SCIENTIFIC JOURNAL OF THE UNIVERSITY OF HEALTH SCIENCES

(SCI. J. OF UOHS)

Volume 2. 2026

UNIVERSITY OF HEALTH SCIENCES
Towards Better Health

ISSN: 3006-6271 (Print)
3006-7480 (Online

SCIENTIFIC JOURNAL OF THE UNIVERSITY OF HEALTH SCIENCES

(SCI. J. OF UOHS)

Volume 2. 2026

University of Health Sciences
Bosaso-Puntland, Somalia

SCOPE OF THE JOURNAL

» The Scientific Journal of the University of Health Sciences (Sci. J. UOHS) is a biennial and aims at reporting the scientific work produced within the university. However, results from other researchers in Somalia and abroad that report work of scientific relevance in the health field may be accepted and published in the journal.

» Another objective of this journal is to be a platform not only for our researchers to present their research results but also to encourage our graduating students to compete for publishing in this journal the important results of their research thesis work. A selected number of research thesis works of merit might be considered for publication.

» A third objective is to stimulate and motivate our young scientists to conduct research activities within the university and therefore learn and improve the art of both experimental and theoretical research activities.

» Minireviews and scientific comments on topics of interest in the health field and related areas may be considered for publication in this journal.

Published by the UOHS

Address: Airport Rd., Bossaso-Puntland, Somalia

Website: uohs.edu. so

E-mail: Info@uohs.edu.so

Tel. +252096181299

Bossaso, Somalia

AUTHOR GUIDELINES

A: Format and style:

- Word format for submission, and the manuscript must be a single file.
- Double-spaced one-column format; Font: Times New Roman, 12 pt.
- No formal length restrictions, but authors are requested to be as concise as possible.

B. The manuscript should be prepared in the following order:

- **Title:** should be as brief as possible, including spaces. Authors and their affiliation institutions indicated by superscript numbers should be listed below the title on the first page of the manuscript.
- **Abstract:** The abstract should present brief background information on the topic in question, methods, results, and conclusions. The abstract should not exceed 300 words and should not contain citations or unexplained abbreviations.
- Keywords: 3-5 keywords must be written on a separate line below the abstract.
- **Introduction:** should describe the background of the article (previous research), gaps and inconsistencies, aims, and provide a summary of the literature on the issue under investigation.
- **Methods:** This section should outline how the research was carried out, and experiments were performed. Sufficient information must be given to allow reproducibility.
- **Results:** All relevant findings must be described in this section, and the results of the data and the analyzed variables must be presented and illustrated in tables and figures. Titles and legends should be comprehensible without reference to the text.
- **Discussion:** This section discusses the interpretations and observations of the reported results with respect to the study purpose. The main findings are highlighted, with emphasis on similarities and differences relative to prior literature, and the potential implications of the results are discussed.
- **References:** references should be listed at the end of the manuscript in the order they appear in the text. All the information required to retrieve the source must be provided (see examples below):

1) References to articles in journals and periodicals:
Said Jama Isse, Asha Farah Ali (Year), Article title: Journal Name. volume (issue no.), page numbers. Doi: XXXXXXX

2. References to book chapters:
Isse Mohamed, Faduma Ali, Title of the chapter. In: John RC, Ipata AB, eds. Title of the Book. 3rd ed. Publisher name; Year: page numbers.

C. Illustrations
Tables and figures should be numbered in the order they are cited in the manuscript. The table title should be concise, clear, and at the top of the table, and the figure title should be in the legend of the figure (not in the figure itself). The figures and tables should be embedded in the main text where they are first cited.

D. Ethics Compliance
For human investigations, an informed consent statement should be included. Plagiarism of any kind is not acceptable and should be avoided.

E. Submitting the Manuscript
a) Cover Letter
The cover letter should provide the manuscript title as well as the corresponding author's name and contact information (telephone number and email).

Submit the manuscript to the secretary of the scientific journal committee, Hawo Yusuf.
e-mail: yhawa3464@gmail.com

TABLE OF CONTENTS

EDITORIAL COMMENT ON THE 25TH ANNIVERSARY OF THE UOHS

The year 2025 marks the 25th anniversary of the University of Health Sciences, a milestone that invites reflection on the institution's journey and its contributions to improving health in our community. The institution began as a health institute, a move triggered by the scarcity of medical personnel at Bendar Qassim Hospital in 1998. That scarcity prompted the late Prof. Abdirizak to lay the foundations of the first nursing institute in Puntland. The institution grew gradually, first as a college, with the formation of additional health branches. In 2012, the institute was elevated to university status and renamed the University of Health Sciences by the Puntland State and the WHO. On May 13th, 2013, the University was recognized by the Federal Government of Somalia. Today, the university consists of the following faculties: Medicine, Pharmacy, Clinical Nursing, Food Science and Nutrition, Public Health, Medical Laboratory, Radiology and Clinical Midwifery. In addition, there are several postgraduate courses in the health and related fields.

The university has played a key role and continues to do so in improving health in communities across districts and villages, for instance, by training various health professionals and raising awareness of health issues. Since its foundation, over 3000 students, both male and female, have graduated, with a significant impact on the well-being of Somali society in the health field. The University's graduates now work in many parts of Puntland and in Somalia. Furthermore, the University is engaged in community development, for example, it has contributed to the " Ceel Daahir Project", trained community midwives, and assisted in training Yemeni refugee laboratory technicians.

The University is committed to serving the Somali society in the health sector and is also determined to improve further the educational quality in the health and related areas. A testimony reflecting this commitment, and which additionally highlights the University's achievement, is the foundation and continuation of our journal.

EDITORIAL NOTE

Dear Colleagues and Readers,

It is with great pleasure that we present the second volume of the Scientific Journal of the University of Health Sciences (Sci. J. UOHS). The publication of Volume I in April 2024 marked the beginning of a journey, rooted in curiosity and a commitment to cultivating a culture of scientific research and knowledge advancement. Among the themes covered in that volume, to mention a few of them, were investigations of food insecurity in Bossaso; family planning among women of reproductive age in Bossaso City; a study of Giardiasis among patients who attended Bossaso General Hospital; the use of pesticides in khat cultivation and the associated health risks; and other health-related topics. The response from our community of readers has been both encouraging and inspiring.

This new volume builds upon that foundation. The articles featured here reflect the journal's diverse research topics and growing reach. The articles in this volume include one on zoonosis, the diseases that can be transmitted from animals to humans. The importance of this work is self-evident: our economy depends primarily on livestock, and contact between animals and our community is indispensable. The author of this article treats the subject from different perspectives. In another article, the drug-disposal practices of pharmacists in Puntland were examined, highlighting adverse health and environmental effects and underscoring the need for nationwide regulations to ensure proper disposal. Furthermore, another article examines investigations into aluminium phosphide, a highly toxic pesticide used for fumigating stored grains in Somalia and neighbouring countries. This article emphasises the health hazards of this pesticide and recommends national regulations to ban such harmful pesticides. In addition, there are articles on the frequency of nonsteroidal anti-inflammatory drug (NSAID) use among patients in Bossaso and on the risks of waste batteries, aimed at raising public awareness of the negative impact of improper disposal. Additionally, there is insightful commentary on the role of artificial intelligence in scientific discovery, as demonstrated by the solution of the 50-year-old protein folding challenge. The implications of this discovery in medicine and biology are thoroughly discussed.

A relevant objective of the foundation of this journal remains to be a platform for our young researchers to publish their research results, but also scientific work performed in other institutions in the country and outside of the country may be accepted for publication in the journal, provided that they are of relevance in the health or related areas. Another key goal of this journal is to motivate and encourage our academic staff to pursue and conduct research at the University. Therefore, we encourage researchers in Puntland and across the country to submit their work to the journal. We aim to strengthen the practice of experimental and theoretical research among young researchers, enabling them to develop their writing skills and publish their work in internationally refereed scientific journals in their fields of interest.

Looking ahead, we are committed to strengthening our experimental research and hope to present experimental results in the next edition.

Finally, we would like to extend our appreciation to the authors for their scholarly contributions, to the reviewers for their efforts and to the editorial board for their dedication. Their collective efforts make the journal move forward.

A SIGNIFICANT PORTION OF THE COMMUNITY IN SOMALIA IS AT SERIOUS RISK OF ZOONOTIC DISEASES:

(WHERE THERE IS AN ANIMAL, THERE IS ZOONOSIS)

Abdirahman Abdullahi Warfa

ABSTRACT

The term "zoonosis" was first introduced by Virchow in 1888 to refer to diseases that can be transmitted from animals to humans. These diseases, caused by various pathogens such as bacteria, viruses, fungi, and parasites, often spread through contaminated food or water.

Nomadic pastoralist societies face an increased risk of zoonotic disease transmission due to several factors, including shared living spaces with livestock, animal movement, limited access to medical facilities, low literacy rates, scarce freshwater resources, and inadequate sanitation systems.

Rainwater collection in these communities can lead to contamination from animal faeces and human waste, contributing to waterborne zoonoses. Milk-borne zoonotic diseases originate from contaminated milk or milk products, with contamination resulting from dairy animals, human handling, or environmental factors. The use of unhygienic, nonrecyclable plastic containers by milk vendors increases the risk of contamination. Meat-borne zoonoses are linked to inadequate meat inspection, poor conditions in meat-handling and processing facilities, and insufficient water for sanitation and hygiene.

Keywords:
Zoonosis; Pathogens; Nomadic pastoralist; Poor sanitation; Inadequate inspection; Water harvesting

1. INTRODUCTION

Virchow first used the term zoonosis in 1888 (1). All animals naturally carry a group of diseases which can also affect humans. Such diseases are known as zoonoses and are transmitted between animals and humans. These diseases are caused by a wide range of pathogens, including bacteria, viruses, fungi, and parasites, collectively known as zoonotic diseases (2). These include Lyme disease (transmitted by ticks) and rabies (transmitted from mammals). Zoonotic diseases can cause a wide range of effects in people and, many times, even death (the morbidity and mortality are very high). Although humans may display signs of illness, animals do not always exhibit obvious symptoms of being sick. These animals are commonly referred to as "carriers" because they harbour pathogens that cause disease.

Zoonotic diseases are well documented and not a new phenomenon; over more than 100 years of social experience, it has become clear that animal and human health are closely linked. There are more than 200 animal diseases transmissible to people, and at any given time, a new one emerges or re-emerges seasonally and geographically (3-5). In this work, the author discusses the zoonotic diseases and their relevance in our community, as our economy and survival depend on livestock husbandry, as well as how the present situation of limited access to veterinary and medical facilities greatly contributes to the likelihood of the occurrence and the spread of this group of diseases in our society. Furthermore, he outlines the factors that facilitate transmission of these diseases between humans and animals, including water-, milk-, and meat-borne components, among others. The author concludes with recommendations to educate our communities about the risks of zoonotic diseases and advocates improvements in hygiene and sanitation, as well as the establishment of necessary infrastructure for meat inspection and water hygiene.

2. DISCUSSION

2.1. Livestock production in Somalia

Somalia's livestock sector is a vital component of the national economy, contributing significantly to the country's GDP, foreign exchange earnings, and employment, particularly for nomadic and semi-nomadic populations. The country boasts a large livestock population, including camels, cattle, sheep, and goats, and is a major exporter, particularly to the Middle East. Despite its importance, the sector faces challenges like climate change impacts, drought vulnerability, and market access issues.

After the civil war, the entire infrastructure collapsed, and unemployment increased across communities. The shift toward livestock production and its products has significantly increased the risk of zoonotic disease transmission across the country's human and animal populations.

Characteristics of the nomadic pastoralist society that favour zoonotic disease transmission include sharing the same environment with livestock, movement of animal populations, limited access to human and veterinary medical facilities, low literacy rates, a lack of fresh water, poor sanitation/hygiene, and artificial disasters (such as civil unrest or war).

While the Somali community is involved in livestock production, including taking care of their livestock, trading, utilizing it as food, handling its products and byproducts, and sharing shelter, water, and the environment (both micro and macro environments). From these intimate, direct, and indirect interactions between our community and animals, it is clear how readily zoonotic diseases can spread between animals and humans.

2.2. Waterborne zoonosis and hygiene

Water in its natural state is among the purest substances known. Today, however, it is difficult to find a source of fresh water that has not been disturbed by humans, animals, or the surrounding environment. And the nastiest problem of zoonosis is the waterborne disease, in the pastoral agriculture, and internally displaced camps (IDP camps), all the families are using poorly harvested rainwater, which is contaminated with faeces from livestock, wildlife and human leftovers. This type of water is contaminated with a large number of microorganisms, including protozoa (e.g., Giardia, Amebiasis, Cryptosporidium), Vibrio cholerae, mycobacteria, and parasites (6-9). Also, there are other opportunistic environmental organisms and decomposed materials (plant leaves, organic materials such as dead insects or small animals such as lizards, etc.), to mention a few, and chemicals are not absent (such as detergents, pesticides, etc.). Cholera outbreaks are frequently reported during the dry seasons because of water scarcity (the contaminant load increases).

2.3. Milk-borne and milk hygiene

Milk contains nutrients that support the rapid multiplication of bacteria that cause spoilage (microorganisms). Unhygienic production, poor handling, and undesirable practices, such as adding already contaminated water or other substances, can introduce more bacteria (germs) that cause spoilage. Some of these germs are disease-causing organisms that can adversely affect human health, such as cholera, typhoid, brucellosis, amoebiasis, Giardiasis, and tuberculosis (10,11).

Also, the use of plastic containers which are recycled and are un-cleanable are taking the biggest role of contaminating and worsening the milk hygiene, these containers are altering the composition of the milk (physical characteristic of the milk), the test and its odour; these plastic containers are originally from petroleum by product residues and some are from hazardous chemicals that can cause

hepatitis and cancer to the community, as well as precipitation of milk clots and milk fats settle in the container and are difficult to remove or clean because of its narrow inlet opening, so these plastic containers cannot be easily washed, cleaned or disinfected.

Milk-borne zoonotic diseases are usually caused by the ingestion of contaminated milk or milk-containing food. Disease organisms in milk may be derived from the dairy animal, human handling or the environment.

2.4. Meat-borne disease

Red meat is a nutrient-dense food that provides a significant amount of protein, essential amino acids, vitamins, and minerals, which are among the most common nutrient deficiencies worldwide, including vitamin A and zinc (12). Red meat provides 91% of the recommended daily intake of vitamin B12. As a result, meat hygiene became a crucial issue and subject of legislation approximately 100 years ago, with the primary purpose of preventing the use of meat from diseased animals for human consumption. Meat hygiene then was synonymous with meat inspection. This was to control zoonotic diseases in communities or populations (meat-borne diseases) (13).

The importance of meat-borne pathogens to global disease transmission and food safety is significant for public health. These pathogens, which can cause a variety of zoonotic diseases, include bacteria, viruses, fungi and parasites. Consuming pathogen-contaminated meat or meat products can cause a variety of diseases, including gastrointestinal illnesses. Humans are susceptible to several diseases caused by zoonotic bacterial pathogens transmitted through the consumption of meat, most of which affect the digestive system. Various stages of production, processing, transportation, and food preparation can expose meat and meat products to bacterial infections and/or toxins. Generally, bacterial meat-borne zoonotic diseases are caused by strains of Escherichia coli, Salmonella (14, 15), Listeria monocytogenes, Shigella, Campylobacter, Brucella, Mycobacterium bovis and toxins produced by Staphylococcus aureus, Clostridium species, and Bacillus cereus (16).

In Somalia, following the collapse of the central government, the conditions in slaughterhouses, the meat transportation system, and meat markets deteriorated hygienically. These infrastructures are known to be critical for safe guiding meat hygiene (16). In the meat facilities, there is no adequate water for cleaning or sanitation for the locations or the utensils in use, all the contamination factors accumulated and facilitated the multiplication of hazardous microorganisms (Salmonella, Shigella spp., C. Botulism etc.), and meat-born zoonosis or food poisoning increased in particular in the tropical areas, also meat inspection system is not existent at all.

The clinical laboratories in the Puntland State (Somalia) frequently report cases of Salmonella, Brucella, and nematodes; however, no accurate data are collected or archived.

2.5. Other sources of zoonosis in Bossaso

A large number of women are involved in the goat trade in Bossaso town. These women are taking care of their animals in their houses, and in the residential area around (goats are semi-scavengers). The goats wander from house to house searching for leftovers from the families in the garbage collection area. These goats are sufficient to contaminate the microenvironment and spread the zoonotic disease. Other significant sources of the spread of zoonotic diseases include scavenging cats, rodents, insects, birds, and wildlife, among others.

2.6. How do zoonotic diseases (germs) spread between animals and people?

Due to close contact between people and animals, it is essential to be aware of the common ways people can contract zoonotic germs. These common ways include:

Direct contact: coming into contact with body fluids such as saliva, blood, egg, urine, mucous and faeces of infected animals. Examples include petting or touching animals, as well as bites or scratches.
Indirect contact: coming into contact with the shelter area where animals live, objects, or contaminated utensils that contain harmful zoonotic germs. For example, water tanks, animal feed, watering equipment, restraint tools, and soil or dust from the farm, as well as contaminated human food.

2.7. More exclusively and highly susceptible individuals: Occupational zoonosis *(through contacts and inhalation of dust).*

Although the entire society is susceptible to the disease, certain individuals are more vulnerable than others (17, 18) and are:

- Slaughterhouse and meat market workers and meat/milk vendors,
- Nomadic pastoralist families sharing everything with their livestock (environment, shelter and water),
- Hospital and laboratory personnel dealing with sick persons and handling hazardous biological materials,
- Veterinarians and vet. Assistants are frequently in contact with infected animals and contaminated sample materials,
- Children, the elderly, childbearing women and immunocompromised individuals.
- Garbage collection personnel (collecting rubbish from hospitals, private clinics and laboratories).
- And the civil war internally displaced community (IDPs)

2.8. Conclusion and recommendations

✓ Zoonotic diseases will persist beyond our lifetimes; therefore, prudent measures must be taken today to prevent and control disease tomorrow.

✓ Conduct awareness-raising activities and educate the community about the risks and hazards of zoonoses, as well as the need to enforce sanitation and hygiene measures.

✓ Establish a task force comprising veterinary public health and human health experts. This team must conduct research to evaluate the situation on the ground and periodically monitor the status of zoonoses in the country.

✓ Our slaughterhouses and meat markets are in poor hygienic condition, utilizing rudimentary equipment, and have inadequate water supplies for cleaning and sanitation purposes. To minimize contamination and hazards, it is very important to take immediate action in accordance with the international standards (clean water system and cleanable equipment).

✓ The community and the government must improve water systems to provide potable water, particularly for nomadic and urban communities and their livestock. It is essential to implement boreholes with potable water.

References

1. Anon (1959). Zoonosis Technical Report Series No 169. World Health Organization, Geneva. (Technical report defining zoonosis).

2. Palmer SR, Lord Soulspy DIH. (1998). Zoonosis. Biology, clinical practice and public health control. Medical Publication, Oxford. (Comprehensive textbook including all zoonoses).

3. Chomel, BB.(1998). New emerging zoonosis: a challenge and an opportunity for the veterinary profession. Comp Immunol Microbial Infect Dis. 21: 1-14.

4. Desselberger, U. (2000). Emerging and reemerging infectious diseases. Journal of Infection. 40: 3-15.

5. Smith HV, Rose JB. (2000). Emerging parasite zoonoses associated with water and food. International Journal for Parasitology 30: 1379-1393. [Review of the issues of food and waterborne parasites].

6. Ford TE.(1999). Microbiological Safety of Drinking Water: United States and Global Perspectives. Environmental Health Perspectives 107, 191-297.

7. Cang, S. L. (1961).Viruses, amebas, nematodes and public water supplies. J. Am. Wares Works Assoc. 52: 288-296.

8. R. M. Chalmers. UK Cryptosporidium Reference Unit. NPHS Microbiology, Swansea, Singleton Hospital, Swansea. UK.

9. Thompson RCA. (2000). Giardiasis as a remerging Journal for parasitology 30: 1259-1267.

10. Schwabe.Veterinary medicine and human health, second edition, Baltimore, 1969, 549-555.

11. Helvio, R. J (1959). Tuberculosis and brucellosis as milk-borne diseases. J. Milk Food Tech. 22: 182-185.

12. McNeill SH. (2014). Inclusion of red meat in healthful dietary patterns. Meat Sci. doi: 10.1016/j. Meat sci. 2014.06.028.

