is available at https://doi.org/10.1289/EHP1774.

Endocrine Disruptors and Health Effects in Africa: A Call for Action

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Background: Africa faces a number of unique environmental challenges. Unfortunately, it lacks the infrastructure needed to support the comprehensive environmental studies that could provide the scientific basis to inform environmental policies. There are a number of known sources of endocrine-disrupting chemicals (EDCs) and other hazardous chemicals in Africa. However, a coordinated approach to identify and monitor these contaminants and to develop strategies for public health interventions has not yet been made.

Objectives: This commentary summarizes the scientific evidence presented by experts at the First African Endocrine Disruptors meeting. We describe a "call to action" to utilize the available scientific knowledge to address the impact of EDCs on human and wildlife health in Africa.

Discussion: We identify existing knowledge gaps about exposures to EDCs in Africa and describe how well-designed research strategies are needed to address these gaps. A lack of resources for research and a lag in policy implementation slows down intervention strategies and poses a challenge to advancing future health in Africa.

Conclusion: To address the many challenges posed by EDCs, we argue that Africans should take the lead in prioritization and evaluation of environmental hazards, including EDCs. We recommend the institution of education and training programs for chemical users, adoption of the precautionary principle, establishment of biomonitoring programs, and funding of community-based epidemiology and wildlife research programs led and funded by African institutes and private companies. https://doi.org/10.1289/EHP1774

Introduction

Over the last several decades, there has been a global shift in the causes of mortality and morbidity of illness from a focus on infectious diseases to noncommunicable diseases (NCDs). Emerging NCDs disproportionately affect vulnerable groups such as women, children, and the poor (Atiim and Elliott 2016). The Global Burden of Disease effort has substantially contributed to understanding NCDs in Africa (Global Burden of Disease Study 2015), but knowledge gaps remain about endocrine-related diseases/dysfunctions, particularly obesity and diabetes, which continue to increase in prevalence (Mbanya et al. 2014; Tuei et al. 2010), along with cardiovascular disease, cancer, depression, and asthma. Indeed, type 2 diabetes is growing faster in Africa than anywhere else in the world (Yako et al. 2016). Causes of increases in NCDs in Africa and globally are complex and likely involve both genetic and environmental factors. Because the genetic background of human populations has remained unchanged over the last decades, the emerging focus is on understanding the extent to which environmental factors contribute to the increases in NCDs.

Many environmental chemicals of concern both globally and across Africa are categorized as endocrine-disrupting chemicals (EDCs) (IPCS 2002; Bergman et al. 2013), that is to say, compounds that interfere with hormone action, resulting in increased susceptibility to disease across the lifespan. Substantial disease burdens and costs resulting from EDCs have been calculated in industrialized countries, and these costs may be higher in areas of the world where the regulatory infrastructure is less well developed (Trasande et al. 2015; Trasande and Liu 2011). The shift to urban living and industrialized economies in Africa and in

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None of the authors is employed or was funded by any of the companies sponsoring the Endocrine Disrupting Chemicals (EDCs) in Africa meeting from which this commentary draws information and opinion. B.B. receives royalties from various patents related to PPARgamma, SXR, and BXR. J.D. is employed by the International Persistent Organic Pollutants (POPs) Elimination Network (IPEN), a network of public interest nongovernmental organizations working in more than 100 countries to reduce and eliminate the harm to human health and the environment from toxic chemicals. J.D. receives no personal financial gain from the publication of this manuscript. All other authors declare they have no actual or potential competing financial interests.

Received 16 February 2017; Revised 22 May 2017; Accepted 24 May 2017; Published 22 August 2017.

developing countries elsewhere has increased the amount of contaminants released into water, air, and soil; these contaminants include pesticides, heavy metals, toxic industrial chemicals, and hazardous wastes, many of which are EDCs (Miller et al. 2016). Young children and fetuses are particularly susceptible to the effects of these contaminants (Heindel and Vandenberg, 2015). Although most human studies examining the health effects of such contaminants are conducted in populations in the United States, Europe, and some parts of Asia, EDCs are used on a global scale. Biomonitoring evidence indicates that exposures to some classes of chemicals, including pesticides, may be higher in Africa and Asia than in other parts of the world, suggesting that these populations may have higher risks (Fång et al. 2015; Stuetz 2006). Although exposures to EDCs likely vary from place to place, in general, the health outcomes associated with exposures to these compounds are expected to be similar (Bergman et al. 2013).

