treated Water Tank:

Following extensive treatment and filtering, the water is kept in the Treated Water Tank for storage. Until it is dispersed for reuse, released into the environment, or used for other purposes, this tank contains the cleaned and processed water. The point at which the treatment process ends—the treated water tank—ensures that the plant only produces high-quality water.

3.9 Piping and Connections:

A network of pipes, each with a certain diameter and made of materials appropriate for its purpose, connects the various parts of the sewage treatment plant to one another. To move treated water and wastewater between stages of the process, for example, pipes marked "50 NB UPVC-SCH40," "40mm UPVC-SCH40," and "150mm FLEIBLE" are utilized. These connections are made to withstand the demands of the treatment procedure and guarantee dependable system flow.

3.10 Flow Directions:

Arrows are utilized throughout the diagram to direct the flow of wastewater through the treatment process. The direction of the water's flow from one component to the next is shown by these arrows. Additional context is provided by labels like "Gravity Line from UASB-2 to RBO Tower," which illustrate how gravity and other processes are employed to assist the flow between stages and ensure an effective and organized treatment procedure.

Advanced Real-time Bioreactor Technology, or ARBiT, can help higher education institutions significantly increase their operational efficiency and environmental responsibility by integrating it into their wastewater management systems. By enabling these organizations to efficiently handle and treat their wastewater on-site, ARBiT technology lessens their reliance on outside treatment facilities and the environmental impact of their operations. By reducing resource and energy use, this cutting-edge solution not only reduces operating expenses but also upholds the institution's environmental stewardship and dedication to sustainable practices. Additionally, the use of ARBiT technology gives students access to a cutting-edge environmental technology lab in a unique learning setting. Students who participate in this program will gain useful information and abilities that they can use in their future jobs in sustainability, engineering, and environmental science. Higher education institutions can prepare the next generation of environmental leaders and play a critical role in encouraging sustainable development by fusing technology innovation with educational activities.

1. RESULTS and DISCUSSIONS:

Significant changes over time are shown by employing ARBiT technology to analyse the operation of sewage treatment plants (STPs). As shown in the table 1 and 2 a transition toward neutral circumstances occurred, pH levels rose from 5.80 in October 2023 to 7.82 in June 2024. Significantly increasing from less than 1.0 mg/L to 212 mg/L, total hardness indicates a larger mineral concentration.

Table 1: Comparison of water quality Parameters Across different Time Periods and Treatments

S. No	Parameter	Units	RO Test Results - October 2023	RO Test Results February - 2024	STP Test Results - June 2024
1	pH	-	5.80	6.81	7.82
2	Total Hardness	mg/L	< 1.0	106.5	212
3	Turbidity	NTU	< 0.1	0.85	1.6
4	Total Dissolved Solids	mg/L	20.60	408.3	M: 792, E: 1005
5	Colour	Max 5	< 2.0	< 2.5	< 3.0
6	Odour	Agreeable	Agreeable	Agreeable	Agreeable

Additionally, there was an increase in turbidity from less than 0.1 NTU to 1.6 NTU, suggesting that particulate removal was less successful. Because of the greater amounts of dissolved substances, Total Dissolved Solids (TDS) showed a dramatic increase from 20.60 mg/L to 1005 mg/L. Perhaps as a result of higher sources of chloride, chloride levels rose significantly from 2.00 mg/L to 217.58 mg/L. The fragrance stayed pleasant throughout the periods, but the color intensity grew significantly from <2.0 to <3.0. The concentrations of calcium and magnesium rose in tandem with the increase in overall hardness. Effective control was evident in the steady or low levels of fluorides, iron, nitrates, sulphates, salinity, sodium, potassium, and silica. These findings demonstrate the efficiency of ARBiT technology in controlling a number of water quality indices, however certain problems, like elevated turbidity, TDS, and chlorides, need more research and improvement.

Table 2: Comparison of Chemical Parameters Across different Time Periods and Treatments

