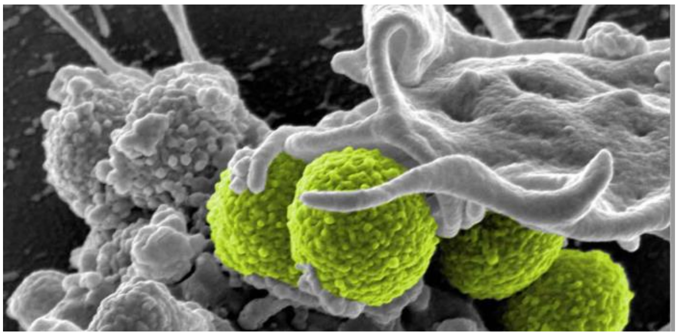
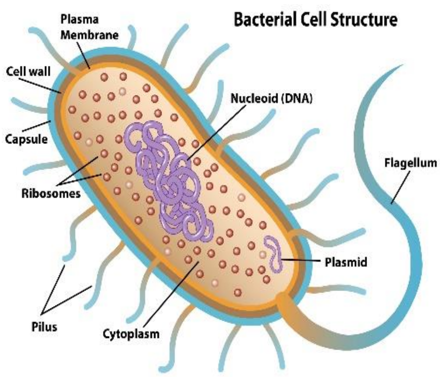
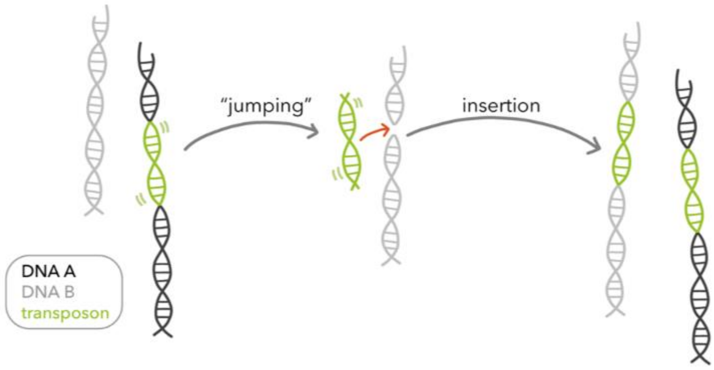


ENVIRONMENTAL CONSIDERATIONS IN THE MANAGEMENT OF ANTIMICROBIAL RESISTANCE: CONTRIBUTIONS TO THE ANTIMICROBIAL RESISTANT (AMR) NATIONAL ACTION PLAN (AMR-NAP)





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SEPTEMBER 2021

Environmental Considerations in the Management of Antimicrobial Resistance:
Contributions to the Antimicrobial Resistant (AMR) National Action Plan (AMR-NAP)

Prepared by Anthony Headley, Director, Environmental Protection Department, Ministry of Environment and National Beautification

Introduction

Globally, the world has recognised the dangers of the growing threat of antimicrobial resistance (AMR) to human and animal health, and the social and economic consequences of infectious diseases that result from resistant microorganisms. Some of those important common enteric pathogens for humans are *Salmonella spp*., *Campylobacter spp*., *Enterococcus spp*., *Escherichia coli* and *Staphylococcus aureus* (McEwen and Collignon, 2018). When pathogens are resistant to the medications used to treat infections complications can arise. The foreseen consequences of infections from resistant organisms are longer illnesses, increased mortality, prolonged stays in the hospital, loss of protection for patients undergoing operations and other medical procedures, loss of productive hours from work, and increased treatment costs (WHO, 2015). The growing threat of AMR could retard global social and economic growth hindering the achievement of the sustainable development goals (SDGs) in some of the most vulnerable countries.

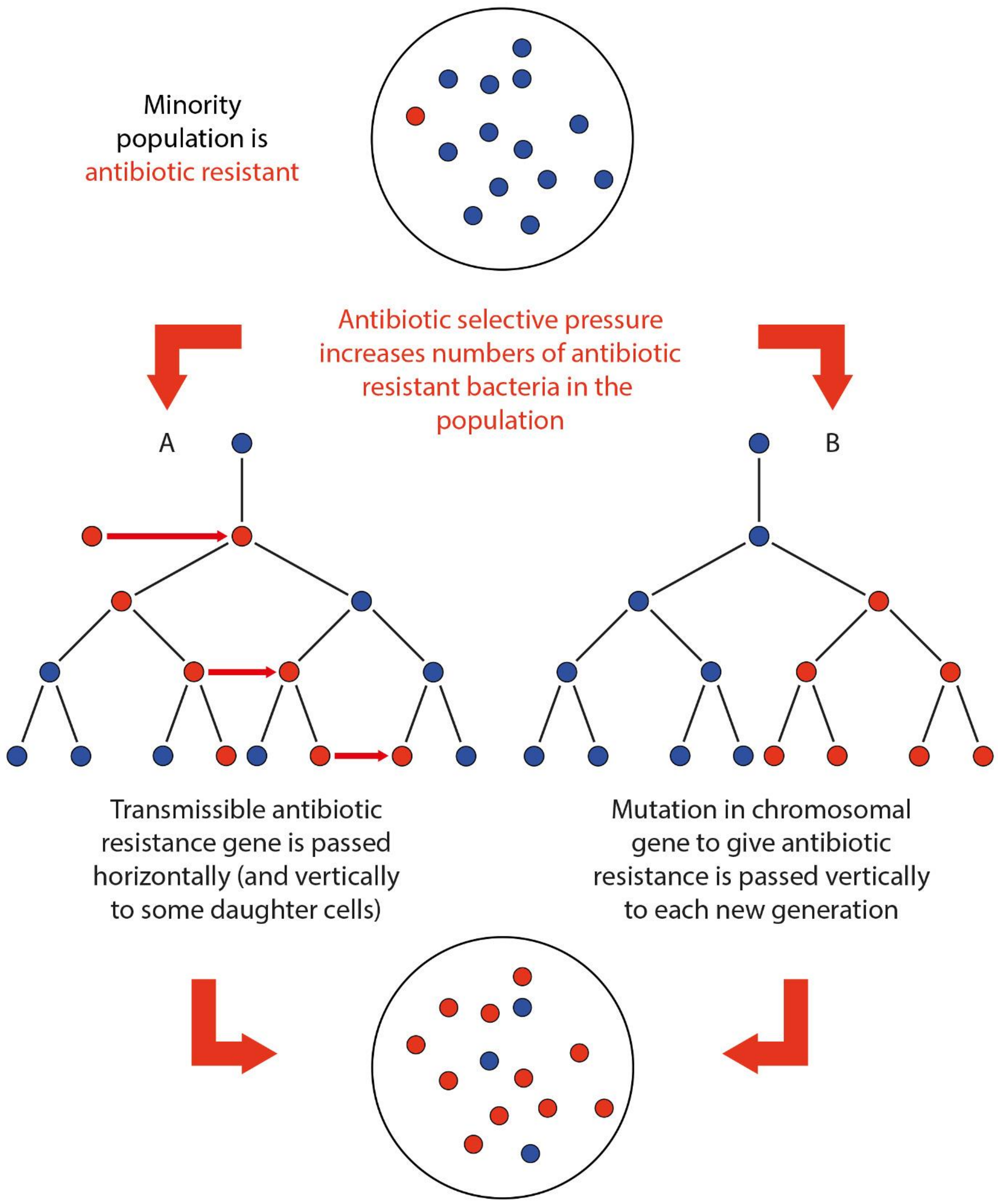
Recognising the implication of AMR, the World Health Organisation (WHO) established a tripartite collaborative Global Task Force on Antimicrobial Resistance with membership from the Food and Agriculture Organization (FAO), World Organisation for Animal Health (OIE) and WHO itself in 2014. Guided by the outputs from this task force, several countries including Barbados have developed National Action Plans (NAP) on AMR within the framework of WHO's decision WHA68.7 of May 2015 to complement the Global Action Plan on Antimicrobial Resistance, (WHO, 2015). These plans are limited in their environmental scope and mainly focuses on the clinical aspect of AMR, wastes from human and animal, manufacturing wastes, and antibiotics genes as the drivers of AMR (Singer et al, 2016). Consequently, limited research and investment to understand the impacts of AMR on the ecosystems and ecosystems services and how to address all drivers of antimicrobial residence genes (ARGs) in the environment is part of the paradigm at this stage to manage AMR.

