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Promoting Sustainable Clean Water Access: An Eco-Friendly Rainwater Filtration System Using Coconut Shell-Based Activated Charcoal and Crushed Glass in Water-Scarce Communities

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Abstract: ***Water scarcity and declining water quality continue to affect many communities in the Philippines, particularly in Batangas, where contamination of groundwater and rainwater sources has become a growing concern. This study developed and evaluated an eco-friendly rainwater filtration system utilizing coconut shell–based activated charcoal and crushed recycled glass as sustainable filtration media. Three charcoal-to-glass ratios (3:1, 1:3, and 2:2) were tested to determine their effectiveness in improving rainwater quality, as measured by color clarity, odor removal, and reducing impurities. Using a quantitative experimental research design supported by a community-based survey, the study assessed both the filtration performance and practical applicability of the system. Results demonstrated that the 3:1 ratio consistently produced the best outcomes, showing the clearest water, complete odor removal, and the highest reduction of particles. Comparative analysis further revealed that the proposed system is more cost-efficient, accessible, and environmentally sustainable than conventional commercial filters due to its reliance on low-cost, biodegradable, and locally available materials. Survey responses indicated strong acceptance of the system for household and community use. Overall, the findings suggest that combining coconut shell–based activated charcoal with crushed glass presents a viable, affordable, and sustainable solution for improving rainwater quality in water-scarce communities.***

Keywords: ***activated charcoal; crushed recycled glass; rainwater filtration; water quality improvement; sustainable water treatment; eco-friendly filtration system; water-scarce communities.***

I. INTRODUCTION

One of the most important natural resources for the survival of all living forms is water. Several factors contribute to the water issue, including rapid urbanization and population growth, changes in precipitation patterns driven by climate change, and pollution and contamination of water sources. Water is an abundant source in the Philippines because it is a tropical country surrounded by bodies of water. However, the country's water challenges have been worsened by industrialization, environmental degradation, urbanization, and climate change. This has resulted in problems with scarcity of water and water source contamination, which further reduces the amount of safe, drinkable water available (Corporation, 2024). As a result, communities all throughout the country are looking for sustainable and alternative ways to get drinkable water for domestic and agricultural usage.

In the province of Batangas, located in the Calabarzon region of the Philippines, water scarcity and contamination have become major environmental problems. The province's economy depends heavily on industry, agriculture, and coastal tourism; therefore, it needs a steady supply of clean water. However, the Provincial Inter-Agency Task Force on Arsenic – Taal Volcano Protected Landscape (TVPL) reveals high pollution levels in important water sources, including tributaries of Taal Lake and nearby rivers. Several areas in Batangas had significant levels of arsenic, which suggests a health concern to people (Ozaeta, 2022). Additionally, a study by Apostol et al. (2022) discovered high levels of arsenic in groundwater samples from several Batangas municipalities, which could be harmful to the health of locals who depend on untreated wells and collected rainfall. These results demonstrate the province's increasing demand for sustainable, cost-effective, and locally applicable water treatment alternatives.

Given these circumstances, rainwater harvesting has become common as a practical and eco-friendly approach to addressing water scarcity in Batangas.

Rainwater collection provides a sustainable and affordable means of enhancing domestic water requirements, especially for non-potable uses like sanitation, irrigation, and cleaning. However, untreated or raw rainwater is not always suitable for human use. Rainwater can become contaminated by airborne contaminants like smoke and dust. According to Zdeb et al. (2025), rainwater is contaminated with a variety of microorganisms, including fecal pathogenic bacteria, which might be harmful to users' health. If the water is not properly treated, these pollutants can change its color and odor while also increasing bacterial burdens and making it dangerous.

Filtration systems are required to guarantee that collected rainwater satisfies acceptable quality standards. However, traditional commercial water filters can be costly and make use of materials that aren't biodegradable. Therefore, cost-effective and sustainable filtering systems have been proposed as good alternatives. Coconut shell–based activated charcoal has demonstrated exceptional potential as a natural adsorbent because of its high porosity, broad surface area, and capacity to capture both organic and inorganic pollutants (Po et al., 2023). In the Philippines, which is one of the world's largest coconut-producing nations, coconut shells are a common agricultural byproduct, particularly in provinces like Batangas where coconut farming is common. Using this waste material for water filtration is consistent with the country's sustainability goals since it minimizes waste and promotes circular resource use. Moreover, the Philippine Coconut Authority is currently developing a national standard for coconut shell–based activated carbon, highlighting its growing importance in water treatment and environmental sustainability efforts (Monzon, 2025).