13. Schwabe. Veterinary Medicine and Human Health, by Schwabe, second edition, Baltimore, 1969. 534-539.

14. Ayers, J. C. (1955). Microbiological implications in the handling, slaughtering and dressing of meat animals. Adv. In Food Res. 6: 110-161.

15. Blanche Koelensmi. W. A. A., and Van Rhee, R. 1964. Salmonella in a meat product. Ann. De l'Inst. Pasteur de Lille. 16: 85-97.

16. Kaplan, M. M. (1957). Meat-Hygiene problems in tropical areas. IN. Meat Hygiene Series No. 33, Geneva.

17. Abrams, H. K. and Warr, P. 1951. Occupational disease transmitted via contact with animals and animal products. Indust. Med., 20: 341

18. Abinanti, F. R. (1964). Respiratory viruses of animals. In: Occupational Disease Acquired from Animals. Univ. of Michigan School of Public Health.

Annex

The annexes below report figures illustrating the various sources of meat, milk, and water contamination, and consequently, the potential for zoonotic diseases.

Fig. 1. The meat market table is riddled with cracks that support the growth of microorganisms that cause meat contamination.

Fig. 2. Between the meat and the table, there are recycled cartons.

Fig. 3. Meat swung in the open air for daring, but the dust and flies are ready to contaminate it.

Fig.4. Even the children are at risk of zoonosis.

Fig 5. The recycled cartons between the table and the meat (the cartons might have been emptied of drugs, chemicals, food, etc.)

Fig. 6. Pulled harvested water for drinking and for family use (one of the worst health constraints in the country).

Fig. 7. The water supplier is using recycled, uncleanable plastic containers for the market and families.

Fig. 8. Humans and animals drink from the same water trough.

Fig. 9. Recycling plastic containers for milk; milk vendors use these containers many times. The containers are uncleanable because the opening is tiny.

Fig. 10. Unhygienically handling milk from a filthy container; the milk had been in the container for several hours, allowing enough time for germs to multiply.

A HIGHLY POISONOUS INSECTICIDE (ALUMINIUM PHOSPHIDE) HAS BEEN USED FOR DECADES IN SOMALIA FOR GRAIN PRESERVATION

Ahmed M. Osman and Abdirahman Abdullahi Warfa
University of Health Sciences (UOHS),
Puntland State (Somalia)

ABSTRACT

Aluminium phosphide (AlP) is a poisonous pesticide used to fumigate stored grains. Here, we investigated the widespread use of this product in Somalia by assessing its employment by establishments in Bossaso city, a commercial centre in Puntland State, which has strong business activities with the rest of the country and neighbouring countries. We interviewed 43 individuals working at establishments that operate retail shops and grain storage facilities. We found that aluminium phosphide has been used in Somalia for decades, primarily for grain preservation. Our results reveal that approximately 51% of participants handle the product with their bare hands during fumigation, indicating a lack of knowledge about its hazards. Indeed, 46.5% of participants believed the pesticide was harmless to public health and the environment, whereas 39.5% thought it had a negative impact. The rest (14%) were unaware of its effect. Moreover, the participants disposed of the damaged tablets and spent powder residues in the trash, which is not the recommended procedure. Furthermore, almost half of the participants experienced accidents during the fumigation process with the product, such as suffocation, headache, nausea and allergy. It appears that no national regulations governing the sale and storage of aluminium phosphate are in place. The participants added that they did not receive local authority inspections or guidance on the safety and hazards of the pesticide.

In conclusion, due to the lethality of aluminium phosphide, we recommend that national and local authorities take immediate action by establishing laws to ban such harmful pesticides and raising public awareness of their health risks.

Keywords:

Aluminium phosphide poisoning, Grain fumigation, Public health threats, Somalia

1. INTRODUCTION

Pesticides are used in many developing countries to improve the quantity and quality of agricultural products. But improper use of these pesticides leads to the death of about 300,000 people every year globally (1). Metal phosphides are a group of pesticides commonly used as fumigants, including aluminium, magnesium, and calcium phosphides. One of the most lethal metal phosphides is aluminium phosphide (AlP), which is used for grain preservation in many parts of Asia, including India, Iran, the Middle East, and certain African countries (2). Aluminium phosphide is one of the most common causes of poisoning deaths in India, Iran, Oman and Morocco (3-7), but not in Western countries (8-9), where strict regulations exist for the sale and usage of this product under their national pesticide acts. Aluminium phosphide can be formulated into tablets, pellets, or powder sachets, with additional compounds such as ammonium carbamate, ammonium bicarbonate, urea, and paraffin to reduce flammability and control the release of the fumigant (10). Principally, it is marketed as a dark grey 3g tablet under the brand names such as Celphos, Alphos, Quickphos, Phosfume, Phostoxin, Talunex, Degesch, Synfume, Delicia, etc. (10). The toxicity of this product is due to hydrogen phosphine gas (PH3) formation when water reacts with aluminium phosphide (3). A three-gram tablet releases one gram of phosphine. This is why ALP tablets lose potency over time due to the gradual release of phosphine gas upon contact with atmospheric moisture (11). Phosphine gas is toxic to all aerobic organisms, including humans. The intoxication of aluminium phosphide can occur by ingestion or inhalation of phosphine gas and through damaged skin (12). After ingestion, aluminium phosphide reacts with water and hydrochloric acid, producing phosphine gas. The liberated phosphine gas is absorbed in the gastrointestinal tract and rapidly distributed

throughout systemic circulation, diffusing into the rest of the body, resulting in adverse effects. Essentially, phosphine gas blocks cellular respiration, causing an energy crisis in organs such as the heart and kidneys, leading to oxidative stress in tissues (13). Additionally, concentrated phosphine gas can potentially ignite and cause explosions at room temperature (10).

Although high morbidity and mortality are associated with aluminium phosphide, which originates from occupational exposure and intentional incidents, and consequently merits raising public awareness and urging the establishment of national regulations on the sale and usage of this pesticide, there is a shortage of data on aluminium phosphide's health concerns in East Africa, though its usage is widespread. To our knowledge, only a recent work has reported the emergence of metallophosphides as a significant public health threat in Ethiopia (14). The present study aims to explore the frequency of aluminium phosphide usage, the establishments involved, the duration of its use in the country, and how consumers store and handle the product. Additionally, we investigated whether consumers experienced incidents, their knowledge of the health and environmental impacts, and the disposal methods for the damaged and residual products.

2. RESEARCH METHOD

This qualitative research employed a structured questionnaire as an interview tool to collect data on aluminium phosphide from participants working in retail shops and storage facilities for various types of grains and agricultural products in Bossaso city, the commercial city of Puntland State, Somalia. The sample size was 43 participants. The participants were chosen at random.

2.1. Data Analysis

The collected data were analysed in Excel, and the results were presented in figures and tables.

2.2. Ethical considerations

Participants were informed of the research purpose, and their consent was obtained prior to participation. Confidentiality is maintained, and the approval of the research board of the University of Health Sciences was obtained.

3. RESULTS

Figure 1 reports the types of establishments (retail shops and storage houses) and the number of men and women who were interviewed and engaged in the business. The number of shops was slightly more than the number of warehouses. More men worked in shops than women.

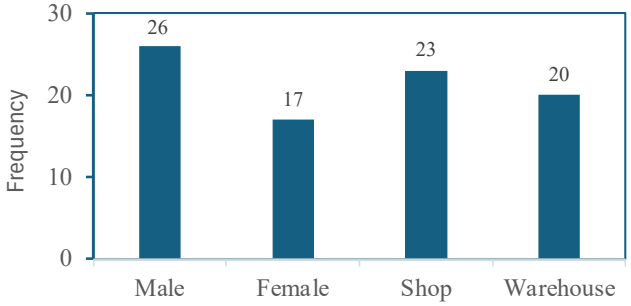


Figure 1. Number of males and females interviewed and types of establishments (retail shop and storage house)

The period during which a participant has been handling aluminium phosphide ranged from 1 to 43 years (data not shown), indicating that this pesticide has been used for decades in Somalia. The typical formulation used in the country is a tablet. The primary purpose for which customers purchase aluminium phosphide is grain preservation, and it is rarely used for rodenticide (Figure 2).

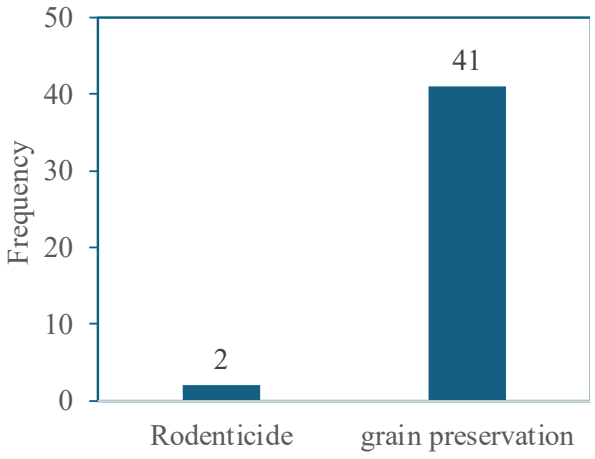


Figure 2. The primary purposes employed for the aluminium phosphide

When participants were asked whether they had ever experienced any incident or accident related to aluminium phosphide, their responses are shown in Figure 3. Approximately 46.5% of participants reported affirmative responses, and 53.5% reported no incidents.

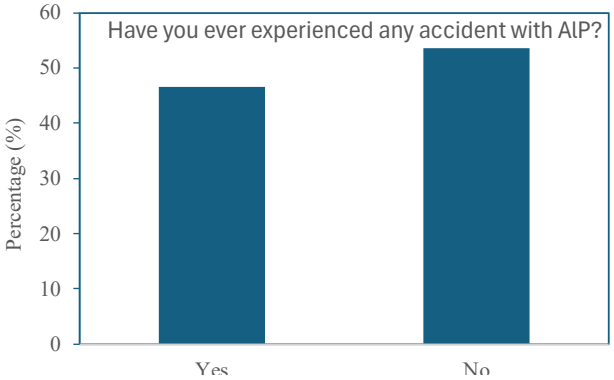


Figure 3. Percentage of customers who experienced accidents related to aluminum phosphide

To gain insight into whether participants were aware of the product's dangers, we asked them how they handled the tablet when applying it to their grains. In other words, we wanted to know whether or not they use gloves and masks. As shown in Figure 4, almost half used their bare hands without resorting to other tools. Furthermore, the participants were asked if this product harms the environment.

Most participants (46.5%) believed that the product does not affect the environment, whereas 39.5% stated that it has an adverse effect (Figure 5). The remaining 14% indicated that they were unaware of it.

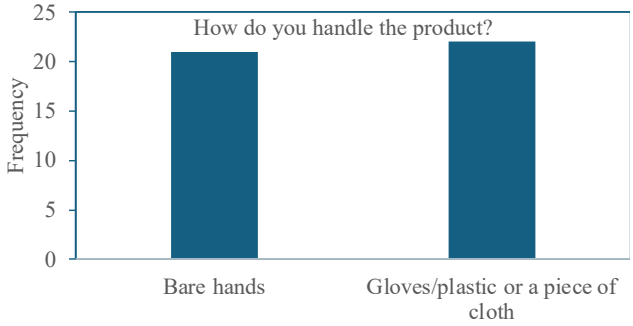


Figure 4. The possible ways customers handle the product

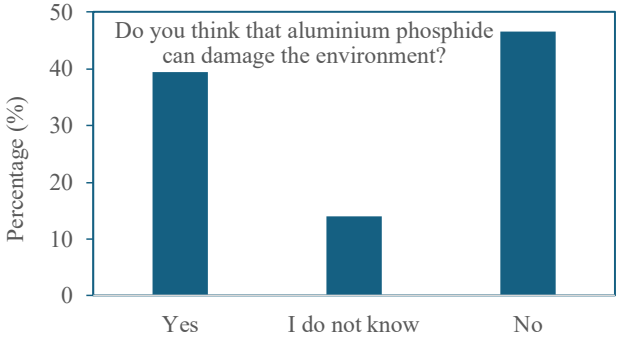


Figure 5. Knowledge of the customers about the environmental impact of aluminium phosphide

As shown in Table 1, we asked the participants additional questions regarding aluminium phosphide. One of these questions was to list the most frequent accidents that the participants have experienced with the pesticide, to which they replied: headache, suffocation, nausea and allergy (Table 1). It is relevant to note that some of them stated they had slept in the fumigated place during its active phase. Further, they stored the product in the storehouse or shop (Table 1). When asked how they dispose of the damaged tablets and residues, the participants answered that they dumb them into the trash (Table 1). Finally, we asked the participants whether they were familiar with

national regulations governing the sale or storage of this pesticide, and whether they had ever received any inspections or guidance from local authorities on the safety of aluminium phosphide (Table 1). The participants' answers were unanimously negative to both questions (Table 1).

Table 1. Some additional questions regarding aluminium phosphide for the customers

Questions	Responses	Number of participants (n= 43)	Percentage (%)
1. What are the most frequent accidents of aluminium phosphide?	a) Headache b) Suffocation c) Allergy d) Nausea	20 23 (met no accident)	46.5 53.5
2. Where do you store aluminium phosphide?	In the shop/ storage room	43	100
3. How do you dispose of the damaged products and residues?	Into the trash	43	100
4. Are you aware of any Puntland state or national regulations governing the sale or storage of this product?	No	43	100
5. Do you receive any authority inspection or guidance from local regulatory authorities?	No	43	100

4. DISCUSSION

The present study revealed that aluminium phosphide, a highly toxic pesticide, has been widely used in Somalia for decades to preserve grain. Retail shops and storage houses in Bossaso city, the commercial centre of Puntland State, use this insecticide as a grain-preservation fumigant in tablet form (Figures 1 and 2). Most of the grains originate from southern Somalia or neighbouring countries, with the pesticide already present in the grains; therefore, this pesticide is used throughout the country. The toxicity of the aluminium phosphide is due to phosphine gas, which is formed when water reacts with AlP as follows:

$$AlP + 3H2O \rightarrow Al(OH)3 + PH3$$

Phosphine gas is very toxic, and currently, there is no antidote for its poisoning. In the workplace, an air phosphine level of 50 mg L-1 (50 mg ppm (parts per million) may damage health, and 400-600 mg ppm may cause death in 30 minutes (15). Our study revealed that users of this pesticide are unaware of its adverse effects. Indeed, most participants handle the tablets with bare hands, without any other safety measures, such as masks (Figure 4). Some of the participants experienced accidents with this product, such as headache, suffocation, nausea, and allergy (Figure 3 and Table 1). Furthermore, most participants (46.5%) believed that AlP does not harm the environment (Figure 5). In fact, all participants stated that they dispose of the spent tablet residues in the trash (Table 1). This is contrary to the recommended practice, in which the residues of the spent powder are deactivated with a water

and detergent mixture and then disposed of, as the spent powder still contains 3-5% unreacted aluminium phosphide (16,17). This observation highlights the need to raise public awareness about the safety and hazards associated with dangerous pesticides, such as aluminium phosphide.

Because of the lethality of this pesticide and its intentional or accidental exposure to harm the public, the participants were asked if they were aware of any national regulations governing the sale and storage of this product, and whether or not they received inspections and guidance on the safety and hazards of the product (Table 1). The answers to these questions were negative (Table 1).

In conclusion, the primary purpose of this work was to assess how widespread the use of this lethal product in Somalia is and to what extent the public is aware of its lethality and adverse effects. Aluminium phosphide has been used in Somalia for decades without an evaluation of its negative impact on public health, and even those occupationally involved in its use are unaware of its consequences. It appears that no national regulations governing the sale, storage, or safety guidelines exist, nor are workplace inspections carried out by local authorities. We urge the authority to take immediate action against pesticides, such as aluminium phosphide, and to raise public awareness of their potential dangers.

REFERENCES

1. Gunnell D, Eddleston M. Suicide by intentional ingestion of pesticides: a continuing tragedy in developing countries. Int J Epidemiol 2003;32:902-9. PMCID: PMC2001280

2. Hassanian-Moghaddam H. Phosphides and phosphine: Mechanisms for toxicity and range of the problem. In: XXXIV International Congress of the European Association of Poisons Centres and Clinical Toxicologists (EAPCCT); 27-30 May 2014; Brussels, Belgium. Clin Toxicol 2014;52:397-8.

3. Bogle R, Theron P, Brooks P, Dargan P, Redhead J. Aluminium phosphide poisoning. Emerg Med J 2006;23:e3. doi: 10.1136/emj.2004.015941

4. Gargi J, Rai H, Chanana A, Rai G, Sharma G, Bagga I. Current trends of poisoning: a hospital profile. J Indian Med Assoc 2006;104:72-3, 94. PMID: 16856585

5. Goel A, Aggarwal P. Pesticide poisoning. Natl Med J India 2007;20:182-91. PMID: 18085124

6. Murali R, Bhalla A, Singh D, Singh S. Acute pesticide poisoning: 15 years experience of a large North-West Indian hospital. Clin Toxicol (Phila). 2009;47:35-8. doi: 10.1080/15563650701885807

7. Shadnia S, Sasanian G, Allami P, Hosseini A, Ranjbar A, Amini-Shirazi N, Abdollahi M. A retrospective 7-year study of aluminium phosphide poisoning in Tehran: opportunities for prevention. Hum Exp Toxicol 2009;28:209-13. Doi: 10.1177/0960327108097194.

8. Nocera A, Levitin HW, Hilton J. Dangerous bodies: a case of fatal aluminium phosphide poisoning. Med J Aust 2000;173:133-5. PMID: 10979378.

9. Popp W, Mentfewitz J, Götz R, Voshaar T. Phosphine poisoning in a German office. Lancet 2002;359:1574. doi: 10.1016/S0140-6736(02)08518-5.

10. Fumigation (phosphine) explosions. UK P&I Club [bulletin] 2003;(289). [displayed 9 July 2016]. Available at http://www. ukpandi.com/knowledge/article/289-02-03-fumigation phosphine-explosions-1539/

11. Hashemi-Domeneh B, Zamani N, Hassanian-Moghaddam H, Rahimi M, Shadnia S, Erfantalab P, et al. A review of aluminium phosphide poisoning and a flowchart to treat it. Arh Hig Rada Toksikol 2016;67:183-193.

12. Stephenson, J. B. P. Zinc Phosphide Poisoning. Archives of Environmental Health: An International Journal, 1967; 15(1), 83–88. doi:10.1080/00039896.1967.10664880

13. Singh S, Bhalla A, Verma SK, Kaur A, Gill K. Cytochrome-c oxidase inhibition in 26 aluminium phosphide poisoned patients. Clin Toxicol (Phila) 2006;44:155-8.

14. Altaye et al. Metallophosphide poisoning, a rising public health problem in Ethiopia: a systematic review and meta-analysis. BMC Emergency Medicine (2025) 25:133 https://doi.org/10.1186/s12873-025-01294-w.

15. Sudakin D. Occupational exposure to aluminium phosphide and phosphine gas? A suspected case report and review of the literature. Hum Exp Toxicol 2005;24:27-33. Doi: 10.1191/0960327105ht496oa

16. Heseltine, H.K. 1973. A guide to fumigation with phosphine in the tropics. Tropical Stored Product Information 24: 25-36.

17. Van S. Graver, J.E. 2004. Guide to Fumigation Under Gas-Proof Sheets. FAO, Produced by ACIAR, Canberra.

EXAMINING THE DRUG DISPOSAL PRACTICES OF PHARMACISTS IN PUNTLAND, SOMALIA: A CALL FOR IMPROVED STANDARDS AND ACCOUNTABILITY

Ahmed Nur Hersi
University of Health Sciences (UOHS),
Puntland State (Somalia)

ABSTRACT

Background: Drug disposal refers to discarding unused and expired medications to prevent improper use and protect the environment. Improper disposal poses significant risks to public health and the environment, particularly in low- and middle-income countries. Thus, this study aimed to investigate drug disposal practices among pharmacists in major cities in Puntland, Somalia.

Method: A descriptive cross-sectional study was conducted between July and October 2024, involving a conveniently selected sample of 81 registered pharmacies across four major cities in Puntland. Data were collected using a structured questionnaire and analyzed using Microsoft Excel and R programming. Descriptive statistics, including frequency tables, were used to identify disposal methods.

