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KENYA Aquatica

A Scientific Journal of Kenya Marine and Fisheries Research Institute

KMFRI

Editorial

Editorial: Kenya Aquatica Journal Vol 10(1) – A Showcase of KMFRI's Pioneering Research in Freshwater Ecosystems

The latest edition of Kenya Aquatica Journal, Vol 10(1) showcases pioneering research by KMFRI scientists on Kenya's freshwater ecosystems. This edition, supported by KMFRI and WIOMSA, covers ecological, socio-economic, and environmental challenges, providing valuable insights into sustainable management practices.

One notable study investigates disease surveillance and antimicrobial resistance in fish from lacustrine caged farms, emphasizing responsible antibiotic use to maintain fish health. Another study explores the impact of organochlorine pesticides on macroinvertebrates in Lake ecosystems, advocating for Rhagovelia spp. as a bioindicator for pesticide monitoring across food webs.

Research on Lake Baringo's small-scale fishery assesses the catch and effort composition, stressing the need for regulatory enforcement to avoid overfishing and advocating for capacity building among stakeholders for sustainable management. Additionally, a study on wild fish kills in Lake Victoria focuses on eutrophication and pollution, recommending integrated watershed management to protect the lake's fisheries and local livelihoods.

A comprehensive study on Lake Elementaita – one of Kanya's flamingos' sanctuaries, combines water quality, fisheries studies, and community surveys, calling for integrated watershed management, conservation, and sustainable agriculture. Research on fisheries co-management in Lake Baringo highlights the importance of local community involvement and sustained achievements in ecosystem management, despite challenges in law enforcement.

An article on the socio-economic dynamics of Lake Victoria proposes establishing a regulatory framework incorporating citizen science to manage the lake's resources for long-term sustainability. Addressing plastic pollution in Lake Turkana, a study recommends waste management solutions, public awareness, and better enforcement of regulations to tackle the issue.

The journal also features research on antimicrobial resistance (AMR), with a review exploring Kenya's aquatic biodiversity for potential novel antimicrobial agents. A genetic research study evaluates freshwater fish populations, identifying gaps and proposing future directions for conservation and management.

Lastly, the journal presents an evaluation of fish market dynamics in Lake Naivasha, recommending infrastructure development like fish markets and hatcheries to support the region's fishery sector.

This edition of Kenya Aquatica Journal provides crucial insights into Kenya's freshwater ecosystems, covering a wide range of research on sustainable management, environmental challenges, and the socio-economic factors influencing aquatic resources. The research highlights KMFRI's ongoing contributions to understanding and addressing these issues, fostering a deeper understanding of Kenya's aquatic biodiversity.

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About
Kenya Aquatica

Kenya Aquatica is the Scientific Journal of the Kenya Marine and Fisheries Research Institute (KMFRI). The aim of the Journal is to provide an avenue for KMFRI researchers and partners to disseminate knowledge generated from research conducted in the aquatic environment of Kenya and resources therein and adjacent to it. This is in line with KMFRI's mandate to undertake research in "marine and freshwater fisheries, aquaculture, environmental and ecological studies, and marine research including chemical and physical oceanography", in order to provide sci entific data and information for sustainable development of the Blue Economy.

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Featured front cover picture: Researcher sampling surface plankton in the Kerio River inlet to Lake Turkana. (Photo credit: Mr. John Malala)

Featured back cover picture: Chair of KMFRI Board of Management Amb. Dr. Wenwa Akinyi Odinga Oranga (seated middle), on her right, Ag. KMFRI CEO Dr. James Mwaluma, flanked by KMFRI Heads of Sections: Front (L-R) Dr. Victoria Tarus, Ms Caroline Mukiira, Dr. Jacob Ochiewo, Dr. Irene Githaiga, Mr. Abraham Kagwima. Back (L—R) Mr. Paul Waluba, Ms Jane Kiguta, Dr. Gladys Okemwa, Dr. Eric Okuku, Dr. Joseph Kamau, Mr. Isaac Kojo, Ms Joan Karanja, Mr. Milton Apollo. (Photo credit KMFRI)
Research Vessel MV Mtafiti in the background

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Marine organisms: A hidden treasure trove from the Kenyan waters for antimicrobial resistance (AMR)

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Abstract

Reports from the World Health Organization (WHO) indicate a significant increase in the global emergence of drug-resistant human pathogenic microbial strains since 2021. Antimicrobial resistance (AMR) is a significant global public health threat to modern medicine leading to increased mortality. Microorganisms such as bacteria, viruses, fungi, and parasites evolve to resist the effects of antimicrobial medicines. The current pipeline for new antibiotics is insufficient to keep pace with the growing antimicrobial resistance. Novel antimicrobials are essential to combat resistant pathogens and ensure the continued effectiveness of medical treatments. The marine environment, teeming with diverse marine life, including marine sponges, corals, seaweeds, mollusks, sea squirts, fungi and bacteria hold the potential to combat the growing challenge of AMR. These marine microorganisms have been reported to synthesize bioactive compounds including alkaloids, antibiotics, carotenoids, polyketides and terpenoids with potential therapeutic applications. Marine-derived metabolites such as mytilin sourced from *Mytilus galloprovincialis*, jellyfish collagen peptides, Didemnin B from *Trididemnum solidum*, Ergosta-5,7,22-triene-3β,14α-diol (22Z) from *Ganoderma lucidum*, and Bacillomycin D from *Bacillus amyloliquefaciens*, have been reported to exhibit broad-spectrum antimicrobial effects. Kenyan marine waters within the Western Indian Ocean are rich in biodiversity and host a variety of marine organisms with unique biochemical properties. The coastline is characterized diverse marine ecosystems including coral reefs, mangrove forests, seagrass beds, estuaries, lagoons, sandy beaches and rocky shores. A study on a sponge, *Axinella infundibuliformis* from the Kenyan coast revealed its extracts exhibit significant antimicrobial activity against Gram positive bacterial and fungal pathogens. This comprehensive review delves into the untapped treasure troves of Kenyan marine biodiversity, highlighting the promise they hold for novel antimicrobial agents and solutions in the fight against AMR.

