Development of national health-based target for regulating airborne polycyclic aromatic hydrocarbons exposure in Nigeria

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Abstract. Recent studies in different localities in Nigeria report high concentrations of airborne polycyclic aromatic hydrocarbons (PAHs) –a group of ubiquitous hazardous chemicals produced by incomplete combustion or pyrolysis processes. Inhalation exposure to PAHs has been shown to elicit both cancer and non-cancer adverse effects. Yet, there is currently no national guideline for regulating exposure to airborne PAHs in Nigeria. In this study, we developed national health-based target for 16 priority PAHs using literature information on the toxicity of the PAHs, the baseline severities of the diseases in Nigeria and the population demography. We developed our health-based target (ng/m³) from 10 cancers and 34 non-cancer adverse health outcomes linked to PAH exposure. Our proposed limits for the PAHs ranged from 0.02 ng/m³ for dibenzo[ a,h]anthracene to 1.0 ng/m³ for benzo[g,h,i]perylene – the most or least toxic PAH, respectively. On the basis of benzo[a]pyrene equivalent concentration, our national PAH limit of 0.15 ng/m³ is however less stringent than the global PAH limit of 0.12 ng/m³.

1. Introduction
Polycyclic aromatic hydrocarbons (PAHs) are a group of ubiquitous hazardous chemical pollutants that are produced from incomplete combustion or pyrolysis of organic compounds. Globally, approximately 500 gigagrams of PAHs are released every year from several incomplete combustion processes including burning of firewood or coal for household cooking and space heating, burning of fossil fuels for transportation and power generation and combustion of agricultural and domestic wastes[1]. Because these processes typically occur in places where people are and at times when people are actively breathing, a large proportion of people are repeatedly exposed to PAHs. Human exposure to PAHs has been shown to cause different types of cancer including upper respiratory tract/pharynx cancer, lung cancer, liver cancer and kidney cancer [2–3]. Exposure to PAHs has also been shown to cause non-carcinogenic effects such as reproductive, developmental and immunological adverse effects [3].

Recent studies revealed that PAHs are ubiquitous in Nigeria’s air. Reported concentrations of PAHs mixture in the atmosphere of some localities in Nigeria ranged from 0.17ng/m³ to 9200 ng/m³[4–5]. Yet, there is currently no national standard for regulating PAHs exposure in Nigeria [6]. However, due to magnitude of the adverse health effects linked to atmospheric PAHs exposure, the World Health Organization [2, 7] has provided a global PAH target limit of 0.12 ng/m³ of benzo[a]pyrene. But, this global target does not take into account the current health problems of people in Nigeria. Therefore, in this study, we developed national health-based target for sixteen priority PAHs, combining both the risk to health from PAHs exposure and the severities of PAH-related diseases in Nigeria.
2. Methodology
We utilized the burden of disease approach, expressed in disability-adjusted life years (DALYs), to develop the national health-based target for PAHs. The DALYs metric has the ability to account for not just the risk to health, but also the differential disease severity in Nigeria [8, 9]. Based on the DALYs approach, we estimated the burden of disease per ng/m³ of PAH using the algorithm[10]:

\[
BoD_{B[a]P} = \sum_{i=1}^{ED} IUR_i \times S_i \times P_{Fi} \times L
\]

where:

- \( BoD_{B[a]P} \) is the burden of disease, expressed in DALY per person-year, per ng/m³ of benzo[a]pyrene (B[a]P). B[a]P was used as the index PAH because of the extensive literature on its toxicity.
- \( L \) is average life expectancy of people in Nigeria = 65.1 years (female = 66.4 years and males = 63.7 years)[11].
- \( ED \) is exposure duration for a period \( n \). We used \( n = 30 \) years for the non-cancer exposure assessment, while for the cancer exposure estimation, \( n = 2, 14 \) and 14 years, respectively, for 0 – <2, 2 – <16 and >16 years old, so as to integrate age-dependent adjustment factors (ADAF) of 10, 3 and 1, respectively, for early-life vulnerability to cancer [3].
- \( IUR_i \) is the central estimate of the inhalation unit risk of an endpoint or disease \( i \).
- \( S_i \) is the severity of a disease \( i \).
- \( P_{Fi} \) is the fraction of Nigerian population that is female (0.49) or male (0.51)[12].

We calculated the central estimate of the inhalation unit risks (IURc) of several cancers and non-cancer endpoints (Tables 1& 2) from the human equivalent concentration (HEC) benchmark concentration (BMC10) using the following algorithm:

\[
IUR_{c10} = \frac{0.1}{BMC_{10(HEC)}}
\]

BMC10 is B[a]P concentration that caused 10% response for an adverse effect compared to background. Etchie et al. [10] derived the \( BMC_{10(HEC)} \) values for the endpoints from a detailed systematic review of the toxicology of B[a]P[3, 7].

