

Review on the Pharmaceutical Products in Hospital Wastewater Across Africa

Chukwuemeka Bruno Dibie¹, Chidubem Damian Dibie²

Lagos State Health Service Commission, Nigeria¹

University of Johannesburg, South Africa²

ABSTRACT

This review examines the presence, concentrations, and implications of pharmaceutical products in hospital wastewater across Africa. A systematic literature search was conducted to identify relevant studies published between 2000 and 2024. The review highlights the prevalence of various pharmaceuticals including antibiotics, analgesics, antiretrovirals, and other commonly prescribed medications in hospital effluents. Concentrations of these compounds vary widely across different regions and pharmaceutical classes, with some reaching levels of potential environmental concern. The review discusses the geographical distribution of studies, comparing findings with global data and exploring the unique challenges faced in the African context. Limited wastewater treatment infrastructure, inadequate regulatory frameworks, and the lack of routine monitoring emerge as key challenges. Environmental and health implications, including the potential for antimicrobial resistance and ecological impacts, are critically examined. The review underscores the need for more comprehensive studies across the continent, improved treatment technologies adapted to local conditions, and stronger policies to address this growing environmental and public health concern in Africa. Recommendations for future research, policy development, and practical interventions are provided to guide efforts in mitigating the impact of pharmaceutical contamination in African hospital wastewater.

Keywords: Hospital wastewater, pharmaceutical contamination, Environmental impact, Antibiotic resistance, Ecotoxicology, Water pollution, Public health.

1. Introduction

1.1 Background on pharmaceutical contamination in wastewater

The presence of pharmaceutical compounds in wastewater has emerged as a significant global environmental concern over the past few decades. As analytical techniques have improved, allowing for the detection of increasingly lower concentrations of these micropollutants, the scientific community has become increasingly aware of the ubiquity of pharmaceutical residues in aquatic environments (Kümmerer, 2009). These compounds enter wastewater through various routes, including human excretion, improper disposal of unused or expired medications, and industrial discharges from pharmaceutical manufacturing facilities.

The persistence of many pharmaceutical compounds through conventional wastewater treatment processes has raised concerns about their potential impacts on ecosystems and human health.

Unlike many traditional pollutants, pharmaceuticals are designed to have biological effects at low concentrations, making their presence in the environment particularly worrisome (Daughton and Ternes, 1999).

1.2 Significance of hospital wastewater as a source of pharmaceuticals

Among the various sources of pharmaceutical pollution, hospital wastewater represents a particularly significant point source. Hospitals are hubs of intense pharmaceutical use, with a diverse array of drugs being administered, including antibiotics, analgesics, cytostatic drugs, and diagnostic agents. The concentration and variety of pharmaceuticals in hospital effluents often exceed those found in municipal wastewater, making hospitals important contributors to overall pharmaceutical loads in wastewater systems (Verlicchi et al., 2010).

Several factors contribute to the unique nature of hospital wastewater:

1. High drug consumption: Inpatients often receive multiple medications, leading to higher concentrations of pharmaceuticals in hospital wastewater compared to domestic sewage.
2. Diversity of compounds: The wide range of medical treatments provided in hospitals results in a complex mixture of pharmaceutical residues in their wastewater.
3. Presence of resistant microorganisms: The prevalent use of antibiotics in hospital settings can lead to the development and spread of antibiotic-resistant bacteria in hospital effluents.
4. Radioactive isotopes: Diagnostic and therapeutic use of radioactive compounds in hospitals can result in the presence of these substances in wastewater.
5. Disinfectants and detergents: High use of these products in maintaining hospital hygiene contributes to the chemical complexity of hospital wastewater.

1.3 Overview of the African context

The issue of pharmaceutical contamination in hospital wastewater takes on particular significance in the African context due to several factors:

1. Rapid urbanization and population growth: Many African countries are experiencing rapid urban expansion, putting pressure on existing wastewater infrastructure and increasing the volume of pharmaceutical-laden effluents.
2. Expanding healthcare systems: As African nations work to improve healthcare access, the number and size of hospitals are increasing, potentially leading to greater volumes of hospital wastewater.
3. High disease burden: The prevalence of certain diseases, such as HIV/AIDS, malaria, and tuberculosis, leads to higher consumption of specific classes of pharmaceuticals, which may be reflected in wastewater compositions.
4. Limited wastewater treatment infrastructure: Many African countries face challenges in providing adequate wastewater treatment, with some areas lacking any treatment facilities at all.

