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A Narrative Examination of the Effects, Difficulties, and Adaptation Techniques of Climate Change on Medical Laboratory Operations

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Abstract

Globally, medical laboratory operations are being progressively disrupted by climate change, which has an impact on supply chain stability, infrastructural integrity, and diagnostic accuracy. Puerto Rico, a significant center for the production of medical supplies, was severely damaged by Hurricane Maria in 2017, which resulted in severe shortages of blood bags and reagents in American hospitals. The stability of temperature-sensitive reagents and biological samples has also been threatened by rising global temperatures; research shows that even a 2°C increase in ambient temperature can dramatically lower enzyme activity in diagnostic tests. Concerns regarding the accuracy of test results in illness diagnosis and monitoring are raised by laboratories' inability to maintain ideal storage conditions, especially in settings with limited resources. These difficulties are made worse by extreme weather and changing disease trends. Microbiology labs in South Asia have frequently been disturbed by flooding, which has resulted in waterborne pathogen contamination and delays in testing for infectious diseases. Rising temperatures in Sub-Saharan Africa have increased the range of mosquitoes that spread malaria, driving up demand for diagnostic services beyond what many labs can handle. As seen during the COVID-19 pandemic when heatwaves impacted the manufacture and shipping of medical reagents, supply chain disruptions brought on by climate-related disasters have resulted in protracted shortages of crucial testing materials. In order to guarantee laboratory resilience and continuity in healthcare services, climate-adaptive solutions are desperately needed. Laboratories must implement sustainable operational procedures and infrastructure to lessen these effects. Important suggestions include investing in climate-resilient laboratory buildings, improving digital diagnostic capabilities to lessen reliance on physical sample transportation, and switching to solar-powered refrigeration to prevent sample degradation during power outages.

Keywords: Medical Laboratory Operations, Climate Change, Laboratory.

Introduction

The stability of healthcare systems, particularly medical laboratory operations, is at risk due to the growing worldwide catastrophe of climate change. Globally, laboratories are facing new problems due to rising temperatures, extreme weather, and changing disease patterns, especially in settings with low resources. To guarantee the precision of diagnostic tests, the integrity of biological samples, and the dependability of laboratory chemicals, laboratories rely on steady environmental conditions. However, laboratory efficiency is increasingly compromised by

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climate-related disturbances including power outages, flooding, and excessive heat, which pose major hazards to public health. Due to their lack of resources and infrastructure, developing nations like Uganda have even more obstacles when it comes to adapting to climate-related issues (Fox et al., 2019 ; Sherman et al., 2020).

The regular occurrence of power outages, which are made worse by rising temperatures and growing energy needs, is one of the most urgent issues facing Ugandan medical laboratories. The Uganda Electricity Transmission Company Limited claims that the nation frequently has power outages, which negatively affect labs that depend on a steady supply of electricity for refrigeration and diagnostic equipment. Many labs, especially those in rural locations, lack backup power supplies, which causes biological samples and temperature-sensitive reagents to degrade (Ali I, 2022). Another issue brought on by climate change is flooding, which puts Uganda's laboratory infrastructure at serious risk. Frequent laboratory floods caused by heavy rains and inadequate drainage systems contaminate sterile settings and damage equipment. The frequency and severity of rainfall have increased, according to the Uganda National Meteorological Authority (UNMA), especially in Kampala and other urban areas where laboratory facilities are concentrated. Mulago National Referral Hospital's laboratory facilities were swamped by extreme flooding in Kampala in 2019, which caused temporary closures and delays in vital diagnostic services. The loss of patient information and microbiological cultures as a result of flooding highlights how susceptible laboratories are to climate-related calamities (Sherman , 2023).

In addition to infrastructure issues, Uganda's infectious illness burden has increased due to climate change, which has raised the need for laboratory diagnostics. The spread of vector-borne illnesses including dengue fever and malaria has increased due to rising temperatures and erratic rainfall patterns. According to estimates from the World Health Organization (WHO), climate changes that encourage mosquito hatching have caused a 10% increase in malaria transmission in Uganda over the last ten years. As a result, laboratories deal with excessive workloads and frequently lack the resources needed to meet the rising demand for diagnostic services. Laboratory capacity is further strained by the low workforce and antiquated equipment found in many rural health clinics. Climate change has impacted not only infectious diseases but also the quantity and quality of water supplies, which are essential for laboratory operations. Clean water is necessary for sample processing, reagent preparation, and sterilizing processes in laboratories. (Gordon et al., 2021).

On the other hand, because of their strong infrastructure, cutting-edge technology, and financial resources, labs in wealthy nations are better able to handle disturbances brought on by climate change. Climate-adaptive tactics, like solar-powered backup systems, automated sample preservation techniques, and climate-controlled laboratory facilities, have been implemented in many wealthy countries. To lessen reliance on electricity derived from fossil fuels, laboratories in Germany, for instance, have implemented energy-efficient refrigeration and alternative cooling methods. These discoveries underscore the critical need for customized adaptation techniques in developing nations by highlighting the striking differences between laboratories in settings with high and low resources (Ni K, 2018 ; Ebi KL, 2021).