Results: Most respondents were male (54.3%), of whom 38.3% belonged to the age group of 17–26 years. About 51.9% of the pharmacists held a Bachelor's degree. A significant proportion (93.8%) of the pharmacists had no prior training on proper disposal methods. The most common drug disposal methods were discarding into general garbage (65.4%) and open burning (23.5%). Circa 44.4% of the respondents identified the lack of designated disposal areas as a primary barrier, followed by a lack of knowledge on the issue. Of the disposed drugs, antibiotics represented the majority (38.3%), followed by antifungals (26%). Further, 97.5% of the respondents emphasized establishing a state agency for the drug disposal system, and 90.1% recommended training pharmacists and healthcare workers in proper disposal practices.

Conclusion: Based on this study's results, we found that pharmacists in Puntland engage in inappropriate disposal practices, underscoring the urgent need for regulatory interventions. Furthermore, there is a significant association between drug disposal methods and pharmacists' educational level, highlighting the need for workshops and training for healthcare workers, including pharmacists.

Recommendation: We propose establishing a state agency responsible for drug disposal procedures, conducting training programs for pharmacists and waste collectors, and enforcing standardized disposal guidelines necessary to enhance pharmaceutical waste management in Puntland, Somalia.

Keywords: **Drug disposal methods, Barriers of Drug Disposal, Environmental Pollution, Public Health**

Corresponding author: Ahmed Nur Hersi; E-mail: ahmedhersi@uohs.edu.so

INTRODUCTION

Treatment with medicines is one of the most cost-effective healthcare interventions (1). However, it is known that drugs may expire before use, leading to financial losses and the need for proper disposal (2). Improper management of expired drugs can cause serious environmental problems, including air, water, and soil pollution, endangering life, including human life. Safe disposal methods are crucial to minimize these risks and protect both public health and the environment (3). The WHO (World Health Organization) recommends several methods for the disposal of expired drugs: returning them to the donor or manufacturer (e.g., antineoplastic drugs), direct landfill disposal, and encapsulation in solid blocks within drums. Certain liquid medications, like syrups and fluids, can be diluted with water and flushed into sewers. However, open burning at low temperatures is discouraged due to the risk of releasing toxic pollutants (2).

Pharmaceutical waste has become a critical issue worldwide, particularly in regions facing conflicts or natural disasters, where large-scale donations of medicines often arrive in excess or near expiration, leading to their accumulation and improper disposal (4). In countries like Ethiopia and Uganda, expired medication donations have been identified as a major source of pharmaceutical waste (5). Additionally, patient behaviors, such as frequently changing prescriptions or accumulating medications due to easy access, contribute to the buildup of unused drugs, increasing the risk of irrational use, accidental poisoning, and environmental contamination (6,7).

The environmental impact of improper pharmaceutical disposal is profound. Pharmaceuticals enter ecosystems through various channels, including manufacturing waste, human excretion, improper consumer disposal, and agricultural runoff (8). Contaminants like synthetic estrogens disrupt aquatic life, while psychiatric medications have been shown to alter the behavior of fish species, affecting their activity and feeding patterns (9,10). These findings highlight the urgent need for proper waste management to mitigate potential ecological and health risks (11). The improper disposal of antibiotics, in particular, is alarming as it contributes to the development of antibiotic-resistant bacteria and endocrine disorders, posing a serious global health threat (12, 14).

Inappropriate disposal of unused and expired drugs further exacerbates environmental and health issues, particularly in developing countries. The lack of proper disposal practices can lead to irrational medicine use, poisoning of children, the elderly, and animals, drug misuse, and environmental contamination. Improper disposal of antibiotics is particularly concerning as it contributes to antibiotic resistance, with emerging pollutants in water sources posing significant health threats, such as the development of antibiotic-resistant bacteria and endocrine disorders (13). Studies performed in countries like Tanzania and Nigeria showed improper disposal practices such as flushing medications or burning them, resulting in environmental pollution and potential health risks (14,15).

Despite the increasing global focus on pharmaceutical waste management, there is a significant gap in understanding drug disposal practices in low- and middle-income countries, especially Somalia. This relevant issue has received little attention, and there is a lack of awareness about proper pharmaceutical disposal methods. Further, the lack of national guidelines exacerbates this issue, leading to widespread improper disposal practices that may have severe consequences for public health and the environment (16). To our knowledge, only one study in Somaliland highlighted inadequate handling of expired medicines, revealing that hospitals lack effective waste management systems (17). No comprehensive studies have been conducted in Somalia to assess how unused and expired medications are managed.

In Puntland, especially in rural areas, residents rely on Berkads (retention ponds) for water storage, which can be contaminated by pharmaceutical waste from open landfills. Rainwater and floods often carry waste, including pharmaceuticals, into these water sources, posing health risks to humans and animals. A study conducted in Mogadishu revealed significant contamination in retention pond water, raising concerns about water quality (18). In the present study, we aim to investigate drug disposal practices among pharmacists in Puntland, assess current disposal methods and identify barriers. Based on the findings presented here, we suggest solutions to improve drug disposal systems in the country.

METHODS

Study Area and Study Population

Puntland State is geographically located in the north-eastern part of Somalia. It borders the northern part of Somalia (Somaliland) to the northwest, the Gulf of Aden to the north, the Indian Ocean to the southeast, the central regions to the south, and Ethiopia to the southwest. Like the rest of Somalia, Puntland has a tropical hot climate, with little seasonal variation and daily temperatures that vary from 27°C to 37°C. The country experiences low annual rainfall and four seasons: Gu' and Deyr are the rainy seasons, and Haga and Jilal are the dry seasons (19). The participants of this study were registered pharmacies located in Bossaso, Gardo, Garowe, and Galkayo, the main cities in Puntland. \

Study Design and Period

A descriptive cross-sectional study was conducted among registered pharmacies in Puntland between July and October 2024.

Sample Size Determination

A Sloven's formula with a population size (*N*) of 421 and a 90% confidence level was selected for use.

$$n = \frac{N}{1 + N(e)^2} \Rightarrow \frac{421}{1 + 421(0.1)^2} = 81$$

Where,
n= required sample size
N= population size
e= margin of error
Sampling technique

This study employed a convenience sampling method to select pharmacies from four major cities in Puntland: 81 pharmacies participated, of which 23 were selected from Bossaso, 22 from Galkayo, 20 from Garowe, and 16 from Gardo. Convenient sampling was chosen for its practicality and feasibility, allowing the selection of readily accessible pharmacies to represent each city.

Inclusion and Exclusion Criteria

Eligible pharmacies were required to be both registered and large in size. Small pharmacies in less populated areas, such as rural regions and city outskirts, were excluded from the study. Unregistered pharmacies were also excluded from the sample.

Data Collection Tools and Procedures

Data for this study were collected using a structured questionnaire. The questionnaire was first translated into Somali by language experts proficient in Somali and English to ensure clarity and accuracy. It was then distributed to pharmacists via a Google Form link. For participants without internet access or smartphones, data were collected through interviews conducted by an interviewer-administered method. After data collection, the responses were re-translated into English to maintain consistency and reliability. The questionnaire was adopted and modified from several previous related studies and then organized based on the objectives of the study ((14,20,21). The questionnaire consisted of 21 questions and 5 sections. The first section consisted of demographic factors; the second section was intended to assess the quality of pharmacists by asking if they had previously attended workshops on drug disposal, if what they learnt was related to their pharmacy work, and their level of training. Section three was about drug disposal methods, where participants were asked about the frequency of disposal, the method used, storage practices of unwanted drugs, types of unwanted drugs found in health facilities, and barriers to disposal. Section four aimed to understand the pharmacist's perspective on funding the disposal of unwanted medicines and whether Somalia requires state regulations for drug disposal. Section five consisted of 5 questions on recommendations for improving pharmacists' views on drug disposal safety.

Data Quality Control and Management

To ensure data quality, a structured and pre-tested questionnaire was used. The pre-test was conducted on 5% of the calculated sample size, excluding actual study participants, to evaluate the clarity of wording, the appropriateness of the questions, and the respondents' reactions to the questions and the interviewer. Based on the pre-test findings, necessary adjustments were made to improve the questionnaire. During the data collection phase, rigorous supervision and daily monitoring were conducted. Ultimately, completeness and consistency were verified for all collected data during the data-cleaning process.

Data Processing and Analysis

The completeness of the data was thoroughly checked and coded appropriately. Errors were identified and fixed after a review of the original data using the code numbers. After this, the data were entered and cleaned using Microsoft Excel and then exported to R Programming for further analysis.

Results

Table 1 provides an overview of the respondents' demographic characteristics, including gender, age, education level, and years of experience.

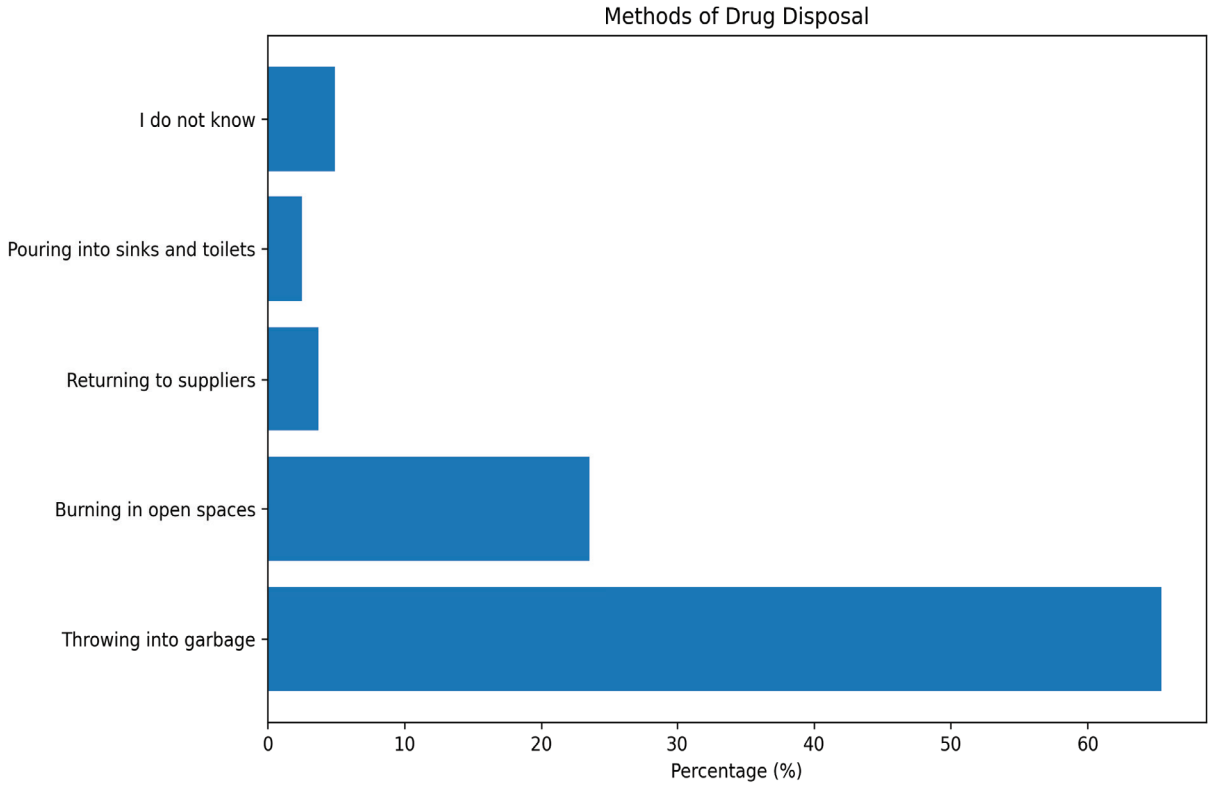
Table 1. Demographic characteristics of the respondents

Variable	Labels	Frequency	Percentage
Gender	Male	44	54.3
	Female	37	45.7
Age	17-26	31	38.3
	27-36	28	34.6
	37-46	12	14.8
	47-56	10	12.3
Level of education	Bachelor's Degree	42	51.9
	C.M.O.A	15	18.5
	Diploma	11	13.6
	Primary School	3	3.7
	Secondary School	10	12.3
Experience	3 years or less	36	44.4
	4-6 years	31	38.3
	7-9 years	9	11.1
	10 years and more	5	6.2

The majority of respondents were male (54.3%), and most belonged to the age group of 17–26 (38.3%) and 27–36 (34.6%). About 51.9% of the pharmacists held a Bachelor's degree, while a smaller portion had education levels ranging from primary school to secondary school. Circa 44.4% of respondents had three

years or less experience, suggesting that many participants were relatively new to the field. (Table 1). About 51.9% of respondents' fields of study are related to pharmacy, whereas 48.1% come from unrelated areas. This result highlights the diversity of pharmacists' educational backgrounds in Puntland, which is more likely to influence their approach to drug disposal practices. When the participants were asked whether they had participated in a workshop or training on drug disposal methods, most participants (93.8%) stated they had not, whereas 6.2% had such training. This lack of formal training suggests a significant gap in awareness and know-how on safe drug disposal practices of Puntland pharmacists.

Concerning the drug disposal methods used by the participants, we found that the most common method of drug disposal was throwing drugs into the garbage (65.4%), followed by burning in open spaces (23.5%) (Fig. 1).



Other methods, such as returning the drugs to suppliers and pouring them into sinks/toilets, were rarely used. On the question of drug disposal frequency, 53.1% of the respondents dispose of drugs every six months, and 24.7% stated "when necessary."Very few of them dispose of drugs annually or biannually, indicating a lack of consistency in disposal schedules (Fig. 2).

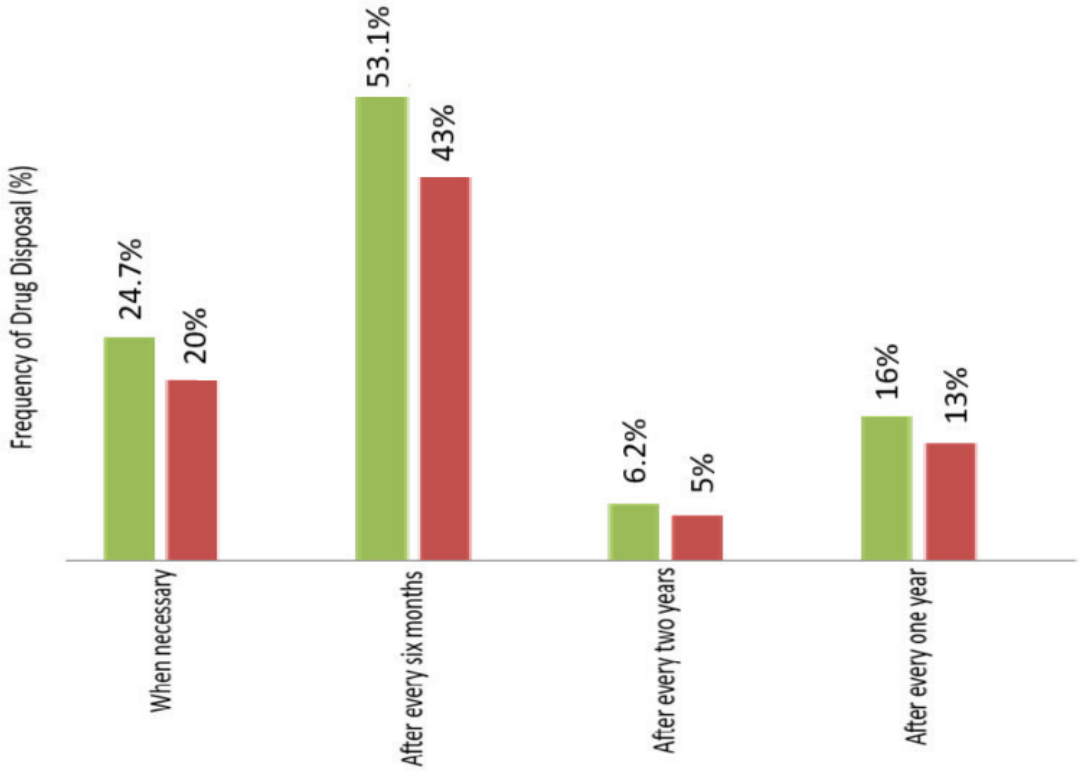


Fig. 2. Frequency of Drug Disposal

Regarding the storage of unwanted drugs before disposal, most respondents (88.9%) segregated unwanted medicines from usable ones, indicating some awareness of safe storage practices (Table 2). Only a small percentage labelled these drugs or had a designated area/box, highlighting opportunities for improvement in pre-disposal handling procedures. Of the unwanted medicines, antibiotics were the most frequently reported (38.3%), followed by antifungals (26%) and antidepressants (16%) (Fig. 3).

Table 2. Storage practice of unwanted medicines before disposal

Storage practice	**Frequency**	**Percent**
I don't know	2	2.5
Labeled properly	2	2.5
Presence of a separate area/box	5	6.2
Segregated from usable medicines	72	88.9

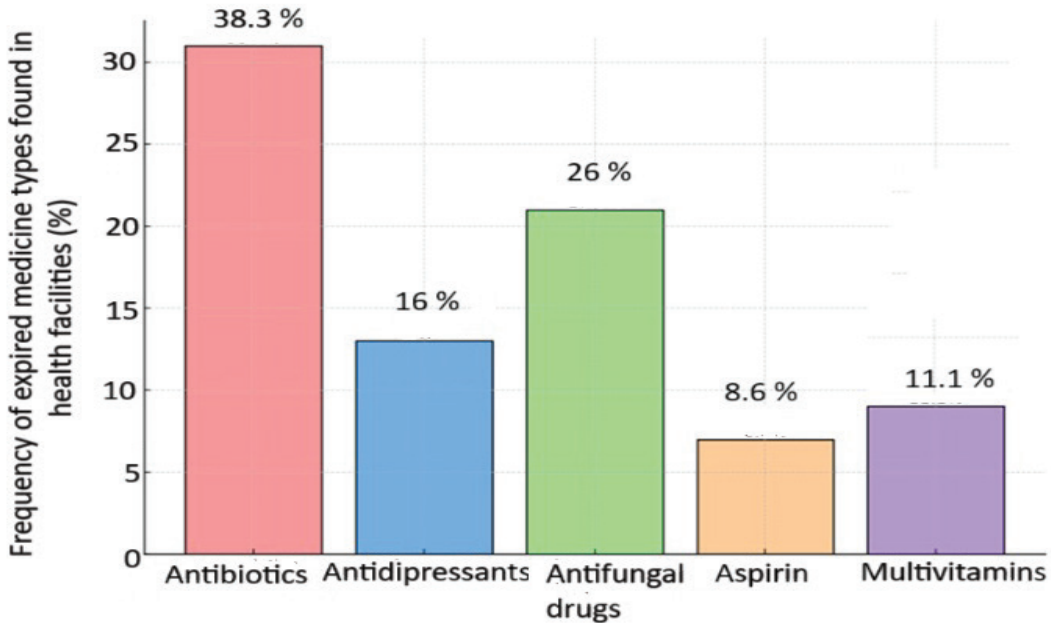


Fig. 3. Frequency of expired medicine types in the health facilities

Furthermore, the participants were asked about the barriers they encountered in disposing of drugs. The most common barrier reported is a lack of designated areas for disposal (44.44%), followed by inadequate knowledge (29.63%) and others, such as the high cost (3.7%) and long disposal procedure (3.70%) (Fig. 4). These findings indicate the need for accessible disposal facilities and increased education on safe disposal.