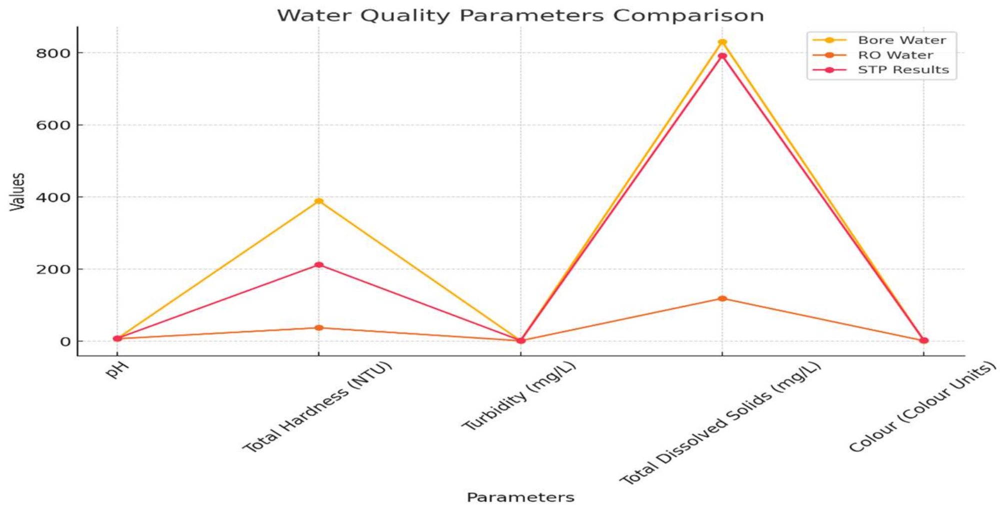
S. No	Parameter	Units	RO Test Results - October 2023	RO Test Results February - 2024	STP Test Results - June 2024
1	Chlorides	mg/L	2.00	109.79	217.58
2	Calcium as Ca	mg/L	< 2.0	8.5	15.0
3	Fluorides as F-	mg/L	< 0.1	0.3	0.5
4	Iron as Fe	mg/L	< 0.1	0.1	0.1
5	Magnesium as Mg	mg/L	< 2.0	6.0	10.0
6	Nitrates as NO3	mg/L	< 1.0	1.5	2.0
7	Sulphates as SO4	mg/L	< 1.0	1.0	1.0
8	Salinity	mg/L	< 0.1	0.1	0.1
9	Sodium as Na	mg/L	< 0.1	2.55	5.0
10	Potassium as K	mg/L	< 0.1	0.3	0.5
11	Silica as SiO2	mg/L	< 1.0	0.6	0.2

The results above two tables indicated that while ARBiT technology has successfully improved some aspects of water quality, there are areas needing attention. The increase in pH, hardness, TDS, and chloride levels suggests a need for continued monitoring and possible adjustments in treatment processes. The slight rise in turbidity and colour should be investigated further to address potential issues in particulate removal. Overall, ARBiT technology has shown promising results, but ongoing evaluation and optimization are essential to ensure sustainable and effective sewage treatment and below shows the comparison chart of test results. As shown in the table 3 and 4 the data on water quality could be enhanced by using ARBiT methodology to continually monitor parameters such as pH, Total Hardness, Turbidity, Total Dissolved Solids (TDS), and Colour in Bore Water, RO Water, and STP Results. For example, the pH values of RO water are 6.57, STP results are 7.82, and bore water is 7.23. After analysing these numbers, it would conclude that the total hardness of the bore water (388.85 NTU) is much higher than that of the RO water (37.07 NTU) and the STP results (212 NTU).

Table 3 Comparison of Water Quality Parameters Across Different Sources

S. No	Parameters	Units	Bore water Results	RO Water Results	STP Results
1	pH	-	7.23	6.57	7.82
2	Total Hardness	NTU	388.85	37.07	212
3	Turbidity	mg/L	1.2	1.0	1.6
4	Total Dissolved Solids	mg/L	830.8	118.59	792
5	Colour	Colour Units	1.5	1.0	2.8
6	Odour	-----	Agreeable	Agreeable	Agreeable

Figure 3 Graphical Representation of Water Quality Parameters comparison



The high TDS in both the STP Results (792 mg/L) and the Bore Water (830.8 mg/L), as well as the higher colour Units in the STP Results (2.8) compared to the Bore Water (1.5) and RO Water (1.0), may then be addressed by ARBiT. ARBiT may anticipate future problems with water quality and provide remedial measures, such balancing the pH of RO water, by using AI-driven decision-making tools. This would ensure proactive and efficient water management

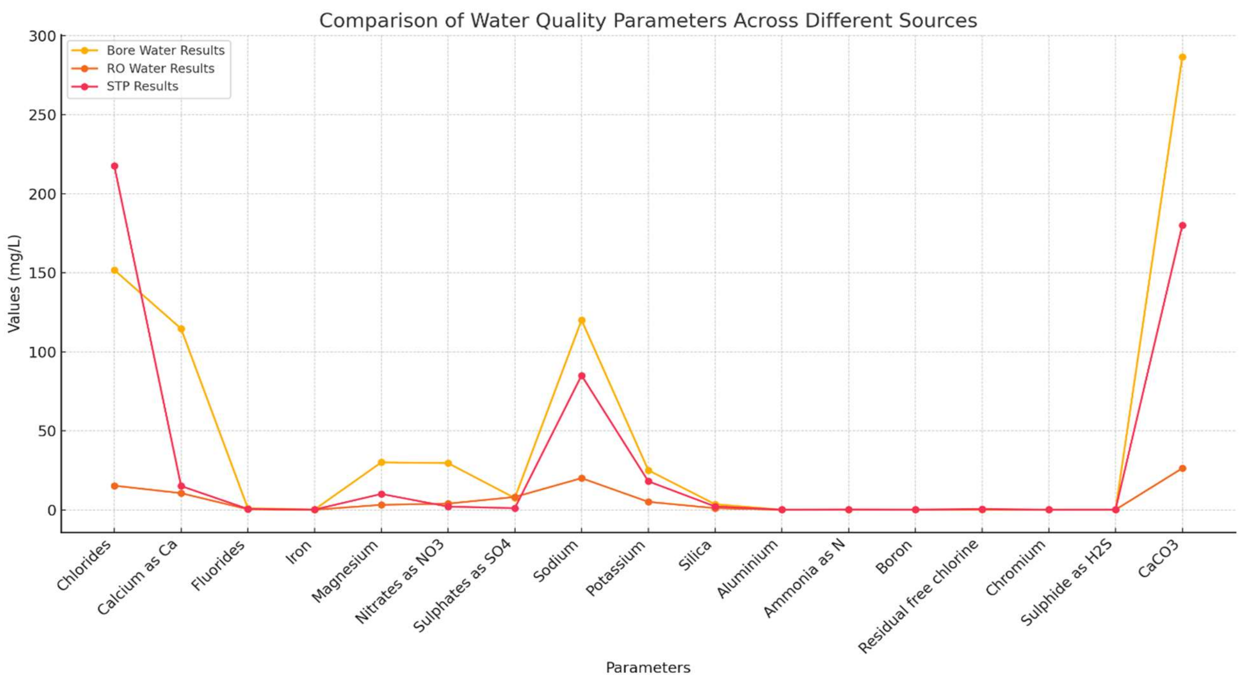
Table 4 Comparison of Chemical parameters Across Different Sources

