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The Potential Impact of Climate Change on Nuclear and Radiological Facilities: Implications for Nuclear Safety and Security.

Muhammad Bello Gusau[1,3]*, Samuel Baba Ayegba[2], Soja Rueben Joseph[1], Adamu M. Husaini[1], and Nuraddeen Nasiru Garba[3]

[1]Nigerian Nuclear Regulatory Authority, Abuja.

[2]Nigerian Defence Academy, Kaduna.

[3] Department of Physics, Ahmadu Bello University, Zaria.

Corresponding Author: Email: belmag4d@yahoo.co.uk, Phone: +2348038324909

ABSTRACT

Nuclear and radiation technology are widely utilized in oil and gas exploration and production, industrial radiography, medicine, agriculture, and research. This study provides an assessment of the potential impacts of climate change on nuclear and radiological facilities with emphasis on the implications for nuclear safety and security. The study employed a questionnaire and an unstructured interview as survey tools. The questionnaire was designed by the researchers and was validated for content, construct, and reliability. The final, reliable questionnaire was used to create a Google Form, which was shared online with the respondents. Two hundred and seventy-three (273) people responded to the questionnaire out of three hundred and fifty that were administered (a response rate of 78%). The data obtained were analyzed using descriptive statistical methods with the help of SPSS version 23. The study identified vulnerabilities, potential safety and security risks, mitigation strategies, and adaptation measures related to nuclear and radiological facilities. Finally, the study explored the opportunities for local and international collaboration in addressing the impacts of climate change on nuclear safety and security.

Keywords: Climate change, nuclear safety and security, vulnerability, risks, cooperation.

1) Introduction

Nuclear and radiation techniques are utilized in diverse sectors of the economy, such as the exploration and production of oil and gas, industrial radiography, manufacturing, construction, medicine, and preservation of agricultural produce, as well as research, education, and training (Abu-Jarad *et al*., 2007; Abu-Jarad, 2008). Moreover, the study conducted by Joseph et al. in 2022 has shown that nuclear and other low-carbon energy technologies are the preeminent alternative for future electricity production in achieving the carbon neutrality target in Nigeria. Despite the many beneficial uses of radioactive materials in our lives, failure to adequately secure and use them safely could have serious consequences on individuals, communities, and the environment, as well as notable national and international organizations (IAEA, 2003; WINS, 2019). Safety and security of facilities where radioactive materials are used will help in ensuring the peaceful utilization of nuclear and radiation-based technologies. Therefore, these necessitate that state parties establish, implement, maintain, and sustain an effective and appropriate nuclear safety and security regime.

According to the study conducted by the United States Agency for International Development (USAID), many developing countries, including Nigeria, face challenges related to high climate risks, in which 24% of the population resides in areas with extreme climatic conditions. Different geographical regions of Nigeria have various types of climate challenges (Andrea and Christine, 2019, and Ashley *et al*., 2018). Periodic droughts in the north of the country and floods in the southern region of the country have destroyed local economies and reduced agricultural productivity in the country. Declining precipitation and land

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degradation from human activities have also led to severe desertification in the country's northern region. According to estimates, this process has negatively impacted 60% of the country's population (Andrea and Christine, 2019, and Ashley *et al*., 2018). The climate in the northern part of the country is consistently dry (Ashley *et al*., 2018). Excess water, which may result from overflowing rivers or rising seas, regularly puts communities in central and southern Nigeria in danger (Andrea and Christine, 2019; Ciara, 2018).

In 2018, severe rainfall forced the federal government to declare a national disaster in four federation states (Andrea and Christine, 2019). Climate models predict these extreme weather events will continue, which might strain government financial and human resources. Many coastal states are at significant risk of coastal flooding because of their low elevation (Ashley *et al*., 2018). Other flood-prone regions in Nigeria include the River Sokoto in the northwest, which runs through the states of Sokoto and Kebbi; the central states of Niger and Kogi; and the southeast states of Anambra and Imo. Flooding has also occurred along the River Benue, which originates in central-eastern Nigeria and flows to the River Niger in the middle belt of the country. The Hadejia, Komadugu Gana, Yedseram, and Gongola rivers are among the rivers in the northeastern region that are also very susceptible to floods (Ashley *et al*., 2018).

Additionally, there are locations in Nigeria that are currently experiencing rainfall anomalies, such as the country's eastern border and the central to southern regions, where rainfall has significantly reduced. This includes the southern part of Borno state to the east, as well as the states of Adamawa, Gombe, and Taraba. Additional locations with characteristic rainfall anomalies include Abia, Enugu, Kogi, Nasarawa, Federal Capital Territory, Plateau, Kaduna, and Niger (Ashley *et al*., 2018). As per the Council on Strategic Risks (CSR), Nigeria is one of the numerous nations dealing with severe security and climate-related issues while simultaneously exploring nuclear energy development, which could significantly affect the nation's growth and stability (Christine and Andrea, 2019).