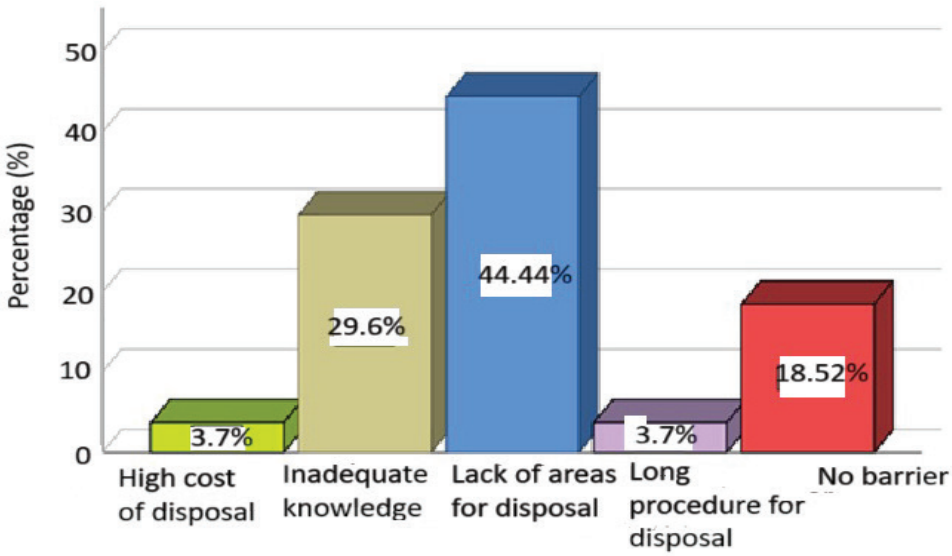


Fig. 4. Barriers to drug disposal

When participants were asked if a state regulation is required for drug disposal, most respondents (97.5%) argued for a national drug disposal system accessible to all pharmacies, underlining the pharmacists' strong support for a more organized disposal system to address existing challenges. Most respondents (46.9%) thought the local government should fund the drug disposal expenses, followed by the district health board (34.6%). Only a few suggested that pharmaceutical companies or patients should fund the costs (Table 3).

Table 3. Who should fund drug disposal systems?

Labels	Frequency	Percent
Community pharmacists	3	3.7
District health board	28	34.6
Local government	38	46.9
Patients	2	2.5
Pharmaceutical companies	10	12.3

Finally, the participants were asked to express their opinions on improving drug disposal practices (see Table 4).

Table 4. Pharmacists' views on improving the drug disposal practices

Variable	Agree	Disagree	Neutral	Strongly Agree
Putting containers for unwanted drugs in the pharmacy and assigning a day of the year to collect and dispose of these medications	25(30.9%)	7(8.6%)	12(14.8%)	37(45.7%)
Pass strict laws regarding the safe disposal of all forms of drugs	27(33.3%)	11(13.6%)	15(18.5%)	28(34.6%)
Organizing events and scientific forums, including conferences and workshops, around the proper disposal of unwanted drugs	16(19.8%)	6(7.4%)	9(11.1%)	50(61.7%)
Distribution of brochures on safe drug disposal to encourage pharmacists to read and stay up to date on the topic continually	20(24.7%)	14(17.3%)	18(22.2%)	29(35.8%)
Providing proper training to healthcare workers regarding the management of expired medications	17(21.0%)	2(2.5%)	6(7.4%)	56(69.1%)

Most respondents (90.1%) supported the proper training of pharmacists and healthcare

workers, followed by organizing educational events and scientific workshops (81.5%). The installation of disposal containers in pharmacies and the passage of strict disposal laws also received strong support (76.6% and 67.9%, respectively). Though the distribution of brochures was endorsed, it received relatively less support (60.5%) than other strategies.

DISCUSSION

Pharmaceutical medications play a vital role in managing and treating various diseases; however, drugs must be used responsibly. Indeed, improper disposal of unused or expired medications can pose serious risks to human health and the environment, with detrimental effects (22). The present study evaluated pharmacists' disposal practices for unused and expired medicines in Puntland, Somalia. We assessed the most common methods of drug disposal, the frequency of disposal, the barriers encountered, methods for storing expired medications before disposal, the main expired drugs, and pharmacists' views on improving and achieving safe drug disposal strategies. The demographic characteristics of the participants of this study are reported in Table 1. The most common method of drug disposal among respondents was discarding medications in the garbage (65.4%) (Fig. 1). This is consistent with previous studies from other parts of the world, particularly in many developing countries, and highlights the prevalent practice of disposing of expired medicines. For instance, about 41% of the respondents in Tanzania and 82% in India used dustbins for drug disposal ((23,24). Likewise, in Pakistan, pharmaceutical waste was typically disposed of alongside municipal and local waste (25). Also, a study in Thailand found that expired and leftover medications were often discarded in trash bins (26). In contrast, developed countries use appropriate methods for drug disposal. A survey study performed in 2007 in Sweden, investigating the level of knowledge of the general public on drug disposal, found that 85% of the respondents knew the correct method for disposing of unused medicines was returning them to a pharmacy, adhering to the government's recommendation (27). Similarly, a study conducted in Barcelona, Spain, showed that (52.4%) of the patients returned their unwanted medicines to community pharmacies, and, in 32.2% of the cases, a relative returned the unwanted drugs (28). Interestingly, a study in Palestine, a developing country, found that 73.3% of community pharmacists disposed of unwanted medicines by returning them to manufacturing companies and warehouses (20). In New Zealand, contractors typically collect and incinerate solid and semi-solid dosage forms returned to pharmacies (29). Similarly, in Nigeria, the National Agency for Food and Drug Administration and Control (NAFDAC) operates a drug take-back system, similar to the contractors used in New Zealand (30).

Another disposal method identified in our study was the open burning of unwanted medications, which 23.5% of the respondents used. Although open burning of unwanted drugs is not a recommended disposal method for pharmaceutical waste, it is still used in various countries (3). A survey by Manyele and Anicetus on existing medical waste management in Tanzanian hospitals showed that open-pit burning was the predominant disposal method (31). Also, in Lithuania, burning pharmaceuticals was reported by 50% of respondents (32).

Further, we found that 53.1% of respondents disposed of drugs once every six months, whereas 24.7% of the participants did "when necessary." (Fig. 2). A few respondents had annual or biannual disposal schedules, indicating inconsistency in disposal practices due to the lack of a standardized disposal schedule, suggesting a need for clear guidelines. Regarding how the respondents stored the expired drugs before disposal, we found

that respondents (88.9%) segregated unwanted medicines from usable ones, demonstrating awareness about safe storage practices (Table 2). However, only a tiny percentage labelled these segregated drugs or used a designated area/box, highlighting areas for improvement in pre-disposal handling. Among expired medicines, antibiotics accounted for the majority (38.3%), followed by antifungals (26%) and antidepressants (16%) (Fig. 3). Similarly, in Tanzania, more than half of the unfit medicines were antibiotics (23). The improper disposal of unused antibiotics poses a significant risk, as they can enter aquatic systems, contributing to the rise of multidrug-resistant microbes and exacerbating antimicrobial resistance (12, 35).

According to the respondents of this study, the most common barrier to drug disposal was the lack of designated areas for unfit medications (44.4%), followed by inadequate knowledge (29.6%) (Fig. 4), stemming from the increasing privatization of land as well as a lack of government awareness regarding the benefits of establishing proper disposal sites. In Somalia, land ownership disputes are a root cause of conflicts, driven by weak institutional capacity and ineffective regulations (34). Designating specific areas for the disposal of unfit medications would improve the efficiency of disposal systems.

Finally, most participants (97.5%) thought that Somalia must establish a state agency responsible for drug disposal issues to address existing challenges. Also, the respondents strongly supported initiatives to improve drug disposal practices. The most favored recommendation was providing proper training to healthcare workers (90.1%), followed by organizing educational workshops and training on matters of drug disposal (81.5%), as well as placing disposal containers in pharmacies (76.6%) (Table 4). These findings highlight the relevance that pharmacists attribute to education, systematic solutions, and regulatory measures in enhancing drug disposal practices in Somalia.

CONCLUSION:

In conclusion, in this study, we assessed issues including the drug disposal methods used by the pharmacists in Puntland State (Somalia), the frequency of disposal, the barriers and challenges met, the most common unused and expired drugs, and the steps needed to be taken by the state to improve the existing disposal approaches. The most common disposal method identified was discarding medications once every 6 months, though other disposal schedules were reported. Antibiotics were the principal type of expired, unused medicines disposed of. Barriers included a lack of designated areas for unused medications, inadequate knowledge of drug disposal issues, the absence of containers, and the absence of structured regulations on drug disposal practices. We recommend establishing a state agency to address drug disposal issues. This could be achieved by increasing pharmacists' and healthcare workers' knowledge through scientific workshops and training, as well as by raising public awareness of these issues, which are of significant importance to the environment and public health.

ACKNOWLEDGEMENT

I want to thank Prof. Ahmed Mohamud Osman for his support and encouragement.

REFERENCE

1. By The Secretariat WHOR. Rational use of medicines: progress in implementing the WHO medicines strategy. Ital J Public Health [Internet]. 2006 Jan 1 [cited 2024 Nov 17];3(1). Available from: https://riviste.unimi.it/index.php/ijphjournal/article/view/23288.

2. World Health Organization, Eastern Mediterranean Regional Office. (2006, May 17). Guidelines for the safe disposal of expired drugs. WHO EMRO. Retrieved November 17, 2024, from https://www.emro.who.int/images/stories/pakistan/documents/pak_documents/Guidelines_for_Expired_Medicines.pdf.

3. Manyele SV. Effects of improper hospital-waste management on occupational health and safety. Afr Newslett Occup Health Saf 2004. 2004;14:30–3.

4. WHO guidelines for safe disposal of pharmaceuticals in emergencies. World Health Organization. Guidelines for safe disposal of unwanted pharmaceuticals in and after emergencies [Internet]. Geneva: WHO; 1999 Dec 20 [cited 2024 Nov 17]. Available from: https://www.who.int/publications/i/item/guidelines-for-safe-disposal-of-unwanted-pharmaceuticals-in-and-after-emergencies

5. 5. Iosue S. Comparative Study of Pharmaceutical Waste Disposal in Ethiopia, Kenya, Sudan and Uganda. [Internet]. PSA Transforming The Supply Chain; 2020 Sep. [cited 2024 Nov 17]. Available from:https://www.pamsteele.org/wp content/uploads/2021/04/20201116_Pharma_Waste_Disposal.pdf

6. Abdo-Rabbo A, Al-Ansari M, Gunn BC, Suleiman BJ. The use of medicines in Oman: public knowledge, attitudes and practices. Sultan Qaboos Univ Med J. 2009 Aug;9(2):124–31.

7. Nepal S, Giri A, Bhandari R, Chand S, Nepal S, Aryal S, et al. Poor and Unsatisfactory Disposal of Expired and Unused Pharmaceuticals: A Global Issue. Curr Drug Saf. 2020 Nov 17;15(3):167–72.

8. Pharmaceutical waste: Overview, Management, and Impact of improper disposal.

9. Brodin T, Fick J, Jonsson M, Klaminder J. Dilute Concentrations of a Psychiatric Drug Alter Behavior of Fish from Natural Populations. Science. 2013 Feb 15;339(6121):814–5.

10. Länge R, Hutchinson TH, Croudace CP, Siegmund F, Schweinfurth H, Hampe P, et al. Effects of the synthetic estrogen 17α-ethinylestradiol on the life-cycle of the fathead minnow (Pimephales promelas). Environ Toxicol Chem. 2001 Jun;20(6):1216–27.

11. Smith CA. Managing pharmaceutical waste: What pharmacists should know. J Pharm Soc Wis. 2002 Nov-Dec.

12. Sharma M, Kumar K, Dubey KK. Disposal of unused antibiotics as household waste: A social driver of antimicrobial resistance. Environ Qual Manag. 2021 Jun;30(4):127–40.

13. Shehu Z, Nyakairu GWA, Tebandeke E, Odume ON. Overview of African water resources contamination by contaminants of emerging concern. Sci Total Environ. 2022 Dec;852:158303.

14. Mwita S, Ngonela G, Katabalo D. Disposal Practice of Unfit Medicines in Nongovernmental Hospitals and Private Medicine Outlets Located in Mwanza, Tanzania. J Environ Public Health. 2019 Mar 3;2019:1–6.

15. Ngwuluka, Ndidi, Ochekpe, Nelson, Odumosu, Patricia O. An assessment of pharmaceutical waste management in some Nigerian pharmaceutical industries. Afr J Biotechnol. 2011 Sep 19;10(54):11259–68.

16. Karungamye P, Rugaika A, Mtei K, Machunda R. The pharmaceutical disposal practices and environmental contamination: A review in East African countries. HydroResearch. 2022;5:99–107.

17. Hassan A. ASSESSMENT OF MEDICAL WASTE DISPOSAL METHODS IN HARGEISA PUBLIC HOSPITAL – SOMALILAND. 2018;6(4).

18. Kullane MA, Abdi-Soojeede MI. Assessment of Retention Ponds and Its Impacts on Health of Residents in Mogadishu, Somalia: Mixed Methods. J Water Resour Prot. 2024;16(04):293–307.

19. Puntland Report 2020 Somali Health and Demographic Survey.

20. Nairat LL, Abahri NA, Hamdan YA, Abdel-khaliq RT, Odeh SM, Abutaha S, et al. Assessment of practices and awareness regarding the disposal of unwanted pharmaceutical products among community pharmacies: a cross-sectional study in Palestine. BMC Health Serv Res. 2023 Sep 27;23(1):1035.

21. Paudel E, Choi DE, Shrestha N. Pharmaceutical Waste Management in Private Pharmacies of Kaski District, Nepal. 2019;4(8).

22. Nepal S, Giri A, Bhandari R, Chand S, Nepal S, Aryal S, et al. Poor and Unsatisfactory Disposal of Expired and Unused Pharmaceuticals: A Global Issue. Curr Drug Saf. 2020 Nov 17;15(3):167–72.

23. Mwita S, Ngonela G, Katabalo D. Disposal Practice of Unfit Medicines in Nongovernmental Hospitals and Private Medicine Outlets Located in Mwanza, Tanzania. J Environ Public Health. 2019 Mar 3;2019:1–6.

24. 24. Kanyari SS, Senapati TR, Kar A. Disposal Practices of Unused and Expired Medicines Among the General Public and Pharmacies: A Mixed-Method Study in the Odisha State of Eastern India. Cureus [Internet]. 2024 Jan 16 [cited 2024 Nov 16]; Available from: https://www.cureus.com/articles/214592-disposal-practices-of-unused-and-expired-medicines-among-the-general-public-and-pharmacies-a-mixed-method-study-in-the-odisha-state-of-eastern-india

25. 25. Ashfaq M, Noor N, Saif-Ur-Rehman M, Sun Q, Mustafa G, Faizan Nazar M, et al. Determination of Commonly Used Pharmaceuticals in Hospital Waste of Pakistan and Evaluation of Their Ecological Risk Assessment. CLEAN – Soil Air Water. 2017 Jun;45(6):1500392.

26. Arkaravichien W, Ruchipiyarak T, Thawinwan W, Benjawilaikul S. A Threat to the Environment from Practice of Drug Disposal in Thailand. 2014;

27. Persson M, Sabelström E, Gunnarsson B. Handling of unused prescription drugs — knowledge, behaviour and attitude among Swedish people. Environ Int. 2009 Jul;35(5):771–4.

28. Coma A, Modamio P, Lastra CF, Bouvy ML, Mariño EL. Returned medicines in community pharmacies of Barcelona, Spain. Pharm World Sci. 2008 Jun;30(3):272–7.

29. Tong A, Peake B, Braund R. Disposal practices for unused medications in New Zealand community pharmacies. J Prim Health Care. 2011;3(3):197.

30. Michael I, Ogbonna B, Sunday N, Anetoh M, Matthew O. Assessment of disposal practices of expired and unused medications among community pharmacies in Anambra State, southeast Nigeria: a mixed study design. J Pharm Policy Pract. 2019 Dec;12(1):12.

31. Manyele S, Anicetus H. Management of medical waste in Tanzanian hospitals. Tanzan J Health Res [Internet]. 2009 Aug 17 [cited 2024 Nov 12];8(3). Available from: http://www.ajol.info/index.php/thrb/article/view/45117

32. Kruopienė J, Dvarionienė J. Management of Environmental Risks in the Life Cycle of Human Pharmaceuticals in Lithuania. Environ Res Eng Manag. 2010;2(52):41–7.

33. Serwecińska L. Antimicrobials and Antibiotic-Resistant Bacteria: A Risk to the Environment and to Public Health. Water. 2020 Nov 25;12(12):3313.

34. Yusuf MI, Yusuf AA, Halane SA, Hussein HA. Land and Conflict in Qardho District: Study of the Root Causes and Solutions. East Afr J Arts Soc Sci. 2024 May 1;7(1):262–73.

AN INSIGHTFUL COMMENTARY ON THE TRANSFORMATIVE ROLE OF ARTIFICIAL INTELLIGENCE IN SCIENTIFIC DISCOVERY, EXEMPLIFIED BY THE PROTEIN FOLDING PROBLEM

Ahmed Mohamud Osman
University of Health Sciences (UOHS),
Puntland State (Somalia)

ABSTRACT

Proteins are miniature machines that carry out cellular functions, including structural roles and dynamic functions such as enzymatic activities, defence (e.g., via antibodies), cell signalling, and transport. Proteins consist of twenty basic building blocks known as amino acids. A protein's biological function depends on its three-dimensional structure, which results from folding its amino acid sequence. About fifty years ago, it was shown that the amino acid sequence of a protein specifies its three-dimensional structure; however, it has been a long-standing mystery to predict the three-dimensional structure from the amino acid sequence. Here, the author traces the birth and development of the protein-folding problem and the solution to the prediction of three-dimensional protein structures, achieving, in some cases, accuracies superior to experimentally obtained models using AlphaFold, a machine-learning method. This remarkable discovery will impact structural biology, medicine, biotechnology, and sustainability solutions, like environmental protection.

1. INTRODUCTION

Proteins are one of the major biomolecules in cells. The word protein derives from the Greek prōteios, meaning "first quality," underscoring the central role of proteins in biology (1). This word was coined by the Swedish chemist Berzelius in 1838. Proteins have structural and dynamic functions in cells. The structural proteins include keratin, collagen, actin, and myosin, for example, present in muscles and skin, etc., among the dynamic functions of proteins, are cellular defence as antibodies, enzymatic catalysis important in metabolism, transport, and storage roles like hemoglobin and myoglobin, cell signalling transmission, receptors, and hormonal activities.

Proteins are made of small building blocks known as amino acids. There are twenty different amino acids present in proteins. However, there are other amino acids present in cells but not in proteins; the first twenty amino acids are known as standard amino acids, whereas the other amino acids not found in proteins have different functional roles in the cell. Each amino acid contains an amine group, a hydrogen, and a carboxyl group, which are common for all amino acids, and an R-group characteristic for each amino acid. In other words, amino acids differ in this R-group. Because of this group, amino acids have different physical and chemical properties. For instance, some are water-soluble, whereas others are hydrophobic (i.e., they do not interact with water). Proteins have various levels of structure. The first level of protein structure is called primary structure and results from the sequence of the amino acids. Every protein has a unique sequence of amino acids. The sequence of amino acids undergoes local folding into α-helices and β-pleated sheets. These local folds are known as secondary structures and are stabilized mainly by hydrogen bonds between the amide and carbonyl groups of amino acid residues in the protein sequence. The third level of protein structure is the tertiary structure, in which a protein assumes a three-dimensional shape. A protein may have a fourth (quaternary) structure when multiple chains called subunits constitute the protein. The biological function of a protein depends on its three-dimensional structure, which is ultimately determined by the folding of its polypeptide sequence (2). In other words, the conformation of a protein determines its function.

A significant challenge in protein structure prediction is predicting a protein's three-dimensional conformation from its amino acid sequence. Recently, an extraordinary achievement has been made in protein structure prediction, and this issue is thought to have been effectively resolved (3, 4). In this commentary, we discuss the origin and development of this more than 50-year-

old puzzle in protein structure and the possible implications of its solution for structural biology, medicine, biotechnology, and sustainability.

2. DISCUSSION

2.1. The genetic code determines the amino acid sequence of a protein.

Following the discovery of the structure of the genetic material, known as DNA (5), the decoding of the genetic code commenced. It was determined that a triplet of purine and pyrimidine bases in the DNA strand encodes one of the amino acids (see the structure of an amino acid, Fig. 1A), and, in some instances, multiple triplet bases may code for the same amino acid, a phenomenon referred to as degeneracy (6). The genetic code is universal across all living organisms, from bacteria to humans. Each protein has a distinct sequence of amino acids (primary structure, Fig. 1B), and substituting even a single amino acid with another may disrupt the protein's function.

