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Impact of Algae-Contaminated Water on Concrete Strength and Durability: An Experimental Study in Monguno, Nigeria

Malli A.A.[1]* Maina U.I.[2]
[1 & 2] Department of Civil Engineering, Faculty of Engineering, Federal Polytechnic Monguno, Borno State, Nigeria
*Corresponding Author: idreesmusman@gmail.com
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ABSTRACT

This experimental study investigates the impact of algae-contaminated water on the compressive strength and workability of concrete using a standard 1:2:4 mix. Concrete specimens were prepared with three types of water: clean potable borehole water (control), mildly contaminated algae water, and highly contaminated algae water. Workability was assessed through slump tests, and compressive strength was measured at 7, 14, 28, and 56 days curing. Results revealed that algae contamination significantly compromised concrete performance, with a 20-25% reduction in compressive strength ranging from 18.5 to 32.5 N/mm² in controls versus 14.2 to 24.8 N/mm² in contaminated mixes failing the 28-day C25 structural grade. The deterioration is attributed to disrupted cement hydration, increased porosity, and weakened interfacial transition zones caused by algal residues. These findings highlight the critical structural risks associated with non-potable water use, emphasizing the necessity for strict water quality enforcement, access to potable water, and education to ensure concrete durability and safety in water-scarce regions.

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Keywords: Abuja, Power outage, Residential Area, Urban Resilience, Solar energy, Sustainability

1.0. Introduction

Concrete remains the most widely used construction material worldwide due to its versatility, durability, and relatively low cost (*Neville & Brooks, 2010*). It is fundamental to modern infrastructure, forming the backbone of buildings, bridges, roads, and other civil engineering structures. The performance and long-term durability of concrete, however, are highly dependent on the quality of its constituent materials—cement, fine and coarse aggregates, and water. While significant attention is often given to cement and aggregates, the role of water is equally critical, as it directly participates in the hydration process, determines the workability of fresh concrete, and significantly influences the strength development and durability of hardened concrete (*Mehta & Monteiro, 2014*).

Water is not merely a mixing agent but an active component in the chemical reactions that lead to the formation of cementitious compounds. The quantity and quality of water used can alter the microstructure of concrete, affecting parameters such as porosity, permeability, and compressive strength. For this reason, international standards such as ASTM C1602 and BS EN 1008 specify that water used in concrete production must be free from harmful substances, including oils, acids, alkalis, organic matter, and microbial contaminants. These standards emphasize that even small concentrations of impurities can adversely affect hydration reactions and compromise the mechanical properties of concrete.

Despite the existence of these standards, access to clean and potable water remains a major challenge in many developing regions. In Nigeria, particularly in rural and conflict-affected areas, water supply infrastructure is often inadequate or damaged, forcing local communities to rely on alternative water sources. Monguno Local Government Area in Borno State is a typical example, where prolonged insurgency has disrupted essential services, including access to safe water. As a result, builders and artisans frequently depend on readily available surface water sources such as ponds, streams, and water storage systems for concrete production (*Olugbenga & Akinola, 2018*).

These alternative water sources are often stagnant and highly susceptible to contamination by algae and other organic materials. Algae are photosynthetic organisms that proliferate rapidly in environments characterized by high temperatures, nutrient availability, and poor water circulation (*Whitton & Potts, 2012*). In semi-arid regions like Monguno, where high temperatures and evaporation rates are common, stagnant water bodies provide ideal conditions for algal blooms. Such blooms introduce organic matter, microbial residues, and biochemical compounds into the water, all of which may interact negatively with cement during the hydration process.

The presence of algae and associated organic impurities in mixing water can significantly affect the physicochemical properties of concrete. Studies have shown that organic contaminants may retard cement hydration, prolong setting time, and reduce the rate of strength gain. Additionally, these impurities can increase the porosity of concrete, weaken the bond between cement paste and aggregates, and ultimately reduce compressive strength (*Al-Ghusain & Terro, 2003*). Increased porosity also makes concrete more susceptible to environmental degradation, thereby compromising its durability and service life.