The integration of coconut shell–based activated charcoal and crushed glass in a rainwater filtration system offers an innovative, sustainable, and affordable method for improving water quality in Batangas, Philippines. Recycled crushed glass functions as a mechanical filtration layer that effectively filters suspended particles and provides structural support for the finer coconut shell–based activated charcoal layer, which is responsible for adsorbing color, odor, and other impurities. Ahmad et al. (2025) claim that recycled glass sand shows incredible potential as a water filter medium, which makes it an ideal complement to natural adsorbents such as coconut shell–based activated charcoal. Together, these components form a dual-filtration system that improves adsorption and mechanical processes, producing safer and cleaner rainwater for household use. Additionally, both materials are affordable, widely accessible, and sustainable because shattered glass is a recyclable waste, reducing its environmental impact, while coconut shell–based activated charcoal is a byproduct of agriculture. This approach not only provides a practical solution to Batangas' water scarcity issues, but it also promotes waste recycling and supports the principles of the sustainable economy by converting local waste into beneficial filtration resources.

Given these circumstances, the need to develop an effective eco-friendly rainwater filtration system in Batangas is of utmost importance. Constructing and evaluating a filtration design that utilizes coconut shell–based activated charcoal and crushed glass serves as a fundamental step toward improving the accessibility and quality of safe water in the region. This study aims to provide a comprehensive evaluation of the filtration efficiency of these materials under varying ratios, offering valuable baseline data for future environmental engineering and community development projects. By systematically testing and documenting the system’s capacity to enhance color clarity, remove odor, and reduce impurities, this research contributes to the foundational knowledge of sustainable water filtration systems designed for Batangas communities. Such data are essential for guiding local conservation, waste management, and water safety initiatives, as well as for advancing the understanding of how locally sourced materials can play crucial roles in addressing water scarcity and pollution.

Hence, the study “Promoting Sustainable Clean Water Access: An Eco-Friendly Rainwater Filtration System Using Coconut Shell–Based Activated Charcoal and Crushed Glass in Water-Scarce Communities” aims to assess the effectiveness of this locally developed filtration system in improving the quality of collected rainwater in Batangas, Philippines, while also evaluating its accessibility, cost-efficiency, and environmental impact as an alternative to traditional filtration systems.

II. OBJECTIVES

This study aims to evaluate the effectiveness of an eco-friendly rainwater filtration system utilizing coconut shell–based activated charcoal and crushed glass in enhancing the quality of collected rainwater. Specifically, this study aims to:

1) Determine the effectiveness of the proposed eco-friendly rainwater filtration system utilizing coconut shell–based activated charcoal and crushed glass across different material ratios (3:1, 1:3, and 2:2) in terms of:

- color clarity;
- odor removal; and
- reduction of impurities?

2) Compare the performance of the eco-friendly filtration system with existing commercial filtration systems in terms of:
- cost-efficiency;
- accessibility; and
- environmental impact?

3) Assess whether the developed filtration system can serve as a practical and sustainable long-term solution for households and communities seeking eco-friendly alternatives to conventional water purification methods.

III. MATERIALS AND METHODS

A. Research Design

To investigate the effectiveness of the filtration system, the proposed study will employ a quantitative experimental design. The study will test the effectiveness of an eco-friendly rainwater filtration system, activated charcoal from a coconut shell, and sea pebbles in the filleting system. The setting is conductive for measurement and comparison that the researcher will measure in testing the quality of the filtered water under a controlled construct in order to achieve fairness and objectiveness of the result. Participants will include residents of the water scarcity affected communities who will be testing the filtration system. Measures will be taken in the operational definition in water quality assessment by taking samples of water before and after the filtration system in order to ascertain cleanliness, safety, and sustainability improvement. Through the experimental approach, the study aims to give scientific verification that will support the development of sustainable clean water solutions.