Keywords: antimicrobial resistance (AMR), bioactive compounds, chemical structures, marine organisms

Introduction

Globally, according to the World Health Organization's (WHO) latest reports, there were an estimated 450,000 incident cases of rifampicin-resistant (RR) or multidrug-resistant tuberculosis (MDR-TB) and 191,000 resultant deaths in 2021 (Lv *et al.,* 2024). The primary reason for the increase in tuberculosis (TB) incidence is attributed to the impact of the COVID-19 pandemic on TB detection (Falzon *et al.,* 2023). Additionally, the emergence of resistance to artemisinin-based combination therapies (ACTs) for *falciparum* malaria in the Greater Mekong subregion poses a significant threat to global malaria control (Imwong *et al.,* 2017). Efforts to combat this resistance include continuous monitoring of drug efficacy and the development of new treatment strategies to prevent the spread of resistant strains (Ahmed *et al.,* 2024).

The misuse and overuse of antimicrobials in humans, animals, and agriculture are primary drivers of antimicrobial resistance (AMR) (Ahmed *et al.,* 2024). Often referred to as the "Silent Pandemic," AMR demands immediate and effective intervention instead of being viewed as a future threat (Tang *et al.,* 2023). AMR poses a threat to modern medicine, making routine surgeries, cancer treatments, and organ transplants riskier due to the potential for untreatable infections (Salam *et al.,* 2023). Without preventive measures, projections indicate that by 2050, AMR could potentially surpass all other causes of mortality worldwide. The rise of AMR has created an urgent demand for novel antimicrobials. Traditional antibiotics are increasingly losing their efficacy, while the current pipeline for novel antibiotics remains inadequate to address this escalating threat (Muteeb *et al.,* 2023). The development of novel antimicrobials, coupled with sound policy and public awareness, is crucial to managing the AMR crisis and safeguarding global health (Coque *et al.,* 2023).

Marine-derived compounds have been found to be effective against drug-resistant pathogens, making them valuable candidates for developing new antibiotics and other therapeutic agents (Bharathi and Lee, 2024). These compounds, sourced from marine organisms such as sponges, algae, corals, mollusks, and bacteria, have shown significant potential in various therapeutic applications (Seedi *et al.,* 2025). Their biological activities include antimicrobial, antiviral, anticancer, anti-inflammatory, and antioxidant properties (Sithranga Boopathy and Kathiresan, 2010). Marine microbes are estimated to produce around 23,000 bioactive secondary metabolites. Among these, marine bacteria are particularly notable for their secondary metabolites, which exhibit a wide range of biological activities, including significant antimicrobial potential (Srinivasan *et al.,* 2021). Metabolites like (+)-aeroplysinin-1 from marine sponges have demonstrated activity against MRSA (Methicillin-resistant *Staphylococcus aureus*) (García *et al.,* 2016). The exploration and utilization of marine bioactive compounds not only contribute to the discovery of new drugs but also highlight the importance of preserving marine biodiversity. Sustainable practices in harvesting and utilizing these resources are essential to ensure the continued availability of these valuable compounds for future research and development (Ahmed *et al.,* 2024).

Kenyan coastal waters are a biodiversity hotspot, hosting a wide variety of marine species, including sponges, corals, algae, mollusks, and bacteria (Cowburn *et al.,* 2018). This diversity provides a wealth of bioactive compounds with potential applications in medicine, biotechnology, and environmental conservation. Marine organisms from Kenyan waters have been found to produce unique bioactive compounds with significant antimicrobial properties (Kaaria *et al.,* 2015; Wacira *et al.,* 2024). The research on marine-derived antimicrobials in Kenya is hindered by the limited number of comprehensive studies, often restricted to preliminary screenings without detailed characterization (Kariuki *et al.,* 2021). Advanced analytical techniques like GC-MS, NMR, and HPLC are lacking, which limits the full characterization and understanding of bioactive compounds (Kiani *et al.,* 2022). Collaborative efforts and increased investment in research infrastructure are needed to unlock the potential of Kenyan marine biodiversity in combating antimicrobial resistance (Endale *et al.,* 2023).

This review aims to highlight the importance of marine-derived bioactive compounds in addressing the global health challenge of AMR and to encourage further research and development in this field. Moreover, it emphasizes exploring the rich biodiversity of marine organisms found in Kenyan waters and their potential as sources of novel antimicrobial agents. The primary focus encompasses the identification, characterization, and evaluation of bioactive compounds derived from marine sponges, corals, seaweeds, fungi, and bacteria. Additionally, the review focuses on identifying study gaps and future directions, particularly concerning the understudied marine organisms in Kenya with potential antimicrobial activity.

Discussion

A global perspective of some antimicrobial compounds and their mechanism of action from marine organisms

Marine organisms represent a vast and largely untapped reservoir of bioactive compounds with potent antimicrobial properties (Srinivasan *et al.,* 2021). Given the rise of antibiotic resistance, the exploration of marine-derived antimicrobial agents has gained significant momentum (Beesoo *et al.,* 2017). These bioactive compounds have been found in a variety of marine life forms, including bacteria, fungi, sponges, algae, actinomycetes, mollusks, tunicates, sea cucumbers, and corals (Hussain *et al.,* 2023).