This article's objective is to investigate how climate change affects medical laboratory operations

and to pinpoint sustainable practices and adaptation techniques that can lessen these effects. This article attempts to increase awareness of the difficulties faced by medical laboratories and to offer insights into practical methods for fostering resilience and sustainability by analyzing the complex effects of climate change on laboratory infrastructure, supply chains, energy consumption, and environmental sustainability. Additionally, this article aims to educate policymakers, laboratory administrators, and healthcare professionals about the significance of proactive action in addressing climate change and promoting sustainable practices within medical laboratory operations by highlighting policy and regulatory considerations as well as cutting-edge green technologies.

Methodology:

Literature search: Using pertinent terms including "climate change," "medical laboratory," "sustainability," "adaptation strategies," and "policy concerns," a thorough search was carried out across academic databases, including PubMed, Scopus, Web of Science, and Google Scholar. To ensure relevance and currency, searches were restricted to publications published within the last ten years in peer-reviewed journals, reports, policy documents, and gray literature.

The effects of climate change on medical laboratory operations:

The operations of medical laboratories around the world encounter a variety of challenges due to climate change. These facilities, which are essential for research, monitoring, and disease diagnosis, are susceptible to the extensive consequences of environmental changes. The interruption of supply chains necessary for medical laboratory operations is one of the biggest problems caused by climate change. Transportation routes can be severely disrupted by extreme weather events like hurricanes, floods, and wildfires, which can cause delays or shortages in the delivery of essential laboratory reagents, consumables, and equipment (Cornish NE, 2021).

The essential requirement for adaptive measures is highlighted by the fact that such disruptions not only hinder diagnostic capacities but also jeopardize patient care. Furthermore, dangers to laboratory infrastructure and worker safety are increased by the increasing frequency and severity of extreme weather occurrences. Because they are frequently located in high-risk areas, laboratories are more vulnerable to structural damage, power shortages, and flooding. These incidents pose serious risks to the health and safety of laboratory personnel in addition to endangering the integrity of laboratory procedures. To reduce these hazards, it is essential to make sure laboratory facilities are resilient and to put strong emergency preparedness strategies into place (Sutherst, 2004).

Concerns about environmental sustainability in medical laboratory operations are made worse by climate change, in addition to physical infrastructure weaknesses. In addition to producing large volumes of trash, including hazardous materials and biohazardous waste, laboratories are major contributors to greenhouse gas emissions (Swim et al., 2011).

Concerns about environmental sustainability:

As part of larger initiatives to lessen the environmental impact of healthcare facilities, environmental sustainability issues are becoming more and more important in the field of medical laboratory operations. Medical laboratories produce significant volumes of trash, including hazardous materials and biohazardous waste, and contribute to greenhouse gas emissions despite being crucial for illness diagnosis and research. The carbon footprint of laboratory operations is further increased by the energy-intensive nature of HVAC systems and laboratory equipment. To reduce environmental effects and encourage an eco-friendly approach to healthcare delivery, it is imperative to address these sustainability issues. Reducing energy use and increasing energy efficiency in medical laboratory facilities is one important area of study (Kovács G, 2021; Altassan, 2023).

Waste management is a crucial component of environmental sustainability in medical laboratories. Chemical reagents, biological specimens, and disposable consumables are only a few of the waste types produced in laboratories. To avoid contaminating the environment and reduce the carbon footprint of laboratory activities, laboratory waste must be properly separated, recycled, and disposed of. Waste generation can be reduced and sustainable practices can be promoted by putting waste reduction strategies into action, such as recycling programs, embracing green chemistry principles, and moving to reusable labware. In order to promote environmental sustainability in medical laboratory operations, water conservation and consumption are also crucial factors. Large volumes of water are needed in laboratories for a number of tasks, such as cleaning, specimen processing, and equipment cooling (Zimmerman, 2004; Nascimento, 2010).

Efficiency and energy consumption:

In order to promote sustainability in medical laboratory operations, energy consumption and efficiency are important factors to take into account. Due to the operation of numerous pieces of equipment, HVAC systems, and lighting required for testing and maintaining conditions that are favorable to correct results, these facilities are notorious for having high energy demands. Using energy-efficient lab equipment is one of the main methods for cutting down on energy use. A variety of specialized equipment, including centrifuges, incubators, autoclaves, and refrigerators, which use a lot of energy, are frequently used in laboratories. Significant energy savings can be achieved while preserving or even enhancing laboratory operation by switching to energy-efficient versions that satisfy strict energy performance requirements. Additionally, by making sure that equipment is only used when necessary, equipment scheduling and utilization optimization can reduce energy waste (Ezzelle et al., 2008).