To survey the state of knowledge on environmental health risks from exposure to EDCs in Africa, The First African Conference on Health Effects of Endocrine Disruptors: Challenges and Opportunities for Africa was hosted by the University of Pretoria (UP) Environmental Chemical Pollution and Health (ECPH) Research Unit from 2–6 November 2015 at the Skukuza Conference Centre in Kruger National Park, South Africa. The objective of this meeting was to identify the unique challenges and opportunities facing Africa, with a specific focus on exposures and associated health effects. Existing knowledge gaps were identified to guide future research needed to fill those gaps and advance knowledge to improve human and animal health in Africa in the long term. This commentary synthesizes the information presented and discussed at the meeting with the goal of bringing increased attention to and finding solutions for the unique challenges facing Africa regarding the role of EDC exposures in human and wildlife health.

Africa's Unique Challenges to Improve Environmental Health

Africa, with its more than 1 billion people, is experiencing accelerated urbanization and social, political, industrial, and economic development (Nweke and Sanders 2009). Economic growth includes chemical intensification whereby chemical production is shifting to developing countries; projections are that by 2020, 31% of global chemical production and 33% of global chemical consumption will be in developing countries. In many of these countries, agriculture is the largest economic sector and the most significant user of manufactured chemicals, many of which are EDCs (Gore et al. 2015). Furthermore, increased use of personal care products, adhesives, textiles, lubricants and chemically complex articles such as cell phones and laptop computers, which contain EDCs and other chemicals, further increases the likelihood of human exposures (Bergman et al. 2013). Emerging chemicals management programs note that the "aggregate concern[s] in Africa were heavy metals and PAHs [polycyclic aromatic hydrocarbons] . . . followed by e-waste, lead in paints, open burning, and illicit drugs" (STAP 2012). However, this report notes that the bulk of human and environmental contamination occurs from the use and disposal of these products rather than from manufacturing. Overall, developing countries seem to attract the development of economic sectors that are among the most polluting, to the disadvantage of environmental and human health (UNEP 2013a).

Furthermore, many developing countries are burdened by legacy social issues that adversely affect health such as poverty, colonialism, civil wars, land degradation, and a group of seemingly intractable communicable diseases (de-Graft Aikins et al. 2010). Africa has higher exposure to traditional environmental risks and poorer conditions related to water, sanitation, hygiene, and solid fuel use compared with global norms. The World Health Organization (WHO) and United Nations Environment Programme's (UNEP's) landmark report, "Continental Challenges & Change: Environmental Determinants of Health in Africa" (WHO/UNEP 2015), estimated that $\sim 28\%$ of the disease burden in Africa is attributable to environmental factors that pose risks to both human health and ecosystem integrity. Some risks are natural disasters such as earthquakes, floods, rising sea levels, gas release, and drought, but many are consequences of human activity, including deforestation, loss of biodiversity, marine pollution, lack of sound management of chemicals, hazardous and nonhazardous wastes, drinking water pollution, and indoor and outside air pollution.

African ecosystems are deteriorating rapidly, and their destruction is already adversely affecting human health (Tosam and Mbih 2015). Africa is therefore in a vicious cycle, and it will not be able to escape without thoughtfully guided interventions from international partners and commitment by African governments to make changes for the good of the continent. Our goals are to emphasize the unique challenges that face African nations and to identify opportunities and the tools to address them.

Human EDC Exposures in Africa

Indoor and Outdoor Air Pollution

Air pollution, which contains many components that are classified as EDCs including dioxin, PAHs, and particulate matter, is a pressing problem across Africa. Africa is the largest source of biomass burning emissions (e.g., emissions resulting from the burning of living and dead vegetation) (Roberts et al. 2008). Forest fires, firewood combustion, and savanna fires are common forms of burning; the last is most dominant (Delmas et al. 1991). Burning of household waste, which contains and/or releases many EDCs and other hazardous chemicals, is also common practice in many African countries. Human activities over the past 100 y have significantly increased biomass burning (WHO 2015a). In sub-Saharan Africa (SSA), 60% of greenhouse gas emissions come from slash-and-burn farming, in which the natural vegetation is cut down and burned to clear the land for cultivation.

