International Journal of Business, Law and Political Science
Homepage : https://e-journal.antispublisher.id/index.php/IJBLPS
Email : admin@antispublisher.com

e-ISSN : 3032-1298
IJBLPS, Vol. 2, No. 3, March 2025
Page 86-94

Applying Frugal Principles in Forensic Sciences in Africa

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DOI : https://doi.org/10.61796/ijblps.v2i3.279

Sections Info

Article history:
Submitted: February 19, 2025
Final Revised: February 26, 2025
Accepted: March 05, 2025
Published: March 12, 2025

Keywords:
Crime scene processing
Forensic science
Frugal forensic science
Africa
Sydney declaration

ABSTRACT

Objective: *This study examines how frugal principles can be applied in forensic sciences, in Africa with a focus on implementing the Sydney Declaration on forensic sciences.* ***Method:*** *The findings highlight significant opportunities for applying frugal principles in forensic sciences across Africa. These principles, which emphasize cost-efficiency, resource optimization, and simplicity without compromising quality, are particularly well-suited to address the challenges faced by many forensic laboratories in the region.* ***Novelty:*** *This study contributes to adopting frugal principles in Africa that aligns with the Sydney Declaration on forensic sciences principles. These innovations have the potential to transform Africa's forensic sciences landscape, enhancing its capacity to deliver timely, accurate, and equitable justice. Ultimately, the integration of frugal principles into forensic sciences offers a pathway to overcoming current limitations while supporting the development of robust, sustainable, and accessible forensic infrastructures across Africa.*

INTRODUCTION

Forensic sciences are grappling with a global surge in technological, social, and economic disparities [1]. This is particularly evident in Africa, where socio-economic issues are resulting in limited resources being dedicated to forensic sciences. Forensic resources are frequently centralised in urban regions, resulting in underprivileged and rural populations lacking prompt access to forensic services [2], [3]. However, there is potential for change. Some African countries, despite being rich in natural resources due to plutocracy, are beginning to shift towards more equitable systems, where political decisions and economic policies are made with the broader population in mind.

The inequities are particularly pronounced in the struggle to meet basic human needs and to consistently apply rigorous scientific principles across diverse contexts. The challenge lies in balancing rapid advancements in forensic technology and methodologies with the uneven distribution of resources and expertise across different regions and communities. This disparity impacts the ability of forensic practitioners to uphold standards of quality and reliability, especially in under-resourced areas where access to state-of-the-art tools and training is limited. Furthermore, the increasing complexity of criminal investigations requires forensic practitioners to adapt to evolving challenges, such as cybercrime, transnational crime, and environmental forensics, while still addressing fundamental societal issues like equitable access to justice and accurate evidence processing.

To address these challenges, the forensic science must prioritize the integration of innovative yet cost-effective solutions. Concepts such as frugal innovation—leveraging minimal resources to achieve robust and reliable results—could play a pivotal role in narrowing these gaps [4]. Frugal innovation is about achieving more value while using fewer resources [5], [6]. By drawing inspiration from nature's efficient biological designs or employing simplified yet scientifically sound technologies, forensic science can better serve diverse communities. Additionally, fostering regional collaborations and capacity-building initiatives will be crucial to ensuring equitable application of forensic expertise, thereby strengthening the foundation of justice systems in Africa.

RESEARCH METHOD

The study utilised a qualitative methodology, employing secondary sources to examine and analyse the topic. Data was obtained from peer-reviewed scientific journals, scholarly books, and esteemed publications pertinent to business, law, and political science. The methodology entailed a comprehensive literature assessment to discern main topics, trends, and theoretical frameworks. This approach facilitated a comprehensive comprehension of the subject and establishing a solid basis for analysis.

RESULTS AND DISCUSSION

The analysis revealed that frugal forensic science focuses on developing cost-effective, accessible, and sustainable methods that maintain scientific rigour while addressing resource limitations in forensic investigations. By leveraging innovative approaches and locally available materials, it plays a crucial role in bridging the gap in forensic services, especially in under-resourced regions, ensuring equitable access to justice**.**

A. Sydney Declaration

The Sydney Declaration (SD) redefines forensic science by focusing on the trace, a remnant of past activities, as the primary object of study [7]. This shift emphasizes problem-solving through the information conveyed by the trace, rather than solely on the technologies used. The SD acknowledges uncertainties in reconstruction and broadens the role of forensic science by recognizing the increasing significance of traces in deciphering atypical activities.

