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Ecological Consequences of Antibiotics Pollution in Sub-Saharan Africa:
Understanding Sources, Pathways, and Potential Implications

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PII: S2405-6650(25)00009-5

DOI: <https://doi.org/10.1016/j.emcon.2025.100475>

Reference: EMCON 100475

To appear in: *Emerging Contaminants*

Received Date: 23 October 2024

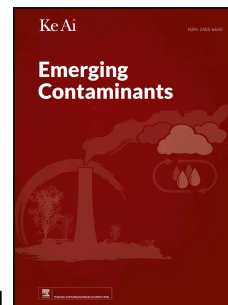
Revised Date: 23 January 2025

Accepted Date: 23 January 2025

Please cite this article as: A. Ripanda, D.M.J. Rwiza, E.C. Nyanza, M. Hossein, M.S. Alfred, A. El Din Mahmoud, H.C.A. Murthy, D.R. Bakari, S.A. Hamad Vuai, R.L. Machunda, Ecological Consequences of Antibiotics Pollution in Sub-Saharan Africa: Understanding Sources, Pathways, and Potential Implications, *Emerging Contaminants*, <https://doi.org/10.1016/j.emcon.2025.100475>.

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Ecological Consequences of Antibiotics Pollution in Sub-Saharan Africa: Understanding Sources, Pathways, and Implications

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1 **Ecological Consequences of Antibiotics Pollution in Sub-Saharan** 2 **Africa: Understanding Sources, Pathways, and Potential** 3 **Implications**

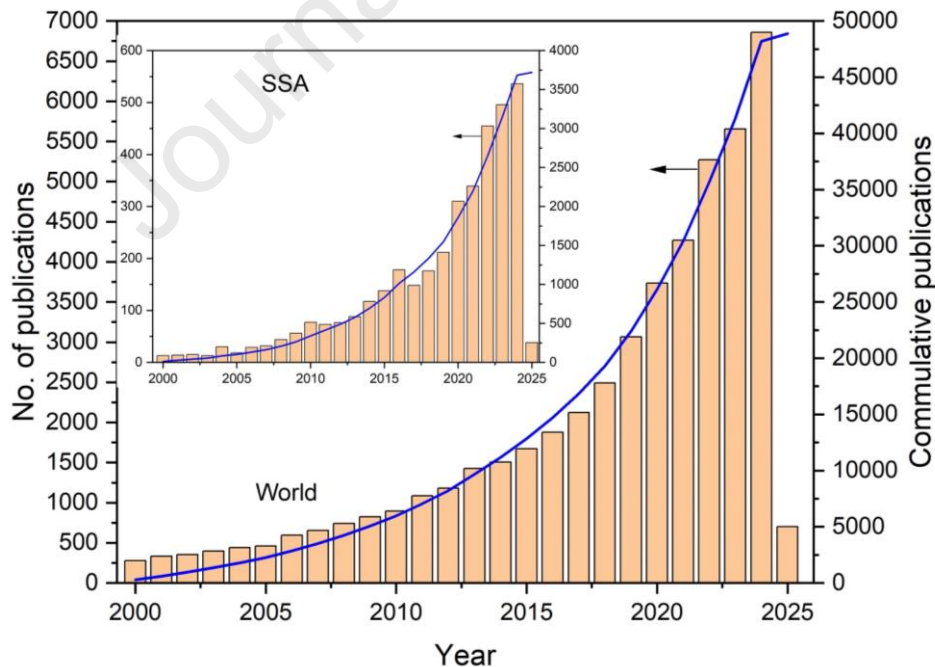
4 **Abstract**

5 In Sub-Saharan Africa (SSA), the increasing use of antibiotics in human and veterinary
6 medicine, combined with inadequate waste and water management systems, has intensified the
7 problem of antibiotic pollution. Untreated or partially treated wastewater from industries,
8 agricultural runoff, residential areas, and healthcare facilities is frequently discharged into the
9 environment, often used for irrigation, contributing to antibiotic accumulation, the spread of
10 resistance genes, and the rise of antibiotic resistance, posing serious threats to public health
11 and environmental sustainability. The region's climatic conditions favour the survival and
12 proliferation of microbial communities, including pathogens. Additionally, the high prevalence
13 of infectious diseases such as HIV/AIDS, tuberculosis, and malaria, which often necessitate
14 antibiotic use, further amplifies the issue. Systemic challenges, including poor waste
15 management, inadequate or absent wastewater treatment infrastructure, weak regulatory
16 enforcement, and the over-the-counter sale of antibiotics, exacerbate the crisis. Limited
17 healthcare access often results in self-medication and improper antibiotic use, accelerating
18 resistance spread. Evidence shows antibiotics in surface water, groundwater, effluents, food
19 crops, environmental samples, and aquatic organisms, indicating their potential circulation
20 through the food chain. However, a lack of comprehensive data on antibiotic pollution and its
21 impacts on aquatic ecosystems in SSA hampers a thorough understanding of its scope and long-
22 term effects. Addressing this crisis requires identifying contamination hotspots, evaluating
23 ecological impacts, and establishing robust, region-specific regulatory frameworks to ensure
24 environmental and public health safety

25 **Keywords:** *Antibiotics; Ecosystem health; Food chain; Contaminants of emerging concerns;*
26 *Sub-Saharan Africa (SSA)*

31 **Introduction**

32 The use of antibiotics for medical treatments dates to ancient times. Initially, humans relied on
 33 extracts from medicinal plants. However, as populations grew, plant extracts alone became
 34 insufficient to meet the increasing demand. This led to the widespread use of synthetic and
 35 semi-synthetic drugs including antibiotics in treating humans, animals, and wildlife, as well as
 36 in agriculture. These substances, along with their metabolites and transformation products,
 37 often end up in sewage systems through various pathways. Urban growth is characterized by
 38 increased human activities, industrialization, and changes in lifestyle. Increased anthropogenic
 39 activities leading to the generation of toxic pollutants such as antibiotics, their metabolites, and
 40 transformational products. Antibiotics are frequently produced by soil microorganisms and are
 41 most likely a means for organisms in a complex environment, such as soil, to control the growth
 42 of competing microorganisms (Cycon et al., 2019; Waksman, 1947). Modern medicine has
 43 been transformed by antibiotics, which are essential for treating bacterial infections and
 44 enhancing both human and other animal health. However, the widespread and indiscriminate
 45 use has resulted in an emerging environmental concern of antibiotics pollution (Hossein et al.,
 46 2018; Hossein et al., 2022; Makaye et al., 2022; Makokola et al., 2019; H. Miraji et al., 2016;
 47 Miraji et al., 2021; Ripanda & Miraji, 2022; A. S. Ripanda et al., 2023). Figure 1, indicates that
 48 generally research on antimicrobial pollution are increasing both in SSA and globally, with few
 49 studies in Africa.



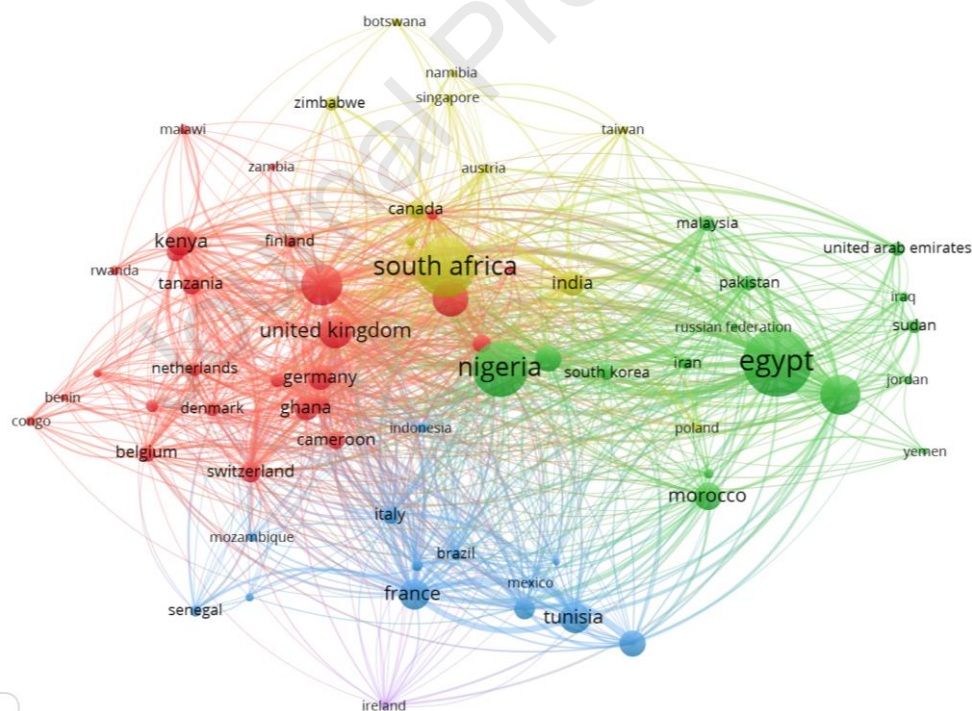
50

51 **Figure 1: The number of absolute and cumulative publications on antibiotics pollution**
 52 **(Source: Scopus data base)**

53 The data on co-authorship representation of African countries with the most publications
54 between 2000 and 2025 provides valuable insights into the antimicrobial research landscape.
55 This analysis was conducted by filtering affiliations to include only those from African
56 countries, which means that while non-African countries like Australia and Canada appear in
57 the data, they are represented solely through their collaborative contributions rather than as
58 primary authors. Further results, indicates Nigeria stands out as the leading contributor, with
59 total of 644 documents and 9,969 citations. This output not only reflects Nigeria's growing
60 research capacity but also its impact on the global academic community. South Africa follows
61 closely, producing 753 documents and garnering 20,037 citations, further solidifying its
62 position as a significant player in scholarly research within Africa. Egypt also emerges as a
63 prominent contributor, with 994 documents and 18,829 citations. This indicates a robust
64 research environment that fosters research output and collaboration. Notably, both Ethiopia
65 and Kenya are making strides in research, with Ethiopia contributing 270 documents and 4,611
66 citations, while Kenya has 179 documents with 4,798 citations. These figures highlight the
67 increasing research capabilities in East Africa, suggesting that these nations are becoming vital
68 contributors to the research discourse, Figure 2.