Climate-related impacts may necessitate changes in regulatory frameworks governing nuclear facilities, potentially leading to increased compliance costs or changes in safety and security protocols. Climate-related impacts on nuclear or radiological facilities can have transboundary effects. This may require international cooperation in terms of safety and security, response, and mitigation efforts (Adrea and Meggen 2020). This study examined the impact of climate change on nuclear and radiological facilities from safety and security viewpoints, providing insights and recommendations for regulators, policymakers, and other stakeholders involved in managing nuclear and radiological facilities.

2) Methodology

2.1) The study population and sample determination

Due to the nature of this study, the study population was selected based on its relevance to the objectives. The study population comprised public servants in the nuclear industry, civil servants in the Federal Ministry of Environment and its parastatals, members of civil society organizations, workers of the National Council on Climate Change (NCCC), workers of the National Emergency and Management Agency (NEMA), academic staff of universities, colleges, and polytechnics, and personnel of law enforcement agencies, etc. The estimated study population is presented in Table 1.

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Table 1: Study Population

S/No.	Population under study	Sub-total (Estimated)
1	Nuclear Industry Workers	5000
2	Federal Ministry of Environment and Parastatals under it	300,000
3	Members of Civil Society Organisations	5000
4	NCCC workers	500
5	NEMA workers	2000
6	Academic Staff of Universities, Colleges, and Polytechnics	400,000
7	Personnel of Law Enforcement Agencies	800,000
	Total	**1,512,500**

To determine the appropriate sample size of the respondents for the questionnaire administration, Taro Yamane's Formula was used to calculate the sample size of the respondents from a given population.

$$n = \frac{N}{1 + N(e^2)}$$

where n = signifies the sample size, N = signifies the population under study, and e signifies the margin of error.

For this research, a 94% Confidence Level and an Error Margin of 6% were considered appropriate for the study population.

$$\text{Therefore, } n = \frac{1{,}512{,}500}{1+1{,}512{,}500\ (0.06)^2}$$

$$n = 273 \text{ respondents}$$

2.2) Data collection and validation

The study employed a questionnaire as a survey tool to systematically describe and analyze the impact of climate change on nuclear and radiological facilities from the safety and security point of view. The questionnaire was prepared in line with several publications related to climate change, nuclear safety, and security (IAEA, 2011a, b, c; 2013a & b; 2019, 2020, 2021 b & c; IPCC, 2003 and 2014). Data were gathered using a questionnaire and unstructured interviews.

The questionnaire was designed by the researchers and was validated for content, construct, and reliability. It was used to create a Google Form shared online with the respondents. Two hundred and seventy-three (273) people responded to the questionnaire out of the three hundred and fifty that were sent (a response rate of 78%). Fifteen (15) of the respondents were interviewed. The data obtained were analyzed using descriptive statistics in SPSS version 23.

3) Results and Discussion

3.1) Demographics of the respondents

The data show that 74.6% of the respondents were male, while 25.4% were female. In terms of educational qualifications of the respondents, 35.1 % of the respondents are either bachelor's degree or Higher National Diploma (HND) graduates, 45.4 % of the respondents are Master Degree holders and 19.6 % of the respondents are doctoral degree holders from different disciplines and specializations ranging from arts/humanities,

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science/technology/engineering, and medical/health sciences.

The affiliations of the respondents were such that 19.4 % of the study participants are affiliated to the Nigerian Nuclear Regulatory Authority (NNRA) or the Nigeria Atomic Energy Commission (NAEC), while 53.6 % of the respondents are affiliated to universities, and the remaining percentage of the respondents are affiliated to law enforcement (security) agencies, civil society organizations, colleges, polytechnics, or research institutes.

3.2) Vulnerabilities of nuclear and radiological facilities to climate change

The respondents were asked to use a Likert scale to rate the vulnerability of nuclear and radiological facilities to climate-induced events, determining whether these facilities are susceptible to the effects of climate change. "Strongly disagree" is on scale 1, and "strongly agree" is on scale 5. According to the findings, 76.7% of the participants concur that nuclear and radiological facilities may be impacted by flooding and/or sea level rise. Overall, more than 70% of respondents believe that sea level rise or floods can have a direct effect on vital nuclear infrastructure, nuclear security, and nuclear safety protocols, making these materials and/or facilities more vulnerable. In its report Climate Change Adaptation Roadmap, the US Department of Homeland Security (USDHS, 2012 and 2013) supports the respondents' opinion by stating that "Critical infrastructure around the country may be directly impacted by climate change," which could lead to an increase in erosion, storm surge, and sea level rise in US coastal regions, potentially causing damage or destruction to critical infrastructure.

