Towards a BETR-Africa: Fate and risk assessment of persistent organic pollutants originating in Africa at local, regional and global scales

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Introduction

The thrust of this paper is that although there are international agreements to control Persistent Organic Pollutants (POPs) at regional and global levels and there are monitoring programs in place, there is a need to complement these activities by developing and applying multi-media mass balance models at national, continental and global scales. These models serve to synthesise available data on POP emissions, concentrations and exposures that provide a coherent picture of the present situation and a predictive mechanism for the future. The focus here is on Africa as a continent with large stockpiles of POPs and a monitoring framework that while inadequate, indicates unacceptable contamination and exposures. It is suggested that the series of Berkeley-Trent (BETR) models can contribute to more effective assessments of POPs in Africa as well as their global impact.

The Regulatory Context

The Stockholm Convention is a global treaty intended to protect human health and the environment from POPs[1]. The Convention requires governments to eliminate or reduce the release of POPs into the environment and it directs industrialised countries to support developing countries in this effort. Developing countries generally lack the necessary resources and scientific infrastructure for effective chemical management. As a signatory of the Convention, Canada has a responsibility to provide such assistance. The transboundary nature of POPs and their potential for long range transport to polar regions, such as the Canadian Arctic, further advocates a pragmatic approach for Canada to account for the global fate of key sources.

The United Nation Environment Programme (UNEP) reports that there is a “data vacuum” on persistent, toxic substances in sub-Saharan Africa[2]. This report further states that capacity building, technology transfer, abiotic and biotic monitoring programs, database development and multi-media models are needed to improve the current understanding of POPs in Africa. Of the forty-seven countries in the region, only South Africa and Zimbabwe have systematic monitoring programs. In these two countries, PCBs and HCB have been detected at relatively high levels in water, vegetation and animals since the 1970’s[2]. Key data gaps identified for POPs in Africa include atmospheric concentrations and transport, levels in other environmental compartments, levels in food webs and humans and the long-term effect of accumulated pesticide stockpiles on the health of humans and the environment. Experts have reported that dioxins and furans, PCBs and organochlorine pesticides (such as DDT, lindane and chlordane) are considered substances with the highest priority for improved understanding.

POPs in Africa

The main sources of POPs in Africa are from the agricultural use of pesticides, vector control, industrial sources, by-products of combustion including open burning of waste and stocks of obsolete and expired pesticides[2]. The list of African obsolete stockpile pesticides includes 9 of 12 Stockholm Convention POPs. Virtually every country across the African continent has accumulated stockpiles of obsolete pesticides and associated wastes over the past 50 years, some of which were donations from developed countries. Currently the precise quantity and location of many contaminated sites and hot spots are unknown but it is estimated that at least 40,000 tonnes of pesticides as well as tens of thousands of tonnes of contaminated soil have accumulated in African countries[2,3]. Many of these hazardous chemicals and their containers are leaking into the environment creating serious threats to humans and ecosystems as well as contributing to land and water degradation. For example, soil sampled from an obsolete pesticide storage site (Vikuge State Farm, Tanzania) in August 2000 report residues of SDDT and SHCH as high 282,000 and 63,400 (mg kg^{-1} dry weight), respectively[3].

UNEP has launched a Global Monitoring Programme (GMP) designed to monitor current POPs and accommodate other chemicals that may obtain Convention status in the future[4]. Environmental monitoring of POP levels in air, water soils, sediments, various wildlife, livestock and human milk throughout Africa is essential for filling in the current data vacuum, improving the scientific understanding of fate, transport and exposure pathways at local, regional and global scales, ensuring Convention compliance and identifying hot spots for effective remedial strategies to reduce health risks to humans and ecosystems. In a global context it is uncertain whether Africa is a net source or sink of POPs[2]. It is believed that the Inter-Tropical Convergence Zone prevents atmospheric transport of POPs to the Northern Hemisphere from the Southern Hemisphere and vice versa. At a global scale, the vast majority of POP production and use has been in the Northern Hemisphere. For example, approximately 90% of the global usage of PCBs occurred in the Northern Hemisphere, yet it has been reported that on average sampled ocean air is only a factor of 2 higher than the Southern Hemisphere[5].

The Need for Models

There is a need to complement monitoring data with the development and evaluation of compartmental mass balance models to build capacity and to address current key issues as well as to prepare for the future[2]. At present there are no indications of applicable modelling approaches for Africa. The development and application of a relevant model will be an essential tool for establishing and predicting the fate and distribution of POPs as well as assisting in the identification of hot spots, forecasting different remediation strategies and assessing potential risks. A model would be an effective and comparatively low cost mechanism to enhance chemical management for the successful protection of the environment and humans from pollutants in Africa at local, regional and global scales. To date, regional scale models for chemical fate have focussed on developed countries. The BETR modelling framework is well suited for the current modelling needs of continental Africa. This model framework has been developed and successfully applied at regional scales in North America and Europe as well as at a global scale[6-9].