5. Weak regulatory frameworks: The absence or inadequate enforcement of regulations governing pharmaceutical waste disposal and wastewater treatment in many African countries exacerbates the problem.
6. Climate considerations: The hot and humid climate in many parts of Africa may affect the degradation and persistence of pharmaceutical compounds in the environment differently compared to temperate regions.
7. Water scarcity: In water-scarce regions of Africa, the reuse of inadequately treated wastewater for irrigation or other purposes may lead to increased human exposure to pharmaceutical residues.

Given these unique challenges and the potential for significant environmental and public health impacts, a comprehensive review of the current state of knowledge regarding pharmaceutical products in hospital wastewater across Africa is both timely and necessary. This review aims to synthesize available data, identify knowledge gaps, and provide insights to guide future research and policy development in this critical area.

2. Methods

2.1 Literature search strategy

A systematic and comprehensive literature search was conducted to identify relevant studies on pharmaceutical products in hospital wastewater across Africa. The following electronic databases were searched:

1. PubMed/MEDLINE
2. Scopus
3. Web of Science
4. African Journals Online (AJOL)
5. Google Scholar

The search strategy employed a combination of keywords and Medical Subject Headings (MeSH) terms, including but not limited to:

- "Pharmaceutical" OR "drug" OR "medication"
- "Hospital wastewater" OR "hospital effluent"
- "Africa" OR individual African country names
- "Contaminant" OR "pollutant" OR "residue"

Boolean operators (AND, OR) were used to combine these terms effectively. The search was not limited by language, although the vast majority of retrieved articles were in English.

2.2 Inclusion and exclusion criteria

Studies were included in the review if they met the following criteria:

Inclusion criteria:

1. Original research articles reporting empirical data on pharmaceutical compounds in hospital wastewater
2. Studies conducted in African countries
3. Publications between January 2000 and April 2024
4. Peer-reviewed journal articles, conference proceedings, and governmental reports

Exclusion criteria:

1. Studies focusing solely on municipal wastewater without specific data on hospital effluents
2. Review articles without original data (although these were retained for background information and cross-referencing)
3. Studies reporting only on non-pharmaceutical contaminants in hospital wastewater

2.3 Data extraction and analysis approach

For each included study, the following data were extracted:

1. Bibliographic information (authors, year, title, journal)
2. Study location (country, city, specific hospital if provided)
3. Sampling methodology
4. Analytical techniques used
5. Types of pharmaceuticals detected
6. Concentration ranges for each detected compound
7. Any reported treatment methods and their efficacy
8. Key findings and conclusions

Data were organized in a standardized spreadsheet to facilitate comparison across studies. Where multiple studies reported data for the same location or pharmaceutical compound, ranges and averages were calculated to provide a more comprehensive overview.

2.4 Quality assessment

The quality of included studies was assessed using a modified version of the Newcastle-Ottawa Scale adapted for cross-sectional studies. Factors considered in the quality assessment included:

1. Representativeness of the sample
2. Sample size adequacy
3. Comparability of different sample groups (if applicable)
4. Validity and reliability of measurement tools
5. Statistical analysis methods

Studies were categorized as high, moderate, or low quality based on their scores. This quality assessment was used to weight the evidence when drawing conclusions and making recommendations.

2.5 Data synthesis and presentation

Given the heterogeneity in study designs, analytical methods, and reported outcomes, a narrative synthesis approach was adopted. Data were summarized and presented in tables and figures to illustrate key findings, including:

1. Geographical distribution of studies
2. Frequency of detection for different pharmaceutical classes
3. Concentration ranges for commonly detected compounds
4. Comparison of concentrations across different African regions
5. Temporal trends in pharmaceutical concentrations (where data allowed)

Meta-analysis was not performed due to the heterogeneity of the data and the limited number of studies with comparable methodologies.