Marine sponges (porifera)

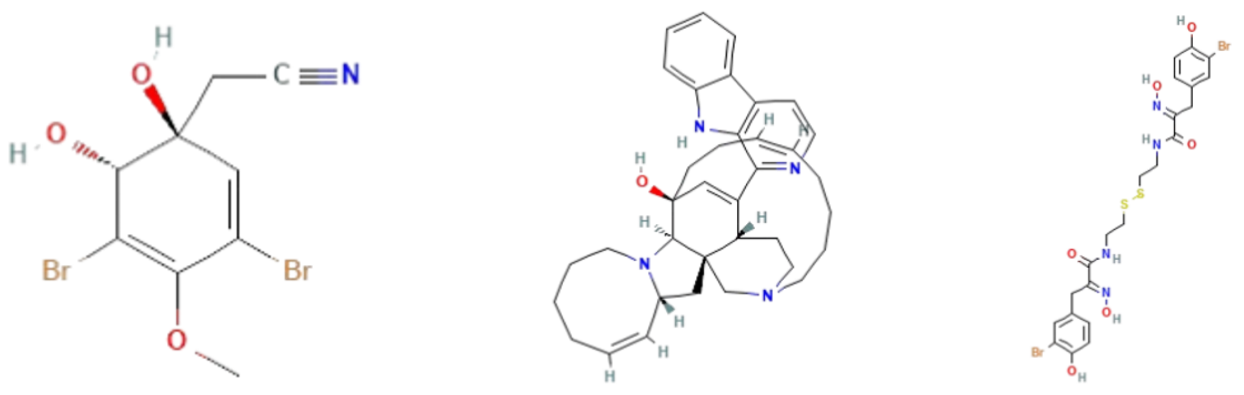
Marine sponges are known for their rich diversity of bioactive compounds. These compounds include alkaloids, terpenoids, and polyketides, which have shown promising antimicrobial, anticancer, and anti-inflammatory properties (Priya and Karthika, 2022).

Brominated alkaloids

Brominated alkaloids, such as bromotyrosines like Aeroplysinin-1, are bioactive compounds derived from marine sponges (Lever *et al.,* 2022) (Fig. 1). These compounds feature a unique chemical structure containing brominated phenol and tyrosine derivatives, which contribute to their potent antimicrobial properties (Patra, 2012). Bromotyrosines have been reported to demonstrate significant inhibitory effects against pathogenic bacteria, including *Staphylococcus aureus, Escherichia coli,* and *Pseudomonas aeruginosa* (Ferreira Montenegro *et al.,* 2024). Their mechanism of action involves disrupting bacterial cell membranes and inhibiting protein synthesis, ultimately leading to microbial cell death (Baran *et al.,* 2023).

Manzamine alkaloids

Manzamine A is a polycyclic alkaloid with a highly complex fused ring system, making it structurally unique among marine-derived bioactive compounds (Wahba *et al.,* 2012) (Fig. 1). This potent antimicrobial agent has demonstrated remarkable effectiveness against *Plasmodium falciparum*, *Mycobacterium tuberculosis*, and methicillin-resistant *Staphylococcus aureus* (MRSA). Its mechanism of action involves interfering with microbial DNA replication, ultimately disrupting cellular processes essential for survival and proliferation (Odunitan *et al.,* 2024).



(a) Aeroplysinin-1 (b) Manzamine A (c) Psammaplin A

Figure 1. Chemical structures of bioactive compounds derived from marine sponges (Porifera).

Halogenated polyketides

Psammaplin A is a remarkable compound characterized by its unique chemical structure, which includes a disulfide bridge and halogen substitutions (Jing *et al.,* 2019)(Fig. 1). This compound is renowned for its antimicrobial properties, notably its ability to inhibit Gram-positive bacteria and fungi, including *Candida albicans* (Kang *et al.,* 2015). The mechanism of action of Psammaplin A involves functioning as a histone deacetylase inhibitor, thereby disrupting bacterial metabolism and curtailing their proliferation (Hillman, 2022).

However, despite these findings, there remains a significant gap in research. Few studies have delved into the microbial symbionts associated with these sponges, which could hold the key to understanding and harnessing their full antimicrobial potential. Further investigation into these symbiotic relationships is essential to unlock the broader pharmaceutical applications of marine sponges (Freitas *et al.,* 2023).

Marine algae and seaweeds

The exploration of seaweeds has been revealed to produce valuable bioactive compounds. Marine algae and seaweeds produce antimicrobial compounds such as polysaccharides, terpenes, and phenolics (Menaa *et al.,* 2021).

Sulfated polysaccharides

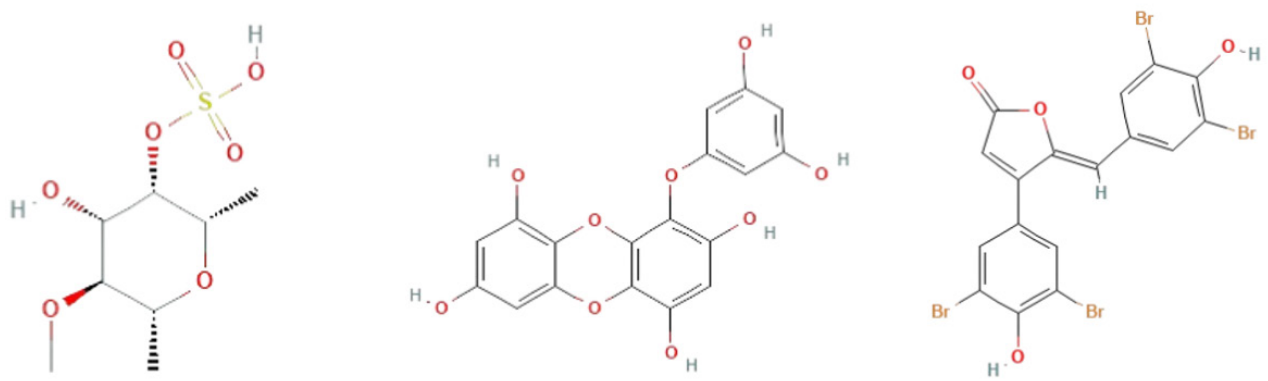
Fucoidan, a sulfated polysaccharide derived from *Sargassum* species, is known for its notable antimicrobial activity, particularly against *Vibrio cholerae* and *Helicobacter pylori* (Mensah *et al.,* 2023) (Fig. 2). The compound's chemical structure is characterized by sulfated fucose polymers, which play a crucial role in its bioactivity. The primary mechanism of action for fucoidan involves binding to bacterial cell walls, thereby disrupting adhesion and colonization processes (Ohmes *et al.,* 2022).