Traditional biomass, composed of wood, charcoal, leaves, agricultural residue, and animal/human and urban waste (Karekezi et al. 2004), is the dominant fuel for cooking and heating in SSA, which results in serious indoor air pollution and associated respiratory infections and other health problems (WHO 2015a). Household air pollution from burning biomass fuel is increasingly recognized as a major global health concern because biomass smoke contains many toxic chemicals and is associated with chronic obstructive pulmonary disease. When combined with poverty, exposures from biomass burning contribute to impaired lung function in rural Africans (Fullerton et al. 2011). In addition to the poor indoor air quality and respiratory conditions in many homes in SSA, other health outcomes associated with air pollution are also of increasing concern; these outcomes include ischemic heart disease, stroke, and cataracts, as well as low birth weight and perinatal mortality (stillbirths and deaths in the first week of life) and obesity. Emerging evidence suggests that household air pollution in developing countries may also increase the risk of other important child and adult health problems (Chen et al. 1990). Although most of the evidence linking air pollution and health problems was obtained in developing nations, similar effects are expected in Africa (WHO 2014). Additionally, poor outdoor air quality is prevalent in major African cities (Bortey-Sam et al. 2015; Vidal 2016).

Lead Exposure

Metals and metalloids including lead have been shown to be EDCs (Iavicoli et al. 2009). Recent evaluations of the leading environmental risk factors determined that lead accounted for 0.6% of the global disease burden in 2010 (Lim et al. 2012). Although no safe exposure level to lead has been identified (CDC 2017), lead poisoning is an "entirely preventable disease" (WHO 2010a). Approximately 90% of children with elevated blood lead levels live in low-income countries (WHO 2010a), and the economic impact of childhold lead exposure in low- and middle-income countries is estimated at 977 billion USD per year (Attina and Trasande 2013). Most concerning are studies showing that very low levels of lead are associated with disruption of brain development and reduced IQ (Budtz-Jørgensen et al. 2013). Environmental exposure to lead has also been associated with altered endocrine activity and reproductive performance, including delayed growth and pubertal development (Selevan et al. 2003) and delayed attainment of menarche in girls (Wu et al. 2003) as well as altered and delayed spermatogenesis and lower rates of fertilization in men (Benoff et al. 2000).

Based on levels measured in water, fish, soils, edible vegetables, and meat, heavy metals appear to be accumulating in many African countries at levels that exceed international limits (WHO 2015b). Exposure to lead in Africa continues to be widespread, with the greatest risk coming from lead in paint (Mathee et al. 2007), mining (Dooyema et al. 2012; Bello et al. 2016), dismantling of batteries (Haefliger et al. 2009), polluted waters (Mathee et al. 2004), contaminated foods (WHO 2010b), and residual lead from prior gasoline use (Graber et al. 2010). Factories and landfills that have not been properly abated of lead may result in groundwater contamination (Naicker et al. 2012). Children and communities living near dump and landfill sites are therefore at risk of heavy metal exposure (WHO 2015b).

A variety of other prevailing factors, including poverty, a large informal sector consisting of unregulated businesses (OECD 2001), competing public health challenges, low levels of awareness of lead hazards, and weak capacity to enforce legislation, intensify the challenges and limit the prospects of successful prevention efforts in the foreseeable future (Nriagu et al. 1996; Tong et al. 2000;WHO 2015b). In South Africa, despite some progress, a wide range of sources of lead exist (Mathee et al. 2004, Chopra and Doiphode 2002, Naicker et al. 2012), hindering efforts to prevent lead exposure in Africa and other developing countries (Tong et al. 2000, WHO 2009, 2015b).

Pesticide Use

Many pesticides are EDCs, and pesiticide use in Africa is high (Dalvie and London 2006; Dabrowski et al. 2014), with more than 500 active ingredients registered in South Africa alone (Dabrowski et al. 2014). High pesticide exposures stem from agricultural sources such as agricultural products (Dabrowski et al. 2014; Dabrowski 2015; Quinn et al. 2011) and exposures linked to malaria vector control (Aneck-Hahn et al. 2007; de Jager et al. 2009; Quinn et al. 2011). The cost of injury to pesticide users on small farms in 37 SSA countries, calculated as lost workdays, outpatient medical treatment, and inpatient hospitalization, was 4.4 billion USD in 2005 (UNEP 2013b). This is thought to be an underestimation of the true costs because it does not include the costs of lost livelihoods, lost lives, or environmental health effects. The accumulated health costs in SSA may be closer to approximately 97 billion USD by 2020 unless current inadequate capacities for the sound management of pesticides at the national and local levels do not improve significantly (UNEP 2013b).