69 The concept of collaboration is illustrated through the metric of total link strength, which
70 reflects the interconnectedness of research efforts. South Africa leads with a link strength of
71 672, closely followed by Nigeria at 482. This strong collaborative network not only enhances
72 their research visibility but also facilitates greater academic partnerships. Meanwhile, countries
73 like Kenya and Ethiopia, with link strengths of 250 and 258, respectively, indicate active
74 participation in collaborative research initiatives, which are essential for addressing complex
75 challenges through shared expertise. When comparing African countries to their non-African
76 counterparts, the data reveals a noteworthy trend. Australia produced 68 documents with 2,344
77 citations, while Canada had 67 documents and 1,468 citations. Although these countries are
78 not the primary authors, their presence in co-authorship arrangements with African researchers
79 illustrates the global nature of academic collaboration and the importance of international
80 partnerships in enhancing research impact. Despite the promising trends, the data also
81 highlights disparities in research output among different African nations. Countries like Benin,
82 with only 13 documents and 191 citations, and Namibia, with 12 documents and 349 citations,
83 demonstrate lower levels of research activity on antimicrobial pollution. This underscores the
84 potential for growth in these regions, where increased investment in research infrastructure and
85 collaboration could significantly enhance their contributions to the scholarly community.

86 In Sub-Saharan Africa (SSA), wastewater is usually treated using waste-stabilization ponds
 87 (WSPs). Designs of the conventional WSPs do not incorporate removal or degradation of
 88 antibiotics which magnify the problem. Reports of occurrences of antibiotics and other
 89 emerging contaminants in the environment are globally available (Hossein et al., 2022; Hossein
 90 et al., 2023; Makokola et al., 2019; H. Miraji et al., 2016; Miraji et al., 2021; Ripanda & Miraji,
 91 2022; Ripanda et al., 2022; Ripanda et al., 2021), and several measures have been proposed for
 92 their remediation (Asha Ripanda, 2022; Asha Ripanda, 2023; Hossein et al., 2023; H Miraji et
 93 al., 2023; A. Ripanda et al., 2023), for a healthier and more sustainable ecology. The occurrence
 94 of more than 15 antibiotics belonging to sulfonamides, β -lactams, macrolides and
 95 aminoglycosides classes, and trimethoprim in hospital effluents, wastewater treatment plants
 96 (WWTPs), and surface waters have been reported in SSA (Makaye et al., 2022; Makokola et
 97 al., 2019; Ngigi et al., 2020; Ripanda et al., 2024a; A. S. Ripanda et al., 2023). Antibiotics
 98 pollution poses significant risks to ecosystem health and functioning (Adelowo et al., 2012;
 99 Grenni et al., 2018; Ramírez-Malule et al., 2020; Wilkinson et al., 2022).



100

101 **Figure 2: Co-authorship representation of African countries with the highest publication**
 102 **outputs from 2000 to 2025, highlighting both local contributions and international**
 103 **collaborations. (Source: Scopus data base)**

104 The continuous exposure of bacteria to low levels of antibiotics in the environment creates
105 selective pressure, favoring the survival and proliferation of antibiotic-resistant strains
106 (Adelowo et al., 2020; Weiss et al., 2018; Yitayew et al., 2022). These resistant bacteria can
107 transfer their resistance genes to other bacteria, including pathogenic microbes, leading to
108 treatment complications (Adelowo et al., 2020; Gupta et al., 2019; Rong et al., 2021; Weiss et
109 al., 2018; Yitayew et al., 2022) , and compromising human and ecological health. The
110 disruption of microbial communities can have cascading effects on ecosystem stability, nutrient
111 availability and recycling, and overall ecosystem functioning (Eapen et al., 2024; Huang et al.,
112 2020; Kulik et al., 2023). Currently, in SSA, there is increased use of antibiotics to mitigate the
113 increased diseases, which may go hand in hand with reports of their occurrences in the
114 environment. These antibiotics are also used in agronomic activities such as aquaculture,
115 human therapeutic agents and veterinary drugs, including wildlife.

116 The potential ecological consequences of antibiotics contamination are significant and can have
117 far-reaching impacts on ecosystems (Z. Li et al., 2023; Yarkwan, 2023). Disruption of
118 microbial communities by antibiotics (da Silva-Brandao et al., 2023; Hossein et al., 2023;
119 Karungamye, 2022; Karungamye et al., 2022; H Miraji et al., 2016; Msigala et al., 2017;
120 Siachalinga et al., 2023; Virhia et al., 2023), can cascade through the food web, affecting
121 primary producers, consumers, and decomposers (Miraji et al., 2021; Ripanda et al., 2022; A.
122 S. Ripanda et al., 2023; Ripanda et al., 2021). Antibiotics pollution can promote the
123 development and spread of antibiotic-resistant bacteria, compromising the effectiveness of
124 antibiotics in clinical setting (Virhia et al., 2023). This may threaten wildlife health, as it can
125 increase the incidence of antibiotic-resistant infections in vulnerable populations (da Silva-
126 Brandao et al., 2023; Z. Li et al., 2023; Mishra et al., 2023; Siachalinga et al., 2023; Stocker et
127 al., 2023), impacting ecological health and resilience. However, SSA faces unique challenges
128 due to regional factors such as climatic conditions that favour growth and proliferations of
129 pathogens leading to increased use of antibiotics hence pollution and related impacts, requiring
130 intervention. To effectively combat antibiotic resistance, clinical facilities must strengthen
131 laboratory capacity, adopt evidence-based prescribing practices, and engage in
132 multidisciplinary collaborations. Investing in these areas will enhance the ability to address the
133 region's unique challenges, such as high disease burdens, climatic factors, and reliance on
134 herbal medicines, while minimizing the spread of resistant pathogens. Reports have been
135 published detailing rampant use of non-prescription drugs by the communities including
136 antibiotics (Kayode et al., 2020; Vickers-Smith et al., 2020), which may increase active
137 chemical load in the environment. The non-prescribed dispensing of antibiotics is a widespread

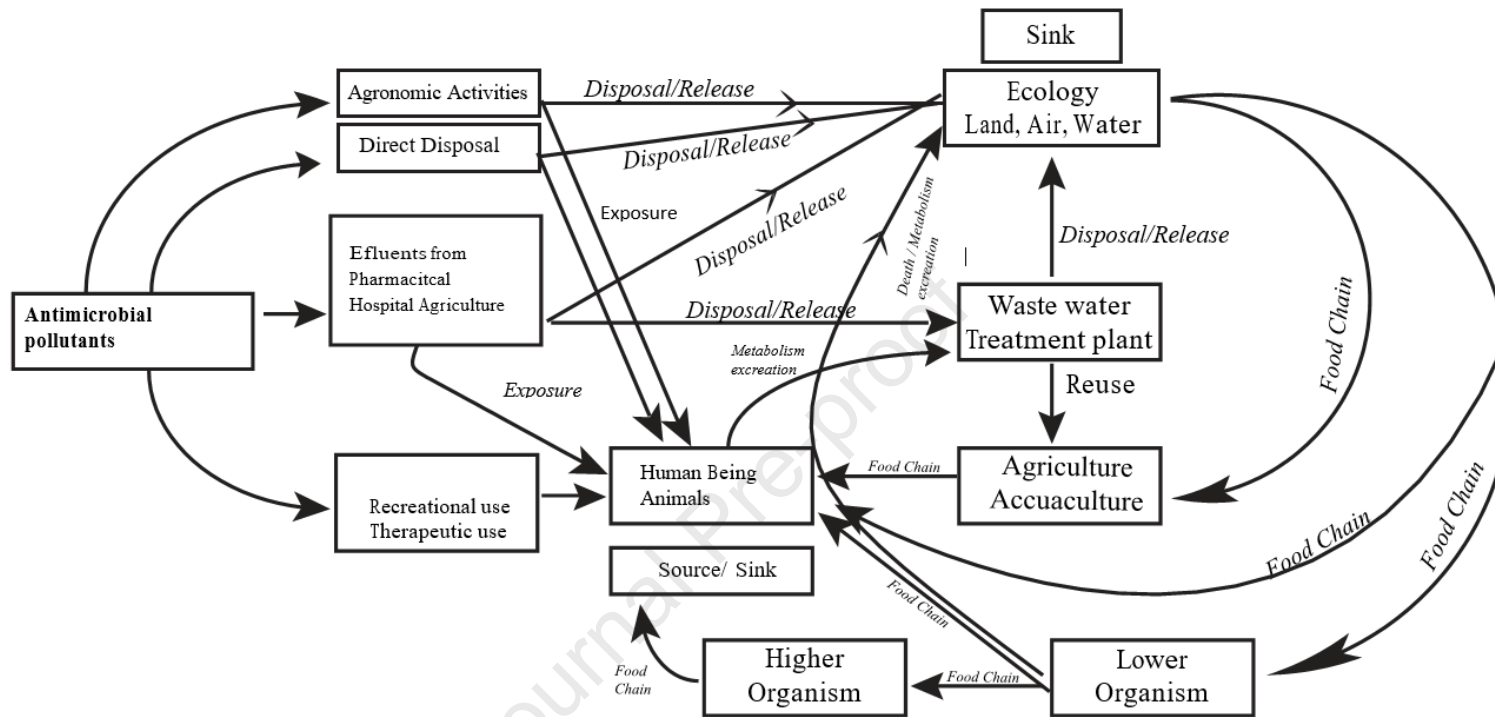
138 practice among community drug retail outlets (CDROs) in many Sub-Saharan African (SSA)
139 countries (Belachew et al., 2021; Belachew et al., 2022; Ndaki et al., 2021; Nsengimana et al.,
140 2023; Sono et al., 2023; Zewdie et al., 2024). This unchecked accessibility and misuse of
141 antibiotics significantly heighten the risk of accelerating antibiotic resistance, undermining the
142 effectiveness of the limited antibiotic in the region (Belachew et al., 2021). The growing
143 concern over potential harm to ecosystems, including aquatic life and the increased risk to
144 human health, domestic animals, and wildlife exposure, arises from the use of contaminated
145 waters (Maranho et al., 2017; Molla, 2018; Ogunlaja et al., 2022; Tell et al., 2019), and food.
146 This risk is exacerbated when partially or untreated wastewater is reused for irrigation,
147 aquaculture, or urban water discharge, impacting the food chain. Therefore, the current work
148 investigates ecological consequences of antibiotics pollution in Sub-Saharan Africa, focusing
149 on the sources of antimicrobial pollutants, resistant genes, pathways, and potential
150 implications.