Empirical evidence from previous studies supports these observations. For instance, *Neville (2011)* noted that the presence of organic impurities in water adversely affects the microstructure and strength characteristics of concrete. Similarly, *Oyebisi and Salau (2016)* reported that the use of water contaminated with organic materials resulted in a reduction in compressive strength of up to 15% when compared to concrete produced with potable water. In another study conducted in Kuwait, *Al-Ghusain and Terro (2003)* demonstrated that the use of inadequately treated wastewater significantly reduced concrete strength and accelerated deterioration processes. These findings highlight the broader implications of water quality on structural performance and durability. The issue of water quality in concrete production is particularly critical in Nigeria, where cases of building collapse have been widely reported. Many of these failures have been attributed to poor material quality, inadequate supervision, and non-compliance with construction standards (*Ogunsemi, 2012*). The use of contaminated water further exacerbates these challenges by introducing hidden weaknesses into concrete structures, which may not be immediately apparent but can lead to premature failure over time.

In Monguno Local Government Area, the situation is even more concerning due to ongoing reconstruction efforts following years of insurgency-related destruction. As infrastructure is rebuilt to support displaced populations and restore socio-economic activities, there is an urgent need to ensure that construction practices adhere to acceptable quality standards. However, the continued reliance on algae-contaminated water for concrete mixing and curing poses a significant threat to the structural integrity of newly constructed buildings and infrastructure. This not only undermines reconstruction efforts but also exposes communities to potential safety risks. Furthermore, while several international guidelines discourage the use of contaminated water in concrete production, there is a notable lack of localized empirical studies that specifically examine the effects of algae-contaminated water under the environmental conditions prevalent in Monguno. Most existing studies are either conducted in different climatic regions or focus on general organic contamination without isolating the specific impact of algal presence. This creates a critical knowledge gap, as the behavior of concrete produced with algae-contaminated water may vary depending on local environmental factors such as temperature, humidity, and water chemistry.

Addressing this gap is essential for developing context-specific recommendations that can guide construction practices in water-scarce and environmentally challenged regions. Understanding the extent to which algae-contaminated water affects compressive strength will provide valuable insights into material performance and help inform decision-making among engineers, builders, and policymakers. Against this backdrop, this study aims to investigate the effect of algae-contaminated water on the compressive strength of concrete, using Monguno Local Government Area as a case study. By generating empirical data and evaluating the extent of strength reduction associated with such water, the study seeks to contribute to improved construction practices, enhance structural safety, and promote sustainable infrastructure development in regions facing similar challenges.

2.0 Methodology

2.1. The Study Area

Federal Capital City (FCC) Phase 1 is situated within the Federal Capital Territory (FCT) of Nigeria, lying between latitudes 8°25′ and 9°25′ North of the Equator and longitudes 6°45′ and 7°45′ East of the Greenwich Meridian (AGIS, 2008). The FCT is bounded by Kaduna State to the north, Nasarawa State to the east, Niger State to the west, and Kogi State to the south, as illustrated in Figure 1.