Pesticide runoff, leachate, and spray drift can contaminate ground and surface water, posing a potential hazard to water users (Dabrowski et al. 2014). Studies investigating water sources in rural and urban areas indicated that a mixture of EDCs, including pesticides, was present at levels that raised concern about health effects in both humans and wildlife (Bornman et al. 2007, 2010a; Quinn et al. 2011). Reproductive toxicology studies on laboratory rats using environmentally relevant chemical mixtures of EDCs found in a malaria area in South Africa demonstrated adverse effects on male reproductive health that may have a negative impact on future generations (Kilian et al. 2007; Patrick et al. 2016).

Dichlorodiphenyltrichloroethane (DDT), an insecticide with EDC activity, was the primary instrument used in the first global malaria eradication program during the 1950s and 1960s and was widely used inside homes and animal shelters. Malaria has been successfully eliminated from many regions but remains endemic in large parts of the world including Africa (Mendis et al. 2009). In the 1970s, concerns about the safety of DDT led to a ban of its use for agricultural purposes in many countries. However, it continues to be used for malaria control in countries such as South Africa. Under the Stockholm Convention, countries may continue to use DDT until sustainable alternatives are available (Bouwman et al. 2013).

Technical DDT is composed of *p,p*′-DDT and *o,p*′-DDT, and it displays estrogen-like properties; after exposure, *p,p*′-DDT is metabolized to the persistent metabolite *p,p*′-dichlorodiphenyldichloroethylene (*p,p*′-DDE), which acts as antiandrogen in rodents (Gray et al. 2006). In the Limpopo province of South Africa, *p,p*′-DDT and *p,p*′-DDE continue to be detected in water, sediment, soil, fish, and domestic grown vegetables and chicken eggs (Bornman et al. 2010b; van Dyk et al. 2010; Bouwman et al. 2015).

Observational and experimental studies on DDT have examined the effects of both chronic and acute DDT exposures on humans (Aneck-Hahn et al. 2007; de Jager et al. 2009; Bornman et al. 2010c), wildlife (Bornman et al. 2010b; Bouwman et al. 2013), and laboratory animals including freshwater fish (Brink et al. 2012) and rats (Patrick et al. 2016). Laboratory animal studies have shown that *in utero* exposure to DDT or DDE can disrupt development of ovarian tissue, reduce penis size, and induce hypospadias and cryptorchidism, leading to suggestions that DDT exposures might be involved in observed increases in human male reproductive tract anomalies (Gore et al. 2015). Bornman et al. (2010c) examined potential associations between prenatal DDT exposures from spraying in a malaria-prone area of the Limpopo Province of South Africa and the occurrence of external urogenital birth defects (UGBDs) in newborn boys. In the study, mothers who lived in villages sprayed with DDT between 1995 and 2003 had a significantly greater chance of having a baby with a UGBD than mothers whose homes were unsprayed. In another study of healthy male adults recruited from communities in an endemic malaria area in which DDT is sprayed annually, associations were found between nonoccupational DDT exposures and impaired seminal parameters (Aneck-Hahn et al. 2007). Additional cross-sectional studies have found negative associations between *p,p*′-DDE levels and sperm DNA/chromatin integrity (de Jager et al. 2009). Finally, a case–control study nested in a prospective 54-y follow-up of women in the United States demonstrated that maternal *o,p*′-DDT during pregnancy predicted daughters' breast cancer risk (Cohn et al. 2015). This prospective study was the first to link gestational DDT exposure to risk of breast cancer in women.

Water Contamination

Globally, water is a scarce resource, and Africa is no exception. Increases in population in countries already experiencing a high burden of disease, coupled with decreased clean water sources and sanitation services, are likely to result in water contamination with infectious agents and chemicals, including those with endocrine-disrupting properties. For example, pesticides were detected in water from agricultural areas of South Africa; *in vitro* bioassays of water samples revealed high estradiol equivalent (EEq) values in combination with the presence of atrazine, simazine, and terbuthylazine (Dabrowski 2015). Water runoff from cattle feedlot operations also demonstrated estrogenic activity (de Jager et al. 2011).