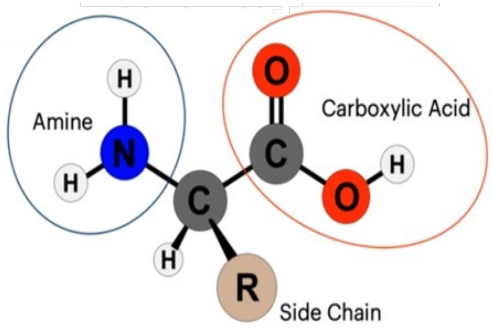


Fig. 1A. The structure of an amino acid

Fig.1B.The Primary structure of a protein

Because the DNA is present in the nucleus of eukaryotic cells and the machinery that synthesizes proteins, the ribosome, is located in the cytoplasm, the genetic information is transcribed from the DNA to another nucleic acid molecule known as ribonucleic acid messenger, consisting of a single strand (RNA messenger). This RNA messenger can pass through the nuclear membrane pores to the cytoplasm. The ribosome reads the genetic information and translates it into a protein sequence of amino acids. During amino acid sequence formation, the protein folds (see Fig. 2) and assumes a defined shape or conformation (tertiary structure, Fig. 2), ultimately determining its function. A legitimate question is what leads a protein to fold and adopt a specific shape?

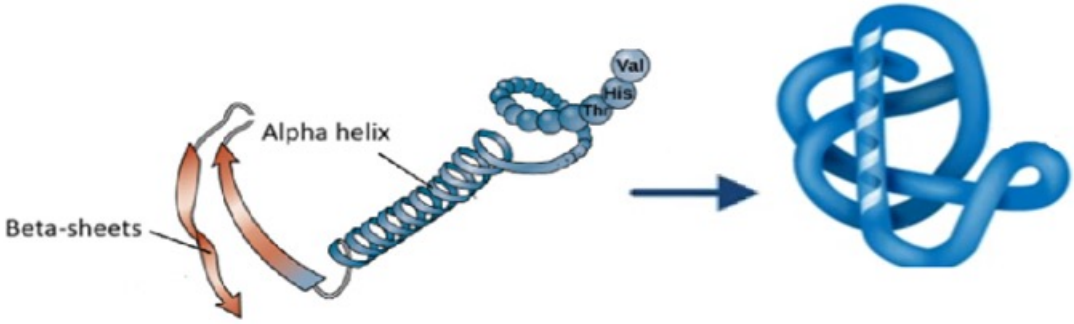


Fig. 2. Protein folding to its 3-dimensional structure

2.2. The amino acid sequence of a protein determines its three-dimensional structure

Studies on the principles governing the folding of a protein into a unique three-dimensional structure were undertaken in the late 1960s by biochemist Christian Anfinsen and his collaborators on the protein ribonuclease (7, 8). This protein has four disulfide bonds. That means eight cysteine residues or amino acids form disulfide bonds in the native state of ribonuclease (Fig. 3A, see the black dots in the protein sequence).

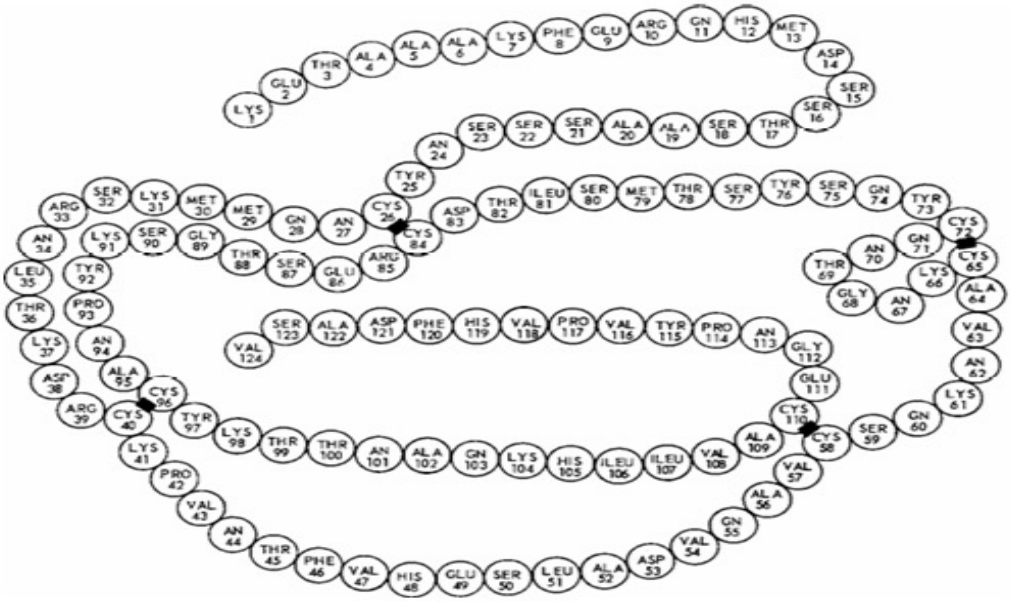


Fig. 3A. The amino acid sequence of bovine pancreatic ribonuclease

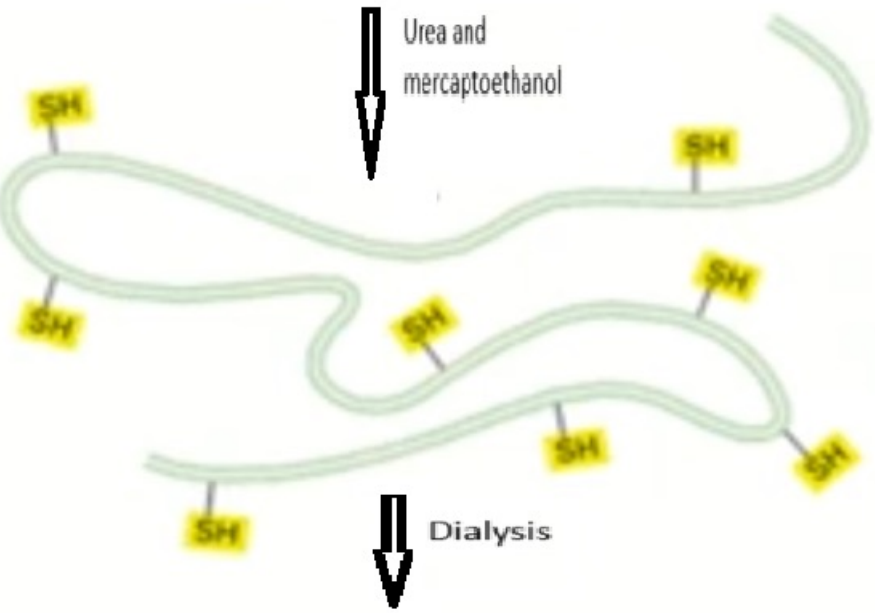


Fig. 3B. Bovine pancreatic ribonuclease after denaturation

When the ribonuclease enzyme is denatured using urea and full reductive cleavage agents (mercaptoethanol) of its disulfide bonds, the protein unfolds and loses its enzymatic activity (Fig. 3B). However, if the urea and reducing agents are removed, the ribonuclease refolds and regains its enzymatic activity. These investigations on ribonuclease and other studies (7-10) induced Christian Anfinsen to propose that the three-dimensional structure of a protein in its normal physiological milieu is the one in which Gibbs' free energy is the lowest. In other words, the native conformation of a protein is determined by its amino acid sequence. The polypeptide, once synthesized, should be capable of folding to its native conformation without additional information from outside. These studies established the relationship between the amino acid sequence and a protein's biologically active conformation, and the biochemist Anfinsen was awarded the Nobel Prize in Chemistry in 1972. Later studies showed that an unfolded protein, for instance, one consisting of 100 amino acids, adopts its native conformation within milliseconds, although the number of alternative conformations is vast (11). The alternative conformations are ≥ 10300 for a chain of 100 residues (11). This protein folding puzzle is known as Levinthal's paradox (12). The correlation between amino acid sequence and protein structure suggested the potential to predict protein structure in advance. This is particularly important since experimental methods employed to determine the three-dimensional structures of proteins are complex, expensive, and laborious. These experimental techniques are briefly outlined below.

2.3. The experimental approaches to three-dimensional protein structure determination

X-ray crystallography has been the most common method for determining three-dimensional protein structures. The oxygen-binding proteins, hemoglobin and myoglobin, were the first two proteins whose 3-D structures were determined using X-ray crystallography (13, 14). The technique requires the macromolecules to be crystals and a beam of X-rays is bombarded on the protein crystals, resulting in a diffraction pattern; by measuring the angles and intensities of the reflection, it is possible to determine the three-dimensional structure of the electron density within the crystal, consequently, the atom coordinates employing mathematical tools.

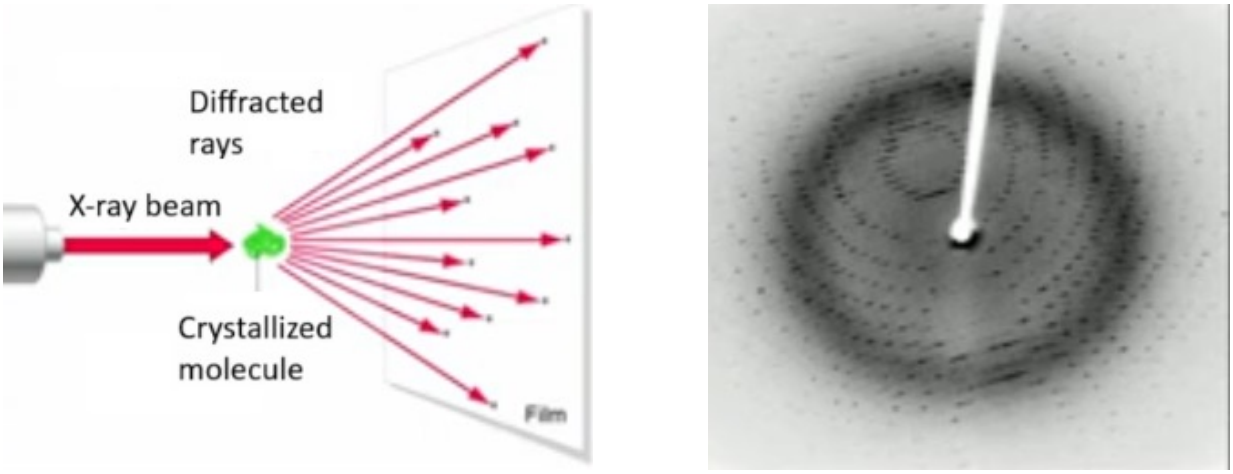


Fig. 4A. A crystal bombarded with X-rays. Fig. 4B. X-ray diffraction pattern

Though this technique has contributed much to our understanding of the structure of matter, it is painstaking work. First, the protein must be purified, a sufficient quantity collected, and crystallized, which is quite challenging. Second, the whole process is expensive and time-consuming. Another important technique for structure elucidation is NMR (Nuclear magnetic resonance) spectroscopy; however, this technique is used for small molecules and not for macromolecules, like proteins. The advantage of the NMR technique is that sample molecules can be analyzed in solution at room temperature. Cryo-electron microscopy is another recently developed experimental approach employed for the 3-D structure of macromolecules. This technique uses an electron beam rather than an X-ray beam to irradiate the frozen protein sample, and the reflection pattern of the macromolecule's shape is detected and analyzed. Cryo-electron microscopy addresses one of the shortcomings of X-ray crystallography: the need for protein crystallization. However, it is mostly suitable for complex macromolecules. In 2017, the Nobel Prize in Chemistry was awarded to Jacques Dubochet, Joachim Frank, and Richard Henderson for their contributions to the development and application of cryo-electron microscopy for 3D protein structure determination. However, due to the constraints of these techniques, the number of proteins with resolved tertiary structures is limited (approximately 200,988 proteins are available in the public resource, the Protein Data Bank (15). This is a fraction of the number of protein sequences that were known at least by January 2023 (229,580,745 entries in UniProtKB) (15). Thus, the only way to overcome this limitation is to develop novel approaches to protein structure prediction.

2.4. A gigantic leap in solving three-dimensional protein structure prediction using an artificial intelligence method

Since Anfinsen discovered that the sequence of amino acids specifies the 3-D protein structure, it has been a major challenge in biology for 50 years to solve the protein structure prediction problem, also known as the "protein folding problem." Two computational approaches have been the main methods for predicting three-dimensional protein structure (15,16). These computational methods are: 1) Computational molecular physics, which uses force fields of atom-atom interactions, solvent interactions, and satisfies physical principles (17). Although theoretically appealing, this approach encountered challenges with even moderate-sized proteins due to the intensive computational demands. 2) The other computational method uses the available protein sequence data and considers the evolutionary information of homologous protein sequence alignment. For instance, if in a given protein sequence two amino acids co-vary across organisms, these two amino acids might be important for the protein's folding process; therefore, the machine learns from this and takes it into account. The British group DeepMind developed a novel learning-based system (AlphaFold) that incorporates physical and biological knowledge of protein structure (16). The computational method of this British group demonstrated high accuracy, comparable to the experimental structures of target proteins, and won the challenging 14th Critical Assessment of Protein Structure Prediction (CASP14) competition (18). This novel computational method is a significant achievement in 3-D protein structure prediction and solves the folding problem of static protein monomers. The Deep Learning and American Baker group of computational protein design was awarded the Nobel Prize in Chemistry in 2024. What occupied structural biologists for years can now be done in a few minutes. Indeed, AlphaFold has predicted the structures of 98.5% of proteins in the human proteome (19).

Despite this remarkable improvement in protein structure prediction, more work is needed, as this computational method has yet to address the dynamic aspects of proteins. Proteins are nanomachines that carry out dynamic activities,

including interactions with nucleic acids, other proteins, and ligands. Enzymes bind with their substrates not like a key-lock approach but in a dynamic process, where the enzymes undergo conformational changes.

2.5. The impact of AlphaFold technology on structural biology and life science in general

Computational protein design technology and DeepMind's artificial intelligence (AlphaFold), used to solve the protein-folding problem, will impact structural biology, medicine, biotechnology, and sustainability solutions, including environmental protection. In structural biology, AlphaFold would enable scientists to determine the 3D structures of many proteins in a short time, thereby facilitating the prediction of their functions. Furthermore, the method will support experimentalists' efforts. In medicine, these computational techniques will help us understand drug interactions with proteins and, therefore, allow scientists to design better drugs; they will also help us understand disease mechanisms resulting from gene mutations. Because of a gene mutation, the amino acid sequence of a protein changes, potentially altering its structure and, consequently, its function. Moreover, some human diseases result from protein misfolding, such as Alzheimer's disease, in which amyloid fibrils form and aggregate. Understanding the structures of these proteins enables us to comprehend aggregation processes and to prevent them by designing proteins that interact with them and halt aggregation. In biotechnology and sustainability, novel proteins not found in living organisms can be designed for various purposes, including enhancing photosynthetic efficiency by harvesting light or creating enzymes that degrade waste products such as plastics, thereby mitigating environmental pollution.

In conclusion, using the computational modelling of AlphaFold a significant advance has been made in predicting 3D protein structure which will certainly have an impact on biological science and will open a new era in improving drug designing, understanding the mechanisms of many diseases including neurodegenerative diseases caused by misfolded proteins and diseases originating from gene mutations as well as potentially designing new enzymes that are not found in living organisms for biotechnology and sustainability of life on our planet.

REFERENCES

1. Hartley, H., Origin of the word protein. Nature, 168, 244 (1951).
2. Lehninger, A., Nelson, D., and Cox, M. (2005). Principles of biochemistry. 4th edition. New York.
3. Callaway, E. (2020). "It will change everything": DeepMind's AI makes a gigantic leap in solving protein structures. Nature, 588, 203–204. https://doi.org/10.1038/ d41586-020-03348-4.
4. Artificial intelligence solution to a 50-year-old science challenge could 'revolutionize' medical research, CASPress Release. (2020). https://predictioncenter. org/casp14/doc/CASP14_press_release.html.
5. Watson, J. D. and Crick, F. H. C., Nature, 171, 737 (1953).
6. Crick, F. H. C., et al. General nature of the genetic code for proteins. Nature 192, 1227–1232 (1961).
7. Sela, M., White, F. H. and Anfinsen, C. B., Science 125, 691 (1957).
8. White, F. H., Jr. and Anfinsen, C. B., Ann. N.Y. Acad. Sci. 81, 515 (1959).
9. White, F. H., Jr., J. Biol. Chem. 236, 1353 (1961).
10. 10. Anfinsen, C. B., Haber, E., Sela, M. and White, F. H., Jr., Proc. Nat. Acad. Sci. U. S. 47, 1309 (1961).
11. Finkelstein, A V., Bogatyreva, N S., Ivankov, DN., Garbuzynskiy, SO., Protein folding problem: enigma, paradox, solution, Biophysical Reviews. 14:1255–1272, (2022) https://doi.org/10.1007/s12551-022-01000-1.
12. Levinthal, C., Are there pathways for protein folding? J. Chim. Phys. Chim. Biol. 65:44–45 (1968). https://doi. org/ 10. 1051/ jcp/ 19686 50044.
13. Kendrew J. C., et al., A three-dimensional model of the myoglobin molecule obtained by x-ray analysis. Nature 181, 662 (1958). 10.1038/181662a0
14. Perutz M. F., et al., Structure of hæmoglobin: A three-dimensional Fourier synthesis at 5.5- resolution, obtained by x-ray analysis. Nature 185, 416 (1960). 10.1038/185416a0
15. Bertoline LMF, Lima AN, Krieger JE and Teixeira SK., Before and after AlphaFold2: An overview of protein structure prediction. Front. Bioinform. 3:1120370, (2023) doi: 10.3389/fbinf.2023.1120370
16. Jumper, J. et al. Highly accurate protein structure prediction with AlphaFold. Nature, 596, 585-589.
17. Brini, E., Simmerling, C., Dill, K., Protein storytelling through physics. Science. 27; 370 (6520) (2020): doi:10.1126/science.aaz3041.
18. Moult, J., Fidelis, K., Kryshtafovych, A., Schwede, T. & Topf, M. Critical assessment of techniques for protein structure prediction, fourteenth round. CASP 14 Abstract Book. https://www.predictioncenter.org/casp14/doc/CASP14_Abstracts.pdf (2020).
19. Ruff, K.M. and Pappu, R.V., AlphaFold and Implications for Intrinsically Disordered Proteins. Journal of Molecular Biology 433, 167208 (2021).

EVALUATION OF THE PRESCRIPTION PATTERNS AND FREQUENCY OF NSAIDS MEDICATION AMONG PATIENTS IN BOSSASO CITY, PUNTLAND STATE (SOMALIA)

Samira Hussein, Ahmed Mohamud, Abdiaziz Salah
University of Health Sciences,
Puntland State (Somalia).

ABSTRACT

Background

Nonsteroidal anti-inflammatory drugs (NSAIDs) are commonly used for pain relief, fever reduction, and the management of inflammation. However, self-medication and misuse can lead to significant health risks, particularly in areas with limited medical access. This study evaluates the frequency of NSAID use, the types of drugs utilized, awareness of their side effects, and pharmacists' prescribing practices for patients in pharmacies and hospitals.
Methods: A cross-sectional survey was conducted with 41 pharmacists and 106 residents in Bossaso, collecting data on sociodemographic traits, NSAID types, usage frequency, self-medication practices, sources, side-effect awareness, and accessibility through structured questionnaires. Descriptive statistical analysis was performed to identify trends.
Results: Most participants (91.5%) reported using NSAIDs, primarily Ibuprofen and Diclofenac, with 59.8% obtaining them over the counter, indicating a high prevalence of self-medication. Most participants used NSAIDs for headache relief, followed by diabetic sufferers. Pharmacists attributed overuse of NSAIDs to easy accessibility (46.3%) and lack of awareness of their side effects by the consumers (31.4%).

Conclusion: The study suggests that to mitigate NSAID-related risks, enhanced pharmacist intervention, stricter prescription regulations, and improved patient education are essential. Targeted campaigns could reduce self-medication and promote safer NSAID use.