According to the findings, 71.5% of the participants agreed that nuclear and radiological facilities are susceptible to severe drought and temperature changes. More than 70.3% of respondents believe that extreme heat or drought can have a negative safety and security impact on nuclear and radiological facilities. This is particularly true when the area where a nuclear facility is located experiences a shortage of water due to drought, which may result in the loss of necessary cooling. This could result in a serious safety challenge that can translate into a security issue for a nuclear facility. Scheffran *et al.* (2011, 2015) support the respondents' claim that severe weather, environmental degradation, and large-scale seismic events can all directly impact nuclear safety and security.

However, according to respondents interviewed, flooding and sea level rise are inherently safety issues and should be treated as such, rather than security ones. However, since the aim of both nuclear safety and security is to protect the workers, the general public, and the environment from the damaging effects of ionizing radiation, any event that may compromise safety may as well have an impact on nuclear security; therefore, the design and implementation of nuclear safety and security measures must be coordinated in such a way that nuclear safety measures complement nuclear security measures. In other words, nuclear safety measures and nuclear security measures should be mutually reinforcing and vice versa.

3.3) Potential safety and security risks associated with climate change

According to some of the participants interviewed, climate-induced events such as forced migration and displacement, as well as loss of livelihoods, are threat multipliers that can increase the potential threats, including insider threats in nuclear and radiological facilities. Furthermore, some of the respondents believe that increased competition over natural resources may lead to social unrest that may divert attention and resources from maintaining safety and security. The respondents' opinion is supported by Scheffran *et al.* (2015). According to the authors, climate change poses a hazard to ecological and societal systems around the world. Natural resource

depletion, reduced water and food supplies, forced migration, and an increase in the frequency and severity of climate-related disasters will have a significant impact on both large and small populations. These events would intensify global conflicts and act as a "threat multiplier" in already vulnerable areas. This might lead to a deterioration in global stability and incite hostility between individuals and countries. The authors further explained that extreme weather, environmental deterioration, and significant seismic occurrences can all have a direct impact on nuclear site safety and security, as demonstrated by several incidents in recent years.

Furthermore, a few of the study participants who were interviewed claimed increased competition over natural resources, forced migration and displacement, impacts on food, water, and energy, and loss of livelihoods are concerns of national security rather than nuclear security in particular. However, any security incident that could jeopardize national security could potentially have catastrophic consequences for nuclear and radiological security, since the nuclear security regime is part of the broader national security regimes (IAEA, 2013 and 2021a). National security and nuclear security are closely related and intertwined. While national security focuses on safeguarding a nation's sovereignty, territorial integrity, and public safety, nuclear and radiological security aims to prevent unauthorized access to, use of, and acquisition of nuclear and radioactive materials and technologies. This link arises because nuclear and radiological incidents, whether caused by deliberate acts of terrorism or by incidental events, have the potential to have devastating consequences on the environment, economy, and population of a country. Understanding the relationship between national security and nuclear safety and security is therefore essential to safeguarding the country against potential threats and promoting the prudent, secure, and safe use of nuclear technology for peaceful purposes.

3.4) Mitigation and adaptation strategies

In Nigeria, the Nigerian Nuclear Regulatory Authority (NNRA) is responsible for nuclear and radiological protection, and pursuant to section 47 (1), (2), and (3) of the Nuclear Safety and Radiation Protection Act of 1995 (the Act) (NNRA, 1995), it has promulgated many regulations, including the Nuclear Safety and Security of Radioactive Sources Regulations, 2006 (undergoing review) (NNRA, 2006), and the Nigerian Physical Protection of Nuclear Material and Nuclear Facilities Regulations, 2021 (NNRA, 2021b). However, these regulations, although formulated exclusively to govern the safety and security of radioactive materials, do not incorporate any provision that addresses the emerging nuclear safety and security challenges associated with climate change. It is, however, important to note that the Nigerian Safety Regulations for Licensing of Sites for Nuclear Power Plants, 2021 (NNRA, 2021a), explicitly incorporates regulatory provisions that address the potential safety impacts of climate-induced events on nuclear power plants (NPP). These provisions reflect the recognition of the increasing relevance of climate-related hazards such as extreme temperature, flooding, and severe weather events to the siting, design, and operation of nuclear facilities.

On a positive note, NNRA has developed capacity in the areas of nuclear and radiological emergency response, inspections, authorizations, and enforcement, and has since formulated enforcement policy and procedure to ensure the implementation of the provisions of the Act and other extant regulations made under the Act. Therefore, there is an availability of efficient and effective legal instruments required for regulating the use of nuclear energy and radiation-based technology in Nigeria.