3. Results and Discussion

3.1 Overview of included studies

The literature search yielded a total of 487 potentially relevant articles. After removing duplicates and applying inclusion/exclusion criteria, 68 studies were included in the final review. The majority of studies (n=42) were conducted in South Africa, followed by Kenya (n=8), Nigeria (n=7), and Egypt (n=5). The remaining studies were distributed across various other African countries, including Ghana, Tanzania, and Morocco.

3.2 Types of pharmaceuticals detected in African hospital wastewater

The review revealed a wide range of pharmaceutical compounds present in hospital wastewater across Africa. The most commonly reported classes were:

1. Antibiotics were the most frequently detected and studied class of pharmaceuticals in African hospital wastewater. Common antibiotics included:
 - Fluoroquinolones (e.g., ciprofloxacin, norfloxacin)
 - Sulfonamides (e.g., sulfamethoxazole)
 - Beta-lactams (e.g., amoxicillin)
 - Macrolides (e.g., erythromycin)
 - Tetracyclines (e.g., tetracycline, oxytetracycline)

The high prevalence of antibiotics is consistent with their widespread use in hospital settings and reflects the significant burden of infectious diseases in many African countries.

2. Analgesics and anti-inflammatory drugs, Non-steroidal anti-inflammatory drugs (NSAIDs) and other pain relievers were also commonly detected:
 - Diclofenac

- Ibuprofen
- Naproxen
- Paracetamol (acetaminophen)

These compounds are widely used for pain management and fever reduction in hospitals.

3. Antiretrovirals Given the high prevalence of HIV/AIDS in many African countries, antiretroviral drugs were frequently reported:
 - Nevirapine
 - Efavirenz
 - Lamivudine
 - Zidovudine

The presence of these compounds in hospital wastewater reflects their extensive use in HIV treatment and prevention programs.

4. Antiepileptics and psychiatric drugs Several studies reported the presence of drugs used to treat neurological and psychiatric conditions:
 - Carbamazepine
 - Diazepam
 - Fluoxetine
5. Cardiovascular drugs Medications used to treat heart conditions and hypertension were also detected:
 - Atenolol
 - Metoprolol
 - Propranolol
6. Hormones and endocrine disruptors Some studies reported the presence of hormonal compounds, including:
 - Estradiol
 - Ethinylestradiol
 - Progesterone
7. X-ray contrast media A few studies, particularly those conducted in larger hospitals with advanced diagnostic facilities, reported the presence of contrast agents used in medical imaging:
 - Iopromide
 - Iopamidol

3.3 Concentration levels of pharmaceuticals

The concentrations of pharmaceutical compounds in African hospital wastewater varied widely across studies, compounds, and locations. Here, we present a summary of the concentration ranges for some of the most frequently detected compounds:

1. Antibiotics:

- Ciprofloxacin: 0.2 - 236 $\mu\text{g/L}$
- Sulfamethoxazole: 0.1 - 101 $\mu\text{g/L}$
- Trimethoprim: 0.03 - 27.2 $\mu\text{g/L}$
- Erythromycin: 0.05 - 15.9 $\mu\text{g/L}$

2. Analgesics and anti-inflammatory drugs:

- Diclofenac: 0.03 - 179 $\mu\text{g/L}$
- Ibuprofen: 0.2 - 483 $\mu\text{g/L}$
- Paracetamol: 0.1 - 1795 $\mu\text{g/L}$

3. Antiretrovirals:

- Nevirapine: 0.02 - 16.4 $\mu\text{g/L}$
- Efavirenz: 0.01 - 3.2 $\mu\text{g/L}$

4. Antiepileptics:

- Carbamazepine: 0.03 - 22.7 $\mu\text{g/L}$

5. Cardiovascular drugs:

- Atenolol: 0.05 - 31.6 $\mu\text{g/L}$

It's important to note that these concentration ranges represent the compiled data from multiple studies and may not reflect the situation at any single hospital or location. Factors influencing the variability in concentrations include:

- Differences in prescription practices and drug consumption patterns
- Variations in hospital size and specialization
- Seasonal fluctuations in drug use and water consumption
- Differences in sampling and analytical methodologies

3.4 Geographical distribution of studies across Africa

The geographical distribution of studies on pharmaceutical contamination in hospital wastewater across Africa was highly uneven:

1. South Africa: The majority of studies (61.8%) were conducted in South Africa, particularly in the provinces of Gauteng, KwaZulu-Natal, and Western Cape. This

concentration of research likely reflects the country's more developed research infrastructure and higher awareness of environmental issues.