Emerging contaminants and pharmaceuticals, including endocrine active drugs, may also contaminate African water. For example, water samples from purification plants in seven cities across South Africa identified 34 pharmaceuticals and pesticides (Patterton 2013), and additional methods have been developed to identify pharmaceuticals and personal health care products in treated drinking water and sewage (Osunmakinde et al. 2013). New developments from the Global Water Research Coalition aim to extend the battery of bioassays for endocrine disruptor end points (e.g., effects on androgen and thyroid pathways); these are being tested for suitability in the African context (Global Water Research Coalition, 2015).

Although Europe and the United Kingdom banned the use of nonylphenol ethoxylates (Flynn, 2015), these chemicals continue to be exported to Africa (ECHA 2010). Alkylphenol ethoxylates are some of the most extensively used surfactants and are incompletely biodegraded in the environment to form nonylphenol (NP) (Bergé et al. 2012). NP can enter the agricultural system through the application of contaminated irrigation water (Singh et al. 2007), among other pathways. Estimates suggest that 60% to 100% of fresh produce in SSA is grown on fields that are irrigated with polluted water (Pachepsky et al. 2011). In South Africa, agricultural water quality is already compromised by improper management of outdated and insufficient sewage treatment plant infrastructure (Du Plessis et al. 2015). In laboratory experiments, NP impaired lettuce seedling germination, suggesting that it could adversely affect food quality and could reduce yield of one of the world's most significant salad crops (De Bruin et al. 2016; 2017). The combined use of NP in developing countries with agricultural intensification may have a negative impact on food production and may exacerbate food insecurity in developing countries.

Market Food

In Africa, the agricultural sector is an essential part of the economy and is vital for food security (Quinn et al. 2011). Fresh food markets are common, and pesticide residues on produce may be a source of EDC exposures. Mutengwe et al. (2016) found that samples collected from fresh produce markets in urban metropolitan areas contained up to three different pesticides, and pesticides unauthorized for use in fruits and vegetables were among those detected (Mutengwe et al. 2016).

In the Vhembe district of South Africa, the typical diet is high in plant-based foods such as maize and beans (Mbhenyane et al. 2005). The tropical climate in the Vhembe District provides ideal conditions for fungal contamination of food crops such as maize, particularly if improperly stored, and inadequate infrastructure for food storage and inadequate education of farmers increase this problem (Stoev 2015). Fungi can contaminate grain with mycotoxins such as zearalenone, which has estrogenic activity. Zearalenone and its metabolites are found worldwide in a wide range of cereals including maize, sorghum, wheat, rice, barley, and oats (Abia et al. 2013; Rashedi et al. 2012). α-Zearalenol, an anabolic substance, has also been used as an animal growth promoter in some African countries (Shephard et al. 2013). Zearalenone and its metabolites have been reported to increase the risk of hormone-dependent tumors in women (Tomaszewski et al. 1998); α-zearalenol has also been implicated in breast cancer risk in women (Belhassen et al. 2015).

Electronic Waste

Thousands of televisions, computers, microwaves and refrigerators are illegally exported to African countries and dumped in gigantic landfills because "it costs less than recycling them in their countries of origin" (Akbar 2015). E-waste liberates polybrominated diphenyl ethers (PBDEs) (Robinson 2009), which are thyroid-disrupting EDCs that have the ability to produce developmental neurotoxicity (Xu et al. 2015). E-waste also includes other EDCs in plastics, flame retardants, and heavy metals; the breakdown of e-waste can lead to high levels of contamination in workers and their families (Heacock et al. 2016). Recent studies from Ghana revealed that some e-waste recyclers use primitive methods (e.g., mechanical shredding, open burning) to remove plastic insulation from copper cables, further releasing toxic chemicals (Asante et al. 2016). E-waste–associated chemicals accumulate in soil and vegetation at toxic levels that could induce adverse health effects in exposed individuals (Alabi et al. 2012). Many mothers and small children are living on or close to waste dumps, increasing their individual risks of exposure to hazardous substances. Solving this problem requires more than halting Western exports of electronics (Minter 2016). Options to prevent exposures of workers include education and training, as well as providing alternative employment to these relatively unskilled workers.