To estimate the severity of B[a]P-related diseases in Nigeria (\( S_i \)), we determined the cause of the disease in the Global Burden of Disease (GBD) database in order to identify diseases that matched the toxicity endpoints of PAHs. A total of 10 cancer disease outcomes and 34 non-cancer disease outcomes were related to PAHs exposure in Nigeria (Tables 1 & 2). Thus, we obtained information on the severity of each disease related to PAH exposure in Nigeria – the disease prevalence (P), number of mortality from the disease (N), the years of life lost due to premature deaths from the disease (YLL), and the years lived in disability due to the disease (YLD) – from the Global Burden of Disease (GBD) 2016 database [11].

We calculated the severity of each disease (\( S_i \)), expressed as DALYs per case of the disease (\( DALY_{ci} \)) using the following algorithms:

\[
S_i = DALY_{ci} = YLL_{ci} + YLD_{ci}
\]

where:

\[
YLL_{ci} = \frac{YLL_i}{p_i}
\]

\[
YLD_{ci} = \frac{YLD_i}{p_i}
\]

\( YLL_i \) or \( YLD_i \) is YLL or YLD, respectively, per case (c) for a disease (i).

We calculated the burden of disease (BoD) per ng/m³ of other fifteen PAHs from that of B[a]P, using relative potency factors (RPFs) [13], and relative toxicity factors (RTFs) derived from quantitative structure-activity relationships (QSAR) [14]as follows:

\[
\log(CTP) = -0.155 \log(K_{ow}) + 3.54 - \log(C_i) - \Delta C
\]

\[
RTF_{PAH} = \frac{CTP_{PAH}}{CTP_{B[a]P}}
\]
where:

- CTP is chronic toxicity potential of a chemical in water (mmol/L).
- $K_{ow}$ is octanol/water partition coefficient.
- $C_{ct}$ is final chronic value critical target lipid body burden for the test organism (e.g. $6.94 \times 10^{-3}$ mmol/g octanol for *Pimephales promelas*) [14].
- $\Delta C$ is correction for chemical classes e.g. -0.263 for PAH members, which exhibit increased toxicity compared to common narcotic chemicals [14].
- $CTP_{PAH, i}$ is chronic toxicity potential of individual PAH, $i$, in water (mmol/L).
- $CTP_{B[a]P}$ is chronic toxicity potential of benzo[a]pyrene in water (mmol/L).

The BoD per ng/m$^3$ of each PAH($BoD_{PAH, i}$) was estimated as:

$$BoD_{PAH, i} = (R_{PPA} \times BoD_{B[a]P_c}) + (R_{TPA} \times BoD_{B[a]P_NC})$$

where:

- $BoD_{B[a]P_c}$ and $BoD_{B[a]P_NC}$ is cancer and non-cancer $BoD_{B[a]P}$, respectively.
Table 2. Non-carcinogenic unit burden of disease (UBoD, expressed in DALYs per person-year per ng/m\(^3\) of B[a]P) in Nigeria

| Risk to health | Severity of PAH-related disease in Nigeria | DALYs/person-year per ng/m\(^3\) of B[a]P ×10\(^{-6}\) |
|----------------|------------------------------------------|-----------------------------------------------|
| Developmental  |                                          |                                               |
| Decreased embryo/fetal survival | 2.37 | 40  | Maternal abortion, miscarriage, and ectopic pregnancy | NA | 0.11 | 0.11 | 0.032 |
| Neurological changes\(c\) | 368 | 0.27 | Idiopathic developmental intellectual disability | NA | 0.012 | 0.012 | 0.23×10\(^{-3}\) |
| Cardiovascular effects\(c\) | 135 | 0.74 | Cardiomyopathy and myocarditis | 46.5 | 0.079 | 46.6 | 0.24 |
| Reproductive   |                                          |                                               |
| Decreased ovulation rate | 4.68 | 20  | Female infertility | NA | 5.41×10\(^{-3}\) | 5.41×10\(^{-3}\) | 0.79×10\(^{-3}\) |
| Decreased testis weight | 2.15 | 50  | Male infertility | NA | 5.67×10\(^{-3}\) | 5.67×10\(^{-3}\) | 1.9×10\(^{-3}\) |
| Decreased sperm motility | 2.15 | 50  | Male infertility | NA | 5.67×10\(^{-3}\) | 5.67×10\(^{-3}\) | 1.9×10\(^{-3}\) |
| Decreased ovarian follicle count\(c\) | 292 | 0.34 | Female infertility | NA | 5.41×10\(^{-3}\) | 5.41×10\(^{-3}\) | 0.013×10\(^{-3}\) |
| Decreased intratesticular testosterone\(c\) | 249 | 0.4 | Male infertility | NA | 5.67×10\(^{-3}\) | 5.67×10\(^{-3}\) | 0.017×10\(^{-3}\) |
| Decreased thymus weight | 1326 | 0.075 | Meningitis | 77.1 | 0.094 | 77.2 | 0.40 |
| Male           |                                           |                                               |
| Decreased number of B cells (IgM & IgA levels) | 5405 | 0.019 | Diarrheal diseases | 71.3 | 0.11 | 71.4 | 0.037 |