This paper looks at the components necessary for the environmental sector to make a greater contribution to the development of the AMR-NAP, the research questions that need to be investigated to better understand the environmental component of AMR, the occurrence of the AMR in the environment, and the potential funding necessary to drive environmental research towards better understanding the indicators to regulate wastes and other chemicals agents that drive AMR.

Situational Analysis

AMR occurs when a microorganism evolves to resist the effects of an antimicrobial agent and multiply in its presence (Gaze and Depledge, 2017). These agents in sufficiently high concentrations can kill bacteria, viruses, protozoa and fungi. However, at sub-lethal concentrations, specific genes enable an organism to adapt through a variety of mechanisms[1] due to the pressures exerted by antimicrobial chemicals. This is known as natural selection and occurs because organisms produce antibiotic to gain a competitive advantage against others. Those without the antibiotic resistant genes (ARGs) are inhibited while other with the gene survive and thrive (Singer et al, 2016). Furthermore, microorganisms when exposed to other chemicals that have antimicrobial properties may adapt to the effects of the chemicals and acquire through co-selection resistance to specific antibiotics creating multidrug resistance microorganisms. Figure 1 demonstrates how distribution and proliferation of antibiotic resistance organisms occur.

Figure 1: An Illustration on how Antibiotic resistance is selected in bacterial populations and how it proliferates (Meek et al, 2015).

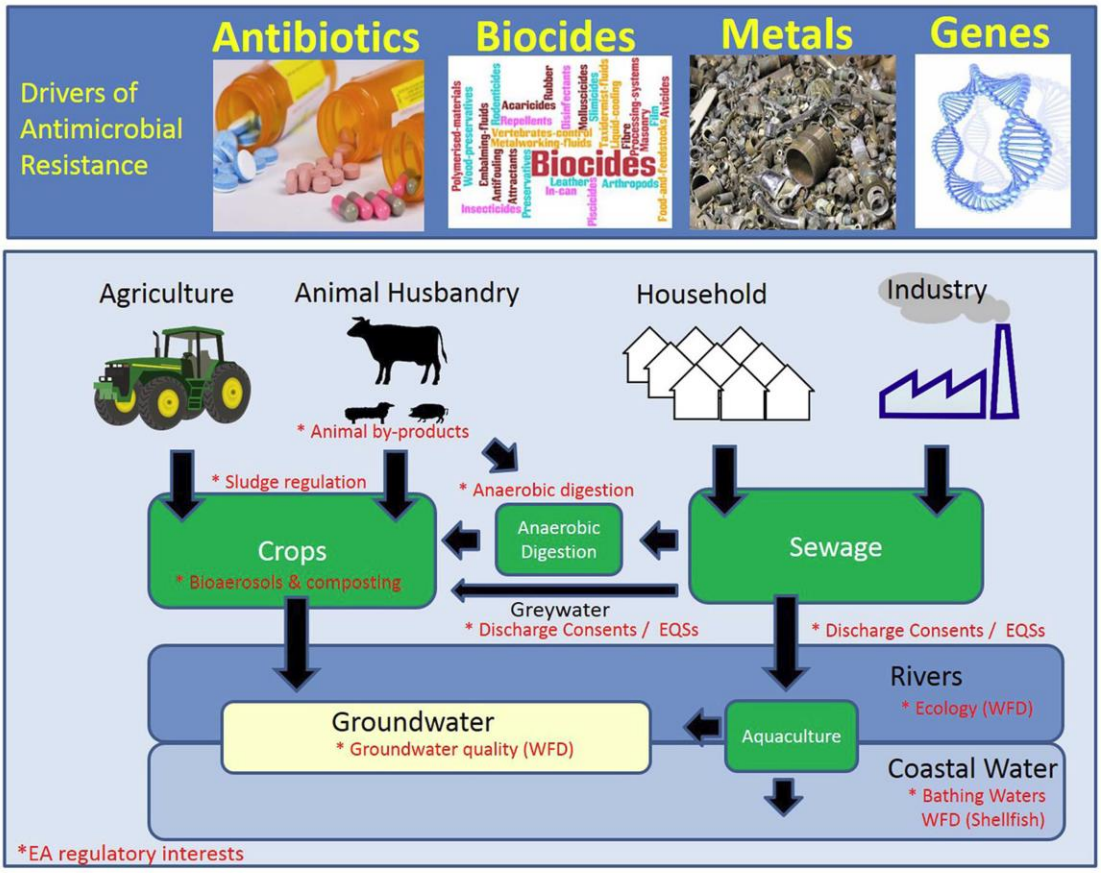


[1] Antibiotic resistance occurs when bacteria change in response to the use of these medicines through the production of enzymes, alteration of target sites, metabolic pathways, outer membrane permeability and efflux pumps.

ARGs can be transferred between non-pathogenic and pathogenic microorganisms by a process of horizontal gene transfer (HGT) on mobile genetic elements (MGEs) such as plasmids, transposons, and other genetic elements (Singer et al, 2016; Gaze and Depledge, 2017; McEwen and Collignon, 2018). Some common enteric pathogens that are important and adversely impact human health are *Salmonella spp*., *Campylobacter spp*., *Enterococcus spp*., *Escherichia coli* and *Staphylococcus aureus* (McEwen and Collignon, 2018). When these pathogens possess the ARG, they may survive the effects of specific antibiotics, and in some cases multiple antimicrobial chemicals, because of a higher minimum bactericidal concentration (MBC) making them more difficult to treat and consequently more dangerous (Meek et al, 2015; Singer et al, 2016; Gaze and Depledge, 2017). Since the 1940s, modern society have increasingly used several chemicals and create varying multi-chemical, hostile environments which can drive natural selection and co-selection providing the opportunity for organisms to benefit from cross-resistance (Gaze and Depledge, 2017). As a result, organisms find there are benefits to carrying the ARG as it may give them a competitive advantage over other organisms present in the environment (Meek et al, 2015).

There are three well-characterized classes of resistance-driving chemicals: (1) antimicrobials, of which there are four subclasses, antibiotics, antifungals, antivirals, and antiparasitics; (2) heavy metals; and (3) biocides (i.e., disinfectants and surfactants) (Singer et al, 2016; Gaze and Depledge, 2017). These classes of chemicals are vital to modern societies. Figure 2 illustrates the drivers of antimicrobial resistant including AMR genes and the potential routes of entry into the environment (Singer et al, 2016; McEwen, and Collignon, 2018).