Principle 1 of the Sydney Declaration underscores that activities and presence leave behind traces and residual physical records of events (e.g., markings, deformations, particles). These traces are scientifically studied to reconstruct past events and answer crucial investigative questions about what, where, when, and how [7]. (Principle 2 accentuates that scene investigation and trace collection is a scientific process that necessitates expertise to recognize and interpret traces based on physical laws, underscoring the vital role of the investigator [7]. Principle 3 underlines the case-based nature of forensic science, relying on scientific knowledge, investigative methodology, and logical reasoning, including abductive reasoning [7]. In the process of developing

and testing hypotheses, forensic practitioners employ both inductive reasoning—drawing general conclusions from specific observations—and deductive reasoning—applying general principles to predict specific outcomes [8]. Principle 4 emphasizes understanding events in a historical context through traces, while Principle 5 acknowledges the continuum of uncertainties in forensic work [7]. Principle 6 recognizes the multi-dimensional role of forensic science in the justice system, and Principle 7 not only stresses but also underscores the importance of contextual interpretation of traces, making the audience feel the need for their expertise in this crucial aspect of forensic science [7].

Together, the SD principles advocate for a scientific approach to trace analysis, event reconstruction, and forensic investigation, aiming to enhance forensic science education and practice through studying traces and case-based problem-solving. Implementing the SD can contribute to Africa's development and foster trust in forensic sciences [9]. The SD provides a framework for harmonization and consensus-building, essential for navigating the evolving landscape of forensic techniques, including emerging technologies like artificial intelligence. In Africa, SD offers guidance for development despite technological limitations and unique challenges, supporting the continent's forensic community in adopting a scientific approach [10], [11].

B. Crime scene processing

The crime scene has been recognised for some time as a scientific problem requiring scientific expertise and scientific methodology [12]. Crime scene processing is a cornerstone of forensic science, demanding precision, accuracy, and resourcefulness to ensure traces are preserved, analyzed, and interpreted effectively [13].

The presence and active engagement of a forensic practitioner at the crime scene during the initial stages of an investigation are indispensable, as emphasized in SD. This early involvement allows for applying scientific problem-solving methodologies to ensure a thorough and systematic approach to trace identification and analysis. By integrating principles of frugal science—emphasizing cost-effective, efficient, and accessible scientific practices such as using readily available materials or tools, the forensic practitioner can maximize the utility of available resources to enhance trace detection, preservation, and interpretation. Engaging a forensic practitioner at this critical juncture mitigates the risk of overlooking vital traces. It reduces the likelihood of errors in reconstructing events or misinterpreting the relationships between traces and the broader investigative context. Their expertise facilitates the alignment of trace analysis with physical laws and processes, ensuring a robust evidentiary foundation for subsequent investigative and judicial phases. Crime scene examiners must consider multiple plausible explanations for traces of interest to tailor search strategies to the event's context. A comprehensive understanding of the scientific investigation process, from discovery to interpretation, is essential for accurate assessment of uncertainties and is emphasized as the initial step in forensic science [12], [14], [15].

Preliminary processing at the crime scene may include developing latent prints and screening for biological materials or substances. Trace evidence is often transferred to a secure location for drying and sampling under controlled conditions. While field tests, such as presumptive screenings, can provide initial insights, to ensure effective trace collection and that confirmatory analyses should be conducted in accredited forensic laboratories by specialized personnel to ensure accuracy and reliability [16], [17].