B. Subjects of the Study

The subjects of this study were residents from a water-scarce community in Taal, Batangas, who participated as respondents in evaluating the eco-friendly rainwater filtration system. These individuals were selected due to their direct experience with limited access to clean and safe water, allowing them to provide reliable and relevant insights regarding the practicality and effectiveness of the proposed system. Their participation ensured that the data gathered reflected the actual conditions and needs of communities in Taal where sustainable water solutions are critically needed.

After interacting with the filtration system, the respondents completed a validated questionnaire designed to assess their awareness, observations, and level of acceptance of the project. Their responses served as essential inputs in determining whether the system is a practical and sustainable long-term solution for households experiencing water scarcity.

Table 1. Distribution of Respondents

Barangay/Area	Number of Respondents
Taal, Batangas	30
Gahol, Taal, Batangas	14
Cubamba, Taal, Batangas	24
Total	63

C. Data Gathering Instrument

To gather enough data for the study “Promoting Sustainable Clean Water Access: An Eco-Friendly Rainwater Filtration System Using Coconut Shell-Based Activated Charcoal and Sea Pebbles in Water-Scarce Communities,” the researchers used a survey questionnaire and an experimental design as the main tool for data collection.

An experimental research design was used for this study to assess the effectiveness of the eco-friendly rainwater filtration system. This approach was used as the researchers could see and quantify the system’s effectiveness by evaluating the filtration system’s water quality before and after the filtration process. In this way, the researchers were able to determine the effectiveness of the materials used in filtering the impurities and the extent to which the system improved the quality of water.

For the researcher’s experimental component, a survey questionnaire was also designed that aimed to measure study participants’ awareness, attitudes, and acceptance of the filtration system and the proposed benefits for promoting sustainable access to clean water.

In order to gather the necessary information, the questionnaire consisted of three sections. Part I includes the demographic profile of the respondents. Part II examined their awareness and knowledge regarding sustainable practices around clean water. Part III examined their perception and assessment of the effectiveness and practical use of the filtration system. The researchers employed closed-ended queries based on a four-point Likert scale, allowing participants to state their degree of agreement or disagreement with each proposition or statement. Such an arrangement simplified response analysis and the calculation of weighted means for interpretation.

Construction of the Questionnaire. The instrument was developed by the researchers themselves, working closely under their research adviser. They studied related literature on sustainable water systems, rainwater collection and natural filtering materials such as coconut shells and sea pebbles. After review they developed questions that were all adapted to the study's goals and provided the adviser with the paper of which feedback was incorporated prior to finalization.

Validation of the Questionnaire. For clarity, relevance, and accuracy of the data collection instrument, the researchers consulted their professor in Chemistry. The professor examined every question, and offered suggestions that the researchers then incorporated to make the content and structure clearer. The researchers then moved on to make the revisions suggested by the professor, and the instrument was then ready for data collection.

Administration of the Questionnaire. Subsequent to the validation of the instrument, the researchers went on to execute the survey by allocating to the respondents printed versions of the questionnaire. The researchers emphasized that all response variables were and would be confidential, and that questionnaire responses would be completely anonymous. Ultimately, the completed questionnaires were given to the statistician for tallying and analysis.

Scoring of Responses. The responses were tallied, tabulated and analyzed to determine the relationship between the community's awareness, perception, and the effectiveness of the eco-friendly filtration system. A four-point Likert scale was used, where 1 represents the lowest and 4 as the highest level of agreement.

Option	Scale Range	Adjectival Rating
4	3.50 – 4.00	Strongly Agree
3	2.50 – 3.49	Agree
2	1.50 – 2.49	Disagree
1	1.00 – 1.49	Strongly Disagree

D. Data Gathering Procedure

A researcher-designed questionnaire that includes knowledge and their perceptions on the eco-friendly rainwater filtering systems which utilizes a sustainable clean water access was conducted for data collection. The survey was designed to provide insights into how the system is perceived as being effective and its potential for assisting with water shortages in people's regions. Upon completion of the survey by participants, researchers recovered returned questionnaires while making conclusions drawn from the responses.

The selected respondents in the water-scarce communities received printed copies of the validated questionnaire directly and completely. The data collection process was made to be fully and accurately done by giving clear instructions and making it a point that the participants would not only respond to all the items but would also take their time to respond thoroughly before turning in their answers.