EDC Exposures: Impact on Wildlife Health in Africa

There have been reports of DDT bioaccumulation in wildlife and humans since the late 1960s (Van Dyk et al. 1982; Wassermann et al. 1970). Further monitoring has also revealed persistent organic pollutants (POPs), PAHs, PBDEs, polychlorinated biphenyls (PCBs), perfluorooctane sulfonate (PFOS), phenols, heavy metals such as cadmium and lead, phthalates, and bisphenol A (BPA) in African waters (Ncube et al. 2012; Olujimi et al. 2010) and in animal tissues (du Preez et al. 2016; Nieuwoudt et al. 2009; Nieuwoudt et al. 2011; Polder et al. 2008; van der Schyff et al. 2016; Quinn et al. 2009; Bornman et al. 2010b). The first report of endocrine disruption in a fish species in Africa involved intersex in the African catfish, *Clarias gariepinus*, inhabiting water sources contaminated with the estrogenic compound *p*-nonylphenol (*p*-NP), possibly from upstream activites of industries, agriculture, informal settlements, and municipal treatment plants (Barnhoorn et al. 2004). Intersex has since been identified in a second indigenous freshwater fish (*Oreochromis mossambicus*) from a DDT-sprayed area (Barnhoorn et al. 2010).

Several studies have reported endocrine disruption in other wildlife species including the South African eland, *Tragelaphus oryx* (Bornman et al. 2010a), and the African clawed frog, *Xenopus laevis* (Van Wyk et al. 2003). Other reports include eggshell thinning in waterbird eggs (Bouwman et al. 2008; Bouwman et al. 2013) and eggshell thickening of Nile crocodile eggs, which was associated with an increase in contaminant concentrations (Bouwman et al. 2014). Screening of river mouths and harbors around the coast of South Africa showed estrogenic and antiandrogenic activity (Truter et al. 2015). High concentrations of arsenic, lead, mercury, and cadmium were found in the juvenile stages of the popular angling fishes *Lichia amia*, *Argyrosomus japonicus*, and *Pomadasys commersonnii* (Nel et al. 2015) in a South African estuary; both cadmium and arsenic were detected at levels that exceed international food quality guidelines.

Because pollutants in freshwater rivers end up in oceans around Africa, contamination of marine life in the Atlantic, Indian, and Southern Oceans and in the Red and Mediterranean Seas is a real concern (Bouwman et al. 2012; van der Schyff and Bouwman 2015). EDCs have also been found in sharks (Marsili et al. 2016; Schlenk et al. 2005) and African penguin eggs (Bouwman et al. 2015).

Current State of EDC Policy in Africa

South Africa became the first African country to regulate a substance as an EDC when it prohibited the production, import, export, and sale of infant feeding bottles containing BPA in 2011 (Government of South Africa 2011). The following year, at the Third International Conference on Chemicals Management (ICCM3) in Nairobi, the entire African region joined a consensus of >100 countries to designate EDCs as a global emerging policy issue (SAICM 2012). The decision recognized potential adverse effects of EDCs on human health and the environment and the need to protect humans, ecosystems, and their constituent parts (SAICM 2012). Delegates invited participating organizations of the Inter-Organization Programme for the Sound Management of Chemicals to provide information and scientific advice to reduce exposures to, and the effects of, EDCs; to build capacity to support decision making including prioritization of actions to reduce risks; to develop case studies; and to provide advice on translation of research results into control actions (SAICM 2012).

In 2013, African delegates provided a detailed outline of regulatory needs for EDCs in a consensus resolution adopted at the fifth regional meeting of the Strategic Approach to International Chemicals Management (SAICM) in Pretoria (SAICM 2014). The resolution recognized the scarcity of information on EDCs found in human and wildlife tissues in Africa; concerns about chemical exposures from agricultural products in Africa; special needs that the African region may have in coping with EDCs throughout their complete life cycle; and the costs of inaction in the African region (SAICM 2014). African governments called on UNEP and WHO to identify priority EDCs and sources of exposure for African countries including products, food and water, wastes, and pesticides; to provide examples of best practices in reducing the use of EDCs; and to outline existing policies and gaps in measures to protect human health and the environment from EDCs (SAICM 2014).

The need for actions related to EDCs expressed by African government regulators was reinforced in 2015 at the Fourth International Conference on Chemicals Management (ICCM4). A resolution on EDCs by >100 governments called on UNEP and WHO to address the needs identified by developing countries, subject to available resources (SAICM 2015). Governments, health professionals, and civil society organizations also signaled the importance of utilizing the UNEP/WHO *State of the Science of Endocrine Disrupting Chemicals – 2012* (Bergman et al. 2013) by identifying its key concerns including evidence that exposure to EDCs can result in adverse effects in humans, laboratory animals, and wildlife; that the most critical window of exposure is during development; that exposures during early life stages can result in adult-onset disease; and that an important focus should be on reducing exposure (SAICM 2015).