Phlorotannins

Eckol, a polyphenolic compound isolated from *Ecklonia* species, exhibits significant antimicrobial activity, particularly against Gram-positive bacteria and dermatophytic fungi (Besednova *et al.,* 2020) (Fig. 2). The chemical structure of eckol includes multiple hydroxyl groups, which play a crucial role in its bioactivity. Its primary mechanism of action involves disrupting bacterial membranes and inhibiting oxidative stress enzymes (Manandhar *et al.,* 2019).

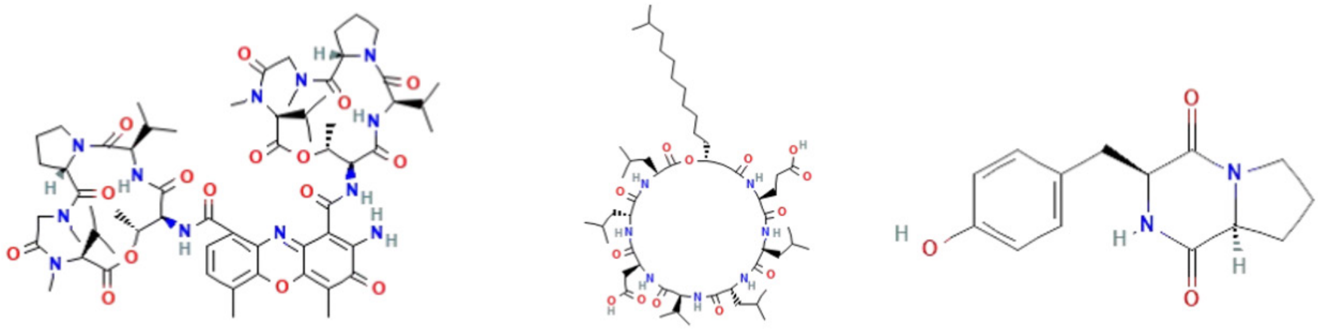
Halogenated furanones

Rubrolide B, a compound characterized by its furanone ring system with halogen substitutions, demonstrates significant antimicrobial activity by blocking bacterial quorum sensing, particularly affecting *Pseudomonas aeruginosa* biofilms (Shariati *et al.,* 2024) (Fig. 2). Its mechanism of action involves inhibiting bacterial cell-cell communication and the expression of virulence factors. However, the current body of research has its limitations, as the number of analyzed species remains limited and there is a pressing need for detailed characterization of the compounds responsible for the observed antimicrobial activity (Danquah *et al.,* 2022).



(d) Fucoidan (e) Eckol (f) Rubrolide B

Figure 2. Chemical structures of bioactive compounds derived from marine algae and seaweeds.



(g) Dactinomycin (h) Surfactin (i) Maculosin-1

Figure 3. Chemical structures of bioactive compounds derived from marine bacteria and fungi.

Marine bacteria and fungi

Actinomycins

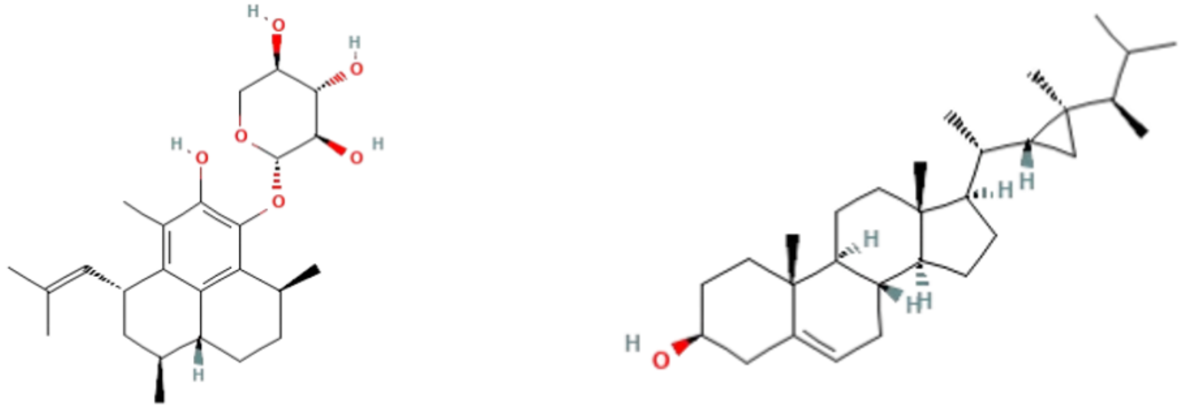
Actinomycin D, also known as dactinomycin, is a cyclic polypeptide derived from *Streptomyces* species (Djinni *et al.,* 2019) (Fig. 3). This compound features a distinctive phenoxazinone core within its chemical structure, contributing to its bioactivity. Actinomycin D exhibits significant antimicrobial activity against *Bacillus subtilis, Klebsiella pneumoniae*, and various drug-resistant fungi. Its primary mechanism of action involves binding to DNA, thereby inhibiting RNA polymerase activity and halting the transcription process (Sharma and Manhas, 2019).

Lipopeptides

Surfactin, a cyclic lipopeptide produced by *Bacillus* species, is characterized by its fatty acid tail and cyclic peptide structure (Théatre *et al.,* 2021) (Fig. 3). This compound exhibits significant antimicrobial activity, particularly against Gram-positive bacteria. The primary mechanism of action for surfactin involves forming pores in bacterial membranes, which leads to cell lysis and death. his highlights its potential as a valuable antimicrobial agent for various therapeutic applications (Tran *et al.,* 2022).