The implementation of comprehensive case coordination, starting with triage at the crime scene, is gaining traction in forensic investigations [17]. This method involves systematically prioritising and managing evidence collection and analysis from the beginning, ensuring that critical information is identified and processed efficiently. By embracing such strategies, investigative teams can significantly enhance the effectiveness and accuracy of their forensic examinations, leading to more robust and confident case outcomes. For example, implementing a triage strategy is essential for efficient evidence processing. This involves two key stages [17]:

a. **Prioritizing Items for Examination:** Selecting which trace items collected and sampled from the crime scene should undergo analysis
b. **Determining Appropriate Forensic Analyses:** Deciding the sequence and type of forensic analyses to be conducted on each selected item, such as testing for biological traces (e.g., blood, semen), fingerprints, or other forensic evidence.

This structured approach ensures that resources are allocated effectively, focusing on the most probative evidence to advance the investigation. However, forensic practitioners often encounter resource-limited settings where traditional methods may be cost-prohibitive or logistically unfeasible. In such contexts, frugal science—an approach prioritizing simplicity, affordability, and accessibility in scientific practices—offers a promising paradigm for efficient and effective crime scene processing.

C. Frugal Science in Forensic Science: Principles and Applications

Frugal science emphasizes innovation tailored to resource constraints [18], without compromising SD principles, scientific rigor or validity. This approach leverages locally available materials, minimalistic yet robust technologies, and creative methodologies to address complex scientific challenges. In the realm of crime scene processing, frugal science advocates for the development and use of low-cost, adaptable tools and techniques that can achieve reliable outcomes in diverse and challenging environments. Frugal forensics is guided by three core principles—Resilience, Economy, and Quality—supported by six key attributes: Performance, Accessibility, Availability, Cost, Simplicity, and Safety This approach emphasizes balancing performance with a broader understanding of jurisdictional challenges, ensuring vulnerabilities are addressed while maintaining transparency and high-quality forensic services [19].

D. Examples of Key Areas of Application

1. Fingerprints

The evaluation of sustainable fingerprint detection protocols aims to address local challenges through innovative, cost-effective solutions, promoting "frugal forensics,"

promoting societal needs without compromising quality or safety [19]. In the context of frugal forensics, modifying fingerprint detection reagents to employ a cost-effective alternative carrier solvent less susceptible to supply chain disruptions is crucial in establishing a more sustainable and robust latent fingerprint detection service. An advantageous strategy is the utilisation of frugal forensics, employing natural ingredients to develop simple, economical, non-toxic, and readily available techniques suited to the African context. Alternative latent fingerprint powders to be used, such as Genipin or turmeric (*Curcuma longa*), have been proposed as cost-effective, non-toxic, and readily available options, utilizing typical household material [20], [21].

2. Trace Collection and Preservation

Effective trace collection and preservation are foundational to crime scene investigation. Under resource limitations, forensic practitioners can adopt cost-effective yet scientifically sound methods:

- **a. Low-cost Evidence Kits**: Instead of relying on expensive commercial kits, forensic practitioners can assemble cost-effective alternatives using locally available materials. For instance, sterile cotton swabs, paper envelopes, and aluminium foil can substitute for specialized trace collection tools while maintaining evidentiary integrity

3. Crime Scene Documentation

- **a. Accurate documentation** is critical for reconstructing events and supporting legal proceedings. Frugal science offers solutions to maintain documentation quality without high-technology equipment:
- **b. Smartphone-Based Imaging:** Mobile phones equipped with high-resolution cameras can substitute for professional-grade photography equipment. Applications like photogrammetry software enable three-dimensional reconstructions of crime scenes, offering cost-effective alternatives to laser scanners [22].
- **c. Sketching and Manual Measurement Tools:** In scenarios where digital tools are unavailable, investigators can revert to traditional crime scene sketching combined with low-cost measuring tapes and rulers to map spatial relationships between traces.

4. Evidence Analysis

Resource constraints often impede access to sophisticated laboratory infrastructure. Frugal science advocates for deploying portable, low-cost analytical tools that can perform on-site or preliminary analyses:

- **a. Paper-Based Microfluidics:** Simple, paper-based devices can perform preliminary tests for blood, drugs, or explosives, significantly reducing the need for laboratory-based confirmatory tests [23].
- **b. Portable DNA Analysis Kits:** Emerging technologies in miniaturized DNA analysis systems allow investigators to perform rapid and accurate genetic testing at the crime scene, enhancing decision-making efficiency [24].