IV. RESULTS AND DISCUSSION

A. Assessment on the Quality of Eco-friendly Rainwater Filtration System Across Ratios.

The assessment and observations of the researchers on the effectiveness of the filtration system using the self-made checklist in the quality of eco-friendly rainwater filtration system using color clarity, odor removal, and reduction of impurities.

1) Color Clarity

Table 2. Researchers' assessment on the quality of eco-friendly rainwater filtration system in terms of color clarity

Color Clarity	WM	VI	AR
Set 1 - 3:1 (Charcoal: Glass)	3.85	Very Effective	Very Clear
Set 2 - 1:3 (Charcoal: Glass)	2.42	SlightlyEffective	Slightly Clear
Set 3 - 2:2 (Charcoal: Glass)	2.85	Effective	Clear
Composite Mean	3.04	Effective	Clear

The results revealed that the assessment of color clarity among the three filtration sets showed varying levels of performance depending on the charcoal-to-glass ratio, as supported by their verbal interpretations and adjectival ratings. Set 1, which utilized a 3:1 ratio, obtained the highest weighted mean of 3.85 and was classified as Very Effective, with the water described as Very Clear. This demonstrates that a greater proportion of charcoal significantly improves color removal due to its strong adsorption properties. In contrast, Set 2, with a 1:3 ratio, achieved a weighted mean of 2.42 and was rated as Slightly Effective, producing water that was only Slightly Clear, indicating reduced efficiency when charcoal content is minimized. Set 3, which applied a 2:2 ratio, recorded a weighted mean of 2.85 and was considered Effective, with an adjectival rating of Clear, showing moderate improvement in water clarity.

The composite mean of 3.04, interpreted as Effective and rated as Clear, suggests that the eco-friendly filtration system is generally capable of enhancing water color clarity. Overall, the findings indicate that higher charcoal proportions consistently yield clearer water and more efficient filtration outcomes.

2) Odor Removal

Table 3. Researchers' assessment on the quality of eco-friendly rainwater filtration system in terms of odor removal

Odor Removal	WM	VI	AR
Set 1 - 3:1 (Charcoal: Glass)	3.57	Very Effective	Complete odor remova
Set 2 - 1:3 (Charcoal: Glass)	2.28	Slight Effective	Slight odor removal
Set 3 - 2:2 (Charcoal: Glass)	2.42	Slight Effective	Slight odor removal
Composite Mean	2.23	Slight Effective	Slight odor removal

The results revealed that the effectiveness of odor removal in the filtration system depended on the charcoal-to-glass ratio. Set 1, with a 3:1 ratio, achieved the highest weighted mean of 3.57 and was rated Very Effective, meaning the water had no detectable odor. This indicates that higher charcoal content significantly improves the system's ability to remove odor. Sets 2 (1:3) and 3 (2:2) had weighted means of 2.28 and 2.42, were rated Slightly Effective, producing water with only slight odor removal.

The composite mean of 2.23, interpreted as Slightly Effective, shows that the system improves water quality overall, but odor removal works best with higher charcoal content. These findings highlight the important role of activated charcoal in enhancing the filtration system's performance.

3) Reduction of Impurities

Table 4. Researchers' assessment on the quality of eco-friendly rainwater filtration system in terms of reduction of impurities

Reduction of Impurities	WM	VI	AR
Set 1 - 3:1 (Charcoal: Glass)	3.14	Moderate Reduction	Effective
Set 2 - 1:3 (Charcoal: Glass)	2.14	Slight Reduction	Slight Effective
Set 3 - 2:2 (Charcoal: Glass)	2.14	Slight Reduction	Effective
Composite Mean	2.47	Slight Reduction	Slight Effective

The results show that impurity reduction varied depending on the charcoal-to-glass ratio. Set 1, with a 3:1 ratio, was the most effective, achieving a weighted mean of 3.14 and rated as Moderate Reduction, meaning most impurities in the water were removed. Sets 2 (1:3) and 3 (2:2) had weighted means of 2.14 and were rated Slight Reduction, indicating that lower charcoal content reduced the system's ability to remove contaminants. The composite mean of 2.47, interpreted as Slight Reduction, suggests that all filtration sets improved water quality, but higher charcoal content enhanced the removal of impurities. These findings emphasize the key role of activated charcoal in adsorbing dissolved particles, while the crushed glass mainly contributed to mechanical filtration, highlighting the combined effectiveness of both materials in the eco-friendly filtration system.