151 **Methodology**

152 This literature review focuses on Sub-Saharan Africa, with countries selected based on the
153 availability of data regarding antibiotics pollution, antibiotic resistance, and their genes,
154 various environmental matrices including surface water, ground water, wastewater effluents,
155 sediments, hospital waste, soils, and food chain. TITLE-ABS-KEY (("Antibiotic pollution"
156 OR "antibiotics" OR "antibiotic resistance" OR "resistant genes" OR "resistant microbes" OR
157 "resistant drug" OR "health impacts") AND ("Wastewater" OR "surface waters" OR "waters"
158 OR "groundwater" OR "aquatics")), and 45,971 documents found. Some of keywords used
159 are presented by Figure 3, together with these also included environmental matrices, and the
160 names of individual Sub-Saharan African countries were used for the search.

181 that antibiotics originates from therapeutic use in both human and veterinary, other agronomic
182 activities, direct disposal, effluent release untreated or after partial treatment from
183 pharmaceutical industry, or hospitals (Hossein et al., 2023; Novick & Ness, 1984; Ripanda et
184 al., 2024b; A. S. Ripanda, 2024; A. S. Ripanda et al., 2023), and contaminated agricultural field
185 (Manyi-Loh et al., 2018). This leads to their persistent occurrences in the environment and
186 circulation through food chain creating harm to entire ecology. Nantaba and Coalleges
187 reported occurrences of quantifiable levels of antibiotics in Lake Victoria, and their ecotoxic
188 risk assessed (Nantaba et al., 2024). Report of levofloxacin (2–120 ng g⁻¹ dm; dry mass),
189 ciprofloxacin (3–130 ng g⁻¹ dm) enoxacin (9–75 ng g⁻¹ dm), ibuprofen (6–50 ng g⁻¹ dm),
190 metoprolol (1–92 ng g⁻¹ dm) and propranolol (1–52 ng g⁻¹ dm) being predominant (Nantaba
191 et al., 2024). Murchison Bay, being the chief recipient of sewage effluents, municipal and
192 industrial waste from Kampala city and its suburbs, had the highest levels (Nantaba et al.,
193 2024), this indicates potential impacts to this ecosystem, including bioconcentration,
194 bioaccumulation, in fish and other lower aquatic species and biomagnification in higher
195 animals, leading to their circulation in food chain. Report of prevalence of antimicrobial
196 determinants in fish from Lake Victoria are available (Khatiebi et al., 2024; Mumbo et al.,
197 2023; Onjong et al., 2021). Marijani (2022) reported that *E. coli* isolates were resistant to
198 penicillin, erythromycin, gentamicin, azithromycin, and tetracycline, while *Salmonella spp.*
199 isolates exhibited resistance to gentamicin, tetracycline, penicillin, and erythromycin
200 (Marijani, 2022), a similar study in Nile pech reported similar results (Ally, 2022). . These
201 isolates were from marine and freshwater fishes consume in the region. Similar report from
202 Nigeria indicated that isolates from shellfish were 100% susceptible to ciprofloxacin,
203 azithromycin and erythromycin and resistant to cefotaxime, cefuroxime, imipenem/clastatin,
204 augmentin and nitrofurantoin (Oramadike et al., 2024), and from fish ponds (Ayedun et al.,
205 2022). The introduction of antimicrobial pollutants to the environment, their sources and
206 circulation in the environment and through food chain is detailed in Figure 4.

207



208

209 **Figure 4: Sources, and flow of antimicrobial pollutants such as antibiotics in different environmental compartments, and through food chain**
 210 **as summarized (A. Ripanda, 2024).**

211

212 Studies indicate that up to 70% of antibiotics used in aquaculture and livestock are excreted
213 without being metabolized, subsequently contaminating surrounding water bodies (Kumar et
214 al., 2020; Van et al., 2020). Additionally, the inadequate treatment of wastewater from
215 healthcare facilities and industrial processes further exacerbates the problem (Hossein et al.,
216 2023; Makaye et al., 2022; Makokola et al., 2019; Miraji et al., 2021; Ripanda & Miraji, 2022;
217 Ripanda et al., 2022; A. S. Ripanda et al., 2023; Ripanda et al., 2021), which threaten the
218 ecosystem safety and sustainability. Furthermore, the improper disposal of expired or unused
219 medications contributes to this pollution, as many communities lack proper waste management
220 systems. These practices not only threaten water quality but also pose significant risks to human
221 health and the environment, highlighting the urgent need for improved regulatory frameworks
222 and sustainable management practices across the continent.

223 **Environmental Consequences of Antibiotic pollution**

224 Antibiotic pollution may pose potential ecological consequences across Africa, significantly
225 impacting ecosystem health, biodiversity, and agricultural sustainability. Report of occurrences
226 of 47 pharmaceuticals, 31 of which were detected in African waters. Seven of detected
227 pharmaceuticals (propyphenazole, sulfamerazine, levamisole, tryptophan, dibucaine, albuterol,
228 and fenpropimorph) are not approved medications in South Africa (Madikizela, Nuapia, et al.,
229 2022). These results suggest a need for further research into the fate of pharmaceuticals in
230 surface waters, and a quantification of the risks associated with the identified drugs because
231 they are likely to accumulate in the tissues of fish/aquatic organisms, thus affecting humans
232 (Madikizela, Nuapia, et al., 2022), as similarly, reported in Kenya (Kandie et al., 2020), and
233 other SSA countries (Khatiebi et al., 2023; Nantaba et al., 2020). This contamination was
234 associated with a marked decrease in microbial diversity and an increase in antibiotic-resistant
235 bacteria, raising concerns about the potential for resistant strains to enter the food chain and
236 compromise public health. Similarly, research indicates that the use of effluents from
237 wastewater treatment for irrigation not only elevated antibiotic levels in agricultural soils but
238 also resulted in reduced soil microbial activity, which is crucial for nutrient cycling and plant
239 health (Bougnom et al., 2020; Slobodiuk et al., 2021). The presence of these pollutants has far-
240 reaching implications, as they can disrupt essential ecosystem functions, threaten food security
241 by diminishing crop yields, and exacerbate the public health crisis of antibiotic resistance.
242 These findings highlight the urgent need for comprehensive strategies to address antibiotic
243 pollution, safeguard environmental health, and protect the livelihoods of communities
244 dependent on agriculture in Africa.

245 **Impacts of environmental parameters on fate of antibiotics**

246 Environmental parameters such as pH, organic matter, and the presence of other substances
247 play a crucial role in the behavior and fate of antibiotics in soil and water, as well as in the
248 transfer of antibiotic resistance genes (ARGs) (Deng et al., 2024). The pH influences the
249 solubility and degradation rate of antibiotics; in more acidic or alkaline conditions, certain
250 antibiotics degrade faster, reducing their persistence in the environment (Feng et al., 2021).
251 Organic matter can either bind antibiotics, reducing their bioavailability, or facilitate their
252 mobility through complexation, depending on the antibiotic's properties (Conde-Cid et al.,
253 2020; Feng et al., 2021). Studies show that high organic matter content in soil can act as a
254 reservoir, slowing antibiotic degradation and prolonging their environmental presence (Guo et
255 al., 2024; Nkoh et al., 2024). Additionally, the presence of metals like copper or zinc, which
256 are common in agricultural and industrial runoff, can co-select for ARGs (Maurya et al., 2020;
257 Mazhar et al., 2021). In such environments, bacteria exposed to both antibiotics and metals are
258 more likely to develop and transfer resistance due to shared stress responses impacting
259 ecological health. Further, the soils with high organic carbon and metal concentrations were
260 hotspots for ARGs, and similar findings have been reported in wastewater-impacted
261 environments in Africa (Agramont et al., 2020; Bosch et al., 2023). These interactions highlight
262 the importance of environmental conditions in both the persistence of antibiotics and the
263 dissemination of resistance genes.

264 In the environment, antibiotics can be absorbed by plants through their roots, especially when
265 present in soil or irrigation water (El Gemayel & Bashour, 2020; Marques et al., 2021). The
266 uptake and interaction of antibiotics with plants depend on the type of antibiotic, plant species,
267 and environmental conditions (El Gemayel & Bashour, 2020). Research has shown that
268 antibiotics like tetracycline and sulfonamides are readily absorbed by plants such as lettuce,
269 radish, and wheat (Camacho-Arévalo et al., 2021; Tasho et al., 2020), with antibiotics
270 accumulating in edible plant tissues which may impact human and other animal health through
271 food chain. Plants may develop tolerance to these compounds by modifying their metabolic
272 pathways, such as producing detoxifying enzymes or altering cell membrane permeability to
273 reduce antibiotic accumulation (El Gemayel & Bashour, 2020). Studies revealed that antibiotic
274 uptake is higher in crops grown in soils irrigated with wastewater, posing risks to food safety
275 and human health through the consumption of contaminated crops.