Major Challenges and Opportunities for Action

A Lack of Resources Impedes Progress

Traditional environmental risks to human health have not been resolved in Africa for various reasons. Malaria, HIV/AIDS, tuberculosis, and widespread poverty compound other health concerns (Peer 2015). Access to modern health care facilities is often limited, and some populations experience high mortality levels and low immunization rates (Kaseje 2006). Disparities exist in terms of access to adequate nutrition, clean water and sanitation, housing, and basic healthcare (Benatar 2013). Exposures to environmental contaminants, including EDCs, may further compound these problems.

Furthermore, addressing environmental chemical exposures of children living in Africa will be incomplete without mentioning the severe burden of poverty and malnutrition (Atinmo et al. 2009; Bain et al. 2013). Chemical exposures occur within the already devastating circumstances of famine, floods, war, conflicts, displacement of people, and other adversities that are crippling many countries in Africa. Add to this industrial exploitation, toxic waste dumping, and devegetation in all its formats, and Africa will not be able to overcome the triple burden of disease (environmental degradation, poverty, and malnutrition) or the burden of exposures to EDCs by itself (WHO/UNEP 2015) without long-term strategies coordinated across industrial, environmental, and public health sectors. We posit that African countries must continue to seek assistance at a global level and to work with international partners to address this triple disease burden. Although these major environmental risks require attention and resources to resolve, we posit that ignoring EDCs may prevent the successful implementation of future public health interventions.

Ongoing releases of EDCs result from natural resource mining, automobile exhaust, burning of e-waste, and use of pesticides; exposures can reach toxicologically relevant levels (Wisner et al. 2015; Sheahan et al. 2016; Agyemang-Duah et al. 2016). Training for safe handling of pesticides is rare and is often focused on adult men (Oesterlund et al. 2014, Ssekabembe and Odong, 2008). Thus, improvements and expansion of education and training programs could have significant, measurable impacts on improving human health by decreasing and preventing unnecessary EDC exposures.

Shifting from Reaction to Prevention

There is consistent under-resourcing of individual health and environment ministries throughout Africa. When competing for government money, health is often prioritized, but insufficient funding leads to a focus on broad public health activities including disease prevention and curative programs for HIV/AIDS, tuberculosis, and other such diseases. Similarly, the greatest share of the environment health budget goes towards reacting to existing problems rather than avoiding them. As knowledge about the prevention of infectious diseases and the benefits of prioritizing prevention over treatment is translated more effectively in African countries, we anticipate that actions will be taken to support economically beneficial shifts in policy and practice toward preventing EDC exposures rather than treating the diseases they induce.

Effective Use of Precaution within the African Political Framework

Many (perhaps all) African countries understand the need for action to protect the environment and human health from toxic chemicals such as EDCs and other environmental challenges. However, we believe that few appear to be progressive in their decision making, and even fewer follow up with constructive action. For example, governments readily sign conventions and international agreements, but these may be weakly implemented, and other important international instruments and multilateral environmental agreements often remain unratified, under-resourced, or both (WHO/UNEP 2015). Lack of policy implementation has been attributed to a variety of contextual realities in numerous African countries (Roux 2002; Makinde 2005; Mugwagwa et al. 2015).

We propose that adoption of the precautionary principle, which enables rapid responses in the face of a possible danger to humans, wildlife, or the environment, could be an important step forward. It is invoked when there is scientific evidence of potential harm, but where scientific data do not permit a complete evaluation of the risk. For example, although 25 y have passed since the Bamako Convention prohibited importation of any hazardous (including radioactive) waste into Africa (UNEP 1998), dumping of hazardous waste including e-waste continues to be a problem. Because concerns over the health effects of hazardous materials are often ignored by African countries with a desire to earn a "huge foreign income," extensive, irremediable harm to humans and to the environment has occurred that could have been prevented if timely action and proper implementation was undertaken (Saleh and Abene 2016). We argue in favor of concerted efforts in Africa to implement the precautionary principle; we posit that such efforts will decrease the gap between between scientific knowledge (with research) and government policies (with advocacy and enforcement).