Figure 2: Drivers of Antimicrobial Resistant Organisms.



Greater emphasis is placed on the management of antibiotics in the control of AMR given their pervasive use in the management of infections in humans and animals. As noted previously, the proliferation of ARGs are the result of a range of other chemicals and their use also drive global AMR resistance. The release of these chemicals and genes from the numerous development activities into the environment create multi-chemical environments that drive natural and co-selection AMR processes and the management and control of the use of antibiotics, pesticides, and disinfectants are therefore important within the context AMR control. Singer et al, 2016 discussed some of the environmentally relevant activities that are monitored by the UK's Environment Agency under existing regulations that require intervention to control the spread of AMR. These are presented in Table 1.

Table 1: Activities that could dive ARGs proliferation in the Environment.

Environment	Intersection of Environment Agency with AMR
Wastewater treatment plant (WWTP)	[1]Discharge of treated effluent (from industry and municipal sewage) to land, coast or rivers. [1]Disposal of sewage sludge [1,2,3]Disposal of anaerobic digestate
Agriculture	[1]Land spreading of manure, sewage sludge, and anaerobic digestate as fertilizer or soil conditioner. [1]Bioaerosols from agriculture (pig and poultry farming) and composting.
Animal husbandry	[1]Disposal of animal by-products [1,2]Disposal of animal slurry and manure [1,2,3]Disposal of anaerobic digestate
River water quality	[1,4]Impact of sewage effluent [1,4]Impact of diffuse pollution from farm-yard, manure- and biosolid-amended agricultural soil and storm runoff [1,4]Freshwater fish farm
Coastal and bathing waters	[1,4]Impact of farmyard runoff and sewage effluent on bathing water quality, and shellfish bed water quality [1,4]Impact of aquaculture on coastal water quality.
Groundwater quality	[1,5]Leaching of soil amendments (biosolids and manure) and chemical crop treatments

Evidently, infected humans and animals are known reservoirs for AMR pathogens making the management of feces, sewage and manure important drivers in the control of AMR (McEwen, and Collignon, 2018). Within this context, modelling conducted by Joss et al, 2006 also demonstrated that the removal of pharmaceutical (including antibiotics) and personal care products (PPCPs) from wastewater treatment plants found partial reduction in concentrations occurred through biological transformation and sorption onto sludge in nutrient removing wastewater treatment plants. As a result, Singer et al, 2016 identified from literature three important mechanisms that control the release of antibiotics to the environment specifically from wastewater treatment plants: (1) biodegradation; (2) absorption to sewage sludge; or (3) exit in the effluent unchanged. Sewage may therefore be an important driver in the context of Barbados based however on the burden of disease.

Background

Previous studies

The Environmental Protection Department (EPD) conducts routine water quality monitoring programmes as part of its environmental and heath monitoring and assessment mandate. Groundwater quality monitoring is conducted jointly with the Barbados Water Authority (BWA) to assess the quality of water abstracted from all the potable water abstraction wells, spring sources, and some agricultural wells. A recreational water programme to evaluate marine water bacteriological quality is conducted on a weekly basis. These programmes where designed to address traditional environmental pollutants and not the challenges associated with emerging pollutants. To address emerging pollutants, the Department conducts an annual widescreen monitoring programme and has recently done assessments on the prevalence of AMR microorganisms in different water environments. A summary of the results for those assessments are presented below.

A pilot assessment was conducted in 2010, found that of the forty-two samples that were tested, 103 *Escherichia coli* (E. coli) and 149 *Enterococci* isolates were identified. Samples were collected from ten sites: bathing beaches; springs; groundwater; and brackish water. The study showed that resistance was mainly to the first generation antibiotics: 52% E.coli to Cephalothin and 67% Enterococci to Erythromycin. Further testing by Minimum Inhibitory Concentration (MIC)[2] did not yield any significant change in the resistance profiles among the isolates. The sites which showed isolates with the highest number of resistant colonies were Kendal Plantation, Pebbles Beach and Miami Beach (Trotman, Gail, 2011). The decision of Cabinet based on Note (13) 237/ MED 16 that discussed this assessment is presented at Appendix I. This decision called for a more comprehensive assessment and acknowledged the importance of sewage to antibiotic residual distribution and AMR nationally.

The national assessment was conducted in 2013 and investigated twenty-two (22) public supply wells, eighteen (18) bathing water beaches, one (1) water treatment plant, two (2) sewage treatment plants, three (3) agricultural wells, three (3) surface water sites and nine (9) polyclinics, giving a total of fifty-eight (58) sample sites. The target organisms were *Escherichia coli (E. coli), Enterococcus* spp., faecal coliforms and *Klebsiella* spp. Appendix II is the Cabinet decision based on Note (16) 520/MED (19) which called for a review of the existing legislative frameworks as they pertain to the health care and environmental practices that may contribute to an increase in antibiotic resistance on the island and to determine whether there is a need for new legislation or policy, or amendments to current instruments to regulate the use and disposal of antibiotics. The decision called for more data to be generated on the issue of antimicrobial resistance.

In the study of the two hundred and four (204) *E. coli* isolates analyzed, twenty-four (24) resistant isolates were found at sixteen sites. Eleven (11) of these were beach sites: Accra, Brandons, Brownes, Dover, Coach House, Graveyard, Miami, Paradise, Silver Sands, Pebbles and Worthing. The remaining five (5) were three (3) surface water sites: Graeme Hall, Holetown, Careenage; and two (2) agricultural wells, Kendal and National Hatcheries (EPD et al, 2015).