276 **Development of tolerance mechanisms**

277 Plants have developed several tolerance mechanisms to cope with antibiotic toxicity, allowing
278 them to survive in contaminated environments. One key mechanism is the activation of
279 detoxification pathways, where plants produce enzymes such as peroxidases, cytochrome P450
280 monooxygenases, and glutathione S-transferases (GSTs) to break down and detoxify
281 antibiotics (P. Chakraborty et al., 2023; Jaiswal et al., 2021; Kurade et al., 2021). These
282 enzymes modify the chemical structure of antibiotics, rendering them less harmful. Another
283 tolerance mechanism is the sequestration of antibiotics in vacuoles or cell walls, isolating the
284 toxic compounds from critical cellular functions (Martín, 2020; Wei et al., 2023). Additionally,
285 plants can alter their membrane permeability to restrict antibiotic uptake or actively pump
286 antibiotics out of cells through transport proteins, such as ATP-binding cassette (ABC)
287 transporters (Seukep et al., 2022).

288 Research has shown that plants like lettuce accumulates enrofloxacin and ciprofloxacin from
289 intensive animal husbandry (McCormick et al., 2024). Enrofloxacin levels was 7.3 µg/kg in
290 fresh poultry litter, while its metabolite ciprofloxacin was 39.22 µg/kg after storage. Although
291 no fluoroquinolones were detected in soils, lettuce from manured plots contained 14.97 µg/kg
292 of enrofloxacin and 9.77 µg/kg of ciprofloxacin at 14.97, providing evidence of
293 fluoroquinolone bioaccumulation in plants. Similarly the abundance of sul1 and intI1 in poultry
294 litter was not affected by storage (McCormick et al., 2024). Plants like wheat and lettuce (Choe
295 et al., 2024), and rice, produce higher levels of antioxidant enzymes, such as superoxide
296 dismutase and catalase in response to antibiotic exposure, reducing oxidative stress caused by
297 stressors such as antibiotics. In some cases, plants may also use bioaccumulation as a defence
298 strategy, storing antibiotics in less metabolically active tissues. Studies in Africa, particularly
299 in wastewater-irrigated agricultural regions, have demonstrated that plants exposed to
300 antibiotic-laden environments develop such tolerance mechanisms (Bougnom et al., 2020;
301 Gudda et al., 2020; Onalenna & Rahube, 2022), allowing them to survive but potentially
302 introducing these contaminants into the food chain.

303 **Antibiotics, soil health, fertility, and agriculture productivity**

304 Antibiotics can significantly impact soil health and fertility, which are critical for sustainable
305 agriculture. When antibiotics enter the soil through agricultural runoff, wastewater irrigation,
306 or manure application (Zalewska et al., 2021), they can disrupt the microbial communities
307 essential for nutrient cycling and organic matter decomposition. Studies have shown that the
308 presence of antibiotics such as tetracyclines and sulfonamides can reduce the diversity and
309 abundance of beneficial soil microbes (Conde-Cid et al., 2020; Li et al., 2024), including

310 bacteria involved in nitrogen fixation and organic matter breakdown. This disruption can lead
311 to decreased soil fertility, as key nutrients become less available to plants. Additionally,
312 antibiotics can inhibit important soil processes such as the decomposition of organic materials
313 (Li et al., 2024), which is vital for maintaining soil structure and nutrient availability. A study
314 by Xie et al (2020) (Wang et al., 2020), reported that soils contaminated with antibiotics
315 exhibited lower enzyme activity associated with nutrient cycling, indicating impaired soil
316 function. Moreover, the persistence of antibiotics in the soil can lead to the selection of
317 antibiotic-resistant bacteria, which can further complicate agricultural practices by
318 compromising plant health and food safety. The accumulation of resistant strains in the soil
319 can also pose risks to human health, particularly through the consumption of crops grown in
320 contaminated soils. In Sub-Saharan Africa, where agricultural practices often involve the use
321 of wastewater and manure, the effects of antibiotic pollution on soil health are increasingly
322 recognized as a significant concern for food security and environmental sustainability. This
323 indicates potential impact on livelihood for Africa as antibiotic pollution may lead to decreased
324 agricultural production, which is a major economic activity. Additionally, antibiotic residues
325 can accumulate in crops, raising food safety concerns and limiting market access (Arsène et
326 al., 2022). vegetables grown in antibiotic-contaminated soils contained residues exceeding
327 permissible limits (Akhter et al., 2024; Akhter et al., 2023) , which could jeopardize public
328 health and consumer confidence. Furthermore, the proliferation of antibiotic-resistant bacteria
329 in agricultural settings increases the risk of resistant strains entering the food chain (Akhter et
330 al., 2024), complicating treatment options for infections and threatening human health. As
331 agriculture in Africa faces these interconnected challenges, addressing antibiotic pollution is
332 crucial for promoting sustainable farming practices, ensuring food security, and safeguarding
333 public health across the continent.

334 **Antibiotics use and prescription practices in SSA**

335 Antibiotic prescription rates are notably elevated in hospitals across sub-Saharan Africa
336 (Siachalinga et al., 2023). This is largely attributed to the prevalent practice of empirical
337 prescribing, primarily driven by the absence of microbiology testing (Siachalinga et al., 2023).
338 Furthermore, guidelines for antibiotic use are either absent or inadequately adhered to when
339 they are available (Siachalinga et al., 2023). Further results revealed a widespread occurrence
340 of antibiotic utilization in hospitals, with rates frequently exceeding 50% (Siachalinga et al.,
341 2023). The prevalence varied, ranging from 37.7% in South Africa to a substantial 80.1% in
342 Nigeria. Notably, there was a significant trend towards the prescription of broad-spectrum

343 antibiotics, possibly influenced by the limited availability of facilities within hospitals
344 (Siachalinga et al., 2023). Concerns related to co-payments for microbiological tests might be
345 contributing to the reliance on empirical prescribing. This situation is compounded by the lack
346 of guidelines or poor adherence to existing guidelines, with adherence rates dropping as low as
347 4% (Siachalinga et al., 2023). The double-edged sword of antibiotic prescription and pollution
348 is intricately linked to the lifecycle of antibiotics, from their production to their use and
349 eventually disposal (Anuar et al., 2023). In Africa, the acquisition of antibiotics without a
350 prescription remains prevalent, and in certain African countries, all community pharmacies
351 engage in dispensing antibiotics without the requirement for a prescription (Sono et al., 2023).

352 Similarly, the manufacturing process can contribute to environmental pollution as residual
353 antibiotics, as well as by-products and impurities from manufacturing, may enter waterways if
354 not effectively managed, creating harm. Similarly, the use of antibiotics in clinical settings
355 results in pollution. After consumption, antibiotics are partially metabolized and excreted by
356 humans and other animals. Untreated effluents from households, industries, and healthcare
357 facilities may contain trace amounts of antibiotics, releasing effluents may contaminate surface
358 water, groundwater, and entire ecology. Equally important, antibiotic use in agriculture for
359 disease prevention and growth promotion in livestock, may lead to their release into the
360 environment through animal waste and runoff. Antibiotics, once in the environment, can persist
361 for long periods. This persistence increases the likelihood of them interacting with ecosystems
362 and contributing to antibiotic resistance. The presence of antibiotics in the environment exerts
363 selective pressure on bacteria. This can lead to the development and spread of antibiotic-
364 resistant strains, contributing to the global issue of antibiotic resistance. Practices such as
365 overprescription, misuse, and improper disposal of unused antibiotics can contribute to the
366 presence of varying concentrations of these drugs in the environment.

367 Strategies to address antibiotic pollution include improved prescription practices in healthcare,
368 better management of pharmaceutical waste, enhanced wastewater treatment, and sustainable
369 agricultural practices that minimize the use of antibiotics. Efforts to combat antibiotic pollution
370 require a holistic approach, involving healthcare professionals, regulatory bodies,
371 pharmaceutical companies, and the agricultural sector. Implementing proper disposal methods,
372 promoting responsible antibiotic use, and investing in advanced wastewater treatment
373 technologies are essential steps to mitigate the environmental impact of antibiotics.
374 Additionally, raising awareness among the public and healthcare providers about the

375 importance of antibiotic stewardship can contribute to reducing unnecessary prescriptions and,
376 consequently, antibiotic pollution.