Diketopiperazines

Cyclo-(L-Pro-L-Tyr), also known as maculosin-1, is a cyclic dipeptide with aromatic substitutions derived from marine fungi (Bojarska *et al.,* 2021) (Fig. 3). This compound exhibits broad-spectrum antimicrobial activity against multidrug-resistant (MDR) bacteria. Its primary mechanism of action involves inhibiting bacterial protein synthesis and disrupting biofilm formation (Khameneh *et al.,* 2021).



(j) Pseudopterosin (k) Gorgosterol

Figure 4. Chemical structures of bioactive compounds derived from marine corals.

Coral-Derived Metabolites

Pseudopterosin, a diterpene glycoside isolated from soft corals, demonstrates significant antimicrobial activity, particularly against *Staphylococcus aureus* and *Candida albicans* (Tran *et al.,* 2022) (Fig. 4). Its chemical structure comprises a diterpene backbone linked to sugar moieties, which plays a crucial role in its bioactivity. The primary mechanism of action for pseudopterosin involves disrupting bacterial membrane integrity, leading to the inhibition of microbial growth and proliferation (Zhu *et al.,* 2024).

Sterols

Gorgosterol, a modified sterol derived from *Gorgonia* species, exhibits significant antimicrobial activity against Gram-negative bacteria and fungi (Hunt *et al.,* 2012) (Fig. 4). Its chemical structure includes side-chain alterations that differentiate it from other sterols. The primary mechanism of action for gorgosterol involves modulating membrane permeability, ultimately leading to cell death (Darnet *et al.,* 2021).

Overview of marine ecosystems along the Kenyan coastline

The Kenyan coastline stretches approximately 536 kilometers (333 miles) along the Indian Ocean. The marine ecosystems along the Kenyan coastline are diverse and dynamic, offering numerous ecological, economic, and cultural benefits. These ecosystems are interconnected and contribute to the overall health and resilience of the marine environment (Gesami and Nunoo, 2024). Conservation and sustainable management of these ecosystems are crucial to preserving their biodiversity and the services they provide to local communities and the global environment (Rasowo *et al.,* 2020).

Coral reefs

The Watamu Marine National Park, situated on the central coast of Kenya, is renowned for its rich biodiversity and vibrant coral reefs. This marine protected area features various coral species, including massive *Porites* colonies and balanced compositions of genera *Acropora* and *Pocillopora*. To the north, the Malindi Marine National Park, located in proximity to the town of Malindi, is an integral component of the larger Malindi-Watamu Marine National Reserve (Cowburn *et al.,* 2018). This Park is notable for its heterogeneous coral reefs, seagrass meadows, and mangrove ecosystems. In the vicinity of Mombasa, the Mombasa Marine National Park and Reserve is recognized for its renowned coral reefs, which provide habitat for a diverse array of marine fauna, including various fish species, sea turtles, and dolphins. On the southern coast, the Kisite-Mpunguti Marine National Park is distinguished for its pristine coral reefs and rich marine biodiversity, rendering it a preferred site for snorkeling and diving activities (Ransom and Mangi, 2010). These coral reef systems serve as essential ecosystems that support a diverse range of marine species and contribute significantly to the overall health of the oceanic environment. Additionally, they play a critical role in the livelihoods of local communities by facilitating fishing and tourism-related activities (Wambua *et al.,* 2021).

Seagrass meadows

Gazi Bay, located on the southern coast of Kenya, is renowned for its extensive seagrass meadows. These meadows are composed of various seagrass species, including *Thalassodendron ciliatum*, *Cymodocea rotundata*, and *Halophila ovalis* (Omollo *et al.,* 2022). Gazi Bay has become a significant site for seagrass research, especially in the context of carbon storage and ecosystem services (Githaiga *et al.,* 2017). Further along the southern coast, Diani Beach is another important location for seagrass meadows. The seagrass species found here include *Thalassia hemprichii* and *Syringodium isoetifolium* (Mwikamba *et al.,* 2024). These meadows provide critical habitats for marine life and contribute to the overall health of the coastal ecosystem. Nyali Beach, situated near Mombasa, is home to diverse seagrass meadows, with species such as *Enhalus acoroides* and *Halodule uninervis*. These meadows play a vital role in supporting marine biodiversity and protecting the coastline from erosion (Uku and Björk, 2005). Kanamai and Vipingo, areas along the Kenyan coast, also host significant seagrass meadows. The seagrass species found here include *Zostera capensis* and *Halophila stipulacea*. These meadows are essential for maintaining the ecological balance and providing habitats for various marine organisms. These seagrass meadows are vital ecosystems that support a wide range of marine species and contribute to the overall health of the ocean environment. They also play a crucial role in carbon sequestration, helping to mitigate climate change (Aboud and Kannah, 2017).

Mangrove forests

One of the most significant mangrove forests is found in Gazi Bay, located on the southern coast of Kenya. This area is renowned for its extensive mangrove coverage and has been the focus of numerous conservation and restoration projects (Aboud and Kannah, 2017). The mangroves in Gazi Bay include species such as *Avicennia marina, Rhizophora mucronata*, and *Ceriops tagal* (Neukermans *et al.,* 2008). Further along the coast, Mida Creek near Watamu is another important mangrove forest characterized by its rich biodiversity. It supports a variety of mangrove species, including *Bruguiera gymnorrhiza, Sonneratia alba*, and *Xylocarpus granatum* (Kairo *et al.,* 2002). Mida Creek is also a vital habitat for numerous bird species and marine life. Moving to the northern part of Kenya's coastline, the Lamu Archipelago is home to extensive mangrove forests. The mangroves in this region play a critical role in protecting the coastline from erosion and providing habitats for fish and other marine organisms (Kirui *et al.,* 2011). The dominant species in this area include *R. mucronata* and *A. marina*. The Tana River Delta is another significant location for mangrove forests in Kenya. The delta's mangroves are essential for maintaining the ecological balance of the region and supporting local communities' livelihoods (Gitau *et al.,* 2023). The species found here include *Ceriops tagal, Bruguiera gymnorrhiza*, and *Xylocarpus moluccensis (Okello et al., 2022)*. These mangrove forests are vital ecosystems that contribute to the overall health of the coastal environment in Kenya. They provide essential services such as coastal protection, habitat for marine life, and carbon sequestration, helping to mitigate climate change (Huxham *et al.,* 2015).