Green technologies in laboratory operations:

By providing creative ways to lessen environmental effect while upholding strict performance and efficiency criteria, green technologies are essential to fostering sustainability in medical laboratory operations. These technologies include a broad range of tools, methods, and approaches intended to limit energy use, cut down on waste production, and improve environmental sustainability. Energy efficiency is one of the main areas where green technology are having a big influence. Due to the operation of numerous pieces of equipment, HVAC systems, and lighting, laboratories are notorious for having high energy requirements.

Centrifuges, refrigerators, and fume hoods are examples of energy-efficient lab equipment that uses cutting-edge technologies to reduce energy use without sacrificing performance. Additionally, laboratories can track and optimize energy usage in real-time, finding areas for improvement and minimizing energy waste, thanks to smart energy management technologies, such as building automation systems and energy monitoring software (Eckelman m 2016; Lopez , 2017).

Strategies for adaptation:

To lessen the effects of climate change and guarantee the continuation of vital healthcare services, medical laboratory operations must implement adaptation measures. These tactics include a variety of preventative actions meant to improve resilience, reduce risks, and preserve operational efficacy in the face of shifting environmental circumstances. Building climate-resilient infrastructure is one of the main adaptation options for medical laboratories. Extreme weather, flooding, and power outages are just a few of the climate-related risks that laboratories are susceptible to. These risks can interfere with operations and jeopardize testing capabilities. These hazards can be reduced and laboratory services can continue in an emergency by making investments in robust infrastructure, such as flood barriers, backup power systems, and climate-controlled storage facilities. Furthermore, putting in place thorough emergency preparedness plans that include evacuation and communication protocols can assist reduce the impact of climate-related disasters on laboratory operations and guarantee the security of laboratory personnel (Janik-Karpinska E, 2023).

Recommendations:

Although a number of issues and solutions for climate-resilient medical laboratories have been identified, geographical differences are sometimes overlooked in discussions. Different geographic and socioeconomic situations have different effects of climate change on laboratory operations, **this Study limitations:**

- Laboratory activities are impacted by water constraint, especially in arid and semiarid areas. Up to 30% of medical institutions in Uganda may not always have access to clean water. Water is needed in laboratories for reagent preparation, testing, and equipment cleaning. In their pathology labs, the All India Institute of Medical Sciences installed rainwater collection and filtering systems. This tactic has produced a sustainable water supply, guaranteeing continuous diagnostic services even during dry spells.

- Excessive heat and humidity have an impact on equipment performance: In tropical regions, high levels of heat and humidity hasten the corrosion of lab equipment and compromise the precision of temperature-sensitive tests. Brazil's national laboratories have used energy-efficient air conditioning and dehumidifiers to create humidity-controlled settings in order to counteract these effects. This has enhanced test accuracy, especially for microbiological cultures, and decreased equipment failures.

Disruptions to the laboratory reagent and consumable supply chain: Transport delays caused by climate change have an impact on the prompt delivery of diagnostic kits and reagents. Testing for infectious diseases was impacted by over 50% of laboratory shipments being delayed by Bangladesh's severe flooding. To lessen reliance on global supply chains, the South African

Medical Research Council has made investments in domestic reagent manufacturing. As a result, operational disturbances have decreased and laboratory resilience has increased.

Conclusion:

The ability of medical laboratories to provide precise diagnoses and uphold public health is severely hampered by climate change. A proactive strategy to adaptation is required because to the rising frequency of extreme weather events, temperature swings, and changing disease patterns. It is crucial to put mechanisms in place that not only improve resilience but also guarantee the continuation of vital health services as laboratories deal with these difficulties. Future studies should focus on a few important topics. First, evaluating the economic viability of suggested adaptation solutions will give labs the information they need to allocate resources wisely. Securing funds and guaranteeing long-term viability require an understanding of how cost-effective infrastructure improvements, training initiatives, and sustainable practices are. It is crucial to look into how climate change affects the accuracy of laboratory tests. Finding out how environmental conditions impact sample and reagent stability and creating standardized procedures to lessen these impacts should be the main goals of research. Patient outcomes will be improved and laboratory credibility will be increased if test results are reliable under different circumstances.

Additionally, investigating the long-term health consequences associated with altered disease patterns brought on by climate change would assist labs in anticipating changes in diagnostic requirements. Laboratories can better plan for new health risks and modify their operations by comprehending these dynamics. Furthermore, improving laboratory capacities in the face of climate change requires the development of climate-resilient technology. Automation and portable diagnostic tools are examples of creative solutions that can lessen the effects of environmental interruptions and guarantee ongoing service delivery. Documenting local case studies and best practices can encourage cooperation and knowledge exchange across labs dealing with related issues. Laboratories can implement customized tactics that meet certain environmental challenges by learning from successful programs around the world.

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