377 **Status of antibiotics pollution in SSA**

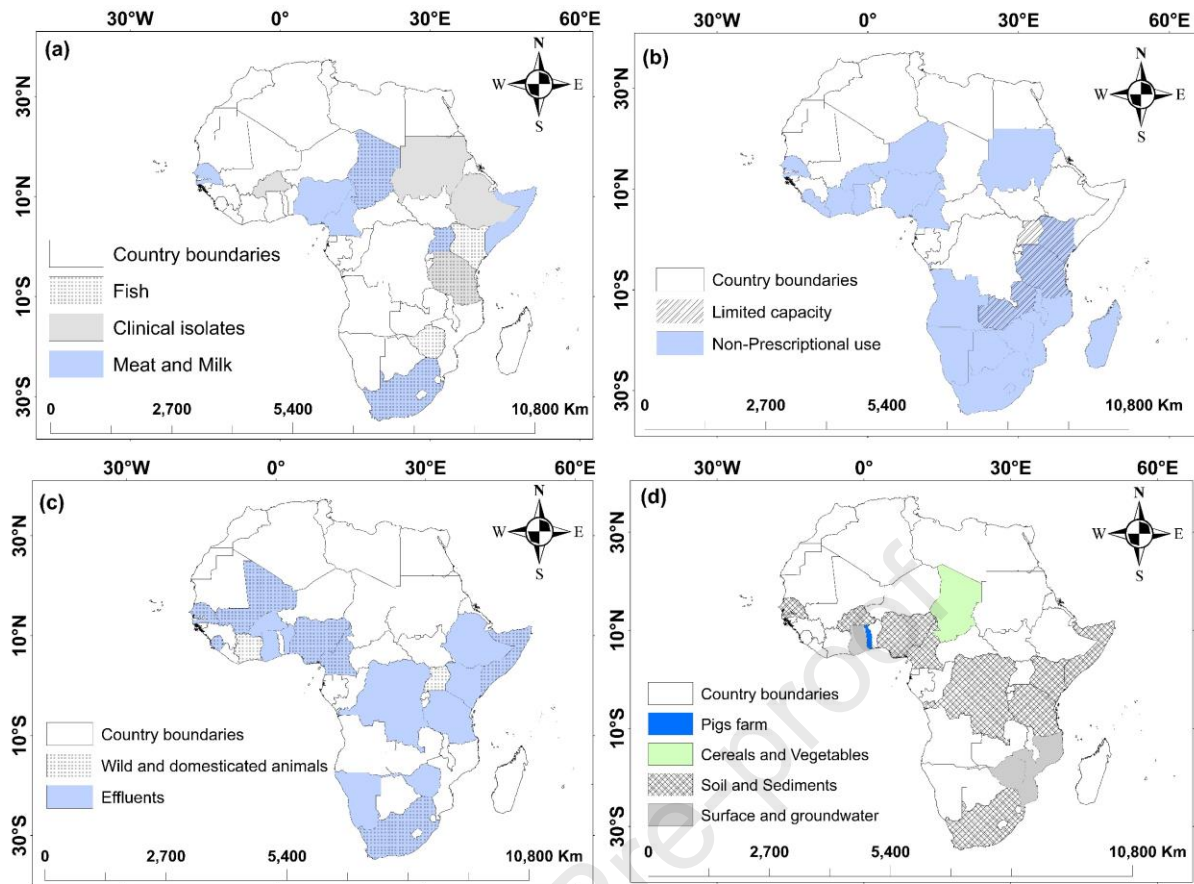
378 Currently, there is increased report of antibiotic pollution in the region including Tanzania
379 (Baniga et al., 2020; Hossein et al., 2018; Kihampa, 2014; Makokola et al., 2019; A. S. Ripanda
380 et al., 2023), Kenya (Kairigo et al., 2020; Kimosop et al., 2016; Muriuki et al., 2020; Ngigi et
381 al., 2020; Ngumba et al., 2016; Yang et al., 2016), Uganda (Onohuean & Igere, 2022; Wamala
382 et al., 2018; Weiss et al., 2018), and (Doutoum et al., 2019; Koumaré et al., 2022; Mansaray et
383 al., 2022; TALAKI et al., 2020; Woksepp et al., 2023) in other SSA countries. Concerns about
384 antibiotic pollution are due to practices such as release of contaminated effluents, reuse of
385 effluents for irrigation, and improper waste management, misuse, and overuse of antibiotics
386 resulting into development and dissemination of antibiotic-resistant pathogens. Recent views
387 by Madikizela et al. and Faleye et al., indicates higher levels of environmental antibiotic
388 concentrations in Africa than anywhere in the world (A.C. Faleye et al., 2018; Madikizela,
389 2023; Madikizela, Nuapia, et al., 2022; Madikizela, Rimayi, et al., 2022; Thu et al., 2022),
390 report on how this status can reflect SSA is lacking .The aquatic food and their products, on
391 the other hand, have been identified as potential transmission root and aquatic habitats as
392 potential reservoirs of extended-spectrum-lactamase (ESBL)-producing bacteria (Moto et al.,
393 2023a; Nnadozie & Odume, 2019; Tzouvelekis et al., 2012) , raising the risk of ecological
394 degradation and increasing wildlife disease. The presence of antibiotic residue such as
395 metronidazole may have effects to the ecosystem as there are reports of the ability of
396 metronidazole to affect soybean plants and soil microbiota (Jjemba, 2002), cause toxicity effect
397 in intestinal tissue of fish (*Onchorhynchus mykiss*) (Gürücü et al., 2016) and aquatic ecosystem
398 as a whole (Lanzky & Halting-Sørensen, 1997), which indicates a possibility of increased
399 disease burden in wildlife populations and the deterioration of the ecological health. Figure 4
400 presents map of SSA, showing report of antibiotic pollution in selected matrices in
401 environmental compartments, and reported non prescripational use of antibiotics.

402

403

404

405



406

407 Figure 5: Selected SSA countries showing report of antibiotic pollution, presence of antibiotic
 408 resistant microbial populations, including pathogens, and resistant genes in selected matrices
 409 in environmental compartments, and reported non-prescriptional use of antibiotics (Base map
 410 data source: OCHA, <https://data.humdata.org/dataset/cod-ab-tza>. Map created by authors.)

411 Presented studies (Figure 4) indicate the potential ecosystem exposure to antibiotics, their
 412 metabolic and transformational products (Abdallah et al., 2022; Agyarkwa et al., 2022; Gyese
 413 et al., 2022; Odonkor et al., 2022; Otoo et al., 2022; Quarcoo et al., 2022), antibiotic resistant
 414 microbes (Abasse et al., 2021; Al Salah et al., 2020; Couliadiaty et al., 2021; Devarajan et al.,
 415 2017; Gufe et al., 2019; Kagambèga et al., 2022; Limya et al., 2020; Markkanen et al., 2023),
 416 and resistant genes (Assoumy et al., 2021; Fall-Niang et al., 2019; Mugadza et al., 2021;
 417 Salamandane et al., 2022; Salamandane et al., 2021; Taviani et al., 2022), which may harm
 418 ecosystems. Further, the presented studies indicate the presence of antibiotics (Cige et al., 2023;
 419 Deguenon et al., 2022; Mohamed et al.; Mohamed et al., 2020), in surface waters including
 420 organism living in (Kairigo et al., 2020; Matee et al., 2023; Ngigi et al., 2020; Ngumba et al.,
 421 2016; Yang et al., 2016), effluents (Mbanga et al., 2023), (Baniga et al., 2020; Kihampa, 2014;
 422 Musa et al., 2019; A. S. Ripanda et al., 2023), soil, poultry farm (Doutoum et al., 2019;
 423 TALAKI et al., 2020; Woksepp et al., 2023), agricultural areas (Ajibola et al., 2021; Lateefat

424 et al., 2022; Ngogang et al., 2020; Takemegni et al., 2021; Tsafack et al., 2021), sediments
425 (Denku et al., 2022; Ergie et al., 2019; Esemu et al., 2022; Mohammed et al., 2022; Teshome
426 et al., 2020), feeds, milk (Enurah et al., 2019; Founou et al., 2018), wild animal (Baron et al.,
427 2021), and other matrices (Agrawal et al., 2020; Jesumirhewe et al., 2022; Kimosop et al.,
428 2016; Koumaré et al., 2022; Manishimwe et al., 2021; Mansaray et al., 2022; Muriuki et al.,
429 2020; Onohuean & Igere, 2022; Wamala et al., 2018; Weiss et al., 2018). These results indicate
430 potential for exposure to human through food chain. Exposure to antibiotics can select for
431 resistant strains of pathogenic bacteria, which can then transfer their resistance genes to other
432 microbial community in the environment (Z. Li et al., 2023; Mishra et al., 2023; Salam et al.,
433 2023a) posing a significant concern for human and animal health as it reduces the effectiveness
434 of antibiotics in treating infections (Kulik et al., 2023; Moyo et al., 2023).

435 Additionally, the presence of antibiotics in the environment can disrupt natural microbial
436 communities and ecological processes. Antibiotics can have unintended effects on non-target
437 organisms, including beneficial bacteria and other microorganisms that play vital roles in
438 ecosystem functioning (Costanzo & Roviello, 2023; Kulik et al., 2023; Nakakande et al., 2023;
439 Yarkwan, 2023). Furthermore, the disruption of the natural balance in ecosystems due to the
440 presence of antibiotics and other chemical loads can have cascading effects on wildlife health.
441 Changes in microbial communities and the emergence of antibiotic-resistant bacteria can lead
442 to an increased prevalence of diseases in wildlife populations (Kulik et al., 2023; Yarkwan,
443 2023), this can have implications for the overall health and stability of ecosystems. Antibiotic
444 contamination and resistance are known to impose ecosystem injury and their effects are
445 transboundary, and interdisciplinary measures and collaborative efforts are required for
446 ecological safety. Ripanda et al. [7] suggested wastewater effluents treatment and reduced
447 discharge, while Onohuean et al. [112] highlighted food safety and market surveillance.
448 Similarly, in a recent work it was observed that in some SSA countries limited data on active
449 chemical pollution such as antibiotics is due to absence of state of art equipment [6], and further
450 Siachalinga and colleagues [35], reported a trend of considerable prescribing broad-spectrum
451 antibiotics which could be due to lack of facilities within hospitals, along with concerns of co-
452 payments to perform microbiological tests, resulting in empiric prescribing hence potential
453 antimicrobial pollution [35], as similarly reported by other scholars [123, 124]. Similarly,
454 report of lack of guidelines or low adherence to guidelines of antibiotics prescription [35], was
455 raised. There is the need for microbiological facilities and testing, within hospitals to be made
456 available and the cost subsidized to eradicate empirical prescription. Similarly, environmental
457 surveillance and monitoring is needed, to ensure public health safety. Key components may

458 include monitoring water sources, foods and feeds, and aquatic foods for the presence of
459 antibiotic residues, assessing soil quality to understand the impact of agricultural practices and
460 antibiotic use in livestock, and tracking air quality to gauge the dispersion of antimicrobial
461 agents.