Keywords: **NSAIDs; Self-medication, Usage frequency; Side effects; Bossaso City.**

1. INTRODUCTION

Nonsteroidal anti-inflammatory drugs (NSAIDs) are used extensively throughout the world to control inflammation, lower fevers, and manage pain. By blocking cyclooxygenase (COX) enzymes, these medications reduce the production of prostaglandins, which are essential for pain and inflammatory reactions [1]. Because they are easily accessible as both prescription and over-the-counter (OTC) drugs, NSAIDs are commonly used to treat musculoskeletal injuries, headaches, and arthritis [2].

Despite their efficiency, NSAIDs carry several dangerous side effects, such as bleeding, kidney damage, cardiovascular problems, and stomach ulcers [3]. These issues highlight the necessity of keeping an eye on NSAID prescription procedures, consumption trends, and public knowledge to reduce any potential side effects.

Although NSAIDs are commonly used in Somalia to treat pain, fever, and inflammation, to our knowledge, no research has been conducted on how often they are used, how they are prescribed, or the knowledge of patients about the health risks associated with them. Inadequate patient information, fake drugs, and financial difficulties, together with limited access to healthcare in Somalia, exacerbate NSAID-related health issues [4].

Thus, in the present study, we focused on NSAID usage patterns, the types employed, sources, pharmacist prescribing procedures, and the knowledge of patients frequenting hospitals and pharmacies in Bossaso city. By gaining insight into NSAID use patterns among patients, we aim to provide crucial information to improve patient education and inform regulatory changes, ultimately contributing to enhanced public health in the country.

In this study, we focused on the usage patterns of non-steroidal anti-inflammatory drugs (NSAIDs) among patients in Bossaso city. We examined the types of NSAIDs used, the sources from which they

are obtained, the procedures pharmacists follow when dispensing them, and the level of knowledge patients have regarding these medications. Our goal is to gain insights into how patients use NSAIDs, which will help us enhance patient education and inform regulatory changes. Ultimately, we aim to contribute to the improvement of public health in the country.

1. METHODOLOGY

2-1. Study Design

This study used a cross-sectional survey approach to evaluate NSAID prescribing practices, usage patterns, awareness of side effects, and patients frequenting pharmacies and hospitals in Bossaso City, Puntland (Somalia).

2.2. Study Population and Sampling

Participants included 106 individuals resident in Bossaso city and 41 pharmacists. Convenience sampling was applied, focusing on individuals who agreed to participate while visiting pharmacies or medical facilities.

2.3. Data Collection Methods

A consumer questionnaire collected data on sociodemographic characteristics, NSAID types and usage patterns, self-medication practices, and knowledge of associated health risks. A pharmacist questionnaire focused on prescribing practices, patient counselling, and suggestions for regulation.

2.4. Data Analysis

Quantitative data were analyzed using SPSS software, employing descriptive statistics. The results obtained were displayed in tables and figures.

2.5 Ethical Considerations

Conducted under the supervision of the University of Health Sciences, the study adhered to ethical standards. Participants provided informed consent, ensuring voluntary participation, confidentiality, and the right to withdraw. The research followed the guidelines for studies involving human subjects.

2. RESULTS

To determine the prevalence of NSAID (non-steroidal anti-inflammatory drug) use and knowledge of related side effects among individuals frequenting hospitals and pharmacies in Bossaso city, Somalia, a total of 106 participants were evaluated in this study. Among the participants, 8.5% reported not using NSAIDs, while 91.5% did. In this study, 41 pharmacists were also included to assess NSAID prescription practices, their side effects, the frequency of NSAID use in the city, and to identify the most commonly used NSAIDs.

Table 1 compares NSAID users and non-users based on gender, age, occupation, and medical history. The gender distribution indicated that 38 women (30.2%) and 59 men (60.8%) reported using NSAIDs. NSAID use was highest in the age groups 18-20 (38.1%) and 21-44 years (42.3%), while it decreased among older age groups, with 13.4% of users aged 45-65 and 6.2% over 65. Based on medical history, NSAID use was most prevalent among headache sufferers (30.9%), followed by diabetics (20.6%), and lowest among individuals with hypertension (17.5%) (Fig. 1).

Table 1. NSAID Use Across Demographics and Types: Frequency & Chronic Pain Management

Demographic Variable	NSAID Users (n=97)%
Gender	
Female	38 (39.2%)
Male	59 (60.8%)
Age Group	
18-20	37 (38.1%)
21-44	41(42.3%)
45-64	13 (13.4%)
65+	6 (6.2%)
Type of NSAID Used for Chronic Pain	
Ibuprofen	12 (12.4%)
Naproxen	14 (14.4%)
Aspirin	19 (19.6%)
Diclofenac	52 (53.6%)
Frequency of NSAID Use for Acute Pain	
Everyday	19 (19.6%)
Once a week	8 (8.2%)
Once a month	4 (4.1%)
Occasionally	66 (68%)
Do you suffer from chronic pain conditions?	
Yes	64 (66%)
No	33 (34%)
Frequency of NSAID Use for Chronic Pain	
Daily	23 (23.7%)
Weekly	8 (8.2%)
Monthly	11 (11.3%)
Occasionally	55 (56.7%)

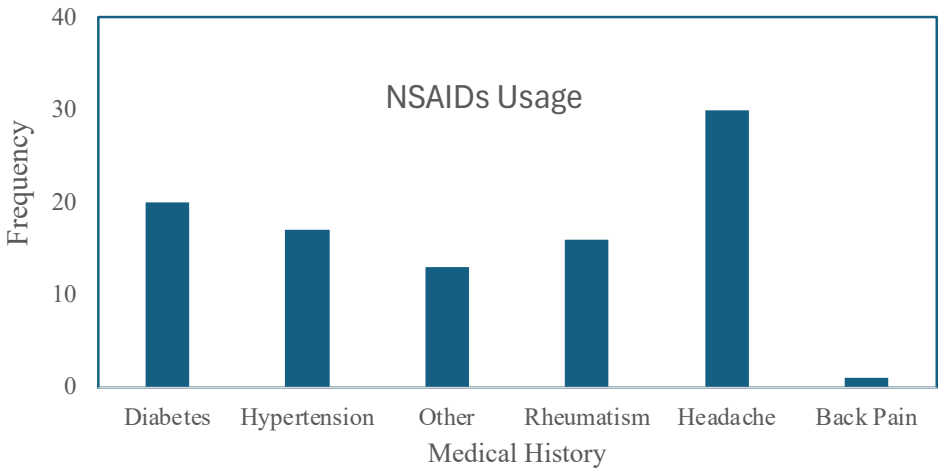


Figure 1. The medical conditions leading to NSAID usage

Most respondents (68%) indicated that they use NSAIDs occasionally for acute pain, while 19.6% reported daily use (Table 1). Figure 2 shows that the most frequently utilized NSAIDs for acute pain management were Ibuprofen (37.1%) and Naproxen (27.8%), with Aspirin being the least commonly used.

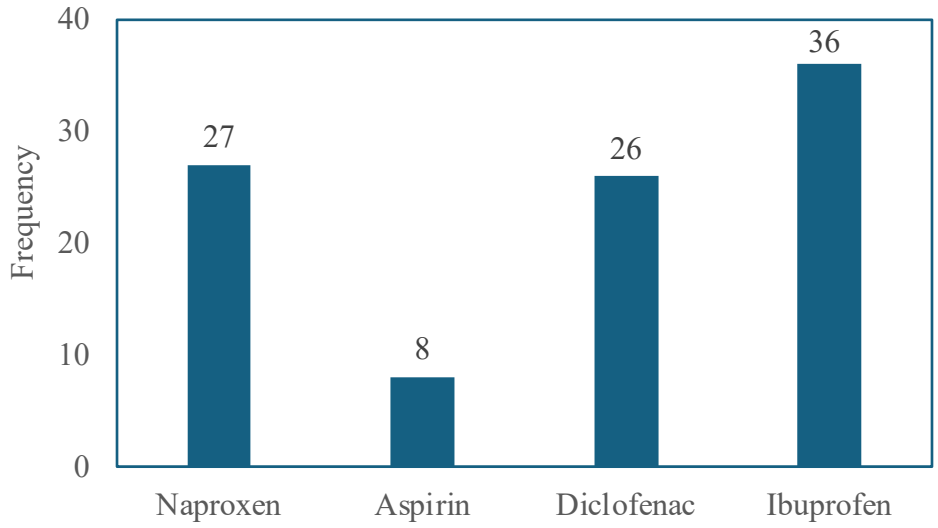


Figure 2. Types of NASIDs used for acute pain management

In contrast, the most popular NSAID for managing chronic pain was Diclofenac (53.6%), followed by Aspirin (19.6%) and Naproxen (14.4%) (Table 1). Notably, despite its popularity for acute pain, Ibuprofen was the least frequently used for chronic pain management (12.4%) (Table 1). For chronic pain, most participants (56.7%) stated they use NSAIDs occasionally, and 23.7% reported daily use (Table 1).

Table 2. Sources of NSAID Use for Acute Pain Management, Knowledge and Awareness of Side Effects

Variable	Yes (n=97, %)
Self-Rated NSAID Knowledge	
Excellent	47 (48.5%)
Good	11 (11.3%)
Moderate	35 (36.1%)
Poor	4 (4.1%)
Awareness of NSAID Side Effects	
High Blood Pressure / Cardiovascular Disease	91 (85.8%)
Asthma / Allergy Risk	89 (84.0%)
Digestive System Problems	84 (79.2%)
Kidney Problems	94 (88.7%)
Do you read NSAID information leaflets?	
Always	33 (34.0%)
Never	10 (10.3%)
Sometimes	54 (55.7%)

Has anyone explained the side effects of NSAIDs to you?	
Yes	80 (82.5%)
No	17 (17.5%)
Does combining NSAIDs provide better relief?	
Agree	76 (78.4%)
Disagree	21 (21.6%)
Do you know NSAIDs can interact with other medications?	
Yes	84 (86.6%)
No	13 (13.4%)

We also explored how NSAID users obtain their medications. Most participants (59.8%) sourced NSAIDs from over-the-counter options, followed by prescription sources (36.1%), while 4.1% obtained them from friends or relatives (Fig. 3). Participants with lower incomes tended to rely more on over-the-counter NSAIDs, while those with higher incomes had better access to prescription-based options (data not shown).

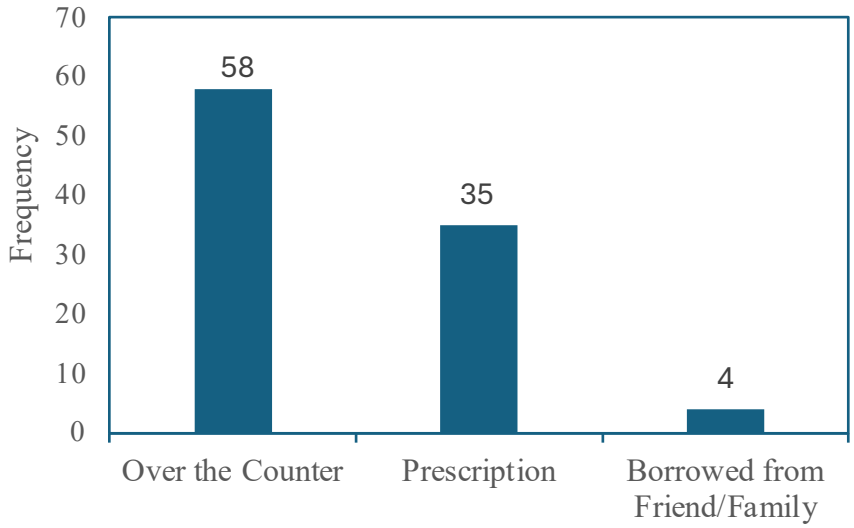


Figure 3. Sources of NSAIDs for acute pain management

When asked about their knowledge of NSAIDs, 48.5% of respondents rated their knowledge as excellent, 11.3% as good, 36.1% as moderate, and 4.1% as poor (Table 2).

Furthermore, we assessed pharmacists' prescribing practices regarding NSAIDs. We found that 53.7% always requested a prescription to dispense NSAIDs, while the remaining 41.5% occasionally demanded prescriptions, and 4.9% never did (Table 3). This highlights the inconsistency in prescription demands for NSAIDs.

Table 3. Perspectives of Pharmacists on NSAID Use and Awareness in Bossaso

Question	Response	Frequency	Percent (%)
Do you give NSAIDs with a prescription?	Always	22	53.7
	Often	10	24.4
	Sometimes	5	12.2
	Rarely	2	4.9
	Never gives	2	4.9
Do you think the use of NSAIDs in Bossaso is excessive?	Strongly agree	24	58.5
	Neutral	9	22
	Disagree	7	17.1
	Unclear	1	2.4
What are the most commonly requested NSAIDs by Bossaso clients?	Ibuprofen	16	39
	Aspirin	6	14.6
	Naproxen	5	12.2
	Diclofenac	12	29.3
	Others	2	4.9
What measures do you think can be taken to reduce the excessive use of NSAIDs in Bossaso?	Strict regulations on non-prescription dispensing	26	63.4
	Public awareness campaigns	9	22
	Access to quality healthcare services	1	2.4
	Patient education on medication use	3	7.3
	Training for healthcare professionals	1	2.4
	Others	1	2.4

When pharmacists were asked whether there is excessive NSAID use in Bossaso, 58.5% responded affirmatively, indicating frequent use in the city (Table 3). Regarding factors that facilitate excessive NSAID use, 34.1% attributed it to clients' lack of knowledge about NSAID side effects. In comparison, 46.3% pointed to the ease of access to NSAIDs without prescriptions (Fig. 4).

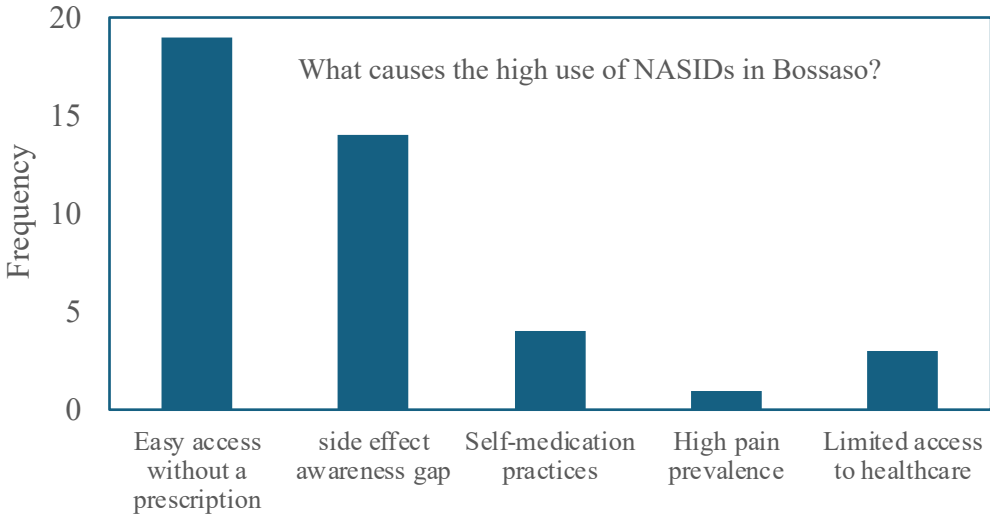


Figure 4. The main causes of high use of NSAIDs in Bossaso

Additionally, over 75.6% of pharmacists believed their clients had poor knowledge of NSAID side effects (Figure 5).

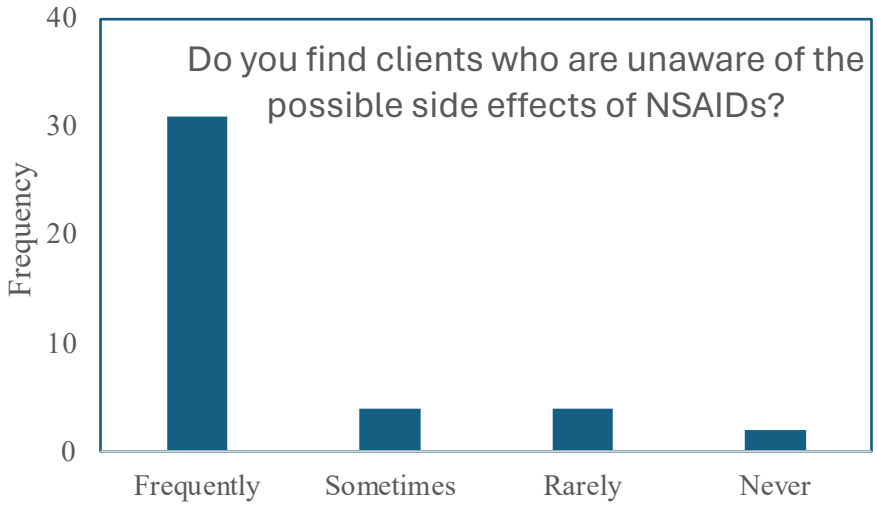


Figure 5. Pharmacists' perspective on clients' knowledge of NSAID side effects

When asked about the most commonly requested NSAIDs by clients, the majority of pharmacists (39%) identified Ibuprofen as the most common, followed by Diclofenac (29.3%) and Aspirin (21.1%) (Table 3). Finally, 63.4% of pharmacists suggested implementing more stringent dispensing regulations to reduce excessive NSAID use, and 22% advocated for public awareness programs (Table 3).

4. DISCUSSION

Millions of individuals around the world take non-steroidal anti-inflammatory medicines (NSAIDs) every day to manage their pain. Despite their effectiveness, NSAIDs pose significant risks, including kidney damage, gastrointestinal bleeding, and effects on the cardiovascular system [5]. In this study, we examined NSAID usage patterns and awareness of side effects among 106 individuals visiting hospitals and pharmacies in Bossaso, Puntland (Somalia), and assessed 41 pharmacists' prescribing practices, the frequency of NSAID use, the most commonly used NSAIDs, and their opinions on their clients' knowledge of NSAIDs.

Most participants used NSAIDs for headache relief, followed by diabetic patients (Fig. 1). The type of NSAID used depended on whether the pain was acute or chronic. Ibuprofen was favored for acute pain relief, followed by Naproxen (Fig. 2), whereas Diclofenac was more frequently used for chronic pain relief (Table 1). When the respondents were asked about the sources of the NSAIDs, the majority stated that they got them from an over-the-counter source (Fig. 3). Income levels affected access to NSAIDs; those with lower incomes were more likely to buy them over-the-counter, while those with higher incomes had easier access to prescription-based alternatives (Data not shown). Most participants indicated awareness of the side effects and interactions of NSAIDs with other medications (Table 2).

About 53.7% of the pharmacists demanded a prescription, while almost the rest occasionally gave out NSAIDs without a doctor's prescription (Table 3). Furthermore, 58.5% of the pharmacists held that there is excessive use of NSAIDs in Bossaso (Table 3). According to the pharmacist, the main factors responsible for the high use of NSAIDs in the city include the easy accessibility of these medications without a prescription and the lack of knowledge of the clients about NSAIDs' side effects (Figs. 4 and 5).

Finally, the pharmacists emphasized the need for regulatory reforms and improved healthcare guidance to tackle the issue of NSAID overuse. They advocated for stricter prescription regulations and awareness campaigns. By expanding access to patient education, enhancing pharmacist training, and providing medical counselling, we can promote responsible NSAID use and reduce the unnecessary risks associated with self-medication.

CONCLUSION

Nonsteroidal anti-inflammatory drugs (NSAIDs) are frequently used for pain relief, lowering fever, and managing inflammation. However, self-medication and misuse can pose significant health risks, especially in areas with limited access to healthcare. This study assesses how often NSAIDS are used, the types of drugs involved, awareness of their side effects, and pharmacists' prescribing practices.

REFERENCE:

1. Wolfe, M.M., Lichtenstein, D.R., and Singh, G. 1999. Gastrointestinal toxicity of nonsteroidal anti-inflammatory drugs. New England Journal of Medicine, 340(24), pp.1888–1899.

2. Vergani, C. and Vierling, J., 2010. Topical NSAID therapy for musculoskeletal pain. Pain Medicine, 11(4), pp.535–549.

3. Smith, R., Fernando, S. and Chang, R., 2021. Are NSAIDs safe? Assessing the risk-benefit profile of nonsteroidal anti-inflammatory drug use. The American Surgeon, 87(6), pp.872–879.

4. Ahmed, M.M., 2019. Revolutionizing healthcare in Somalia: the role of digital innovations in enhancing access and quality. Exploration of Digital Health Technologies, 2, pp.360–368.