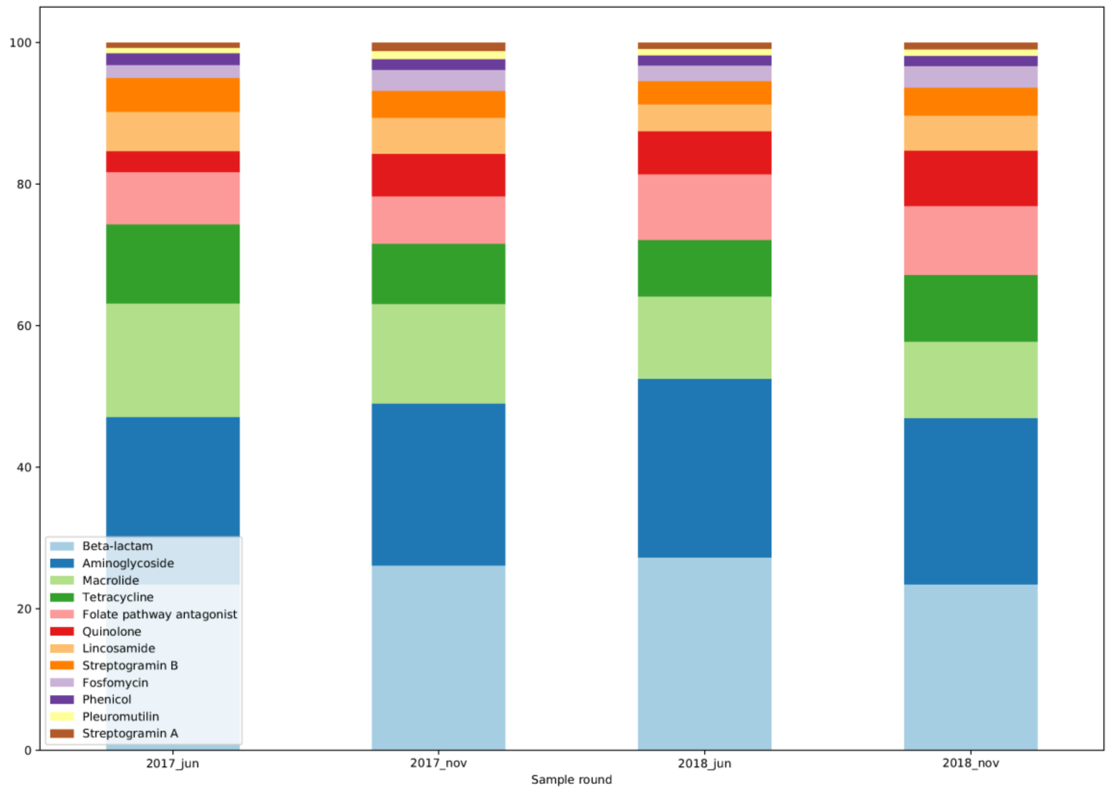
Similarly, two hundred and forty-one (241) *Enterococci* isolates were analyzed, of which, fifty-two (52) resistant isolates were found at a total of twenty-five (25) sites. Fifteen (15) of these were beach sites: Worthing, Pebbles, Mullins, Miami, Heywoods, Graveyard, Dover, Accra, Amaryllis, Brandons, Brighton, Brownes, Batts Rock, Silver Sands and Coach House. Resistant isolates were also found in three (3) public supply wells (Bowmanston, Benn Spring and Codrington), three (3) agricultural wells (Kendal Plantation, Engine Field and National Hatcheries), two (2) sewage treatment plants (Bridgetown and South Coast Sewerage), one (1) water treatment plant (Desalination waste: Brine) and one (1) surface water site, Holetown Lagoon. Additionally, no resistant organisms were found in any drinking water sampled from the polyclinics or Queen Elizabeth Hospital (EPD et al, 2015).

[2] The Minimum Inhibitory Concentration (MIC) in clinical settings refers to the concentrations needed to inhibit the growth of, or kill, a target pathogen (Singer et al, 2016).

In response to the Cabinet's decision of July 2016 based on Note (16) 520/MED (19), the EPD collected water samples for assessments between June 2019 to July 2020. Forty-eight (48) sites were assessed with five hundred and eighty-six (586) samples collected and six-hundred and forty-two (642) isolates found. In addition to water samples, one hundred grams (100 g) of soil and animal manure from animal husbandry and sporting locations were also collected and submitted to the laboratory. Samples were also collected from health care institutions and analysed. The analysis and interpretation of the results from this study are continuing as the COVID-19 pandemic interrupted the process. However, a preliminary assessment of the samples to date show that isolates includes *Klebsiella spp*, *Citrobacter spp* and *Escherichia coli*. A number of the *E. coli* exhibited resistance to more than five antibiotics including 2nd and 3rd generation drugs. The occurrence of intermediate resistance to newer drugs e.g. beta lactams, aminoglycosides and quinolones as well as carbapenems is of significant concern from this assessment. It was also observed that isolates from the healthcare institution, showed significantly more resistance than those isolated from the environment, which showed many different resistant mechanisms. The full report will be completed and submitted based on available resources (EPD under preparation).

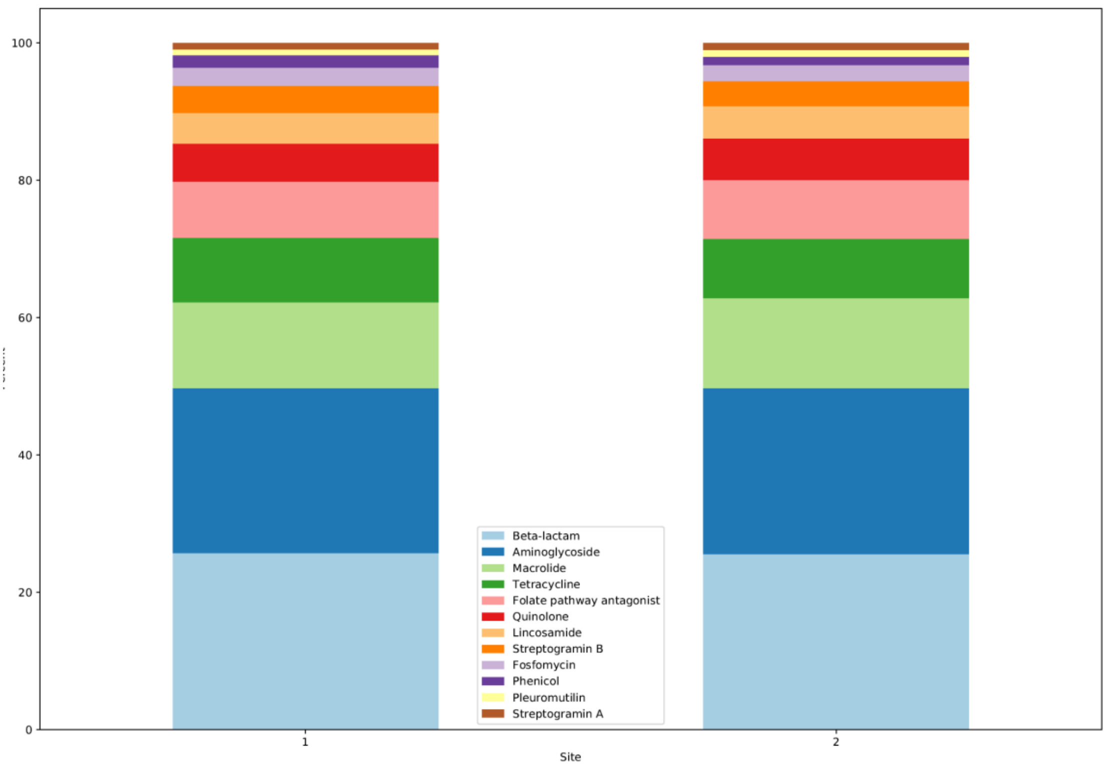
Through the EPD, Barbados participated in the Global Sewage Surveillance Project between 2016 and 2018. Samples were collected from Southern Meats and Six Roads Meat abattoirs, and the Bridgetown and South Coast Sewage Treatment plants. Across the two years of sampling, see Figure 3, Beta-lactam, Aminoglycoside, Macrolide, and Tetracycline are the most prevalent ARGs present in the sewage discharge. Some of these classes of antibiotics were previously identified (Trotman, 2011; EPD 2015) in environmental samples from previous EPD assessments.

Figure 3: Barbados Resistome by Sampling Round



Similar to the temporal distribution of the ARGs, the percentage distribution of ARGs shows little variation by site when Figure 3 and Figure 4 are compared[3]. Both sewage treatment plants discharge through ocean outfalls: Bridgetown Treatment Plant discharges via a 900m outfall off Princess Alice Highway; and the South Coast Sewage Treatment Plant now discharges 800m off Worthing Beach in 30m of water (Baird, 2019). Though the bacteriological water quality remains good and in compliance with the USEPA recreational water quality standards, after the installation of the temporary outfall, minor changes in water quality were observed from EPD's routine monitoring programme at Accra Beach. Previous assessments (EPD, 2015) showed that beaches can meet the recreational water quality criteria but have resistant organisms present.