462 **Challenges unique to Sub-Saharan Africa**

463 SSA faces unique challenges that may potentially amplify antibiotic pollution, and therefore
464 the ecological consequences. Climatic conditions, such as high temperatures, humidity, and
465 seasonal rainfall (Chowdhury et al., 2018; Nguru & Mwongera, 2023; Situma et al., 2024),
466 create environments conducive to bacterial survival and proliferation. This, combined with
467 inadequate sanitation, release of contaminated effluents, and inadequate waste management,
468 contribute to the persistence and spread of antibiotic-resistant bacteria (Asif et al., 2024;
469 Gomes, 2024). This results into increased burden of infectious diseases. Data indicates the
470 region faces a significant disease burden, including infectious diseases like malaria,
471 tuberculosis, and HIV, which often require prolonged antibiotic treatments (Baral et al., 2024;
472 Duffey et al., 2024; Makam & Matsa, 2021). According to WHO regional office, as of 2022,
473 approximately 25.6 million people in the African region are living with HIV, with 20.8 million
474 in East and Southern Africa and 4.8 million in West and Central Africa (Kareem et al., 2023;
475 Tadesse et al., 2024). Similarly, about 760,000 individuals contracted HIV in 2022, with report
476 of approximately 380,000 deaths from AIDS-related illnesses, while women and girls
477 accounted for 62% of all new HIV infections in sub-Saharan Africa in 2023 (Eaton et al., 2021).

478 Several SSA countries are among the 30 high TB burden countries globally. For instance,
479 Sierra Leone had an estimated TB burden of 289 cases per 100,000 population in 2021 (Asare
480 et al., 2021; Jemiluyi & Bank-Ola, 2021; Nunes et al., 2025). TB remains a leading cause of
481 death among people living with HIV in SSA, exacerbating the public health challenge in the
482 region 2021 (Asare et al., 2021; Jemiluyi & Bank-Ola, 2021; Nunes et al., 2025). SSA bears a
483 disproportionately high share of the global malaria burden. In 2021, the region accounted for
484 approximately 95% of malaria cases and 96% of malaria deaths (Oshagbemi et al., 2023;
485 Sempungu et al., 2023). Children under five are particularly vulnerable, representing about
486 80% of all malaria deaths in the region (Aheto, 2022; Mbishi et al., 2024; Oguoma et al., 2021).
487 (Doohan et al., 2024; Duvignaud et al., 2021; P. Li et al., 2023; Malik et al., 2023; McLean et
488 al., 2023; Sharif et al., 2023; Woolsey & Geisbert, 2021). This high disease prevalence further
489 accelerates the emergence and transmission of resistant infections, presenting a complex
490 challenge for public health and ecological stability.

491 This further threatens public health as many healthcare facilities in the region are under-
492 resourced, with limited access to advanced diagnostic tools for identifying resistant infections
493 and monitoring antimicrobial resistance trends (Loosli et al., 2021; Pokharel et al., 2019). A
494 study by Umutesi and Coallegues recommended strengthening of antimicrobial resistance
495 diagnostic capacity in rural Rwanda (Umutesi et al., 2021). Similarly, Okoliegbe and
496 Coallegues reported that many African laboratories confront substantial difficulties in
497 implementing efficient quality assurance programs (Musa et al., 2023). This hampered AMR
498 surveillance due to lack of laboratory capacity, insufficient data collection and analysis, and
499 poor stakeholder collaboration (Musa et al., 2023). Yet, several initiatives and programs,
500 including the World Health Organization's Global Antimicrobial Resistance and Use
501 Surveillance System (GLASS), the Africa Centres for Disease Control and Prevention (Africa
502 CDC) Antimicrobial Resistance Surveillance Network (AMRSNET), and the Fleming Fund, a
503 UK government initiative aimed at tackling AMR in low- and middle-income countries, have
504 been established to strengthen AMR surveillance.

505 However, some positive steps are being taken. Facilities that implement infection prevention
506 and control (IPC) measures, such as proper hygiene protocols, handwashing, and isolation of
507 infected patients, have shown a reduction in resistant infection rates. While there have been
508 significant strides in reducing the incidence of some infectious diseases, the region continues
509 to grapple with high prevalence rates, particularly in countries like Eswatini, Lesotho, and
510 South Africa, which have some of the highest HIV rates globally. Efforts to combat these
511 diseases are further complicated by socioeconomic factors, limited healthcare infrastructure,
512 and emerging health threats. Sustained investment in healthcare systems, education, and access
513 to treatment is crucial to mitigate the burden of infectious diseases in SSA. Collaborative efforts
514 between international organizations and governmental agencies have led to training healthcare
515 workers in antimicrobial stewardship, improving awareness of resistance mechanisms, and
516 encouraging the prudent use of antibiotics. To effectively combat antibiotic resistance, clinical
517 facilities must strengthen laboratory capacity, adopt evidence-based prescribing practices, and
518 engage in multidisciplinary collaborations. Investing in these areas will enhance the ability to
519 address the region's unique challenges, such as high disease burdens, climatic factors, and
520 reliance on herbal medicines, while minimizing the spread of resistant pathogens.

521 **Potential implications of antibiotic resistance**

522 Antibiotic resistance is a pressing global health concern with profound implications for both
523 human, animal populations and the entire ecology (Zinsstag et al., 2023). The overuse, misuse

524 and improper disposal of antibiotics have fueled the emergence and spread of antibiotic-
525 resistant bacteria (da Silva-Brandao et al., 2023; Siachalinga et al., 2023; Tadesse et al., 2023;
526 Virhia et al., 2023; Yismaw et al., 2023; Zinsstag et al., 2023), rendering previously effective
527 treatments ineffective, resulting into treatment hospitalizations, complications, and increased
528 mortality rates. Antibiotic residues induce and accelerate antibiotic resistance development,
529 promote the transfer of antibiotic-resistant bacteria to humans and other organisms, cause
530 allergies (penicillin) (Macy & Adkinson Jr, 2023), and may induce other severe pathologies,
531 like cancers (furazolidone, sulfamethazine, and oxytetracycline) (Arsène et al., 2022), bone
532 marrow toxicity (Arsène et al., 2022), anaphylactic shock, nephropathy (gentamicin),
533 mutagenic effects, and reproductive disorders (chloramphenicol) (Elisabeth, 2023). This
534 resistance arises through various mechanisms, such as genetic mutations and horizontal gene
535 transfer (Abdallah et al., 2022; Mugadza et al., 2021; Yitayew et al., 2022), allowing bacteria
536 to withstand the effects of antibiotics. This is particularly concerning (Moyo et al., 2023), in
537 SSA, where infectious diseases like malaria, tuberculosis, and bacterial infections are
538 prevalent. As of 2019, SSA had the highest mortality rate of about 24 deaths per 100,000
539 attributable to AMR compared to other regions (Kariuki et al., 2022), this may impair ability
540 to manage common infections, which results in prolonged illness (Holloway & Everard, 2023;
541 Moyo et al., 2023; Nakakande et al., 2023; Stocker et al., 2023) , greater mortality rates, and
542 more expensive healthcare. Antibiotic resistance also can make interventions such as surgeries,
543 chemotherapy, and organ transplants (Costanzo & Roviello, 2023; Salam et al., 2023a), more
544 difficult and additional burden on healthcare systems. Similarly important, the use of
545 antibiotics such as glycopeptide and avoparcin as feeds additives for the growth promotion of
546 animals may result to the occurrence of vancomycin-resistant enterococci in food animals. In
547 this case, vancomycin-resistant enterococci and vancomycin resistance determinants can
548 therefore spread from animals to humans complicating treatments (Oliveira et al., 2020;
549 Wegener, 2003). Therefore, surveillance, infection prevention and control measures,
550 responsible antibiotic use in both human and other organisms, and the development of new
551 antibiotics and alternative treatments is needed for ecological safety and sustainability.

552 **Ecosystem health**

553 Ecosystem health is a holistic measure of the well-being and resilience of an ecological system,
554 reflecting its capacity to sustain biodiversity, support vital ecological processes (Asha
555 Ripanda, 2022; S. K. Chakraborty et al., 2023; Davis et al., 2023) , and resist or recover
556 from disturbances. A healthy ecosystem is characterized by a dynamic balance where various
557 species coexist, interact, and contribute to the overall stability and functionality of the
558 environment. It encompasses the intricate web of relationships between living organisms, their

559 physical surroundings, and the countless interactions that define the ecosystem's structure (S.
560 K. Chakraborty et al., 2023). Ecosystem health is not only vital for the persistence of diverse
561 flora and fauna but also crucial for the well-being of human societies that depend on these
562 systems for resources, climate regulation, and other essential ecosystem services (Nozarpour
563 et al., 2023). Human activities, such as pollution (Shi et al., 2023; Wilkinson et al., 2022),
564 habitat destruction (Shaikh et al.; Sun et al., 2023), and climate change (Campbell et al., 2018;
565 S. R. Gupta et al., 2023; Noureen et al., 2022), can pose significant threats to ecosystem health,
566 underscoring the importance of sustainable practices and conservation efforts to ensure
567 sustainability.