B. Comparison of the Eco-friendly Filtration System with Commercial Filtration System

The researchers assessed the eco-friendly filtration system in comparison with commercial system, based on cost-efficiency, accessibility, and environmental impact.

1) Cost-efficiency

Table 8. Comparison of the Eco-friendly Filtration System with Commercial Filtration System based on Cost-efficiency

Cost-efficiency	WM	VI
Eco-friendly Filtration System	4	Very Cost-Efficient
Commercial Filtration System	2	Less Cost-Efficient
Composite Mean	3	Cost-Efficient

The finding shows that the eco-friendly filtration system is more cost-efficient than the commercial system. It achieved the highest weighted mean of 4, rated Very Cost-Efficient, while the commercial system had a lower mean of 2, rated Less Cost-Efficient.
This difference is due to the eco-friendly system using inexpensive, locally available materials, such as coconut shell-based activated charcoal and crushed recycled glass, which reduce reliance on costly imported components. These features make the system both affordable and practical for local communities, supporting its suitability as a low-cost water filtration solution.

2) Accessibility

Table 9. Comparison of the Eco-friendly Filtration System with Commercial Filtration System based on Accessibility

Accessibility	WM	VI
Eco-friendly Filtration System	4	Very Accessible
Commercial Filtration System	2	Less Accessible
Composite Mean	3	Accessible

The assessment shows that the eco-friendly filtration system is more accessible than the commercial system. It achieved the highest weighted mean of 4, rated Very Accessible, while the commercial system had a mean of 2, rated Less Accessible.
This greater accessibility is due to the system using widely available materials such as coconut shell-based activated charcoal and crushed recycled glass. These materials are abundant in many communities across the Philippines, allowing the system to be built and maintained using local resources. As a result, the eco-friendly filtration system is practical and suitable for use in rural and agricultural areas.

3) Environmental Impact

Table 10. Comparison of the Eco-friendly Filtration System with Commercial Filtration System based on Environmental Impact

Environmental Impact	WM	VI
Eco-friendly Filtration System	4	Very Eco-Friendly
Commercial Filtration System	2	Less Eco-Friendly
Composite Mean	3	Eco-Friendly

The comparison highlights the environmental performance of the two filtration systems. The eco-friendly system scored the highest weighted mean of 4, rated Very Eco-Friendly, while the commercial system scored 2, rated Less Eco-Friendly.
This difference is due to the use of sustainable, locally sourced materials in the eco-friendly system, such as coconut shell-based activated charcoal and crushed recycled glass. These materials reduce waste and minimize reliance on imported or non-recyclable components, making the system more sustainable and environmentally responsible.

C. Assessment on the Practicality and Sustainability of Eco-friendly Rainwater Filtration System

This study aims to determine if the filtration system serve as a practical and sustainable long-term solution for households and communities seeking eco-friendly alternatives to conventional water purification methods.

Table 11. Community Assessment of the Practicality and Sustainability of the Eco-Friendly Rainwater Filtration System

Statements	WM	VI
1. The system can be used effectively in households.	3.35	Agree
2. The system is suitable for community-level use.	3.45	Agree
3. The system provides a reliable long-term water filtration solution.	3.40	Agree
4. The system is safe to use for non-potable purposes.	3.40	Agree
5. The system encourages eco-friendly practices.	3.40	Agree
Composite Mean	3.40	Agree

The results revealed that the community perceived the eco-friendly rainwater filtration system as both practical and sustainable, as indicated by a composite mean of 3.40, interpreted as "Agree". Respondents agreed that the system can be effectively used in households (WM = 3.35) and is suitable for community-level use (WM = 3.45). They also acknowledged that the filtration setup provides a reliable long-term solution for water filtration (WM = 3.40). Additionally, the community perceived the system as safe for non-potable uses (WM = 3.40) and supportive of eco-friendly practices (WM = 3.40). Overall, these findings indicate strong community acceptance and support for the filtration system as a sustainable and practical option for improving access to cleaner water.

V. RECOMMENDATIONS

Given the findings and conclusions of the study, several recommendations can help improve and strengthen the use of the rainwater filtration system:

1) Adopt the 3:1 charcoal-to-glass ratio for future applications, since this mixture consistently gave the clearest water and the most effective removal of odor and impurities.