Figure 4: Barbados Resistome by Site



The overall study found that genes showed resistance to a total of 19 different classes of antibiotics across all regions. Figure 5 shows the variation in the Barbados Samples superimposed on the on the global variation in resistance mechanisms. Barbados data is identified as black points grouped near the axis. The average 10 most abundant classes are presented in Figure 6 and Figure 7, which show the distribution by region (Brinch and Aarestrup, 2020). Whilst Beta-lactam, Aminoglycoside, Macrolide, and Tetracycline are the four main mechanisms of a total of twelve (12) identified for Barbados; Macrolide, Aminoglycoside, Streptogramin B and Tetracycline are the dominant mechanisms identified globally when Figure 3 and Figure 4 are compared to Figure 6 and Figure 7.

[3] Personal communication with Professor Christian Brinch on the Barbados Resistome 10 September 2021.

Figure 5: Barbados Resistome Variation Compared to the Global Resistome Variation by Region

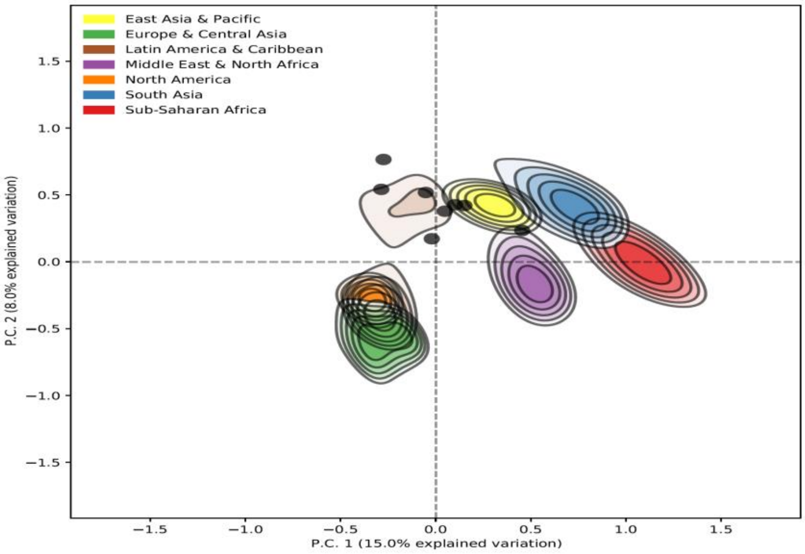


Figure 6: 10 Most Abundant Classes of Antibiotics

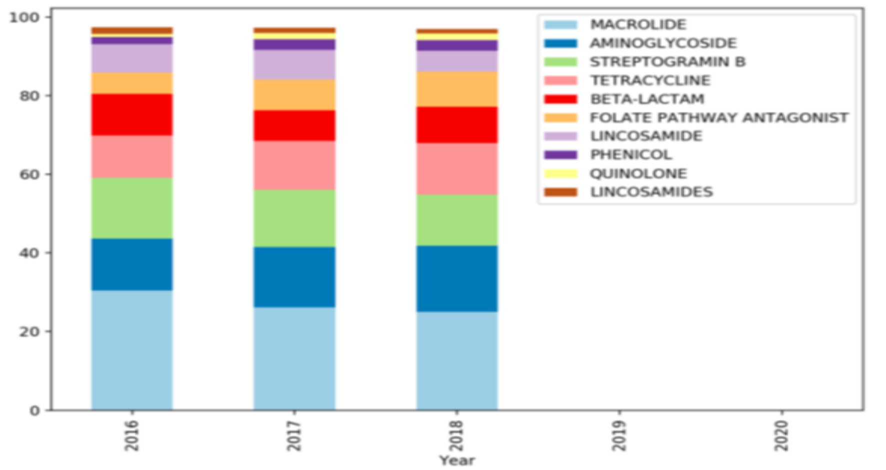
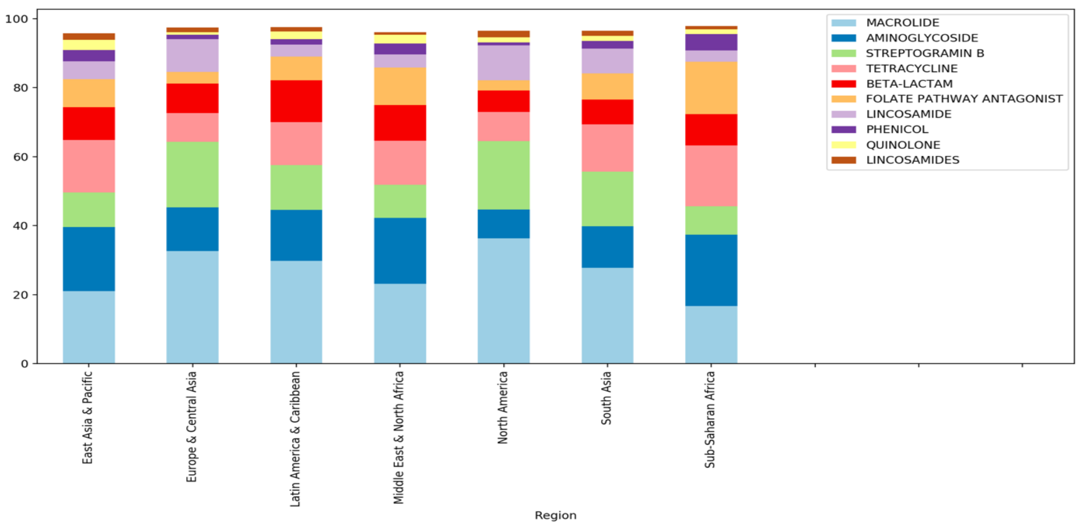
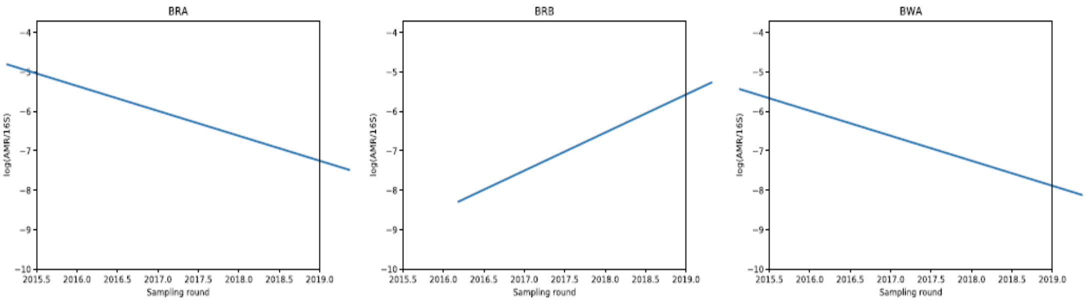