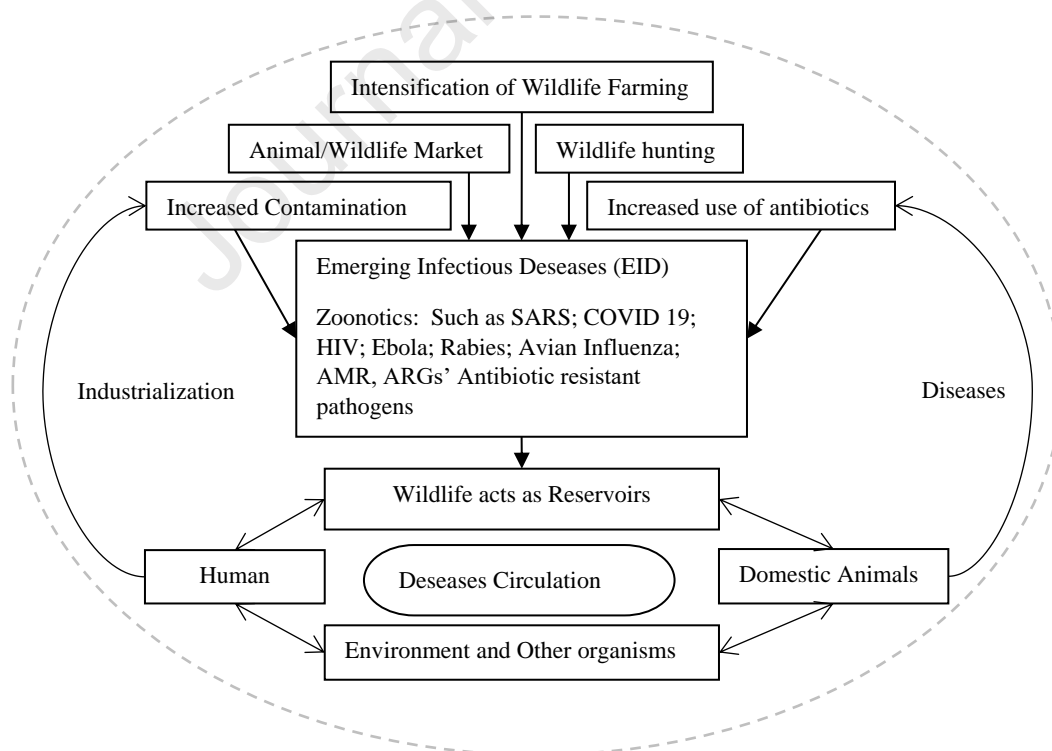
568 Antibiotic pollution, can disrupt natural microbial communities, affecting the balance of
569 microorganisms essential for nutrient cycling, soil fertility, and other ecological
570 processes (Lencastre et al., 2023; Traore et al., 2023). Similarly, antibiotics may
571 accumulate in organisms, magnify within the food chain. This bioaccumulation can lead
572 to higher concentrations of antibiotics in predators at the top of the food chain,
573 potentially posing risks to higher organisms, including humans. The presence of
574 antibiotics in the environment exerts selective pressure on bacteria, favoring the
575 survival and proliferation of antibiotic-resistant strains (S. K. Chakraborty et al., 2023;
576 da Silva-Brandao et al., 2023; Holzinger et al., 2023; Hossein et al., 2023; Rapport et
577 al., 1998), leading to the transfer of resistance genes among bacteria, further
578 contributing to the global antibiotic resistance crisis. Efforts to combat antibiotic
579 pollution are needed including focus on implementing improved waste management,
580 including wastewater treatment, promoting responsible antibiotic use, and raising
581 awareness about the environmental impact of contamination. Revisiting regulation to
582 include other contaminants and international collaboration are essential to mitigate the
583 long-term effects on ecosystems.

584

585 **Status of ecosystem health and its connection to wildlife diseases**

586 The presence and frequency of wildlife diseases in SSA are closely related to the state of the
587 ecological health (Berkhout et al., 2023; Islam et al., 2023). SSA is home to a diverse array of
588 ecosystems, ranging from expansive savannas and rainforests to freshwater and marine
589 environments. A variety of wildlife species, many of which are endemic and of great
590 conservation significance, rely on these ecosystems for vital habitats (Akani, 2023). However,
591 numerous factors, including human activities, climate change, and habitat degradation, have

592 significantly impacted ecosystem health in the region. Deforestation, land conversion for
 593 agriculture, and unsustainable resource extraction have led to habitat loss and fragmentation,
 594 disrupting natural ecological processes (S. R. Gupta et al., 2023). Contamination from
 595 industrial activities, mining, and improper waste disposal further contribute to environmental
 596 degradation (Ulucak & Baloch, 2023). Figure 5 presents conceptualization of the relationships
 597 between human, animal, wildlife, ecosystem, and circulation of diseases. The consequences
 598 of these ecosystem disturbances are manifold and have profound implications for
 599 wildlife health (Ulucak & Baloch, 2023). Disrupted ecosystems can lead to changes in
 600 species interactions, alter population dynamics, and increase the risk of disease
 601 transmission (Ulucak & Baloch, 2023). When ecosystems become imbalanced, there
 602 can be an increase in the prevalence and emergence of infectious diseases in wildlife
 603 populations, which may be transferred to human and domestic animals and the entire
 604 ecosystems. SSA has experienced several notable wildlife disease outbreaks, such as
 605 Ebola in great apes and bats, anthrax in herbivores, and various zoonotic diseases like
 606 rabies and trypanosomiasis (Gilbert et al., 2023). These outbreaks not only pose threats
 607 to wildlife but can also have spillover effects on human populations, leading to public
 608 health crises (Manes et al., 2023; Vora et al., 2023).



609

610 **Figure 6:** Conceptualization of the circulation of wildlife diseases and factors that magnify
 611 their occurrences.

612 Furthermore, the interconnectedness of ecosystems in SSA means that changes in one
613 ecosystem can have ripple effects across the region (Lakshmisha & Thiel, 2023;
614 Lencastre et al., 2023; Schaeffer et al., 1988; Vora et al., 2023). For example, alterations
615 in freshwater ecosystems due to contamination or water scarcity can impact aquatic
616 wildlife populations, disrupt food chains, and affect the livelihoods of communities that
617 rely on these resources (Berkhout et al., 2023; Ogwu et al., 2023; Rapport et al., 1998;
618 Schaeffer et al., 1988). To address the status of ecosystem health and its connection to
619 wildlife diseases in SSA, there is a need for integrated and holistic approaches.
620 Conservation efforts should focus on preserving and restoring habitats, promoting
621 sustainable land and resource management practices, and enhancing environmental
622 monitoring and surveillance systems as reported by previous researchers (Berkhout et
623 al., 2023; Ogwu et al., 2023; Rapport et al., 1998; Ray, 2023; Schaeffer et al., 1988;
624 Traore et al., 2023). Collaboration between governments, local communities,
625 researchers, and conservation organizations is crucial to develop effective strategies
626 that consider the complex interplay between ecosystem health, wildlife diseases, and
627 human well-being. By safeguarding ecosystem health, we can protect wildlife
628 populations, mitigate disease risks, and ensure the long-term sustainability of SSA
629 biodiversity.

630 **Impact of Human activities on ecosystem health and wildlife diseases**

631 Anthropogenic activities (Berkhout et al., 2023; Rapport et al., 1998; Schaeffer et al.,
632 1988), have significant contribution to the deterioration of ecological health and the
633 increased occurrence of wildlife diseases. As human populations grow and expand, the
634 demand for resources and the alteration of natural landscapes intensified, leading to a
635 range of negative impacts on ecosystems and wildlife (Gabyshev et al., 2023;
636 Lakshmisha & Thiel, 2023; Schaeffer et al., 1988). A study by Namusisi and colleagues
637 (Namusisi et al., 2021), reported twenty-nine percent (29.0%, CI: 24.4–33.9) of respondents
638 were engaged in hunting of wildlife such as chimpanzee (*Pan troglodytes*) and 45.8% (CI:
639 40.6–51.0), cane rats (*Thryonomyidae spp*), indicating presence of anthropogenic activities.
640 Among the named reasons as why communities hunt, includes acquisition of animal protein
641 (55.3%, CI: 50.1–60.4), medicinal and cultural uses of wildlife and or its parts (22.7%, CI:

642 18.6–27.4) (Namusisi et al., 2021). Similarly, hunting and bushmeat consumption is persistent
643 for other perceived reasons; including bushmeat strengthens the body, helps mothers recover
644 faster after delivery, boosts one’s immunity and hunting is exercise for the body (Namusisi et
645 al., 2021). However, it was reported that respondents fall sick after consumption of bushmeat
646 at least once (7.9%, CI: 5.3–11.1), with 5.3% (CI: 2.60–9.60) reporting similar symptoms
647 among some family members (Namusisi et al., 2021). The participants have awareness of
648 diseases transmissible from wildlife to humans (37.0%, CI: 32.1–42.2), although 88.7% (CI:
649 85.0–92.0) (Namusisi et al., 2021), had heard of Ebola or Marburg without context. Similarly,
650 hunting non-human primate poses a health risk (cOR = 0.4, 95% CI = 0.1–0.9), compared to
651 edible rats (cane rats) and wild ruminants (cOR = 0.7, 95% CI = 0.2–2.1). These results
652 suggests that pathways for zoonotic disease spillover to humans exist at interface areas driven
653 by livelihoods, nutrition, and cultural needs. The negative impacts of anthropogenic
654 activities on ecosystem health and wildlife diseases need concerted efforts for their
655 mitigation. It is crucial to prioritize habitat protection, restoration (Gilbert et al., 2023;
656 Mwakupuja et al., 2013; van Heezik & Brymer, 2018), and sustainable land management
657 in conservation programs.