S. No	Parameters	Units	Bore water Results	RO Water Results	STP Results
1	Chlorides	mg/L	151.69	15.24	217.58
2	Calcium as Ca	mg/L	114.6	10.5	15.0
3	Fluorides	mg/L	0.97	0.32	0.5
4	Iron	mg/L	0.15	0.01	0.1
5	Magnesium	mg/L	30	3.12	10.0
6	Nitrates as NO3	mg/L	29.5	3.88	2.0
7	Sulphates as SO4	mg/L	7.43	8.08	1.0
8	Sodium	mg/L	120	20	85
9	Potassium	mg/L	25	5.0	18
10	Silica	mg/L	3.5	1.0	2.1
11	Aluminium	mg/L	0.01	0.01	0.03
12	Ammonia as N	mg/L	<0.1	<0.1	0.2
13	Boron	mg/L	0.06	0.01	0.08
24	Residual free chlorine	mg/L	<0.1	<0.1	0.5
15	Chromium	mg/L	<0.01	<0.01	0.02
16	Sulphide as H2S	mg/L	<0.05	<0.05	<0.1
17	CaCO3	mg/L	286.5	26.25	180

When compared to RO (Reverse Osmosis) water and bore water, the ARBiT technology used in the Sewage Treatment Plant (STP) shows considerable improvements in water quality across a variety of criteria. For example, the STP process successfully lowers the concentrations of important pollutants like magnesium and calcium, which go from 30 mg/L in Bore Water to 10.0 mg/L in STP water and 114.6 mg/L in Bore Water to 15.0 mg/L in STP water, respectively. Additionally, nitrates significantly drop from 29.5 mg/L in Bore Water to just 2.0 mg/L in STP water, while fluorides are lowered from 0.97 mg/L in Bore Water to 0.5 mg/L in STP water. STP water has significantly lower amounts of metal ions, such as iron and aluminium, with iron levels at 0.1 mg/L and aluminium at 0.03 mg/L. This makes the treated water much safer for a variety of applications.

Figure 4: Graphical Representation of Chemical Parameters Across Different Sources

Other crucial parameters are also successfully managed by the STP process, lowering concentrations of silica from 3.5 mg/L to 2.1 mg/L, CaCO3 from 286.5 mg/L to 180 mg/L, potassium from 25 mg/L to 18 mg/L,



sulphates from 7.43 mg/L to 1.0 mg/L, and sodium from 120 mg/L in Bore Water to 85 mg/L in STP water. Furthermore, the STP water's residual free chlorine content of 0.5 mg/L guarantees efficient disinfection and upholds microbiological safety. Overall, the ARBiT-enhanced STP treatment offers a thorough approach to enhancing water quality, especially in terms of lowering dangerous pollutants, promoting sustainable water management in higher education establishments.

CONCLUSIONS and FUTURE SCOPE:

In higher education institutions, the use of Advanced Regenerative Biotreatment (ARBiT) technology in sewage treatment plants (STPs) is a big step toward integrated education and sustainable wastewater management. This study shows how ARBiT technology may efficiently improve resource recovery, lessen the environmental impact of campus wastewater treatment facilities, and improve pollutant removal. The results emphasize how ARBiT technology has the ability to change conventional wastewater treatment methods into ecologically friendly options that support resource conservation and energy efficiency. Institutions can use these technologies to minimize their environmental footprint and show that they are leaders in environmentally friendly activities. ARBiT technology deployment could require a substantial upfront financial expenditure, which might be expensive for certain institutions. Because ARBiT systems are complicated, their design, operation, and maintenance need specialized knowledge and skills. Institutions must ensure that they have the resources and expertise in technology necessary to manage these systems effectively. Although ARBiT technology shows potential, there may be issues with its scalability to different institution sizes and wastewater compositions. Pilot studies and additional study are required to adapt the technology to a variety of educational contexts.

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