Figure 7: Resistome composition by Region



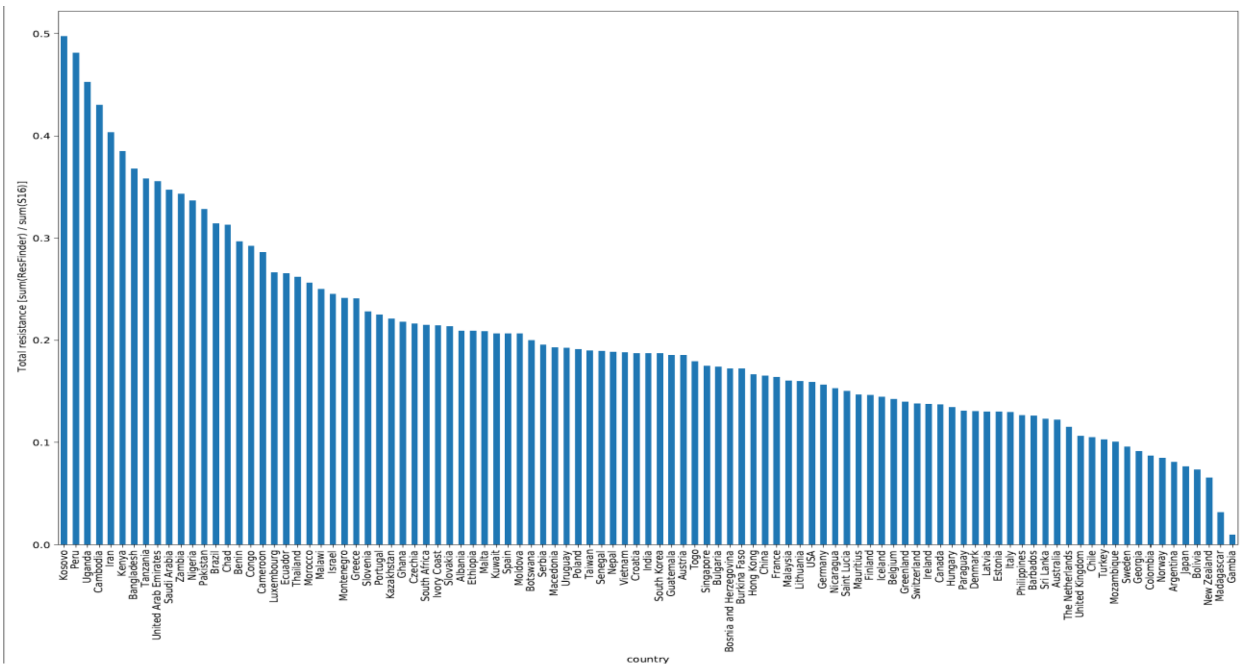
Based on a linear regression, the authors suggested with reservation, the possible direction in the AMR load in each country (Brinch and Aarestrup, 2020). Figure *8* presents the estimated changes in AMR load by country and suggest that there may be an increasing trend for Barbados (BRB).

Figure 8: Possible changes in AMR loads by Country[4]



Finally, Figure *9* shows the total resistance for all participating countries in the global study. Barbados is ranked in 18th position from the right at approximately 0.15 total resistance.[5]

Figure 9: World Distribution of Total Resistance



[4] Barbados information is presented as BRB between Brazil and Bowswana.
[5] Personal Communication with Professor Christian Brinch September 10, 2021.

National Situation

Figure 2 presented the main drivers of AMR organisms of antibiotics, antifungals, antivirals, and antiparasitics; (2) heavy metals; (3) biocides (i.e., disinfectants and surfactants). All of these chemicals are used in varying quantities in Barbados. Of the chemicals that are of concern in relation to AMR, only pharmaceuticals (antibiotics, antifungals, antivirals, and antiparasitics) and those classified as pesticide are regulated in Barbados. Pharmaceuticals are regulated through the Drug Service Act CAP 40A which establishes a Barbados National Drug Formulary. Pesticides are regulated through the Pesticide Control Board and are managed under the Pesticides Control Act CAP 395 and the Pesticides Control (Approval of Pesticides) Regulations, 1974; and the Pesticides Control (Labelling of Pesticides) Regulations, 1976. All other chemicals are not controlled or regulated.

Antibiotics

Antibiotics are used to treat infections in humans and animals and are considered the greatest concern globally as the main drivers for AMR (O'neill, 2016). Specifically there are used to treatment disease and as prophylaxis for the prevention of disease (O'neill, 2015). Common non-medical applications where antibiotics are used include animal husbandry, bee-keeping, fish farming and other forms of aquaculture, ethanol production, horticulture, antifouling paints, food preservation, and domestically (Meek et al, 2015). There are also used in animal husbandry as growth promoters to increase feed-to-gain efficiency (O'neill, 2015). The importance of nonmedical uses of antibiotics is that, resistance developed during nonmedical use of antibiotics can confer resistance to clinically useful antibiotics (Meek et al, 2015).

The distribution in their used was discussed by O'neill, 2015 who noted that in the United States of America, seventy percent (70%) of the antibiotics deemed medically important for human health were utilizes in the food chain in animal husbandry. As antibiotics are used to treat infections, it is expected that the burden of disease will also contribute to the geographical occurrence of antibiotics in the environment. Singer et al, 2016 indicated that a large fraction of the antibiotics consumed by humans are excreted in the urine and feces in the biologically active form. The expected routes for antibiotics to enter the environment are therefore through sewage disposal, manure, wastes water from antibiotic and other AMR select chemical manufacture, and improper disposal of unused antibiotics and AMR chemicals (Gaze and Depledge, 2017). It is assumed that an animals' utilisation of antibiotics is similar to that of humans, further suggesting that environmental microorganisms may be exposed to antibiotics, and other organisms with the ARGs in unnatural quantities, which can drive natural selection and HGT via the MGE processes in sewage treatment plants, other sewage disposal systems and in the used and disposal of animal manure.

For instance**,** EPD, 2009 reported in its assessment of land based sources of marine pollution that poultry rearing produced a significant amount of litter, consisting of animal excreta and an absorbing medium (bedding) such as sand, saw dust, or bagasse. This was disposed using a variety of methods such as landfilling, burning, burying, dumping, selling, and the manure may be used directly or in compost as a fertilizers. The assessment (EPD, 2007a; EPD, 2009**)** showed that significant quantities of pollutants are generated within the food chain which are discharged to the environment and may affect the groundwater and marine environment through several pathways. Stantec Consulting International Ltd., 2003 also provided evidence based on surveys of gully systems and found that in two hundred and sixty-six (266) gully segments inspected, a total of 369 dumpsites were found to contain bulky, domestic and construction wastes. Bulky, domestic and construction wastes were the most frequently encountered wastes in dumpsites, in that order. However, a total of 49 liquid waste sites were found in 39 gully segments, with grey and animal wastewaters being the most frequently encountered waste types. These studies demonstrate the potential pathways for agricultural wastes into the environment.

Barbados has one secondary municipal sewage treatment plant and one preliminary treatment plant that both collect sewage from approximately 4500 property connections (PCG and GIZ, 2021). Based on the ground water protection policy, approximately 95% of sewage generated is discharged directly into disposal wells without treatment. R. J. Burnside, 2010 in their analysis of the threats to the groundwater aquifers, used a modified DRASTIC[6] assessment approach, produced a vulnerability classification of high, very high or extremely high for 80.4% of the island. Combining this information with the geology of the island, disposal of untreated sewage pose a threat to groundwater aquifers and could increase the probability of AMR microorganisms being abstracted as part of the potable water system. This however, depends on the burden of disease across the island and the quantity of antibiotics and other ARG chemicals present in sewage and used within developments within water abstraction areas. Table 2 presents the mass of antibiotic imported into Barbados which is approximately 8416 Kg over the ten year period. Understanding the defined daily dose (DDD) per 1,000 inhabitants for antibiotic use in humans and the per population correction (PPC) dose in food-producing animals would provide better insight into the annual usages by sector as well as establish an indicators to track antibiotic usage trends at the national level.