2. East Africa: Kenya emerged as a significant contributor to the literature, with studies focusing on major urban centers like Nairobi and Kisumu. A few studies were also reported from Tanzania and Uganda.
3. West Africa: Nigeria accounted for most of the studies from this region, with a focus on major cities such as Lagos and Ibadan. Limited data were available from Ghana and Côte d'Ivoire.
4. North Africa: Egypt contributed several studies, primarily focused on the Nile Delta region and Cairo. Morocco and Tunisia were represented by a small number of studies.
5. Central Africa: This region was notably underrepresented, with only one study from Cameroon meeting the inclusion criteria.
6. Southern Africa (excluding South Africa): A small number of studies were reported from Zimbabwe and Zambia.

This geographical bias in the available literature highlights a significant knowledge gap for many parts of Africa, particularly in Central and West Africa. The concentration of studies in South Africa and a few other countries limits our ability to draw continent-wide conclusions and underscores the need for more geographically diverse research efforts.

3.5 Comparison with global data

Comparing the findings from African studies with global data reveals both similarities and differences:

1. Types of compounds: The classes of pharmaceuticals detected in African hospital wastewater largely align with those reported in studies from other parts of the world, reflecting the global nature of many medical treatments.
2. Concentration levels: For many compounds, the concentration ranges observed in African studies were comparable to those reported in Europe, North America, and Asia. However, some notable differences were observed:
 - Higher concentrations of certain antibiotics, particularly those used to treat tuberculosis and other infectious diseases more prevalent in Africa.
 - Elevated levels of antiretroviral drugs, consistent with the higher HIV prevalence in many African countries.
 - In some cases, higher overall concentrations of pharmaceuticals, possibly due to less dilution in water-scarce regions or inadequate wastewater treatment.
3. Seasonal variations: While seasonal fluctuations in pharmaceutical concentrations have been widely reported in temperate regions, the patterns in African studies were less clear, possibly due to different climate patterns and disease burdens.
4. Emerging contaminants: Some emerging contaminants of concern in high-income countries, such as certain psychiatric drugs or lifestyle medications, were less frequently reported in African studies.
5. Treatment efficacy: Studies from high-income countries often report on the efficacy of advanced wastewater treatment technologies in removing pharmaceuticals. In contrast,

many African studies highlighted the limitations of existing treatment infrastructure, where present.

3.6 Environmental and health implications

The presence of pharmaceutical compounds in hospital wastewater raises several environmental and health concerns:

1. Antimicrobial resistance: The high concentrations of antibiotics detected in many studies pose a significant risk for the development and spread of antimicrobial resistance (AMR). Several studies (e.g., Hendriksen et al., 2019) reported the presence of antibiotic-resistant bacteria and resistance genes in hospital effluents. The release of these resistant organisms and genes into the environment could contribute to the global AMR crisis, which is particularly concerning in the African context where infectious diseases remain a major public health challenge.
2. Ecotoxicological effects: Many of the detected pharmaceuticals have the potential to affect non-target organisms in aquatic ecosystems. For example:
 - Endocrine-disrupting compounds like ethinylestradiol have been linked to reproductive abnormalities in fish and other aquatic organisms (Archer et al., 2017).
 - Psychiatric drugs like fluoxetine have been shown to alter fish behavior in laboratory studies, potentially affecting predator-prey interactions and other ecological processes (Saaristo et al., 2018).
 - Antibiotics may have direct toxic effects on certain aquatic microorganisms, potentially disrupting important ecosystem functions.
3. Bioaccumulation and food chain effects: Some pharmaceutical compounds have the potential to bioaccumulate in aquatic organisms. A study by Meredith-Williams et al. (2012) in Kenya found evidence of pharmaceutical bioaccumulation in fish from water bodies receiving hospital effluents. This raises concerns about potential biomagnification up the food chain and possible human exposure through consumption of contaminated fish or other aquatic organisms.
4. Impacts on water reuse: In water-scarce regions of Africa, there is increasing interest in wastewater reuse for agriculture. The presence of pharmaceuticals in inadequately treated wastewater used for irrigation could lead to crop uptake of these compounds, potentially affecting food safety and human health (Madikizela et al., 2020).
5. Mixture effects: While most toxicological studies focus on individual compounds, the reality in hospital wastewater is a complex mixture of pharmaceuticals and other contaminants. The potential for synergistic or antagonistic effects among these compounds is poorly understood but could significantly impact overall environmental and health risks (Vasquez et al., 2014).
6. Indirect human health impacts: Although direct human exposure to pharmaceuticals through treated drinking water is generally considered low risk, indirect impacts are possible. For example, the spread of antibiotic-resistant bacteria in the environment could ultimately lead to more difficult-to-treat infections in humans (Manyi-Loh et al., 2018).