Sandy beaches and dunes

Diani Beach, located in Kwale County, is one of the most famous beaches in Kenya. Stretching about 17 km, it has been Africa's top beach destination for several years. The beach is characterized by its white sand, blue waters, and tall palm trees. Visitors can enjoy activities such as swimming, camel riding, and snorkeling (Ndivo and Waudo, 2012). Mambrui Beach, near Malindi, is known for its unique golden sand dunes formed by powerful ocean winds. This unspoiled natural beach is dotted with palm trees and is perfect for picnicking, swimming, and kitesurfing (Kimani *et al.,* 2017). Nyali Beach, situated near Mombasa, is another popular destination. It features soft white sand, clear blue and green waters, and gentle winds. The beach is ideal for swimming, sunbathing, and building sandcastles. Watamu Beach, located approximately 105 kilometers north of Mombasa, boasts pristine white sands and a vibrant marine park. The crystal-clear waters make it perfect for snorkeling and diving. These sandy beaches and dunes are not only beautiful but also play a crucial role in supporting local tourism and providing habitats for various marine species (Mwakumanya and Bdo, 2007).

Rocky shores

Kilifi Creek, located in Kilifi County, features rocky shores rich in marine biodiversity. The rocky outcrops and tidal pools provide habitats for various marine organisms, including crabs, mollusks, and sea urchins (Oyugi, 2007). Further South, near the border of Kenya, Shimoni is known for its rocky shores and coral reefs. This area is popular for snorkeling and diving, offering visitors a chance to explore the diverse marine life that inhabits the rocky crevices and coral formations (Mwadzombo *et al.,* 2023). Near Mombasa, the Mombasa Marine National Park and Reserve includes rocky shores that are home to a variety of marine species. The rocky coastline, combined with coral reefs and seagrass beds, creates a rich and diverse marine ecosystem. North of Mombasa, the Watamu Marine National Park features rocky shores and coral reefs. These rocky areas provide habitats for numerous marine organisms and are popular spots for snorkeling and diving. These rocky shores are vital ecosystems that support a wide range of marine species and contribute to the overall health of the coastal environment in Kenya. They also offer unique opportunities for marine exploration and recreation (Cowburn *et al.,* 2018).

Estuaries and lagoons

Estuaries and lagoons that play a crucial role in supporting marine biodiversity and local communities. One of the most significant estuaries is the Tana River Delta, located in the northern part of Kenya's coastline. This estuary is formed by the Tana River, the longest river in Kenya, as it empties into the Indian Ocean (Kitheka and Mavuti, 2016). The Tana River Delta is a vital habitat for various bird species, fish, and other wildlife. It also supports local communities through fishing and agriculture. Another important estuary is the Sabaki River Estuary, also known as the Athi-Galana-Sabaki River Estuary. This estuary is located near Malindi, where the Sabaki River meets the Indian Ocean (Thoya *et al.,* 2022). The Sabaki Estuary is characterized by its mangrove forests, sandbanks, and freshwater pools. It is an essential habitat for fish, birds, and other marine life, and it plays a significant role in supporting local livelihoods. In addition to estuaries, Kenya also has notable lagoons, such as the Mida Creek Lagoon (Okuku *et al.,* 2022). Located near Watamu, Mida Creek is a tidal lagoon surrounded by mangrove forests. It is a biodiversity hotspot, providing habitats for various marine species, including fish, crabs, and birds. The lagoon is also a popular destination for eco-tourism activities such as bird watching and kayaking. These estuaries and lagoons are vital ecosystems that contribute to the overall health of the coastal environment in Kenya. They provide essential services such as habitat for marine life, coastal protection, and support for local communities through fishing and tourism activities (Cowburn *et al.,* 2018).

Open ocean

The open ocean, also known as the pelagic zone, is characterized by its deep waters and is home to a wide variety of marine life, including large fish, marine mammals, and seabirds. The open ocean off the coast of Kenya is part of the Western Indian Ocean, which is known for its rich biodiversity and productive fishing grounds (Groeneveld, 2015). This region is influenced by the East African Coastal Current, which brings nutrient-rich waters from the south, supporting a diverse range of marine species. The open ocean in this area is also important for various economic activities, including commercial fishing, shipping, and tourism. Additionally, it plays a crucial role in regulating the climate by absorbing carbon dioxide and heat from the atmosphere (Gesami and Nunoo, 2024).

Previous studies on Kenyan marine organisms and their bioactivity

Previous studies on Kenyan marine organisms have demonstrated the immense potential of these organisms as sources of bioactive compounds. The research highlights the importance of conserving marine ecosystems and promoting sustainable use of marine resources. Continued exploration and study of Kenyan marine biodiversity can lead to the discovery of novel bioactive agents with significant therapeutic applications (Karthikeyan *et al.,* 2022).