Table 2: Annual volume of antibiotics imported in Barbados

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Annual Imports (kg)	385	828	642	2879	553	1112	192	705	828	292

Source: Statistical Services Department

The national storm water drainage study conducted assessments on groundwater and surface wasters and showed that all waters were impacted by human activity with contaminants of emerging concern including artificial sweeteners, caffeine, biocides (including herbicides), polymer precursors, pharmaceuticals, personal hygiene products, and degradation products from detergents and nicotine along with chemicals used for many other purposes (Baird, 2017). Specifically, pharmaceuticals such as Carbamazepine,[7] Erythromycin, and Quinoline were identified in the assessment. Previous assessments by Edwards et al, 2015 showed that the presence of caffeine in water bodies were are principally attributed to anthropogenic sources as caffeine-producing plants are not commonly grown on the island of Barbados. Later assessments by Edwards et al, 2019 detected that concentrations of carbamazepine, ibuprofen, and trimethoprim correlated well with the concentrations of indicating

[6] The acronym DRASTIC stands for the seven parameters used in the model which are: Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and hydraulic Conductivity.

[7] Carbamazepine is in a class of medications called anticonvulsants. It works by reducing abnormal electrical activity in the brain.

contamination of groundwater by infiltration from domestic sewage. This confirmed work done by the EPD over the period 2007 to 2010 that detected pharmaceuticals and personal care products in groundwater (EPD, 2011). The National Antibiotic Resistance Study of 2015 found resistant isolates at both municipal sewage treatment plants on the island (EPD et al 2015). This suggest that conditions are being created within wastewater treatment systems and the groundwater environment that favour the growth of resistant organisms, particularly where antibiotic concentrations are below the MIC (Meek et al, 2015).

Pesticides, Metals and Disinfectants

Pesticide means any substance, or mixture of substances, or micro-organisms including viruses, intended for repelling, destroying or controlling any pest, including vectors of human or animal disease, nuisance pests, unwanted species of plants or animals causing harm during or otherwise interfering with the production, processing, storage, transport, or marketing of food, agricultural commodities, wood and wood products or animal feeding stuffs, or which may be administered to animals for the control of insects, arachnids or other pests in or on their bodies (WHO, 2010). Pesticides are used widely and include: herbicide, insecticides nematicide, molluscicide, piscicide, avicide, rodenticide, bactericide, insect repellent, animal repellent, antimicrobial, fungicide, and lampricide. Approximately four hundred and thirty-six (436) pesticides were registered by the Pesticide Control Board between 2017 and 2020[8] for local consumption.

Pesticides are used in both the agricultural and domestic setting and are applied by pest control operators, farmers or householders to control pest. The local uses include fumigation, termite control, pest control, rodent control, vegetation control, and insect control among other applications (EPD, 2007b). The importance of pesticides to AMR proliferation are those formulations that contain heavy metals and biocides like Acticide, which is used as a microbiocides in paints. Metals such as Lead, Copper, Zinc, Cadmium, and Arsenic have been used in pesticides and as animal growth promoters and nutritional supplements, fertilizers, and fungicides in aquaculture and agriculture applications (Singer et al, 2016). Twenty (20) metal resistance genes have been identified experimentally with copper genes being the most abundant. Metal genes share similar traits to antibiotics in the mechanism for destroying microorganism and therefore spread ARGs through co-selection but must be bioavailability to drive the process (Singer et al, 2016; Gaze and Depledge, 2017; Meek et al, 2015). Recent work completed by the EPD demonstrated the presence of Cadmium, Lead and Mercury in soils and sediment samples as well as in agricultural crops and fish species in varying concentrations. Some levels detected in the samples exceeded the threshold levels for some fish species (EPD 2019a; EPD 2019b; EPD 2019c). The EPD also identified hexavalent Chromium (Cr^{6+}) in 2005 at levels ranging from 0.11 to 0.23 mg/l in groundwater monitoring boreholes at Arch Hall, Molyneux and Sandy Lane during the preliminary assessment of the impact of leachate from the Mangrove Pond Sanitary Landfill on groundwater (EPD et al 2005).

Another group of chemicals used in modern society are biocides. These are disinfectants that are commonly used in hospitals, cosmetics, household cleaning products, wipes, and furniture preservatives, farms and an array of industrial

[8] Data provided by the Pesticide Section, Ministry of Agriculture and Food Security from the Pesticide Registration Database.

processes. Personal care products may also contain biocides such as triclosan and quaterium ammonium compounds (QACs) which are effective at killing bacteria, but at sub-lethal concentration, can render organisms less susceptible to a wide range of antibiotics (Meek et al 2015; singer et al 2016). Table 3 shows that pesticide imports over the last ten years have been relatively stable at an average of 905,051 kg annually with total imports of 9,955,562 kg over the period. The total imports for disinfectant were 2,589,385 kg less than pesticide imports but showed a mark increase of 87% between 2019 and 2020 to 1,029,048 kg. The average annual imports were 669,652 kg demonstrating the impact of the Covid-19 pandemic and the expected consumption of antimicrobial disinfectant products in an effort to protect against the virus. This data is not totally reflective of antimicrobial agency usage but would have to be segregated to determine actual usage of antimicrobial agents nationally.

Table 3: Pesticide and Disinfectant Imports for 2010 to 2020

Year	Pesticides (Kg)	Disinfectants (Kg)
2010	1,101,427.00	753,460.00
2011	997,834.00	632,403.00
2012	1,154,442.00	670,999.00
2013	960,390.00	656,697.00
2014	877,732.00	665,631.00
2015	738,346.00	618,370.00
2016	721,062.00	619,768.00
2017	848,338.00	551,106.00
2018	769,036.00	617,589.00
2019	848,338.00	551,106.00
2020	938,617.00	1,029,048.00

Source: Barbados Statistical Services

Metals

Technology has advance to the stage where the traditional uses of metals are now supplemented by more efficient delivery systems based on nanotechnology. Metals, because of their numerous applications are incorporated into a variety of products as nanomaterials, such as food, cosmetics, personal care products, antimicrobial agents and disinfectants, clothing and electronic devices using nanotechnology. Some examples of these applications are the use of silver, titanium and zinc and their oxides, in sunscreen, toothpaste, cosmetics, food, paints, and clothing. Nanosilver, because of its antimicrobial properties, is widely used in consumer products such as sports textiles, shoes, deodorants, personal care items, washing powder and washing machines (McGlade, 2017). The growing use of nanomaterials through nanotechnology may make metals with antimicrobial properties more bioavailable to drive resistance to metals and impart antibiotic resistance in microorganism when those genes are transferred on the MGE. It is anticipated that antibiotic, biocides and metals will all end up in the sewage and wastewater generated from all types of human developments. This will generally increase the abundance of ARGs in the environment.

SWOT ANALYSIS OF THE ENVIRONMENTAL SECTOR

An analysis of the strengths, weaknesses, opportunities, and threats of the environmental aspect of AMR in Barbados is presented below.