2) Future studies should include additional trials, more water samples, and a wider range of environmental conditions to further validate the consistency and reliability of the filtration system's performance.

3) Researchers may explore other eco-friendly filtering materials or adjust the system design to improve durability, flow rate, and ease of maintenance. Testing different setups or adding layered media may also enhance filtration efficiency.

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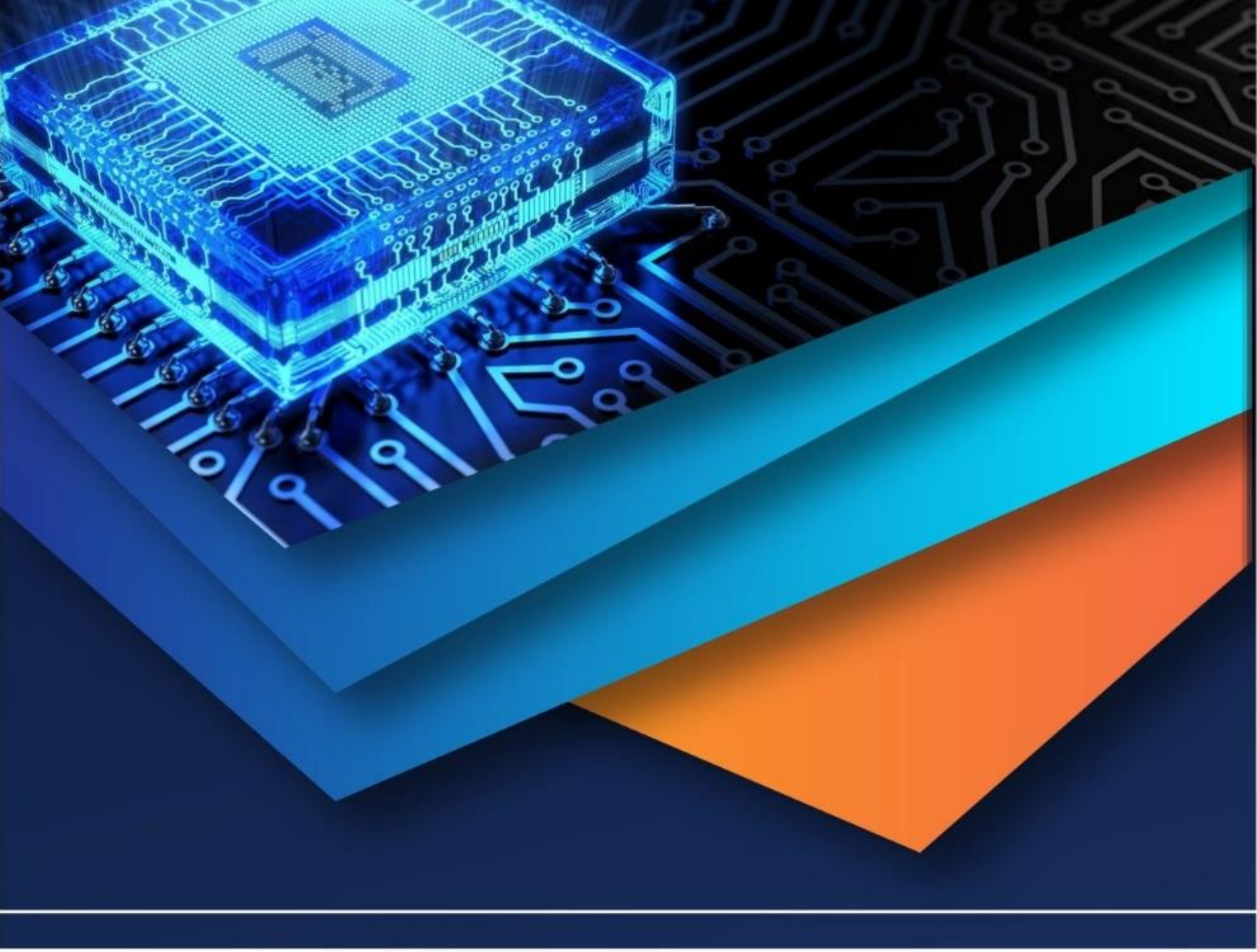

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