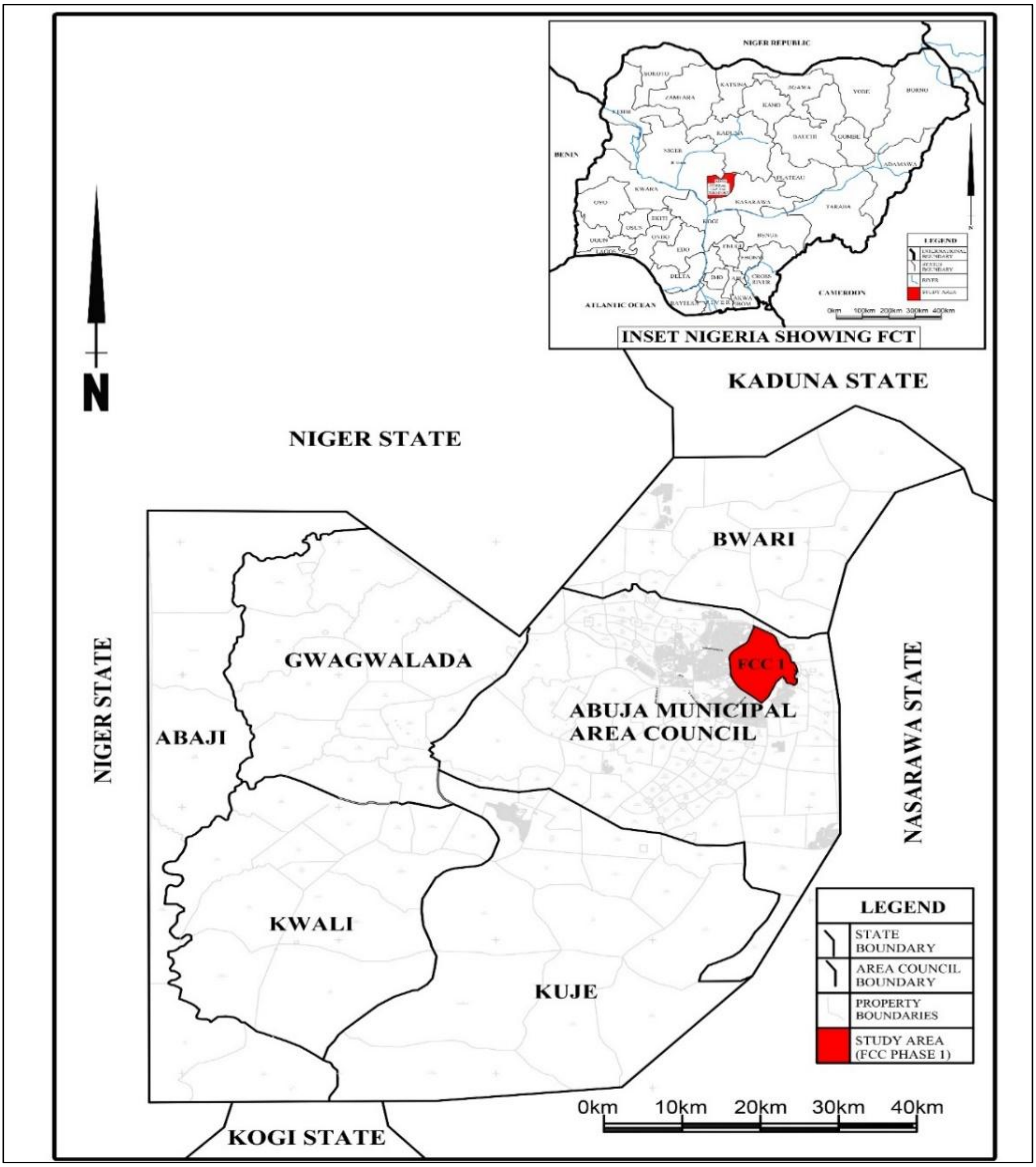

Figure 1: Locational Map of Federal Capital City Phase 1, in FCT.
Source: Abuja Geographical Information System (AGIS) (2008).

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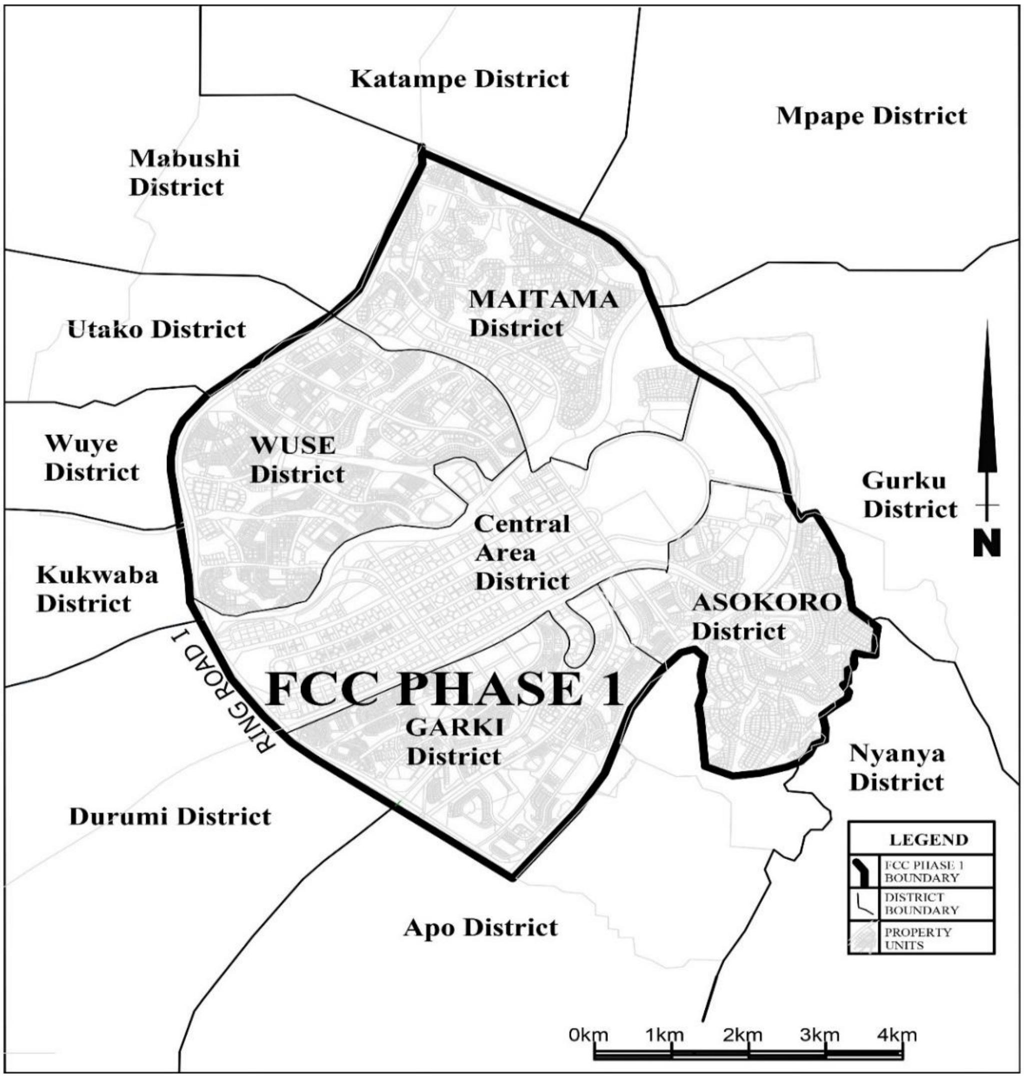