Table 4: SWOT Analysis of Environmental Aspects of AMR in Barbados

	INTERNAL		INTERNAL
STRENGTHS	• Modern clinical laboratory. • Strong medical systems. • Laws to control drugs and pesticides.	**WEAKNESSES**	• No comprehensive chemicals, pharmaceuticals and pesticide information management system. • No policy, law or standards for chemicals in products. • Limited research on the impacts of ARG and AMR on ecosystems and ecosystem services. • Limited understanding of the effects of AMR, pharmaceuticals and personal care products on ecosystems and ecosystem services. • Weak AMR environmental monitoring and evaluation frameworks. • Limited chemicals laboratory capacity. • Limited knowledge of environmental professionals on AMR and ARG process.
	EXTERNAL		**EXTERNAL**
OPPORTUNITIES	• Build partnerships with national, regional and international organisations to improve knowledge on AMR and enhance national capacity. • Explicitly include AMR in the modernization of environmental governance arrangements. • Leverage external financing for capacity development. • Development comprehensive environmental laws to address AMR chemicals agents in products. • Establish research initiatives to address national environmental AMR challenges. • Develop a comprehensive national policy on Antimicrobial resistance (AMR). • Evaluate and upgrade wastewater treatment and water disinfections systems to account for AMR.	**THREATS**	• Prolonged depressed economic activity due to the pandemic • Cost of analytical technology for AMR analysis. • Cost of and access to international financing. • The significant costs of overseas testing of environment samples.

National Action Plan

What Do We Know?

Based on the literature review and the Strengths, Weaknesses, Opportunities and Threats Analysis there are a number area where knowledge is sounded.

a. The resistome for sewage samples collected from the Bridgetown and South Cost Sewage treatment plants showed resistance to twelve classes of antibiotics. The classes of antibiotic with the higher percentage represent those drugs that were more frequently used to treat infection. Some classes of drugs are used to treat infection where the organism is resistant to other antibiotics.

b. ARGs occur naturally but when those genes are transferred to pathogenic organisms and humans and animals get infected, these infections are more difficult to treat.

c. The geology of Barbados is such that eighty-five percent (85%) of the land mass is unconsolidated coral limestone with the groundwater aquifers being classified as highly vulnerable to pollution. Sewage disposal and certain types of agricultural activity have been identified by several studies as threats to the groundwater aquifer.

d. Approximately ninety-five (95%) percent of the sewage generated in Barbados is disposed directly to the sub-surface via suck well or drainage wells. At most, this sewage only undergoes preliminary treatment using septic tanks in Zone 1 classified lands. Sewage is an excellent environment for the proliferation and distribution of the ARGs and consequently AMR under certain conditions of pharmaceutical and other chemicals usage in the home, commercial and industrial settings.

e. Several studies have identified sewage as a significant pollutant to the groundwater and the nearshore marine environment. Marine waters around Barbados were classified within the Cartagena Convention State of the Convention Area Report as anoxic. Subsurface discharge of sewage and storm water to the groundwater aquifer can be contaminated with groundwater from aquifers then contributing pollution to the marine environment.

f. Pharmaceuticals, personal care products, and pesticides were identified in groundwater suggesting that sewage and storm water runoff contribute to the current quality of these water resources.

g. Antimicrobial resistant organisms were found at several locations including beaches, farming areas and agricultural wells.

h. Infections from resistant organisms are more difficult to treat and increased AMR in the nearshore marine environment can adversely affect residents and the tourism sector.

i. The Ministry of Agriculture identified eleven (11) cases of multi-drug resistance organisms within dogs, horse, parrot and a primate over the period 2015 to 2017.

j. In 2013, *Carbapenem Resistant Klebsiella Pneumonia* (CRKP), which WHO classified as a priority 1 resistant organism, was identified at the Queen Elizabeth Hospital.

k. Occasionally, E. Coli, and or faecal streptococci are detected at the source of the potable water supply wells prior to distribution. Detection of microorganisms generally occurs when there is inadequate chlorination.

What We Don't Know?

There are several areas where a better understanding of the extent of AMR could improve policy and actions to protect the public and the environment.

a. What is the extent, distribution and proliferation of the ARGs in the groundwater?

b. Microorganisms with the ARGs have a higher minimum bactericidal concentration and take longer to kill, is the method of disinfection at the potable water supply well adequate? Should the chlorine contact times at each potable water supply source and reservoir be evaluated to determine adequacy and whether the effective chlorine contact time is achieved before distribution of the water?

c. Are the resistance organisms found in the health care institutions present in environmental media and have these organisms transferred the ARGs to environmental organisms?

d. What is driving the frequency of AMR detected on the island: the use of antibiotics, disinfectants, metals, pesticides, biocides or a combination of all these chemicals?

e. Are infections from AMR organisms only acquired in health care institution or are some of the infections acquired from environmental sources, food and agricultural activity?

f. Will there be a time when the ARGs will be ubiquitous in environmental organisms? Can the process be reversed?

Potential Area of Research[9]

To fill the information gaps research should be conducted in the following areas:

a. Conduct a national soil, groundwater, farm animal and food survey to determine the AMR resistome for each medium and evaluate the impacts of antimicrobial agents on soil ecology, coral reefs and reef ecology. The preliminary cost estimate is $1.5 million.

[9] The cost estimates provide for research are preliminary with error between 20% to 40% and more accurate costs need to be generated based on better define scope for each potential research topic.

b. Conduct a national assessment to determine the distribution of AMR drivers inclusive of pharmaceuticals, biocides, metals and disinfectants. The preliminary cost estimate is $30,000.

c. Do a survey of laboratories involve in microbiology and the proliferation of ARG to determine method of disposal of ARGs. The preliminary cost estimate is $5,000.

d. Conduct an ecological assessment to determine the impact of pharmaceuticals, biocides and detergents on the ecology of the environment (soils and water). The preliminary cost estimate is $30,000.

e. An evaluation of the ARG resistome in the Bridgetown and South Coast Sewage Treatment Plants, the sewage sludge disposed at the Spencers plot, and the potential transport of AMR organisms in storm water to groundwater and the marine environment from the Spencers plot. The preliminary cost estimate is $30,000.

f. A Survey of the medical and agricultural sectors to determine the burden of disease for which antibiotics are prescribed to treat the infections. This would estimate the doses per annum of antibiotics used to control infections in humans and animals. The preliminary cost estimate is $20,000.

g. A desk top assessment on the volumes/mass and uses of antibiotics agents (Pharmaceuticals, biocides, pesticides, and metals) imported for consumption and the potential non-hazardous alternatives to these chemicals. The preliminary cost estimate is $10,000.

h. Source tracking assessment and genome sequencing to identify if health care and agriculture multi drug resistant organisms are present in environmental samples collected from sewage treatment plants, groundwater and marine species. The preliminary cost estimate is $40,000.

i. An assessment of the AMR profile in landed reef fish at the fisheries markets which were captured from areas around the Bridgetown and South Coast Sewage Treatment Plants outfalls. The preliminary cost estimate is $30,000.

Proposed Activities for the AMR National Action Plan

a. A review of disinfection systems in water and sewage treatment and upgrade of the systems where necessary.

b. Strengthen environmental monitoring for AMR with the inclusion of full genome sequencing and conduct the marine water quality assessment every five years.

c. Establish an information management systems to track locations where AMR organisms are detected, the resistant mechanisms and the associated chemical agents driving the resistance profile.

d. Strengthen the laboratory capacity to conduct ARGs resistome and full genetic sequencing of resistant organisms to determine the resistant mechanisms.

e. Research alternative chemicals to antimicrobial agents for non-medical purposes.

f. Draft an AMR Policy to capture the approach to the importation, use, handling and disposal of AMR agents.

g. Prepare comprehensive legislation to support the policy provisions identified in the proposed AMR Policy.

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