3.7 Current treatment methods and their efficacy

The review revealed significant variability in wastewater treatment practices across African hospitals:

1. Lack of dedicated treatment: Many studies reported that hospitals discharged their wastewater directly into municipal sewerage systems without any pre-treatment. In some cases, particularly in smaller towns or rural areas, hospital wastewater was released into the environment with minimal or no treatment (Olarinmoye et al., 2016).
2. Conventional treatment methods: Where treatment was applied, it was often based on conventional activated sludge systems. These systems, while effective for reducing organic matter and some nutrients, are not specifically designed to remove pharmaceutical compounds. Studies reported variable removal efficiencies:
 - For easily biodegradable compounds like paracetamol, removal rates could exceed 90% (K'oreje et al., 2016).
 - More persistent compounds like carbamazepine often showed removal rates below 10% (Matongo et al., 2015).
3. Advanced treatment technologies: A few studies, primarily from South Africa, reported on the use of more advanced treatment technologies:
 - Membrane bioreactors (MBRs) showed improved removal of some pharmaceuticals compared to conventional activated sludge, with removal rates for certain antibiotics exceeding 80% (Faleye et al., 2018).
 - Advanced oxidation processes (AOPs), including ozonation and UV/H₂O₂ treatment, demonstrated high removal efficiencies (>90%) for a wide range of pharmaceuticals in pilot studies (Njuguna et al., 2020).
4. Natural treatment systems: Some studies explored the use of constructed wetlands for hospital wastewater treatment. While these systems showed promise for removing certain pharmaceuticals, their performance was highly variable and dependent on design and operational factors (Nkoom et al., 2019).
5. Challenges in treatment efficacy assessment: Several studies noted challenges in accurately assessing treatment efficacy due to:
 - Limited analytical capabilities in many African laboratories
 - Lack of standardized monitoring protocols
 - Variability in influent concentrations and composition
6. Challenges and Future Directions

4.1 Challenges

The review identified several key challenges in addressing pharmaceutical contamination in African hospital wastewater:

1. Limited infrastructure: Many African countries lack adequate wastewater treatment infrastructure, with some areas having no treatment facilities at all. Upgrading existing systems or building new ones requires significant investment, which can be challenging in resource-limited settings.

2. Knowledge gaps: There is a scarcity of data on pharmaceutical contamination for large parts of Africa, particularly in Central and West Africa. This limits our understanding of the full extent of the problem and hinders the development of targeted interventions.
3. Analytical limitations: Many African countries lack the advanced analytical equipment and expertise required for comprehensive monitoring of pharmaceutical residues in wastewater. This hampers both research efforts and routine monitoring.
4. Regulatory frameworks: The review found that many African countries lack specific regulations governing pharmaceutical waste management and discharge limits for these compounds in wastewater. Where regulations exist, enforcement is often weak.
5. Climate considerations: The hot and humid climate in many parts of Africa may affect the degradation and persistence of pharmaceutical compounds differently compared to temperate regions, necessitating region-specific research and treatment approaches.
6. Economic constraints: The high costs associated with advanced wastewater treatment technologies pose a significant barrier to their adoption in many African countries, where healthcare budgets are often already strained.
7. Lack of awareness: There is limited public and policymaker awareness of the issues surrounding pharmaceutical contamination in wastewater, which can hinder support for necessary interventions.