Figure 2: Map of Federal Capital City Phase 1.
Source: Abuja Geographical Information System (AGIS) (2008).

The FCC's indigenous population includes the Gbagyi, Koro, Ganagana, Gwandara, Afo, and Bassa, alongside Hausa and Fulani (Balogun, 2001). Today, the area is ethnically diverse due to its status as Nigeria's administrative center. The FCT had 1,406,239 people in 2006 (NPC, 2010), while FCC Phase 1 grew from 267,671 in 2015 (Musa *et al*., 2016) to a projected 544,409 in 2023, based on a 9.28% inter-census growth rate (NPC, 2010). The strength of Abuja's economy is attributed to its diverse socio-economic activities ranging from construction and real estate, tourism and leisure, agriculture and a dynamic service sector that includes infrastructure development (Obiadi, Ezezue and Uduak, 2019). Electricity in the FCC is distributed by the Abuja Electricity Distribution Company, one of Nigeria's 11 DisCos. The rapid population growth in the FCC has intensified pressure on existing infrastructure, particularly electricity supply. Persistent power outages undermine economic productivity, household welfare, and essential public services, highlighting a critical energy deficit. Solar power presents a viable solution, offering households a decentralized and sustainable energy source.

2.2. Methods

This study employed a descriptive research design, incorporating survey method. A systematic random sampling technique was used to collect data from a sample of 400 households. Questionnaires were systematically administered to 400 participants. This process was essential in determining the extent to which solar energy adoption affects the impacts of power outages. At the end of the survey, however, only 330 questionnaires were retrieved from respondents. The analysis was therefore based on 330 questionnaires, representing 82.5% of the total administered, which is acceptable in research given a threshold of 55% (Sataloff & Vontela, 2021). The study applies the Technology Acceptance Model (TAM), developed by Davis (1989), to explore the relationship between power outages and the adoption of solar energy within residential areas of FCC Phase 1. TAM provides insights into how practical perceptions, such as usefulness and ease of use, impact adoption decisions.

Data were analyzed using the Relative Importance Index (RII) because it gives a clear distinction of significant variables (Tonidandel and LeBreton, 2011).

Relative importance Index (RII) is given by the formula:

$$\mathrm{RII} = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1}{A * N} \qquad 1$$

Where:
n_5 = Number of respondents for extremely significant
n_4 = Number of respondents for significant
n_3 = Number of respondents for slightly significant
n_2 = Number of respondents for insignificant
n_1= Number of respondents for extremely insignificant
A (Highest Weight) = 5
N (Total number of respondents) = 67
(Johnson and Lebreton, 2004).

The analysed data were presented both textually and in tabular form to enhance clarity, facilitate comparative analysis, and support effective interpretation of the findings. This methodology provided a reliable framework for generating valid data, ensuring that the analysis accurately reflects household experiences with power outages and the adoption of solar energy in FCC Phase 1.