658 The changes in land use associated with urbanization to cater for growing population
659 (Das & Das, 2019; Komugabe-Dixson et al., 2019; Mwabumba et al., 2022; Peng et al.,
660 2018), are causing destruction of ecosystems and natural services. Land use changes,
661 for example, are largely represented in the transformation of different land types in the
662 riparian area of Lake Tanganyika, where there are more settlements, with the conversion
663 of forestland to arable land being the most prominent. Nonetheless, the rate of land use
664 change in the region was not very high, substantial changes happened in the towns, particularly
665 in the north. As a result, wildlife habitat and other ecosystem services are being lost, potentially
666 leading deterioration of ecosystem health and increased diseases (Sintayehu, 2018). Similarly,
667 pathogenic organisms are spreading more broadly geographically, within and across
668 populations, and between other animals and humans. Most of studies utilize freshwater
669 macroinvertebrate species, to address overall freshwater ecosystem health (O’Brien et al.,
670 2016). As a result of the diminishing health of the freshwater environment, there is a need for

671 more indicators that can capture both short and long-term changes, as well as the overall trend
672 in freshwater ecosystem health (Elias, 2021). The absence of any sensitive taxa or the
673 presence of few if any; increased dominance of only a few taxa that are tolerant to
674 pollution, indicating that pollution has a significant influence on ecosystem health
675 (Elias, 2021; Hossein et al., 2023; Hossein Miraji et al., 2023), requiring intervention.
676 The majority of factors that influence ecological health are anthropogenic in nature, climate
677 change, globalization, population growth, and other new social habits will accelerate the trend
678 (Ford et al., 2020; Pozio, 2020). As global 'traffic' grows, infectious pathogens have increased
679 opportunities to mingle, transfer between species, and exchange genetic materials, potentially
680 resulting in novel fatal pathogens. Bush meat and other wet market products are becoming
681 widely available. These problems are exacerbated by emerging social activities in
682 industrialized countries, such as a love for exotic pets, wild animal products, and unmanaged
683 ecotourism. These factors have a significant impact on pathogen dynamics and cross-species
684 pathogen crossover. Domestic animal grazing zones overlap or are adjacent to wildlife areas,
685 resulting in increased contact and competition for natural resources. Similarly, farmed wildlife
686 including deer and elk and, wildlife relocation countrywide and worldwide. Endangered
687 wildlife species can become infected with a variety of infections including resistant infections.
688 Finally, as people encroach on previously inaccessible habitats and settings, they come into
689 contact with new infections (Mwakaupuja et al., 2013), and could spread them beyond their
690 historical limits.

691 **Potential contribution of antibiotics pollution to deterioration of ecosystem health**

692 Nature is increasingly being considered as a manageable resource for enhancing human well-
693 being in cities (H.-Y. Liu et al., 2021). By treating nature as a product that gives health benefits
694 and determining minimal amounts required to attain benefits, we risk trivializing a profound
695 subjective response to nature (Jimenez et al., 2021). In this case, the world may end up with a
696 diluted, biodiversity-depleted form of nature with harmed ecological functions (Armstrong,
697 2024; Mahecha et al., 2022). We could worsen ongoing movements toward more impoverished
698 settings by establishing a new baseline of what is deemed normal. Among concerns of these

699 substances in the environment, are hormonal disruption in fish (Gairin et al., 2022; Islam et al.,
700 2024), decline sperm count, intersexuality, muscularization of female fish and the antimicrobial
701 resistance (AMR) (Huang et al., 2020), as a result of discharge of antibiotics and other
702 antimicrobial pollutants into the environment, which lead to extinction of some species.
703 Antibiotic, ciprofloxacin caused cardiac dysfunction in zebrafish, such as decreased heart rate
704 and cardiac output (Shen et al., 2019). Short-term exposure to ciprofloxacin doses of 1, 10, and
705 100 g.L⁻¹ had sublethal effects on Neotropical catfish (*Rhamdia quelen*) (Kitamura et al., 2022).
706 In addition, Ciprofloxacin increased antioxidant system activity (Catalase in liver and posterior
707 kidney) (Kitamura et al., 2022). These results indicates that under short-term exposure,
708 Ciprofloxacin causes toxic effects in *R. quelen* that requires intervention, for ecosystems
709 sustainability. Antibiotics are essential in the treatment of diseases; however, AMR has been
710 deemed a threat to public health by the WHO and is expected to cost around 10 million lives
711 per year by 2050. Antibiotics and other emerging contaminants in the environment (Ahmad et
712 al., 2021; Salam et al., 2023b; Tang et al., 2023), are globally available which also may
713 contribute to increased active chemical load and may pose unknown effects in the ecosystem,
714 hence requiring intervention.

715 **Antibiotic pollution mitigation strategies and policy implications**

716 Mitigating antibiotic pollution requires a comprehensive strategy engaging multiple
717 stakeholders, including governments, healthcare providers, the pharmaceutical industry, the
718 agricultural sector, and the public. Addressing antibiotic pollution in already contaminated
719 ecosystems requires a multifaceted approach that combines regulatory, technological, and
720 community-based strategies. Primarily, implementing stricter regulations on antibiotic usage
721 in agriculture and wastewater management is essential to limit further contamination.
722 Additionally, adopting bioremediation techniques, such as using specific microbial strains that
723 can degrade antibiotics or absorb residues, can help restore soil and water quality. Studies
724 indicate that certain bacteria, like *Pseudomonas putida*, can effectively degrade tetracycline in
725 contaminated soils (Chen et al., 2023; H. Liu et al., 2021). Phytoremediation, which utilizes
726 plants to absorb and detoxify pollutants, can also be employed; plants like sunflower and
727 willow have demonstrated effectiveness in extracting antibiotics from contaminated soils
728 (Kafle et al., 2022). Furthermore, enhancing community awareness and engagement in
729 monitoring and managing local water sources can lead to more sustainable practices.
730 Integrating these strategies into a comprehensive management plan, alongside regular
731 monitoring of antibiotic levels and microbial communities, will be crucial for mitigating the
732 impacts of antibiotic pollution and promoting the recovery of affected ecosystems.

733 Similarly, mitigation strategies focusing on at the source are required to ensure safety and limit
734 further pollution. Several crucial policy implications and mitigating tactics for antibiotic
735 contamination (Muhaj & Tying, 2023), are need. The need to promote appropriate and
736 responsible use of antibiotics in both human and veterinary medicine, including the need to
737 promote adherence to treatment guidelines (Muhaj & Tying, 2023), educating healthcare
738 professionals and the public on the risks of antibiotic overuse, improper disposal, misuse, and
739 discouraging the use of antibiotics for non-bacterial infections (H. & Ripanda, 2019; Patel et
740 al., 2023; Zhang et al., 2023). Mitigating antibiotic resistance is a complex challenge that
741 requires a multifaceted approach involving various stakeholders, including healthcare
742 professionals, policymakers, researchers, and the public. Establishment of collection programs
743 for unused or expired medications and promoting safe disposal practices (Costanzo & Roviello,
744 2023). The government, industries and other stake holders need to upgrade and optimize
745 wastewater treatment plants to effectively remove antibiotics from effluents before discharge
746 into water bodies, and if possible, abolish direct disposal to water bodies (Ventola, 2015).
747 Promote and encourage adoption of sustainable farming practices that minimize the use of
748 antibiotics in livestock and aquaculture (Aslam et al., 2018). The need to enforce and strengthen
749 water quality regulations to limit the discharge of antibiotics from industrial sources,
750 agricultural runoff, and sewage treatment plants (Aslam et al., 2018). This includes revising
751 guidelines for quality monitoring and assessment to include strict limits on antibiotic
752 concentrations in effluents and implementing monitoring programs to ensure compliance.
753 Funders need to invest in research and development of innovative technologies for the removal
754 or reduction of antibiotics from water, wastewater, and agricultural runoff. This may potentially
755 be realized through fostering international collaboration and knowledge sharing to address
756 antibiotics contamination on a global scale. The overall combination of regulatory measures,
757 technological advancements, educational campaigns, and collaborative efforts is essential to
758 mitigate antibiotics contamination. The negative effects of antibiotics on the environment can
759 be lessened, protect ecosystem health, and address the worldwide problem of antibiotic
760 resistance by putting these tactics and policy implications into practice.

761 **Conclusions**

762 Anthropogenic activities are a major driver of ecological degradation, contributing to pollution,
763 declining ecosystem health, and amplified disease prevalence. Antibiotic pollution, in
764 particular, has raised significant concerns about the health and sustainability of ecosystems in
765 Sub-Saharan Africa. Although data on antibiotic contamination in the region is limited,
766 evidence from studies conducted in surface water and near industries such as pharmaceutical

767 plants has revealed alarming levels of antibiotic residues in aquatic ecosystems. These
768 pollutants, along with their metabolites and transformation products, can independently or
769 synergistically degrade ecosystem health and intensify wildlife diseases. Reports also have
770 shown antibiotic-resistant bacteria in aquatic wildlife, highlighting the potential for disease
771 transmission between wildlife, livestock, and humans. This interaction exacerbates health risks
772 and creates a ripple effect of harm across interconnected ecosystems. Effective management of
773 aquatic ecosystems, particularly in protected areas and reserves, is critical to maintaining
774 ecological balance and resilience. To address antibiotic pollution in Sub-Saharan Africa, a
775 comprehensive and coordinated policy approach is vital. This may include identifying pollution
776 hotspots. and balancing economic development with environmental protection by conducting
777 risk assessment before approval of any developmental project. The need for raising public
778 awareness on pathogenic microbes and environment that promote their production growth and
779 survival, this will aid to decrease the burden of infectious diseases and hence antibiotic use.
780 Initiate awareness program on proper use and disposal of antibiotics and other antimicrobials
781 to the family level. Similarly, educate farmers on the responsible use of antibiotics in
782 agriculture, emphasizing practices that prevent overuse and misuse, such as adhering to
783 prescribed dosages, understanding withdrawal periods, and using antibiotics only, when
784 necessary, under veterinary supervision. This will promote sustainable farming practices in the
785 region. There is a need for improving waste management systems, and implementing robust
786 monitoring frameworks for antibiotic residues and resistance this may include to make
787 available equipments for analysis of these pollutants available. Similarly, the need for all
788 clinical facilities to have equipped microbiological laboratory for microbiological testing, this
789 will aid to eradicate the practice of empirical prescription of antibiotics. Similarly, improving
790 waste management systems by ecofriendly techniques, but this requires research to tailor these
791 methods to regional challenges. Fostering regional and international collaboration, and
792 investing in research on antibiotic alternatives will further strengthen efforts. These actions will
793 aid to mitigate the impacts of antibiotic pollution, support ecosystem health, and combat the
794 growing threat of antimicrobial resistance, ensuring a sustainable future for both human and
795 ecological well-being.

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Ethics approval and consent to participate.

Not applicable

Consent for publication

Not applicable

Availability of data and material

Not applicable

Competing interest

None