Seaweeds (marine algae)

A study by Kaaria *et al.* investigated the antimicrobial potential of endophytic fungi from marine algae in Kibuyuni, Kenya, and found significant antimicrobial properties in several strains (Kaaria *et al.,* 2015). Similarly, another study along the Kenyan coast collected marine algae and isolated 3,493 bacterial strains. Twenty percent of these isolates showed inhibitory effects against at least one pathogen, with 69 strains displaying broad-spectrum antimicrobial activity. The study also revealed that Gram-positive bacteria were more susceptible to these isolates than Gram-negative bacteria. Additionally, it was noted that geographical location influenced the antimicrobial efficacy of the isolates (Kaaria *et al.,* 2015).

Marine sponges

A pivotal study focused on the sponge *Axinella infundibuliformis*, collected from the Kenyan coast, aimed to evaluate its antimicrobial potential. Researchers extracted various compounds from this sponge and assessed their activity against a range of microbial pathogens. The findings revealed that certain extracts exhibited pronounced antimicrobial effects, particularly against Gram-positive bacteria such as *Staphylococcus aureus* and *Bacillus subtilis*. Additionally, some extracts demonstrated activity against fungal pathogens, including *Candida albicans*. These results underscore the potential of *A. infundibuliformis* as a source of novel antimicrobial agents (Lutta *et al.,* 2008).

Additionally, earlier research presented at the 1st International Congress of the Federation of African Societies of Biochemistry and Molecular Biology in 1996 highlighted the antimicrobial and antifungal activities of selected marine algae and sponges along the Kenyan coast. While specific sponge species were not detailed, the findings underscored the potential of marine sponges in this region as sources of bioactive compounds (Titanji, 2005).

Marine-derived endophytic fungi

Wacira *et al.* in Kenya conducted a study on mangrove endophytic fungi, examining their antibacterial properties. Mangrove species from different locations were collected and their fungal isolates were affiliated to the *Aspergillus* genus. The fungal extracts were tested for antibacterial activity against *E. coli, S. aureus*, and *P, aeruginosa* using the disc diffusion method. The results indicated that *A. marina* and *R. mucronata* had the highest number of fungal endophytes with significant antibacterial activity, even surpassing positive controls (Wacira *et al.,* 2024).

Coral reef-associated microorganisms

A research study assessed the impact of anthropogenic activities on coral reef-associated microorganisms along the Kenyan coast. The study utilized metagenomic approaches to analyze the microbial community structure and functional potential. The findings indicated that coral reefs affected by human activities had distinct microbial communities with unique bioactive properties (Wambua *et al.,* 2021).

Comparative analysis of bioactivity research on marine organisms in Kenyan waters versus global trends

When comparing the research on Kenyan marine organisms to global trends, it becomes evident that while significant progress has been made, there are still gaps to be addressed. Globally, marine-derived antimicrobial compounds have been extensively studied, with numerous compounds identified from various marine organisms such as sponges, corals, and bacteria (Bharathi and Lee, 2024). These studies have led to the discovery of compounds with potent antimicrobial, antifungal, and anticancer properties. In contrast, research in Kenya has primarily focused on a limited number of species and has not yet reached the same level of comprehensive analysis. While Kenyan studies have identified promising antimicrobial compounds, the scope and depth of research are not as extensive as those conducted in other regions (Sohaili *et al.,* 2024).

Analytical Techniques for Identifying Antimicrobial Compounds

Identifying antimicrobial compounds from marine organisms involves several advanced analytical techniques, each with its unique strengths and applications. One of the most widely used techniques is Gas Chromatography-Mass Spectrometry (GC-MS) (Franco *et al.,* 2019). GC-MS combines the features of gas-liquid chromatography and mass spectrometry to identify different substances within a test sample. This technique is particularly effective for analyzing volatile and semi-volatile compounds. The process involves vaporizing the sample and then separating the components based on their mass-to-charge ratio. GC-MS is highly sensitive and can detect even trace amounts of compounds, making it invaluable for identifying antimicrobial agents in complex mixtures (Sinha *et al.,* 2023).

Nuclear Magnetic Resonance (NMR) spectroscopy is used to determine the structure of organic compounds by observing the behavior of nuclei in a magnetic field. This technique provides detailed information about the molecular structure, dynamics, and environment of the compounds (Emwas *et al.,* 2020). NMR is particularly useful for identifying the specific arrangement of atoms within a molecule, which is essential for understanding the mechanism of action of antimicrobial compounds. It can also be used to study the interactions between antimicrobial agents and their targets, providing insights into their efficacy and potential side effects (Phyo *et al.,* 2021).

High-Performance Liquid Chromatography (HPLC) is another analytical technique used to separate, identify, and quantify each component in a mixture. HPLC is particularly effective for analyzing non-volatile and thermally unstable compounds (Schieppati *et al.,* 2021). The technique involves passing a liquid sample through a column packed with a solid adsorbent material. Different compounds in the sample move through the column at different rates, allowing them to be separated and identified. HPLC is highly versatile and can be used to analyze a wide range of antimicrobial compounds, from small molecules to large biomolecules (Badawy *et al.,* 2022).

Study Gaps and Future Directions

Limited number of comprehensive studies on marine-derived antimicrobials

One of the significant gaps in the research on marine-derived antimicrobials in Kenya is the limited number of comprehensive studies. Many studies have focused on preliminary screenings and have not progressed to detailed characterization and mechanism of action studies (Sohaili *et al.,* 2024). Additionally, there is a lack of advanced analytical techniques such as GC-MS, NMR, and HPLC in many Kenyan studies, which limits the ability to fully characterize and understand the bioactive compounds (Mungwari *et al.,* 2025). Furthermore, there is a need for more collaborative efforts and increased investment in research infrastructure to support the identification and development of novel antimicrobial agents from Kenyan marine organisms. Addressing these gaps will be crucial for unlocking the full potential of Kenyan marine biodiversity in the fight against antimicrobial resistance (Rasowo *et al.,* 2020).

By addressing these study gaps and leveraging advanced analytical techniques, researchers can more accurately identify and characterize antimicrobial compounds, leading to the development of more effective treatments for infectious diseases. However, overcoming the current limitations in Kenyan studies will be crucial for realizing the full potential of these techniques (Kariuki *et al.,* 2021).