3.0 Results and Discussion

The findings of this study present the outcomes of the data analysis, highlighting, household responses the extent of solar energy adoption in FCC Phase 1. The results are organized to align with the study objective and provide insights into the socio-economic and environmental implications of solar energy adoption on power outage effects.

3.1 Adoption of Solar Energy

Table 1: Adoption of Solar Energy by Respondents

Adopted Solar Energy	Frequency	Percent (%)
Yes	67	20.3
No	263	79.7
Total	330	100.0
Period of Adoption		
Less than 1 year	12	17.9
1-2 years	30	44.8
3-4 years	13	19.4
Above 4 years	12	17.9
Total	**67**	**100.0**

Source: Field Survey (2023).

The results presented in Table 1 indicate that only 20.3% of respondents reported having adopted solar energy systems in their households, whereas a significant majority, 79.7%, have yet to embrace this technology. These statistics demonstrate that although the adoption of solar energy is gradually increasing, the penetration rate remains relatively low within the study area. Given the socio-economic and environmental benefits associated with solar energy such as cost savings in the long term and the reduction of environmental degradation according to Umeji *et al*. (2023), there is a compelling need to encourage greater adoption.

With respect to the duration of adoption, the findings reveal that most of the respondents (44.8%) have been utilizing solar energy for a period of one to two years. This is followed by 19.4% who reported usage spanning between three and four years, while 17.9% indicated adoption for less than a year, and another 17.9% have maintained usage for over four years. This result suggests that the adoption of solar energy in the study area is relatively recent, implying that households are only beginning to perceive its usefulness and ease of use, as explained by the Technology Acceptance Model (TAM). This early stage of adoption reflects both growing awareness of renewable alternatives and the influence of persistent power outages in shaping attitudes, but it also indicates that wider diffusion will depend on how strongly these perceptions continue to drive acceptance and sustained usage.

3.2Impact of Solar Energy Adoption on Power Outage Effects in FCC Phase 1

This section examines the extent to which the adoption of solar energy mitigates the socio-economic and environmental impacts of power outage within the study area. The empirical results, as presented in Table 2, demonstrate that 65 out of 67 respondents affirmed that solar energy significantly reduces the economic burden associated with reliance on alternative power sources. Specifically, the finding highlights that solar adoption evidently lowers expenditure on alternatives such as fuel-powered generators, which are often costly and environmentally unsustainable. This suggests that beyond the initial investment, solar systems provide long-term financial relief and sustainable energy security.

Table 2: Impact of Solar Energy Adoption on Power Outage Effects

Variables	EI	I	SS	S	ES	Total
Food Spoilage	6	18	0	25	18	67
Communication/Entertainment disruption	0	0	0	18	49	67
Damage to electrical appliances	0	18	6	12	31	67
Sleeping Discomfort	0	18	6	12	31	67
Water supply Interruption	19	24	0	18	6	67
Air Pollution from Generators	0	6	0	25	36	67
Noise Pollution from Generators	0	0	0	12	55	67
Lateness to Work	0	24	19	0	24	67
Expenditure on other Alternatives	0	2	0	0	65	67

Source: Field Survey (2023).

This result is a significant benefit, as the cost of these recurrent alternatives can be a burden for many households who may have to buy fuel when there are power outages. Whereas, water supply interruption shows the highest number for extremely insignificant effect of solar energy on reduction of power outage impact. A detailed analysis of this objective is presented on Table 3.

The results of the Relative Importance Index (RII) analysis presented in Table 3 illustrate the effect of solar energy adoption on mitigating the socio-economic and environmental impacts of power outages. Expenditure on alternative energy sources, with an RII value of 0.9821, is ranked first, indicating the highest level of significance. This finding suggests that the adoption of solar energy substantially reduces household reliance on costly alternatives such as fuel-powered generators, thereby alleviating the recurrent financial burden associated with power outages.

Table 3: Relative Importance Index (RII) of the Impact of Solar Energy Adoption on Power Outage Effects

Variables	Weighted Total	N	A*N	RII	Significance
Food Spoilage	232	67	335	0.692537313	6
Communication/Entertainment disruption	317	67	335	0.946268657	3
Damage to electrical appliances	257	67	335	0.767164179	5
Sleeping Discomfort	257	67	335	0.767164179	5
Water supply Interruption	169	67	335	0.504477612	8
Air Pollution from Generators	292	67	335	0.871641791	4
Noise Pollution from Generators	323	67	335	0.964179104	2
Lateness to Work	225	67	335	0.671641791	7
Expenditure on other Alternatives	329	67	335	0.982089552	1

A (Highest Weight) = 5
N (Total number of respondents) = 67
Source: Field Survey (2023).