BMC\(10\): benchmark concentration at 10% response level; HEC: human equivalent concentration; I/R\(c\): inhalation unit risk (central estimate); \(*[10]\); NA: Not applicable
Table 3. Cancer relative potency factor (RPF) and non-cancer relative toxicity factor (RTF, derived from QSAR) for sixteen priority PAHs

| S/N | PAH             | Cancer RPF | Non-cancer RTF |
|-----|-----------------|------------|----------------|
| 1   | Naphthalene     | 0          | 2.7            |
| 2   | Acenaphthylene  | 0.001      | 2.6            |
| 3   | Acenaphthene    | 0          | 2.2            |
| 4   | Fluorene        | 0.001      | 2.0            |
| 5   | Anthracene      | 0          | 1.8            |
| 6   | Phenanthrene    | 0          | 1.7            |
| 7   | Pyrene          | 0          | 1.5            |
| 8   | Fluoranthene    | 0.08       | 1.4            |
| 9   | Chrysene        | 0.1        | 1.2            |
| 10  | Benzo[a]anthracene | 0.2 | 1.1            |
| 11  | Benzo[a]pyrene  | 1          | 1              |
| 12  | Benzo[b]fluoranthene | 0.8 | 0.9            |
| 13  | Benzo[k]fluoranthene | 0.03 | 0.9         |
| 14  | Benzo[g,h,i]perylene | 0.009 | 0.9        |
| 15  | Indeno[1,2,3-cd]pyrene | 0.07 | 0.8            |
| 16  | Dibenzo[a,j]anthracene | 10 | 0.8            |

*13

3. Results and discussion

Figure 1 shows the burden of specific diseases per unit exposure to PAH in Nigeria, expressed in DALYs per person-year per ng/m³ of benzo[a]pyrene B[a]P or phenanthrene (PHE) – representative of particle-phase or gas-phase PAHs, respectively. The estimates for the other fourteen PAHs are not shown. On a unit exposure basis (i.e. per ng/m³) the burden of disease resulting from the particle-phase PAHs in Nigeria is substantially greater than those of the gaseous phase PAHs.

![Figure 1](image-url)

**Figure 1**: PAH burden of specific diseases in Nigeria, expressed in disability-adjusted life years (DALYs) per person-year per ng/m³ of benzo[a]pyrene (B[a]P) (A) or phenanthrene (PHE) (B) – a representative of the high or low molecular weight PAH, respectively.

Particulate PAHs-induced lung cancer appears to be the greatest amongst the health outcomes considered. Put in other words, Nigerians may suffer more from the effect of PAH-induced lung cancer than other PAH-related diseases due primarily to a combination of high excess risk of lung cancer disease from PAH exposure (e.g. for B[a]P, it is 11 cases in every 1 million persons) and high baseline lung cancer disease severity in Nigeria (24.9 DALYs lost per case of lung cancer disease) (Table 1 and 2). Although the estimated unit risk of B[a]P-induced reproductive effects in males – reduced testis weight, low sperm count, decreased sperm motility or abnormal sperm – of 50 excess cases per 1 million individuals was the greatest, the severity of male infertility in Nigeria is relatively very small (0.00567 DALYs per case). Likewise, although the severity of measles appears to be the largest amongst the health outcome considered, which is 84 DALYs per case in Nigeria, the probability of the PAH inducing immunological effects are relatively very low i.e. about 2 to 8 excess cases per 100 million persons.

Particle-phase PAHs are known carcinogens acting via a mutagenic mode of action, whereas the gas-phased PAHs are typically non-carcinogens. For the gas-phased PAHs, the burden of developmental effects dominates. Our result supports previous reports that particle-phase PAHs are individually more toxic than the gas-phased PAHs [2, 15]. We note however, that the biological...
response to a PAH depends not only on the individual toxicity of the PAH, but also on the dose that reach the target tissues, as well as the biological residence time.

The global gridded surface B[a]P concentration dataset for 2007, with spatial resolution of 0.1° × 0.1° [16], provided us the opportunity to assess the contribution of differential exposure to the overall burden of disease from airborne B[a]P in Nigeria. Utilizing population count datasets for the same year and with the same spatial resolution, we estimated the population-weighted average exposure to atmospheric B[a]P in Nigeria in 2007 and the resulting burden of disease using standard method [17]. Figure 2 shows the share of the per capita or population burden of disease due to B[a]P inhalation exposure at the local sub-national level in Nigeria in 2007.