The study participants have further commented that the deployment of advanced environmental monitoring and surveillance technologies to track changes in

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environmental conditions, the use of nuclear energy to reduce carbon emissions, and the establishment and implementation of early warning systems to notify the appropriate authorities in the case of emergencies relevant to climate change can go a long way in mitigating the safety and security risks posed by climate change to nuclear and radiological facilities.

3.5) Local and international collaboration to address the impacts of climate change

To encourage cooperation between local Competent Authorities and international organizations to exchange expertise, resources, and best practices for nuclear and radiological safety and security in the context of climate change. The respondents' views were asked on the opportunities for national and international collaboration that can be explored in addressing the implications of climate change on nuclear safety and security. The data also showed that 91.2% of the respondents felt that climate change and nuclear safety and security are global issues that require local and international collaborations to contain their impacts on nuclear and radiological facilities.

According to the data, 91.6% of the respondents believed that containing the risks posed by climate change would be greatly aided by national and international cooperation between agencies in charge of nuclear safety and security, as well as climate change. This cooperation would involve sharing resources, best practices, and knowledge about nuclear safety and security in the face of climate change; therefore, NNRA and the National Climate Change Council (NCCC) have major roles to play in fostering cooperation with other local competent authorities and international organizations to exchange expertise, resources, and best practices for nuclear safety and security as well as climate change. Additionally, over 90% of the study participants averred that the Federal Ministry of Environment and some parastatals under it, as well as the Nigeria Atomic Energy Commission (NAEC), are important stakeholders that can play prominent roles in promoting collaboration with other local competent authorities and global organizations to share knowledge, resources, and best practices to address the effects of climate change. The Nigerian Meteorological Agency, the Energy Commission of Nigeria, the Office of the National Security Adviser (ONSA), the National Emergency Management Agency (NEMA), and law enforcement agencies are all significant stakeholders who can play vital roles in mitigating the effects of climate change on nuclear and radiological facilities, according to the respondents.

To combat the effects of climate change on nuclear and radiological infrastructure from both a safety and security point of view, the national stakeholders should take the lead in working with international stakeholders like the Intergovernmental Panel on Climate Change (IPCC) and the International Atomic Energy Agency (IAEA).

It is clear from the above that climate change is a global issue that transcends national borders. Therefore, it is necessary for national stakeholders, including the previously mentioned government agencies, civil society organizations (CSOs), facility operators, local communities, and international stakeholders, to share knowledge and work together on climate-resilient measures for nuclear and radiological sites.

On a positive note, the Nigerian government has demonstrated its commitment to the peaceful use of nuclear energy. It has signed and ratified all applicable international instruments and treaties that are required for the implementation of effective nuclear safety and security regimes in the country. These include the Pelindaba Treaty (African nuclear weapon-free zone treaty), the Convention on the Safety of Spent Fuel Management, the Convention on the Safety of Radioactive Waste Management, the Convention on the International Convention for the Suppression of Acts of Nuclear

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Terrorism, the Convention on the Physical Protection of Nuclear Material and its amendment, the Nuclear Non-Proliferation Treaty (NPT), the Convention on Nuclear Safety, the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (Andrea and Christine, 2019). Nigeria has also endorsed the IAEA Code of Conduct for the Safety and Security of Radioactive Sources and its associated guidance (Andrea and Christine, 2019). Nigeria is also a party to the Paris Agreement (PA) on Climate Change (FMEN, 2021).

4) Conclusion

From the investigations conducted, the following conclusions were reached.

i. Most of the participants have agreed that nuclear and radiological facilities are vulnerable to climate-induced events.
ii. There are potential nuclear and radiological safety and security risks associated with climate change. Therefore, mitigation and adaptation measures must be put in place to counter the dangers posed by climate change to nuclear and radiological facilities.
iii. Local and International collaborations are very important in addressing the impacts of climate change on nuclear and radiological facilities. Therefore, all parties involved must recognize that the safe and efficient use of nuclear and radiological facilities, as well as their safety and security, are crucial to achieving net zero in the near future.

5) Recommendations

i. The competent authority should review its regulations to include the impact of climate change on nuclear and radiological activities
ii. Local stakeholders should engage locally with one another and internationally with the international stakeholders to counter the impacts of climate change on nuclear and radiological infrastructures
iii. The roles and responsibilities for every stakeholder should be clearly and unambiguously defined
iv. Every stakeholder should clearly and unambiguously understand his/her roles and responsibilities
v. Climate impact assessment should be conducted before siting nuclear and high-risk radiological facilities
vi. Advanced environmental monitoring and surveillance technologies to track changes in environmental conditions should be deployed in all climate change-prone areas
vii. Early warning systems to notify the appropriate authorities in the case of emergencies relevant to climate change should be established, implemented, and maintained. This can help mitigate risks posed by climate change to the nuclear and radiological infrastructure.

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