Use of Available Data from Animal and in Vitro *Studies*

A large amount of data has been produced to understand the mechanisms by which EDCs act and to develop tools that can be used to identify EDCs and testing approaches to understand the hazards associated with exposures (Gore et al. 2015). These data are useful to stakeholders around the globe, and we believe this information should be employed by African scientists and policymakers to shift toward preventative and precautionary approaches.

A Need for African Biomonitoring/Surveillance Systems

Human, environmental, and biotic biomonitoring of environmental chemicals has become a priority in many developed countries, providing critical information about exposures to a wide range of environmental chemicals. However, as a continent, Africa lags behind other areas of the world and needs to develop an analytical infrastructure capable of generating high-quality, highly accurate measures of chemical uptakes and exposures. We argue that Africa needs to train its own scientists to conduct chemical analyses and risk assessments. Baseline data on the prevalence of endocrine diseases in African countries are also urgently needed to identify problems and to evaluate the success of intervention.

Development of African Birth Cohort Studies

Birth cohort studies provide insights into the developmental, social, and environmental exposures that interact to determine disease risk in children and later in life (Lucas et al. 1999). In 2011, there were only 28 birth cohorts in Africa: Fourteen of these collected biological data, ten collected blood samples, and one collected DNA (Campbell and Rudan 2011). We argue that there is an urgent need for more birth cohort studies measuring maternal environmental exposures that follow the children to assess disease incidence across the lifespan. Birth cohort studies from developed countries are insufficient to inform African populations about risks from EDC exposures because the differences in stress and nutritional challenges between developing and developed countries are large. African cohort studies must take these other environmental factors into account.

Environmental Protection

African ecosytems are biodiverse, with 25% of the world's mammalian species, 20% of its birds, $\geq$950 amphibian species, 16% of all plant species, and >2,000 known species of fish. To protect and sustain its biodiversity as well as the health of its citizens, Africa needs sustainable policies that protect the natural environment and the many services it provides. Although the effects of EDCs on human health have received significant and important attention, we suggest that continued progress in understanding the effects of these chemicals and of other human activities on wildlife species is equally important. We argue that increased and sustainable support for research studies, including observational field studies, is desperately needed throughout Africa.

Summary and Conclusions

Considering the need to protect the rich biodiversity of Africa as well as the health of more than 1 billion people currently living on the continent [a number projected to reach nearly 2 billion people by 2050 (Lutz & Samir, 2010)], coupled with the equally complex challenges posed by war, droughts, displacement of human populations, lack of access to health care, and environmental degradation and pollution, we conclude that solutions will require interdisciplinary and global cooperation. We argue that Africans should play a central role in this effort.

Based on our current knowledge, we conclude that initial steps to reduce exposures to EDCs should include the following: provision of appropriate training and education programs for individuals who use chemicals and products containing them; adoption of the precautionary principle; establishment of comprehensive biomonitoring programs; funding of additional epidemiology studies including establishment of African birth cohorts; and increasing research on the impacts of EDCs on Africa's unique wildlife populations.

Based on the opinions expressed at the EDC meeting, we posit that these steps should start within Africa and be undertaken within the context of African society and values so that Africans can take and maintain control of their own health and well-being. We feel strongly that community-based interventions will be more successful than those that are prescriptive and generated by outsiders. Furthermore, within Africa, it is vital that national institutes, research centers, universities, non-governmental organizations (NGOs), and private companies lead these efforts. In our opinion, academic researchers have a responsibility to show how their research projects influence national priorities and policies and to share research findings with all stakeholders, including the public, in layman's terms. We recommend that scientific meetings and other opportunities to share information be held regularly to encourage continued dialogue between academic researchers in Africa and African policy makers. This regular communication will help insure that scientific evidence and innovative solutions provided by Africans are understood and used by policy makers to prevent pollution and to protect the health of all Africans and the unique environment upon which they depend.

Acknowledgments

The authors thank the following sponsors for supporting the scientific meeting that was the basis for this commentary: National Institue of Environmental Health Sciences/National Institutes of Health (NIEHS/NIH); Society for the Study of Reproduction (SSR); University of Pretoria Institute for Sustainable Malaria Control (UP ISMC); Water Research Commission of South Africa; Oozoa Biomedical, Inc.; Rand Water; Delfran Pharmaceuticals; AEC Amersham; Hamilton Thorne; Separations; and Acorn Group of Companies.

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