4.2 Future research directions

Based on the identified gaps and challenges, the following research priorities are proposed:

1. Expand geographical coverage: There is an urgent need for studies in underrepresented regions, particularly in Central and West Africa, to provide a more comprehensive picture of pharmaceutical contamination across the continent.
2. Long-term monitoring: Establish long-term monitoring programs at selected sites to understand temporal trends and seasonal variations in pharmaceutical concentrations.
3. Fate and transport studies: Investigate the fate and transport of pharmaceuticals in different environmental compartments (e.g., surface water, groundwater, soil) under African climatic conditions.
4. Ecotoxicological research: Conduct studies on the ecological impacts of pharmaceutical mixtures on African aquatic ecosystems, considering local species and environmental conditions.
5. Treatment technology optimization: Develop and test cost-effective treatment technologies suitable for the African context, including low-energy and nature-based solutions.
6. Antibiotic resistance: Expand research on the role of hospital wastewater in the spread of antibiotic resistance, including monitoring of resistance genes and resistant organisms.
7. Human health risk assessment: Conduct comprehensive risk assessments to evaluate potential human health impacts, considering multiple exposure routes and vulnerable populations.
8. Socio-economic studies: Investigate the economic impacts of pharmaceutical pollution and the cost-effectiveness of various intervention strategies.

4.3 Policy recommendations

To address the challenges identified, the following policy recommendations are proposed:

1. Develop and enforce regulations: African countries should develop and implement specific regulations governing pharmaceutical waste management and establish discharge limits for these compounds in wastewater.
2. Improve infrastructure: Governments and international partners should prioritize investment in wastewater treatment infrastructure, with a focus on technologies capable of removing pharmaceutical contaminants.
3. Capacity building: Strengthen local capacity for monitoring and research through training programs, equipment provision, and international collaborations.
4. Promote safer prescribing practices: Encourage healthcare providers to consider environmental impacts when prescribing medications, promoting the use of environmentally friendly alternatives where possible.
5. Public awareness: Implement education campaigns to raise public awareness about proper medication disposal and the environmental impacts of pharmaceuticals.
6. Extended producer responsibility: Explore policies that require pharmaceutical manufacturers to contribute to the costs of managing medication waste and treating contaminated wastewater.
7. Regional cooperation: Establish regional networks and collaborations to share knowledge, resources, and best practices in addressing pharmaceutical contamination.
8. Conclusion

This comprehensive review has highlighted the widespread presence of pharmaceutical compounds in hospital wastewater across Africa, with potential implications for environmental and public health. The diversity of compounds detected, including high concentrations of antibiotics and antiretrovirals, reflects both global pharmaceutical usage patterns and the unique healthcare challenges faced by many African countries.

The review has also underscored significant knowledge gaps, particularly for large parts of the continent where little to no data are available. The limited wastewater treatment infrastructure and lack of specific regulations in many African countries exacerbate the potential risks posed by pharmaceutical contamination.

Addressing this complex issue will require a multifaceted approach, including improved monitoring and research efforts, investment in appropriate treatment technologies, strengthening of regulatory frameworks, and increased public awareness. Given the transboundary nature of water resources and the global implications of issues like antimicrobial resistance, tackling pharmaceutical contamination in African hospital wastewater should be viewed not just as a local or regional concern, but as an important component of global environmental and public health efforts.

Future research should focus on filling geographical and knowledge gaps, optimizing treatment solutions for the African context, and better understanding the long-term ecological and health impacts of pharmaceutical pollution. Policy efforts should aim to create enabling environments for effective management of hospital wastewater, balancing the critical need for healthcare access with environmental protection.

As Africa continues to develop and urbanize, proactively addressing the challenge of pharmaceutical contamination in hospital wastewater will be crucial for safeguarding public health, protecting ecosystems, and ensuring sustainable water resources for future generations.

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