This infers that the impact of solar energy adoption on the socio-economic effects of power outages, particularly in terms of expenditure on alternative energy sources, is highly significant. It implies that most residents no longer spend on other alternatives once they have adopted solar energy. Noise pollution from generators and environmental effect, ranked second with an RII value of 0.9642. This indicates that it is the next most significant impact of solar energy adoption on the effects of power outages. This finding highlights the critical role solar energy plays in alleviating the pervasive noise challenges associated with generator use, which are common in urban residential areas such as FCC Phase 1. The reduction of noise pollution not only improves the overall quality of life for residents by fostering a quieter and healthier living environment but also mitigates the psychological stress and community disturbances often linked to prolonged generator operations during power outages. Communication/entertainment disruption with RII of 0.9463 ranked as number 3 most significant impact solar energy has on the effects of power outage in the study area. This entails that communication and entertainment especially the use of mobile phones, or television can be sustained since there will be adequate supply to power the gadgets.

The environmental benefits of solar energy adoption are further demonstrated through its impact on air pollution caused by the frequent use of generators. With an RII ranking of 0.8717, air pollution is positioned fourth among the identified effects, indicating that while not the most significant, it remains a considerable area of improvement associated with solar energy use. This finding highlights how the transition to solar energy reduces the dependence on fossil fuel-powered generators, which are a major source of harmful emissions such as carbon monoxide, nitrogen oxides, and particulate matter. By curbing these emissions, solar energy contributes to improved air quality, thereby promoting healthier living conditions for residents and mitigating broader environmental concerns such as greenhouse gas accumulation and climate change. These results show that indeed, solar energy reduces the negative effects of power outage and that solar energy is a panacea for the electricity generation crisis in Nigeria (Agbo *et al*., 2021).

The variables that show the least significance are: water supply interruption and lateness to work with RII of 0.5045, ranked number 8 and 0.6717, ranked number seven respectively. This is because, the use of solar water pumping machines is not widespread among households in the study area, as such, they still have to depend on the grid to pump water to their storage tanks as it is the status quo in some part of the study area. Another factor that affects the result is that some homes are connected to pipe borne water from the municipality, as such they may not need solar energy for water supply. Also, lateness to work does not show high significance since activities such as ironing are high energy consuming activities and require high capacity of solar energy systems which is not easily affordable to households at this time. This is an indication for a need for investments into the solar energy sector that reduces cost of acquisition of high-capacity solar energy systems for homes.

In the lens of the Technology Acceptance Model, solar energy is perceived as useful because it mitigates the adverse effects of power outages by ensuring uninterrupted power supply, reducing financial losses such as food spoilage and generator costs, and improving health and comfort by eliminating noise and air pollution. Its ease of use, enhanced by advancements in solar technology may boosts its acceptance. TAM's focus on usability and benefits drive solar energy adoption, directly reducing the frequency and severity of outage-related impacts, while also fostering long-term resilience and environmental sustainability. This perspective highlights the importance of aligning technological innovation with user-centered motivations to accelerate solar energy adoption.

4.0 Conclusion

The study establishes that the extent of solar energy adoption in FCC Phase 1 Abuja is 20.3% ,whereby the larger population have not adopted it. However, solar energy adoption in the study area significantly reduces the adverse socio-economic and environmental effects of power outages. The most profound socio-economic impact is observed in reducing household expenditure on alternative energy sources, thereby relieving residents of the financial burden of recurrent fuel costs. Although the initial investment in solar systems is relatively high, the long-term economic advantage becomes evident, as solar installations require little to no recurrent expenditure for at least five years. Additionally, the adoption of solar energy mitigates environmental challenges by reducing noise pollution from generators, while also addressing other socio-economic concerns such as communication and entertainment disruption. Viewed through the Technology Acceptance Model (TAM), solar energy is perceived as highly useful by residents, as it not only ensures uninterrupted power supply but also enhances household welfare by minimizing both financial losses and environmental degradation. It is recommended that Government and private stakeholders should promote affordable solar adoption through subsidies, tax incentives, micro-credit schemes, solar panel import policy, innovative financing, and public awareness to enhance socio-economic welfare and environmental sustainability in FCC Phase 1.

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