5. Kifle, S., Ward, B., and Molokhia, M., 2021. The risk of non-steroidal anti-inflammatory drug-induced heart failure in people with chronic kidney disease: a systematic review. Journal of Public Health, 30, pp.1763–1773.

METABOLIC RISK PATTERNS AND SCREENING PERFORMANCE OF ANTHROPOMETRIC INDICES FOR ELEVATED RANDOM BLOOD GLUCOSE IN URBAN SOMALIA: A CROSS-SECTIONAL STUDY

Ali Bile Farah Hassan and Hafsa Ali Mohamud
University of Health Sciences, Puntland State, Somalia

ABSTRACT

Aim: To characterize metabolic risk patterns and evaluate the screening performance of body mass index (BMI), waist circumference (WC), and waist-to-hip ratio (WHR) in detecting hyperglycemia among urban adults in Bossaso, Somalia.

Methods: A community-based cross-sectional study was conducted with 160 adults (aged ≥18 years) in Bossaso. Participants underwent anthropometric measurements and random blood glucose (RBG) testing. Hyperglycemia was defined as RBG ≥140 mg/dL (7.8 mmol/L). K-means clustering was used to identify exploratory metabolic patterns. Receiver Operating Characteristic (ROC) analysis assessed the discriminative ability of anthropometric indices.

Results: The prevalence of screening hyperglycemia was 13.8%. Participants with hyperglycemia had significantly higher BMI (31.5 vs. 26.2 kg/m2, $p<0.001$) and WC (100.9 vs. 94.3 cm, $p=0.003$) than normoglycemic individuals. WHR did not differ significantly between groups ($p=0.761$). In ROC analysis, BMI demonstrated the highest discriminatory power (AUC=0.76, 95% CI 0.64–0.88), followed by WC (AUC=0.71). WHR failed to discriminate hyperglycemia (AUC=0.51). Cluster analysis identified a distinct "High Sugar–Normal BMI" subgroup (30.0% of the sample).

Conclusions: In this urban Somali population, BMI showed higher discrimination for hyperglycemia compared to WHR, contrasting with findings from Somali migrant populations in Europe and other sub-Saharan contexts. The presence of non-obese individuals with high sugar intake suggests a need for comprehensive screening strategies beyond anthropometry alone.

Keywords:
Somalia; Hyperglycemia; Body Mass Index; Anthropometry; Urban Health Screening

1. INTRODUCTION

To our knowledge, there is no published evidence comparing body mass index (BMI), waist circumference (WC), and waist-to-hip ratio (WHR) as screening tools for hyperglycemia among adults in Somalia. This evidence gap constrains informed decision-making by health practitioners and policymakers regarding the selection of appropriate anthropometric indicators for early detection and prevention. The burden of non-communicable diseases (NCDs), particularly type 2 diabetes (T2D) and metabolic syndrome (MetS), is rising rapidly in low- and middle-income countries (LMICs) [1-3]. This epidemiological shift is driven by complex interactions between urbanization, lifestyle transitions, and environmental determinants [4]. In sub-Saharan Africa, the prevalence of metabolic risk factors, including obesity, hypertension, and dysglycemia, varies widely but is consistently higher in urban settings [5-7]. Recent systematic reviews estimate the prevalence of MetS in African populations at approximately 32%, with significant heterogeneity across regions [8,9].

Anthropometric indices are critical, low-cost tools for screening diabetes risk in resource-limited settings. While Body Mass Index (BMI) remains the standard measure for general obesity, its diagnostic accuracy in African populations is debated due to ethnic variations in body composition [10]. Increasing evidence from West and East Africa suggests that measures of central adiposity, such as Waist Circumference (WC) and Waist-to-Hip Ratio (WHR), may be superior predictors of glycemic dysregulation [11,12]. For instance, studies in Ethiopia [13,14], Ghana [15], and Nigeria [16] often report that central obesity markers outperform BMI in predicting diabetes and hypertension. Conversely, data from Malawi suggest BMI may retain stronger associations with cardiometabolic risk in certain urban populations [17].

Specific data on Somali populations are largely limited to diaspora studies. Research among Somali migrants in Finland [18], Norway [19], and the United States [20] indicates a high prevalence of diabetes and obesity, with some studies suggesting WC and waist-to-height ratio (WHtR) are better risk indicators than BMI in these groups [18]. However, environmental factors in the diaspora differ vastly from those in the Horn of Africa. In Somalia, rapidly urbanizing cities like Bosaso face a "double burden" of malnutrition and emerging NCDs, yet local empirical data are scarce. It remains unclear whether the anthropometric cut-offs or preferences established in diaspora or neighboring African studies [21,22] apply to adults residing within Somalia.

This study aimed to: (1) characterize metabolic risk patterns and lifestyle behaviors among urban adults in Bosaso; and (2) evaluate the screening performance of BMI, WC, and WHR in detecting elevated random blood glucose.

2. METHODS

2.1 Study Design and Setting

A community-based cross-sectional study was conducted in Bosaso, a major commercial hub in the Puntland State of Somalia. The setting was selected to reflect an environment undergoing rapid urbanization. Data collection occurred over a defined period on June 5 /2025.

2.2 Study Population

The study population consisted of adult men and women (aged ≥18 years) residing in Bosaso. Participants were recruited via convenience sampling from high-traffic public locations (markets, social gathering spots) to capture a diverse cross-section of the urban population. Exclusion criteria included pregnancy, physical disabilities preventing accurate measurement, and acute illness requiring immediate hospitalization. A total of 160 participants were included.

2.3 Data Collection

Sociodemographic and Lifestyle Data: A structured questionnaire covered demographics and socioeconomic status and included a frequency-based dietary assessment (5-point scale) of key food groups, including sugary foods. *Anthropometry:* Measurements were conducted in accordance with World Health Organization (WHO) protocols [23]. Height and weight were measured to the nearest 0.1 cm and 0.1 kg, respectively, to calculate BMI (*kg/m*^2). Waist circumference (WC) was measured at the midpoint between the lower rib margin and iliac crest. Hip circumference was measured at the widest portion of the buttocks. WHR was calculated as WC divided by hip circumference.

2.4 Biochemical Analysis

Random blood glucose (RBG) was measured in milligrams per deciliter (mg/dL) at the time of data collection using a venous blood sample. Venous blood was collected by standard phlebotomy procedures, and glucose concentration was determined immediately using a calibrated glucose analyzer in accordance with the manufacturer's instructions and standard quality-control procedures.

Because blood glucose was measured in a non-fasting state at a single time point, the outcome is interpreted as *screen-positive elevated RBG* rather than a diagnostic classification of diabetes. Hyperglycemia for screening purposes was defined as an RBG level ≥ 140 mg/dL (7.8 mmol/L), consistent with guidelines for risk assessment in non-fasting populations. [24].

2.5 Statistical Analysis

Data were analyzed using Stata SE (Version 17.0). Continuous variables were presented as means ±standard deviations (SD). Normal RBG vs. screen-positive elevated RBG were assessed using independent t-tests for continuous variables and Chi-square tests for categorical variables. To explore underlying patterns, K-means clustering

was performed using standardized Z-scores of BMI, WC, age, physical activity, and sugar intake. The number of clusters (k=3) was determined based on cluster stability and interpretability. Receiver Operating Characteristic (ROC) curve analysis evaluated the discriminative ability of anthropometric indices for hyperglycemia. The Area Under the Curve (AUC) was calculated, and pairwise comparisons were performed using the DeLong method. Statistical significance was defined as $p<0.05$.

2.6 Ethical Considerations

Ethical approval was obtained from the Institutional Review Board of the University of Health Sciences. Informed consent was obtained from all participants.

3. RESULTS

3.1 Participant Characteristics

The study included 160 adults (51.3% male, 48.8% female). The majority (53.8%) were aged 40–59 years. Socioeconomic indicators revealed vulnerability: 51.3% had no formal education, and 46.3% earned <$100 per month. Notably, 100% of participants reported never having received professional nutritional counseling.

Table 1. Sociodemographic Characteristics of the Study Population

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	82	51.3
	Female	78	48.8
Age Group	< 40 Years	43	26.9
	40–59 Years	86	53.8
	60+ Years	31	19.4
Education Level	No formal education	82	51.3
	Primary education	47	29.4
	Secondary / Tertiary	31	19.3
Monthly Income	Low (< $100)	74	46.3
	Medium ($100 - $200)	42	26.2
	High (> $300)	44	27.5

3.2 Anthropometric Indices by Glycemic Status

The prevalence of screening hyperglycemia (RBG ≥140 mg/dL) was 13.8% (n=22). Participants with hyperglycemia exhibited significantly higher measures of general and central obesity compared to those with normal glucose levels (Table 2).

Table 2. Comparison of Anthropometric Indices by Glycemic Status

Variable	Normal Glucose (n=138)	High Glucose (n=22)	t-value	p-value
	Mean ± SD	*Mean* ± SD		
BMI (kg/m ²)	26.20 ± 4.12	31.52 ± 5.72	-5.31	**< 0.001***
Waist Circ. (cm)	94.28 ± 10.16	100.95 ± 8.01	-2.94	**0.003***
WHR	0.94 ± 0.09	0.95 ± 0.12	-0.31	0.761
Age (years)	47.83 ± 12.16	51.18 ± 13.53	-1.18	0.239

Mean BMI was significantly higher in the hyperglycemic group (31.52 ± 5.72 kg/m2) compared to the normoglycemic group (26.20 ± 4.12 kg/m2; p<0.00). WC was also significantly elevated in the hyperglycemic group (p=0.003). However, WHR did not differ significantly between groups (0.95 vs. 0.94; p=0.761).

3.3 Exploratory Metabolic Profiles

K-means clustering identified three distinct metabolic patterns (Table 3):

1. **Cluster 1 (Obese–High Adiposity):** 38.8% of the sample, characterized by the highest BMI (31.1 kg/m2) and WC (103.6 cm), had the highest hyperglycemia prevalence (24.2%).
2. **Cluster 2 (High Sugar Intake–Normal BMI):** 30.0% of the sample was characterized by normal mean BMI (24.4 kg/m2) but the highest frequency of sugary food consumption.
3. **Cluster 3 (Lean–Lower Intake):** 31.2% of the sample was characterized by the lowest adiposity and sugar intake scores.

Table 3. Characteristics of Data-Driven Metabolic Clusters

Feature	Cluster 1 (n = 62)	Cluster 2 (n = 48)	Cluster 3 (n = 50)	p-value
Cluster Label	Obese–High Adiposity	High Sugar–Normal BMI	Lean–Lower Intake	—
Body Mass Index (kg/m²), mean	31.1	24.4	24.2	< 0.001
Waist Circumference (cm), mean	103.6	89.2	90.5	< 0.001
Sugar Intake Frequency Score, mean	2.5	4.0	1.6	< 0.001
Hyperglycemia Prevalence, % (n)	24.2% (15/62)	8.3% (4/48)	6.0% (3/50)	0.009

Note: Shows means for BMI, WC, Sugar Intake Score, and Hyperglycemia prevalence across 3 clusters.

3.4 Screening Performance of Anthropometric Indices

ROC analysis evaluated the discriminative ability of indices for hyperglycemia (Table 4 and Figure 1).

Table 4. Screening Performance (ROC Analysis) for Predicting Hyperglycemia

Anthropometric Index	AUC (Area Under Curve)	Std. Error	95% Conf. Interval	Interpretation
BMI	0.76	0.06	0.64 – 0.88	Good Accuracy
Waist Circumference	0.71	0.05	0.61 – 0.80	Fair Accuracy
Waist-to-Hip Ratio (WHR)	0.51	0.07	0.38 – 0.65	Poor/No Accuracy

Note: Shows AUC, SE, and 95% CI for BMI, WC, and WHR.

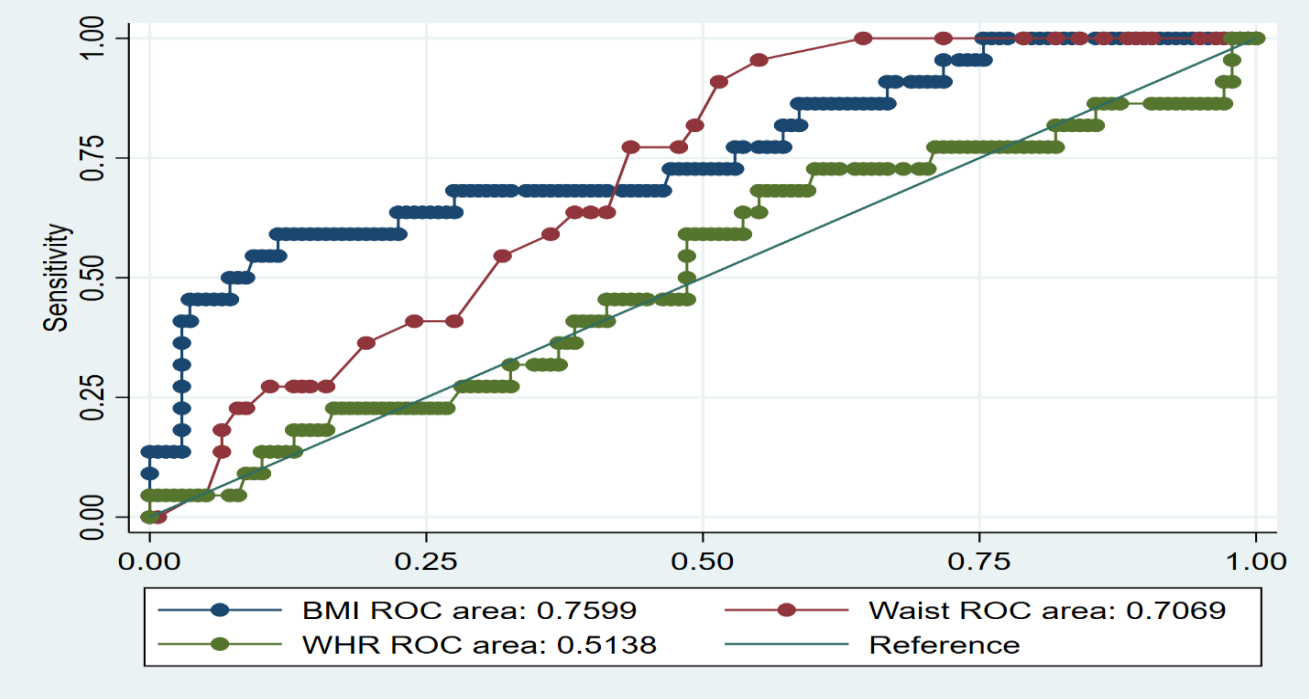


Figure 1. ROC Curves for Anthropometric Indices

Note: Visual comparison of sensitivity vs. 1-specificity.

BMI demonstrated the highest discriminative power (AUC = 0.76; 95% CI: 0.64–0.88), followed by WC (AUC = 0.71; 95% CI: 0.61–0.80). WHR failed to discriminate hyperglycemia effectively (AUC = 0.51), which was not statistically different from chance. Pairwise comparison confirmed that BMI was significantly superior to WHR (p=0.016).

4. DISCUSSION

This study provides valuable empirical data on metabolic risk profiles in urban Somalia. We observed a prevalence of hyperglycemia of 13.8%, consistent with the rising burden of dysglycemia reported in the East African region [25] and across the continent [26,27].

Our finding that BMI (AUC 0.76) outperformed WC (AUC 0.71) and WHR (AUC 0.51) contrasts with findings from Somali migrants in Finland, where WC and WHtR were superior risk indicators [18]. It also differs from studies in Ethiopia [14,28], Ghana [15], and South Africa [10, 29], where central obesity measures often outperform BMI. However, our results align with findings from Malawi [17] and a global analysis of LMICs [30], suggesting BMI remains a robust screening tool. The poor performance of WHR in our sample is particularly noteworthy. While WHR is often cited as a strong predictor of cardiovascular risk [31,32], its utility may vary by ethnicity and environmental context [33]. Questions arising from our study include: Does the Somali body shape phenotype in the Horn of Africa differ from diaspora populations due to environmental or nutritional factors? Or did cultural clothing practices in a field setting affect hip measurement precision?

Further, the identification of a"High Sugar–Normal BMI"cluster (30% of participants) is clinically significant. This group mirrors the "metabolically obese normal weight" phenotype described in global literature [34] and highlights the role of dietary transitions in urban Africa [35]. Relying solely on anthropometry measurements might overlook these at-risk individuals.

However, we met challenges during this study. A major challenge was the lack of baseline population health data, which necessitated a convenience sampling approach. Additionally, measuring anthropometrics in public urban spaces required careful cultural sensitivity, particularly regarding gender norms. Moreover, we relied on RBG for screening feasibility. While this method is suitable for population screening, using HbA1c or Oral Glucose Tolerance Tests (OGTT) would have provided more precise diagnostics [36]. Recent reviews in Africa highlight the high utility of HbA1, but cost remains a barrier [37]. Furthermore, detailed 24-hour dietary recalls would have refined the characterization of the"High Sugar"cluster compared to the frequency score used.

Finally, despite calls to move beyond BMI [38], our data suggest that BMI remains a valid, simple first-line screening tool for hyperglycemia in this specific urban Somali context. However, the presence of high-risk dietary behaviors among non-obese individuals suggests that screening protocols in Bosaso should integrate dietary history. The complete lack of prior nutritional counseling reported by participants emphasizes the urgent need for basic health education interventions, similar to those recommended for other African urban populations [39-41].

5. CONCLUSIONS

In this urban Somali population, BMI demonstrated fair discriminative power for screening hyperglycemia, outperforming WHR. This contrasts with findings from the Somali diaspora and some neighboring regions, suggesting that optimal screening tools may be context-specific. The detection of distinct metabolic clusters, including non-obese individuals with high sugar intake, underscores the need for multifaceted public health strategies [42-44] to address the rising burden of NCDs in Somalia.

REFERENCES

1. Teufel F, Seiglie J, Geldsetzer P, et al. Body-mass index and diabetes risk in 57 low-income and middle-income countries: a cross-sectional study of nationally representative, individual-level data in 685 616 adults. The Lancet. 2021;398(10296):238-248.

2. Lovic D, Piperidou A, Zografou I, et al. The Growing Epidemic of Diabetes Mellitus. Current Vascular Pharmacology. 2020;18(2):104-109.

3. Miranda JJ, Barrientos-Gutiérrez T, Corvalan C, et al. Understanding the rise of cardiometabolic diseases in low- and middle-income countries. Nature Medicine. 2019;25(11):1667-1679.

4. Chew NWS, Ng CH, Tan DJH, et al. The global burden of metabolic disease: Data from 2000 to 2019. Cell Metabolism. 2023;35(3):414-428.e3.

5. Otieno P, Asiki G, Wekesah F, et al. Multimorbidity of cardiometabolic diseases: a cross-sectional study of patterns, clusters and associated risk factors in sub-Saharan Africa. BMJ Open. 2023;13(2):e064275.

6. Bowo-Ngandji A, Kenmoe S, Ebogo-Belobo JT, et al. Prevalence of the metabolic syndrome in African populations: A systematic review and meta-analysis. PLOS ONE. 2023;18(7):e0289155.

7. Noubiap JJ, Nansseu JR, Lontchi-Yimagou E, et al. Geographic distribution of metabolic syndrome and its components in the general adult population: A meta-analysis of global data from 28 million individuals. Diabetes Research and Clinical Practice. 2022;188:109924.

8. Ambachew S, Endalamaw A, Worede A, et al. The Prevalence of Metabolic Syndrome in Ethiopian Population: A Systematic Review and Meta-analysis. Journal of Obesity. 2020;2020:2701309.

9. Yaya S, Ekholuenetale M, Bishwajit G. Differentials in prevalence and correlates of metabolic risk factors of non-communicable diseases among women in sub-Saharan Africa: evidence from 33 countries. BMC Public Health. 2018;18(1):1142.

10. Bigna JJ, Nansseu JR, Katte JC, Noubiap JJ. Prevalence of prediabetes and diabetes mellitus among adults residing in Cameroon: A systematic review and meta-analysis. Diabetes Research and Clinical Practice. 2018;137:109-118.

11. Seiglie J, Seuring T, Flood D, Woolcott O, Manne-Goehler J. Waist circumference-based measures and their relationship to diabetes risk in 50 low- and middle-income countries. Diabetes Research and Clinical Practice. 2023;199:110451.