Understudied marine organisms in Kenya for antimicrobial activity

Kenya's marine biodiversity is a treasure trove of potential antimicrobial agents, yet many marine organisms remain understudied (Kimani *et al.,* 2017). The rich marine ecosystem, including various species of algae, sponges, and other invertebrates, harbors microorganisms that produce secondary metabolites with antimicrobial properties (Srinivasan *et al.,* 2021). In Kenya, research has predominantly been on terrestrial organisms, creating a substantial gap in our knowledge of marine-derived antimicrobials. Future studies should focus on exploring marine organisms to discover new antimicrobial compounds that can tackle the escalating problem of antibiotic resistance (Endale *et al.,* 2023).

Need for bioprospecting and large-scale screening programs

Bioprospecting, the systematic exploration of natural resources for commercially valuable compounds, is crucial for discovering new drugs and other bioactive substances (Manam, 2023). In Kenya, there is a pressing need for large-scale screening programs to identify and evaluate the antimicrobial potential of marine organisms. Such programs would involve the collection and analysis of samples from diverse marine habitats, followed by rigorous screening for antimicrobial activity. This approach not only enhances the chances of discovering new antimicrobial agents but also promotes the sustainable use of marine biodiversity (Kairigo *et al.,* 2020).

Exploration of host-associated microbiomes in marine organisms

The microbiomes associated with marine organisms play a vital role in their health and ecological functions (Ma *et al.,* 2023). These host-associated microbiomes can produce bioactive compounds that contribute to the antimicrobial properties of their hosts. Despite their importance, the interactions between marine hosts and their microbiomes remain poorly understood (Diwan *et al.,* 2023). Future research should focus on elucidating these interactions to harness the full potential of marine microbiomes in antimicrobial drug discovery. Understanding how these microbiomes influence host health and resilience could lead to innovative strategies for managing marine resources and combating microbial infections (Kamel *et al.,* 2024).

Need for standardization in antimicrobial screening methods

The lack of standardized methods for antimicrobial screening poses a significant challenge in comparing and validating results across different studies. Standardization is essential to ensure the reliability and reproducibility of antimicrobial assays (Hossain, 2024). Researchers must adopt uniform protocols for sample collection, preparation, and testing to facilitate the comparison of data and the identification of promising antimicrobial agents. Establishing standardized methods will also enhance collaboration between research institutions and streamline the process of translating laboratory findings into clinical applications (Garcia *et al.,* 2022).

Industrial potential and pharmaceutical development of Kenyan marine bioactive compounds

Kenya's marine bioactive compounds hold immense industrial and pharmaceutical potential. These compounds, derived from marine organisms, have shown promise in various therapeutic applications, including antimicrobial potential (Kaaria *et al.,* 2015). The development of these bioactive compounds into commercially viable products requires a multidisciplinary approach involving marine biology, chemistry, pharmacology, and biotechnology (Ghosh *et al.,* 2022). By investing in research and development, Kenya can capitalize on its marine resources to create new pharmaceuticals and contribute to global health solutions. Additionally, fostering partnerships with the pharmaceutical industry can accelerate the commercialization of marine-derived bioactive compounds, benefiting both the economy and public health (Pereira and Cotas, 2024).

Addressing the study gaps and future directions outlined will significantly advance our understanding and utilization of Kenya's marine biodiversity for antimicrobial drug discovery. By prioritizing research on understudied marine organisms, implementing large-scale screening programs, exploring host-associated microbiomes, standardizing antimicrobial screening methods, and developing industrial applications, we can unlock the full potential of marine bioactive compounds and contribute to the fight against antimicrobial resistance (McCubbin *et al.,* 2021).

Conclusion and recommendations

Summary of key findings

The exploration of Kenya's marine organisms has revealed a vast, untapped reservoir of bioactive compounds with significant antimicrobial properties. The key findings highlight the rich biodiversity of marine species in Kenyan waters, many of which remain underexplored for their potential antimicrobial activities. The study has underscored the critical role of marine microorganisms, algae, sponges, and invertebrates in producing secondary metabolites that can combat antimicrobial resistance (AMR). Despite the promising discoveries, there is a clear need for more comprehensive and systematic research efforts to fully harness this potential.

Recommendations for future research and policy development

To bridge the existing knowledge gaps, it is imperative to implement large-scale bioprospecting and screening programs targeting the diverse marine habitats in Kenya. Future research should prioritize the identification and characterization of bioactive compounds from understudied marine species. Additionally, there is a pressing need to standardize antimicrobial screening methods to ensure consistency and reliability across different studies. Policymakers should support these initiatives by providing funding, infrastructure, and regulatory frameworks that promote sustainable bioprospecting and the conservation of marine biodiversity. Collaborative efforts between research institutions, government agencies, and local communities will be essential in driving these research and policy advancements.

Potential for collaboration with international institutions for marine drug discovery

The journey towards discovering new antimicrobial agents from Kenyan marine organisms can be significantly accelerated through international collaborations. Partnering with global research institutions and pharmaceutical companies can facilitate the exchange of knowledge, expertise, and resources. These collaborations can provide access to advanced technologies and methodologies, enhancing the efficiency and scope of bioprospecting efforts. Furthermore, international partnerships can help in the commercialization of marine bioactive compounds, translating laboratory findings into market-ready pharmaceutical products. By fostering these collaborations, Kenya can position itself as a key player in the global fight against antimicrobial resistance, while also contributing to the sustainable development of its marine resources.

In conclusion, the study of marine organisms in Kenyan waters holds immense promise for addressing the global challenge of antimicrobial resistance. By building on the key findings and implementing targeted research, policy, and collaborative strategies, we can unlock the full potential of this hidden treasure trove and make significant strides towards innovative and effective antimicrobial solutions.

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