Figure 2: Share of per capita (A) or population (B) burden of disease due to benzo[a]pyrene (B[a]P) inhalation exposure at the local sub-national level in Nigeria in 2007.

Lagos State had the greatest DALYs or DALYs per person from B[a]P exposure in 2007, in Nigeria. Also, no state in Nigeria averaged below the global acceptable burden of disease of 1.0 × 10⁻⁶ DALYs per person-year from any single pollutant [8–9, 18–19]. The total number of lost DALYs/person or DALYs) due to B[a]P exposure in 2007, in Nigeria as a whole was 6.3 × 10⁻⁶ DALYs/person (or 970 DALYs), which is about six times the acceptable burden of disease from a single pollutant. The value for Nigeria (i.e. 970 DALYs per year) is substantially greater than the burden of disease attributed to B[a]P-related lung cancer in the USA or the Netherlands, which is 86 or 96 DALYs per year, respectively [20–21]. Our estimate for Nigeria is however lower than the lung cancer burden of disease due to B[a]P inhalation exposure in China, which is 12,000 DALYs per year [22], or the total burden of disease attributed to thirteen airborne PAHs mixture in an Indian district, which is 49,500 DALYs per year [10].

To develop the national health-based target for individual PAH in air, we determined the exposure concentration that corresponds to the global acceptable limit of 1.0 × 10⁻⁶ DALYs per person-year in Nigeria. Table 4 shows the national health-based target for sixteen PAHs in air, and the interim target based on a less stringent burden of disease of 1.0 × 10⁻³ DALYs per person-year. The WHO guideline for PAH, based on B[a]P equivalent concentration, is also highlighted in Table 4.
Table 4. National health-based guideline (ng/m³) for sixteen PAHs in air

| S/N | PAH               | Health-based target¹ | Interim target² |
|-----|-------------------|-----------------------|-----------------|
| 1   | Naphthalene       | 0.35                  | 3.5             |
| 2   | Acenaphthylene    | 0.36                  | 3.6             |
| 3   | Acenaphthene      | 0.42                  | 4.2             |
| 4   | Fluorene          | 0.47                  | 4.7             |
| 5   | Phenanthrene      | 0.54                  | 5.4             |
| 6   | Anthracene        | 0.53                  | 5.3             |
| 7   | Pyrene            | 0.61                  | 6.1             |
| 8   | Fluoranthene;     | 0.50                  | 5.0             |
| 9   | Chrysene          | 0.55                  | 5.5             |
| 10  | Benzo[a]anthracene| 0.43                  | 4.3             |
| 11  | Benzo[a]pyrene    | 0.15 (0.12c)          | 1.5 (1.2c)      |
| 12  | Benzo[b]fluoranthene| 0.18                 | 1.8             |
| 13  | Benzo[k]fluoranthene| 0.85            | 8.5             |
| 14  | benzo[g,h,i]perylene | 1.0              | 10              |
| 15  | Indeno[1,2,3-cd]pyrene | 0.79            | 7.9             |
| 16  | Dibenzo[a,h]anthracene | 0.02            | 0.2             |

¹corresponding to 10⁻⁶ DALYs per person-year; ²corresponding to 10⁻⁵ DALYs per person-year; ³WHO guideline value [2, 7]

The global target or interim PAH limit of 0.12 or 1.2 ng/m³ of B[a]P, respectively, appear to be more stringent than our proposed national PAH limit of 0.15 or 1.5 ng/m³ of B[a]P, respectively. The global guideline was developed to protect the most vulnerable subpopulation in the world regardless of the country. However, our proposed national health-based target developed herein accounts for the actual proportion of vulnerable subpopulation such as the percentage of the very young children, pregnant women or the elderly and people with pre-existing health problems (i.e. baseline disease condition) whom are very likely to be affected by exposure to PAHs in Nigeria. Furthermore, because PAH profile in ambient air may change depending on the pollution source, our proposed national health-based target includes fifteen other PAHs, aside B[a]P, which are hitherto not directly regulated globally. Thus, providing the opportunity to monitor/regulate the concentrations of sixteen priority PAHs based on the actual, real-life health impact in Nigeria.

4. Conclusion

Exposure to PAHs may cause both cancer and non-cancer effects. Current global guideline for PAH in air is based solely on B[a]P, and does not consider the proportion of vulnerable people in Nigeria most likely to be affected by the exposure, or the country’s baseline health condition. Therefore, we have, for the very first time, developed a national health-based target and interim target for sixteen priority PAHs using Nigeria’s demographic and health statistics. Our proposed national health-based guideline for PAH is less stringent than the global guideline for PAH indicating relatively reduced ‘cost’ of intervention.

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