12. Manyara AM. Optimal cut-offs of five anthropometric indices and their predictive ability of type 2 diabetes in a nationally representative Kenyan study. AIMS Public Health. 2021;8(3):507-518.

13. 13. Darko SN, Meeks KA, Owiredu WK, et al. Anthropometric indices and their cut-off points in relation to type 2 diabetes among Ghanaian migrants and non-migrants: The RODAM study. Diabetes Research and Clinical Practice. 2021;173:108687.

14. Oumer A, Ale A, Tariku Z, et al. Waist-to-hip circumference and waist-to-height ratio could strongly predict glycemic control than body mass index among adult patients with diabetes in Ethiopia: ROC analysis. PLoS ONE. 2022;17(10):e0273786.

15. Quaye L, Owiredu WKBA, Amidu N, Dapare PP, Adams Y. Comparative Abilities of Body Mass Index, Waist Circumference, Abdominal Volume Index, Body Adiposity Index, and Conicity Index as Predictive Screening Tools for Metabolic Syndrome among Apparently Healthy Ghanaian Adults. Journal of Obesity. 2019;2019:8143179.

16. Olatunbosun ST, Kaufman J, Bella A. Central Obesity in Africans: Anthropometric Assessment of Abdominal Adiposity and its Predictors in Urban Nigerians. Journal of the National Medical Association. 2018;110(2):193-200.

17. Mudie K, Lawlor D, Pearce N, et al. How does the association of general and central adiposity with glycaemia and blood pressure differ by gender and area of residence in a Malawian population: a cross-sectional study. International Journal of Epidemiology. 2018;47(3):887-897.

18. Skogberg N, Laatikainen T, Lundqvist A, et al. Which anthropometric measures best indicate type 2 diabetes among Russian, Somali and Kurdish origin migrants in Finland? A cross-sectional study. BMJ Open. 2018;8(5):e019166.

19. Bohler L, Meyer H, Leirbakk MJ, et al. Risk factors for non-communicable diseases among overweight and obese women of Somali background in Oslo, Norway. Clinical Epidemiology and Global Health. 2023;23:101384.

20. Westgard B, Martinson BC, Maciosek M, et al. Prevalence of Cardiovascular Disease and Risk Factors Among Somali Immigrants and Refugees. Journal of Immigrant and Minority Health. 2020;22(4):680-688.

21. Nyangasa MA, Buck C, Kelm S, et al. Association between cardiometabolic risk factors and body mass index, waist circumferences and body fat in a Zanzibari cross-sectional study. BMJ Open. 2019;9(7):e025397.

22. Gebreyes YF, Goshu DY, Geletew TK, et al. Prevalence of high bloodpressure, hyperglycemia, dyslipidemia, metabolic syndrome and their determinants in Ethiopia: Evidences from the National NCDs STEPS Survey, 2015. PLOS ONE. 2018;13(5):e0194819.

23. Piqueras P, Ballester A, Durá-Gil JV, et al. Anthropometric Indicators as a Tool for Diagnosis of Obesity and Other Health Risk Factors: A Literature Review. Frontiers in Psychology. 2021;12:631179.

24. Seiglie J, Marcus M, Ebert C, et al. Diabetes Prevalence and Its Relationship With Education, Wealth, and BMI in 29 Low- and Middle-Income Countries. Diabetes Care. 2020;43(4):767-775.

25. Asmelash D, Mesfin Bambo G, Sahile S, Asmelash Y. Prevalence and associated factors of prediabetes in adult East African population: A systematic review and meta-analysis. Heliyon. 2023;9(11):e21286.

26. Musilanga N, Nasib H, Jackson G, et al. Exploring the Prevalence and Components of Metabolic Syndrome in Sub-Saharan African Type 2 Diabetes Mellitus Patients: A Systematic Review and Meta-Analysis. medRxiv. 2024. doi:10.1155/2024/1240457.

27. Chivese T, Hirst J, Matizanadzo JT, et al. The diagnostic accuracy of HbA1c, compared to the oral glucose tolerance test, for screening for type 2 diabetes mellitus in Africa—A systematic review and meta-analysis. Diabetic Medicine. 2021;38(10).

28. Sinaga M, Worku M, Yemane T, et al. Optimal cut-off for obesity and markers of metabolic syndrome for Ethiopian adults. Nutrix Journal. 2018;17(1).

29. Sekgala MD, Sewpaul R, Kengne AP, Mchiza Z, Peer N. Clinical utility of novel anthropometric indices in identifying type 2 diabetes mellitus among South African adult females. BMC Public Health. 2024;24(1):20168.

30. Seiglie JA, Seuring T, Flood D, Woolcott OO, Manne-Goehler J. 1311-P: Waist Circumference Measures for Diabetes Screening in Individuals without Obesity from 61 Low- and Middle-Income Countries. Diabetes. 2024;73(Supplement_1).

31. Gradidge PJ, Norris SA, Crowther NJ. The Effect of Obesity on the Waist Circumference Cut-Point Used for the Diagnosis of the Metabolic Syndrome in African Women: Results from the SWEET Study. International Journal of Environmental Research and Public Health. 2022;19(16):10250.

32. Darbandi M, Pasdar Y, Moradi S, et al. Discriminatory Capacity of Anthropometric Indices for Cardiovascular Disease in Adults: A Systematic Review and Meta-Analysis. Preventing Chronic Disease. 2020;17:200112.

33. Zethof M, Mosterd CM, Collard D, et al. Differences in Body Composition Convey a Similar Risk of Type 2 Diabetes Among Different Ethnic Groups With Disparate Cardiometabolic Risk—The HELIUS Study. Diabetes Care. 2021;44(7):1692-1698.

34. 34. Mohammadian Khonsari N, Khashayar P, Shahrestanaki E, et al. Normal Weight Obesity and Cardiometabolic Risk Factors: A Systematic Review and Meta-Analysis. Frontiers in Endocrinology. 2022;13:857930.

35. 35. Adjanor O, Johnson J, Wuenstel W, et al. A review of social determinants of health for dashboard development for SDG 3.4 for sub-Sahara Africa. European Journal of Public Health. 2020;30(Supplement_5):ckaa166.265.

36. 36. Ekpor E, Akyirem S, Adade Duodu P. Prevalence and associated factors of overweight and obesity among persons with type 2 diabetes in Africa: a systematic review and meta-analysis. Annals of Medicine. 2023;55(1):696-713.

37. 37. Castle AC, Hoeppner SS, Manne-Goehler JM, et al. Identifying sex-specific anthropometric measures and thresholds for dysglycemia screening in an HIV-endemic rural South African population. PLOS Global Public Health. 2023;3(10):e0001698.

38. 38. Seiglie J, Seuring T, Flood D, Woolcott O, Manne-Goehler J. IDF2022-0586 Waist circumference-based measures and their relationship to diabetes risk in 50 low- and middle-income countries. Diabetes Research and Clinical Practice. 2023;197:110451.

39. 39. Jemal A, Girum T, Kedir S, et al. Metabolic syndrome and its predictors among adults seeking medical care: A trending public health concern. Clinical Nutrition ESPEN. 2023;54:264-270.

40. 40. Tusa BS, Weldesenbet AB, Gemada AT, et al. Heath related quality of life and associated factors among diabetes patients in sub-Saharan countries: a systemic review and meta-analysis. Health and Quality of Life Outcomes. 2021;19(1).

41. 41. Njiro BJ, Ndumwa HP, Waithera HW, et al. Epidemiology of non-communicable diseases among professional drivers in LMICs: a systematic review and meta-analysis. Health Promotion International. 2024;39(4).

42. Vera-Ponce V, Loayza-Castro JA, Zuzunaga-Montoya FE, et al. Associations between metabolic phenotypes and diabetes risk: A systematic review and meta-analysis. Endocrine and Metabolic Science. 2023;10:100142.

43. Obsa MS, Ataro G, Awoke N, et al. Determinants of Dyslipidemia in Africa: A Systematic Review and Meta-Analysis. Frontiers in Cardiovascular Medicine. 2022;8:778891.

44. 44. Peer N, Balakrishna Y, de Villiers A, Naidoo P. Differential associations of cardio-metabolic diseases by population group, gender and adiposity in South Africa. PLOS ONE. 2018;13(9):e0202899.

RISKS OF WASTE BATTERIES: RAISING PUBLIC AWARENESS AND EDUCATING ABOUT THE DANGERS OF IMPROPER BATTERY DISPOSAL

Ahmed Mohamud Osman
University of Health Sciences, Puntland State, Somalia

ABSTRACT

A battery is a device that stores energy and converts chemical energy into electrical energy. We use batteries for various purposes, often without realizing that they are a potential hazardous waste with a negative impact on the environment and human health. Batteries are divided into two main types: primary (non-rechargeable) and secondary (rechargeable).

A battery contains electrodes (anode and cathode) and an electrolyte, which is a liquid or a solid (paste/gel). When batteries wear out or are spent, we throw them away, along with non-hazardous household rubbish, into the trash and the soil. Because batteries contain toxic substances such as metals, lead, cadmium, and mercury, these substances are released into the soil, which ultimately contaminates the water, food, and air on which we depend. In this communication, we discuss the basics of a battery structure, its classification, and the potential hazards associated with improper disposal. We also outline the steps required to reduce the negative impact of dead battery products on the environment and human health, including their recycling and the consequent positive effects on the economy and the environment.

Keywords:

Battery; Hazardous waste; Toxic substances; Recycling; Regulations; Public awareness; Environment; Human health

1. INTRODUCTION

A battery is any device capable of transforming chemical energy to electrical energy via oxidation-reduction (redox) reactions of its components, electrodes and electrolyte (1). Batteries are ubiquitous and around us. It is believed that batteries preceded all forms of inventions, providing energy (1). Although some archaeological findings suggest that a form of battery was used in ancient times in Iraq, where iron and copper tubes were used for electroplating, it is documented that Alessandro Volta discovered the first battery in the 1800s (2). The history of battery technology and development is of enormous interest, but outside the scope of this work (1). Batteries are closely linked to human activities, and there is hardly any human activity devoid of their applications. These applications include clocks, calculators, laptops, watches, flashlights, recorders, televisions, portable radios, motorcycles, electric vehicles, signals and alarms, and many others.

Although you encounter batteries frequently in your daily life, you might not be fully aware of their potential as hazardous waste. Indeed, batteries contain toxic metals like lead, cadmium, and mercury. When old, spent batteries are not properly disposed of, but are thrown into the environment, the contents of the batteries leak out and are released into the soil, making the batteries a significant household hazard. The heavy metals contaminate the environment and constitute an undeniable challenge to the safety of humanity and wildlife.

In this article, we describe the main battery types: single-use and rechargeable. We will cover their components, the economic and environmental importance of battery recycling, and the harmful toxic materials that can be released into the soil if spent batteries are improperly disposed of. Additionally, we will explore the impact of these materials on the ecosystem and human health. Finally, we will highlight the role of public authorities in raising awareness, creating regulations, providing guidelines for proper battery waste management, and ensuring the necessary infrastructure is in place.

2. DISCUSSION

2.1. The Main types of batteries

There are two main types of batteries: primary and secondary batteries. Primary batteries, also known as non-rechargeable batteries, are intended for single use. Once their energy is depleted, they need to be replaced. Examples of these batteries include alkaline (AA, AAA, and AAAA) and lithium metal batteries. Alkaline batteries utilise zinc (Zn) as the negative electrode and manganese dioxide (MnO2) as the positive electrode, with an alkaline electrolyte typically consisting of potassium hydroxide (KOH). These batteries are mainly used in electronic devices, flashlights, toys, and portable electronics. Alkaline batteries usually have a long shelf life. On the other hand, lithium metal batteries utilize lithium metal (Li) as the negative electrode, and a combination of substances such as iron disulfide (FeS2) and manganese dioxide (MnO2) as the positive electrode. These batteries have relatively long shelf lives and are used in medical devices, calculators, and watches.

In contrast to primary batteries, secondary batteries can be recharged after discharge by supplying energy to the battery and reversing the current flow. In other words, the redox reaction between the electrodes and the electrolytes is reversed. Thus, the consumer can use these batteries and reuse them until the end of their life. These batteries can be recycled, and the metals they contain can be reused to produce new batteries or for other purposes. Examples of secondary batteries include nickel–metal hydride (NiMH), lead-acid batteries, lithium-ion (Li-ion) batteries, and solid-state batteries. These batteries have a wide range of applications, including cameras, cordless phones, automotive, and electric vehicles.

2.2. The components of a battery

If you look at any battery (see the picture in Figure 1), you will notice that it has two terminals. One terminal has a plus sign marked (+) and is at the top of the battery. This is the positive end of the battery and is referred to as the cathode. The flat end of the battery has a minus sign (-).

The negative end of a battery is called the anode. There is a liquid, solid or paste/gel, depending on the battery type, called an electrolyte between the cathode and the anode.

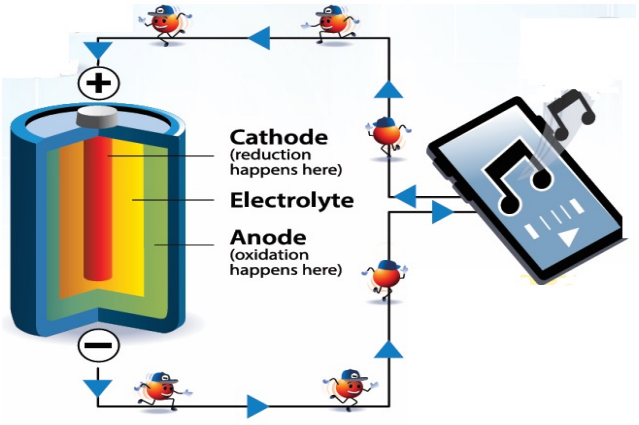


Fig. 1. The components of a battery

Electricity is generated when electrons move from the negative electrode (anode) to the positive electrode (cathode). Electrons move from the anode to the cathode only when the battery is loaded, i.e., when it is connected to a device, such as a light bulb or a radio. The exact number of electrons lost by the anode is gained by the cathode, undergoing oxidation and reduction, respectively. The electrons are produced in a series of chemical reactions between the electrodes and the electrolyte. When the original chemicals (electrodes and electrolyte) wear out and different chemicals form, the battery becomes dead unless you reverse the reaction and reform the original chemicals, a process possible with secondary (rechargeable) batteries. Recycling or proper disposal is the only remaining option for primary batteries, as they are not rechargeable, as described in section 2.1. Even rechargeable batteries will eventually wear out and must be disposed of properly.

2.3. Batteries are hazardous waste

Batteries are classified as hazardous waste because they contain toxic substances, such as lead, mercury, cadmium, and lithium. If these substances are released and leak into the soil, water, and air, they may harm both humans and wildlife. Additionally, some electrolytes are strong acids and bases, such as sulphuric acid and potassium hydroxide. The most common health effects in humans resulting from contamination with these metals are summarised in Table 1(14).

Table 1. Comparison of metals and their health effects[3]

Metal	Potential health effects
Mercury	death, birth defects, neurological damage, impaired vision, reproductive and genetic problems
Cadmium	carcinogen, kidney stones, birth defects
Lead	neurological damage, IQ deficits, kidney damage, carcinogens, reproductive problems
Nickel	carcinogen, kidney damage, liver damage, skin disorders, immunological disorders
Zinc	carcinogen, birth defects, anemia, and kidney damage
Lithium	neurological damage, adverse effects on children, kidney damage, birth defects

Some battery products can ignite fires and cause explosions, such as lithium, a reactive metal that interacts easily with oxygen. Therefore, no wonder that in many countries, especially those with advanced technology, there are regulations and guidelines for disposing of spent batteries. The manufacturer, the transporter and the end-user are expected to follow these regulations. Some of these regulations are: 1) Batteries should not be combined with non-hazardous household rubbish in regular trash bins; they must be separated. 2) Wear protective gloves for handling dead/spent batteries. 3) Batteries must be classified and labelled as they contain different chemicals. Separating the batteries is necessary because different elements may react, leading to contamination. 4) Store batteries in a dry, cool place away from flammable materials and avoid puncturing and crushing batteries to prevent leakage. In many countries, there are waste companies or agencies responsible for the disposal of batteries. These agencies transport dead batteries to their recycling process sites.

2.4. Battery recycling

The importance of recycling batteries cannot be overemphasized. It not only prevents hazardous waste from harming the environment and reducing pollution, but it also recovers precious metals from batteries to make new ones or use them for other applications, thus conserving natural deposits of these elements. To understand how a recycling process works in its simplest form, let's take a lead-acid battery. Many cars that run on gasoline use this rechargeable battery. Lead-acid batteries have plastic containers that hold lead and lead products, and acid as an electrolyte. In recycling this battery, the acid electrolyte is first neutralized, and then the battery is crushed. The crushed parts are put into water. The plastic parts float, and the lead parts sink. Upon separation, the plastic parts are recycled into new batteries, and the lead parts are melted and recycled into new batteries (4).

3. CONCLUSION AND RECOMMENDATION

In conclusion, batteries are ubiquitous in our lives and serve many purposes, yet we often overlook their potential hazards. Many people dispose of used batteries in landfills alongside regular household waste. This practice can release toxic substances into the soil, contaminating our drinking water, food, and air and leading to serious health consequences (see Table 1). In our country, there are currently no guidelines, regulations, or infrastructure in place for the proper disposal of spent batteries. This raises a crucial question: What can we do in these circumstances?

Fortunately, there are at least three established methods to mitigate the negative impact of spent batteries on the environment, commonly referred to as the three R's: Reduce, Recharge, and Recycle. 1. Reduce: To reduce battery waste, we should only use batteries when no alternative power source is available. This is the most effective way to prevent environmental contamination. It is important to be mindful of the number of batteries we purchase and to select batteries that contain fewer or no toxic substances. Additionally, if an electronic device will not be used for an extended period, the battery should be removed and stored in a dry, cool place. 2. Recharge: The advantages of rechargeable batteries are clear. Although these batteries will eventually wear out, they can be reused through recharging for a long time, making them more economical and environmentally friendly than single-use batteries. However, it's worth noting that most rechargeable batteries contain heavy metals such as lead, cadmium, and mercury, which can be more toxic. Despite this, their longer lifespan means fewer are discarded into the environment. 3. Recycle: Recycling spent batteries is essential for both economic and environmental reasons (see section 2.4). However, developing countries, including many in Africa, face significant challenges in the recycling sector due to a lack of infrastructure, regulations, public awareness, and high costs associated with recycling. For instance, recycling lithium-ion batteries can be costly. We recommend establishing infrastructure for recycling batteries containing toxic metals like cadmium, lead, and nickel, as this may be less costly than recycling lithium-ion batteries. Additionally, electronics and battery retailers should form agreements with foreign companies that source these batteries to implement take-back programs for used batteries. These companies should also cover the costs of transporting spent batteries and other related expenses.

Ultimately, the Federal Government and state governments have a responsibility to safeguard our environment and public health. They must raise awareness, establish regulations, and provide resources for the recycling of spent batteries.

REFERENCES

1. Sarma DD, Shukla AK. Building better batteries: A travel back in time. ACS Energy Lett. 2018;3(11):2841-2845. doi:10.1021/acsenergylett.8b01966

2. Milestones: Volta's Electrical Battery Invention, 1799. ieeeghn.org. IEEE Global History Network. Retrieved Apr 12, 2016; and Enterprise and electrolysis. rsc.org. Royal Society of Chemistry. Retrieved 18 Feb 18, 2015. https://en.wikipedia.org/wiki/Alessandro_Volta#cite_ref-5 (2018).

3. Dillon C., The ecological impact of batteries, 1994 (http://repository.cmu.edu/ece).

4. https://www.acs.org/education/celebrating-chemistry-editions/2024-ccew/recycle-that-battery.html Recycle That Battery! - American Chemical Society

5. Kuchhal P, Sharma UC. Battery waste management. In: Gurjar BR, Sharma UC, Singh N, editors. Environmental Science and Engineering Vol. 5 Solid Waste Management, Texas: Studium Press LLC; 2017, p. 141–155.

6. https://www.capmad.com/energy-en/battery-recycling-in-africa-economic-and-environmental-opportunity/

UNIVERSITY OF
HEALTH SCIENCES

Towards Better Health