5. Training and Capacity Building

Frugal science also emphasizes the importance of knowledge transfer and skill development to maximize the potential of limited resources. For example, tailored training programs focusing on the principles of trace evidence, contamination prevention, and basic analytical techniques can empower investigators to apply scientific principles effectively in the field [25], [26].

There is a need for increased cooperation between forensic laboratories and tertiary institutions in southern Africa to ensure the relevance of tertiary qualifications and short forensic courses. New partnerships among disciplines such as science, law, medicine, information technology, and business are essential to develop tailored core curricula and create innovative programs specifically for forensic scientists, supervisors, managers, and senior executives [27]. It also highlights the issue of a few African forensic scientists conducting research and publishing their findings due to design errors. Establishing a permanent committee within the African Union to facilitate cooperation and coordination in the region regarding forensic services and to facilitate frugal forensic science meeting quality standards. This approach would not only facilitate affordable technologies, but also allow tertiary institutions to ensure well-defined research methodologies and facilitate the publication of findings in recognized forensic and scientific journals [28].

The justice system heavily relies on forensic expert evidence to resolve criminal cases. The analysis, interpretation, and evaluation of forensic traces demand the rigorous application of modern scientific theories, statistical methods, and specialized expertise. In Africa, tailored training programs are essential to support the precise and meticulous use of forensic evidence [14]. The sustainable provision of forensic science must be a key focus for the international forensic community, promoting global partnership, fit-for-purpose and affordable methodologies, and consistent quality management practices to advance justice and benefit future generations [29].

E. Case Studies in Frugal Crime Scene Processing

1. Low-Cost DNA Collection in Rural Settings

In rural regions of Africa, investigators have successfully employed frugal science principles to collect DNA evidence. Using sterile swabs and locally sourced storage containers, they preserved genetic material for later laboratory analysis. This method significantly reduced costs while maintaining evidence quality.

2. Smartphone Applications for Crime Scene Mapping

Some law enforcements utilize smartphone-based mapping applications to document crime scenes. By integrating geographic information system (GIS) data with photographic evidence, detailed visual records that aided in investigations without relying on expensive hardware can be created [30].

CONCLUSION

Fundamental Finding : Applying frugal science to crime scene processing offers a transformative approach to managing resource constraints without sacrificing scientific integrity. Forensic sciences needs a strategic framework to strengthen the link between investigative processes and judicial outcomes. This requires a unified strategy involving key stakeholders like law enforcement, forensic practitioners, legal professionals, policymakers, and researchers. This approach ensures forensic sciences evolves while maintaining accuracy, reliability, and transparency, whilst ensuring that the cost-benefits are highlighted to government and funders. **Implication :** By leveraging cost-effective tools, innovative methodologies, and localized expertise, forensic investigators can enhance their ability to collect, preserve, and analyse evidence effectively. This approach aligns with the principles of the Sydney Declaration, emphasizing scientific rigor, adaptability, and contextual problem-solving. As forensic science continues to evolve, integrating frugal science into standard practices will be pivotal in expanding access to justice and improving investigative outcomes globally. To promote a more universally shared view of forensic science, a context-based and problem-solving discipline primarily interested in recognising, exploiting, and interpreting event traces, forensic practitioners across the African forensic science community will need to collaborate. This collaboration will be crucial in developing and implementing strategies. It will also be essential to consider a frugal approach to tackling the challenges and opportunities, encouraging resourcefulness and innovation in the field of forensic science. **Limitation :** While frugal science presents numerous advantages, it is not without challenges. Improvised tools and techniques may face scrutiny in judicial settings, where validation and standardization are paramount. Additionally, the lack of robust training and oversight can lead to inconsistencies in evidence handling and analysis. Addressing these limitations requires collaboration between forensic practitioner's policymakers, and practitioners to develop guidelines and quality assurance frameworks for frugal forensic practices. **Future Research :** Further studies should refine the frugal approach to triaging for different examination types in forensic services to establish robust best practices.

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