The Modelling Approach

The objective of this study is to develop and apply a model to assess the fate, exposure pathways, risks and associated uncertainties of POPs originating in Africa to ecological and human receptors at local, regional and global scales. The first stage develops and parameterises a mass balance model for different regions of Africa integrating fate and food web bioaccumulation models. A Geographical Information System (GIS) facilitates data input and output requirements. The second stage evaluates the model with available empirical data. The third stage assesses the risks of POPs on humans and the environment at local and regional scales in Africa while providing useful information for the global fate of POPs and their pathways into and out of Africa. This will quantify Africa as both a source of global contamination and a receptor of contamination from other regions. This model will also provide a framework for evaluating future candidate POPs and for assisting in chemical management decisions such as establishing environmental quality guidelines in regions of Africa.

Specifically, a regionally segmented multi-compartment continental scale mass balance chemical fate and exposure model is being developed and parameterised for Africa. The model is based on the BETR model fugacity framework linking fate models of individual regions that can be generally applied to large, spatially heterogeneous areas[6-9]. Regions are being selected with consideration for key "ecozone" characteristics (e.g., river basins, soil types), political boundaries and population densities. The fate model calculates steady-state and unsteady-state (dynamic) chemical concentrations in abiotic media from inputs describing the environmental characteristics of Africa, the physical-chemical properties of POPs and emission estimates from key sources of POPs in Africa (i.e., pesticide stockpiles). The focus of the BETR model regional framework is on calculating the fate and intra-continental transport of POPs over the entire continent including transfer, transport and cycling between air, vegetation, soil, surface water, sediments and near-shore coastal water as well as inter-continental transport. Based on steady-state fate predictions in environmental compartments, it is planned that appropriate food web bioaccumulation models representing key ecological receptors such as plants, invertebrates (e.g., bivalves), fish, birds, mammals as well as human receptors will be included[10,11]. These models will also provide information on the biomagnification and bioaccumulation of POPs in African ecosystems. This integrated approach will link sources of POPs to toxicological thresholds such that potential risks can be characterised. Information obtained from regional African fate and transport models will be linked with existing global models to assess the contributions of African POPs at a global scale including the contribution of these sources to circumpolar environments and communities.

The model will be parameterised using Remote Sensing (RS) and GIS data for key abiotic inputs such as soil type, organic carbon and moisture contents for soils, land cover and vegetation type, leaf area indexes, wind speed and direction, precipitation rates, temperatures in air and water, hydroxyl radical concentrations, water flow rates and lake residence times. As well as for integrating model inputs, it is planned that GIS will be used for data generated and output display[12]. Frequency distributions will be used to address spatial heterogeneity and biodegradation rates as well as to characterise potential risks and uncertainty. The model will be evaluated using current empirical data as well as data obtained from the POPs Global Monitoring Programme[4]. These data will include multi-media samples from abiotic environmental compartments, bivalves, fish, bird eggs, marine mammals and human milk.

Discussion

We do not under-estimate the difficulty of parameterising these models and of confirming that their predictions are reliable. Some key challenges are outlined. Africa is comprised of many diverse ecosystems including coastal, marine, tropical rain forests, wetlands, semi-arid regions and deserts with various climatic conditions. Soil types in Africa appear to be quite different than those from temperate climates. The low organic content of soils may have an effect on concentrations and breakdown of POPs whereas temperature and salinity also have an effect on POP solubility. The uniqueness of the African continent in terms of temperature inversions could affect the environmental fate of POPs. There are no major forest regions in the Northern Hemisphere of Africa, therefore dust and particles blowing from the Sahara Desert may be a significant transport mechanism. The degree of Northern-Southern Hemisphere mixing remains unclear and pesticide stockpile quantities and locations are uncertain.

Unfortunately political and socio-economic conditions are dire in many African nations. The recent tsunami induced release of toxic waste sent to the beaches of Somalia by developed countries is further evidence that more vigilant international efforts are required for ensuring effective chemical management in Africa.

Conclusions

The objective here is not to present results of this modelling program, but to set out what is believed to be a feasible and optimal approach. It is envisaged that the work will extend over the next two years and possibly longer. It is hoped that the availability of a reliable model will not only clarify the presence, fate and exposure of POPs in Africa, but also encourage complementary monitoring and regulatory efforts.

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