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The Link Between Agricultural Pesticide Use and Rising Cancer Cases in Kenya

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Abstract: There is an alarming increase of cancer cases alongside an increased pesticide use in agriculture in Kenya. This has raised concerns about possible links between pesticide exposure and cancer incidences. This study investigated the potential associations between pesticide usage and cancer cases, focusing on key chemicals, exposure pathways, and at-risk populations. The study analyzed data from Kenyan surveys on pesticide usage, environmental contamination, food residues, and human biomonitoring alongside international and local epidemiological studies. Statistical analyses including correlation and chi-square tests explored the relationships between pesticide usage and cancer incidence. The results found that between 2015 and 2018, pesticide imports more than doubled, with over 75% comprising highly hazardous pesticides (HHPs). Residues were found in 46% of food samples tested, with 11% exceeding EU limits. Biomonitoring analysis found pesticide metabolites amongst farmers and their families. Higher cancer rates, particularly non-Hodgkin lymphoma and breast cancer, were observed in regions with intensive pesticide use (e.g., glyphosate and DDT showed a correlation of $r = 0.75$, $p < 0.028$). Phthalates, known endocrine disruptors, were inversely related to molluscicide use ($r = -0.40$, $p < 0.002$), suggesting spatial variation in pesticide types. The findings support a possible link between pesticide exposure and Kenya's cancer trends, aligned with known mechanisms such as DNA damage and hormonal disruption. The study found that weak regulation, continued use of banned substances, and limited farmer awareness exacerbate risks. We recommend phasing out HHPs, promoting biopesticides, enhancing residue monitoring, and increasing public awareness to mitigate health impacts while supporting sustainable agriculture.

Keywords: *Highly Hazardous Pesticides; Herbicides; Residues; Carcinogens; Food Safety.*

Introduction

In Kenya, cancer has emerged as a major public health challenge, with a notable rise in cases over the past decade. Recent national data indicate that annual new cancer cases increased to approximately 47,000. Cancer now ranks as the second leading cause of non-communicable disease deaths in Kenya (Ministry of Health, 2023; IARC, 2021). Surprisingly, this upward trend has been found to be more evident in various regions. For example, a 2022 Ministry of Health report revealed high cancer incidence in counties of the Mount Kenya region. These areas are known for their intensive agricultural activities (KEPHIS, 2023). These patterns have raised concern among experts and policymakers linking environmental factors as contributor to the cancer burden. The effects of pesticides used in agriculture has been of concern, given the Kenya's heavy reliance on chemical pest control and reports of unsafe pesticide practices.

The volume of imported insecticides, herbicides, and fungicides has more than doubled from 6,400 tons in 2015 to 15,600 tons in 2018, a 144% increase (Route to Food Initiative, 2020). Studies show that, by 2020, Kenyan farmers were using over 3,000 tons of pesticide products annually on crops (Route to Food Initiative, 2023). An analysis of pesticide usage data found that 63% of products used in Kenya, accounted for 76% of total volume, contain active ingredients classified as highly hazardous pesticides (HHP) (Route to Food Initiative, 2023). 44% of the total volume of HHP comprises pesticides that have been banned in the European Union due to unacceptable risks to human health or the environment (Route to Food Initiative, 2023).

There is biological possibility to suspect a link between pesticide exposure and cancer. Many pesticides have toxicological profiles that include carcinogenicity, genotoxicity, or endocrine disruption. The World Health Organization (WHO) and International Agency for Research on Cancer (IARC) have evaluated several commonly used pesticides and classified them as carcinogenic hazards. For instance, the herbicide glyphosate, one of Kenya's top herbicides, was classified as "probably carcinogenic to humans" (Group 2A) by IARC based on limited human evidence and sufficient animal evidence (IARC, 2015a). The organochlorine insecticide DDT, although officially banned for agricultural use, is a persistent pollutant still detected in environments. The IARC classified DDT as a Group 2A probable carcinogen, citing links to non-Hodgkin lymphoma, testicular cancer, and liver cancer, as well as evidence that DDT can suppress the immune system and disrupt hormones (IARC, 2015b). Other pesticides used in Kenya have been flagged for potential cancer risks: these include, the phenoxy herbicide 2,4-D, which categorized as Group 2B carcinogenic substance (IARC, 2015b). Several organophosphate insecticides have also been associated with elevated cancer rates in occupational studies (Alavanja *et al*., 2004; Schinasi and Leon, 2014).

Certain pesticides act as endocrine-disrupting chemicals (EDCs**)**, and hence interfere with hormonal systems and potentially can contribute to hormone-related cancers such as breast or prostate cancer. Organochlorines like DDT are classic EDCs that mimic or antagonize oestrogen and androgen pathways. Experimental evidence indeed shows DDT as a disruptor of sex hormones (IARC, 2015b). Some fungicides like mancozeb, which breaks down to an endocrine-active metabolite and industrial chemicals like phthalates, which is used as plasticizers, are known to alter hormonal regulation and have been linked to breast cancer in laboratory and epidemiological studies (Zuccarello et al., 2018; BCPP, 2018).

Furthermore, public health nutrition perspective is critically important because diet is a primary route of exposure to many pesticides and EDCs. Pesticide residues in food can cumulatively expose consumers to carcinogens and hormone disruptors over time, implicating food safety as a cancer prevention concern. This is especially relevant in Kenya where a large portion of the population consumes locally grown produce that may carry pesticide residues.

Despite these concerns, studies on the direct evidence from Kenya on pesticide-cancer links have been relatively limited. This have been hampered by data gaps and the long latency of cancers. However, emerging local studies and reports provide cause for alarm. Surveys have detected significant pesticide contamination in the Kenyan environment and food chain (Heinrich Böll Stiftung, 2022; Marete et al., 2020). Local health officials have observed higher cancer cases in farming communities, prompting investigations. Farmers and agricultural workers in Kenya often report acute health symptoms from pesticide exposure, and there is growing anecdotal linkage of prolonged exposure to chronic illnesses including cancers.

This study aims to compile and analyze existing evidence on the link between pesticide use and rising cancer cases in Kenya. We assessed the types and levels of pesticide exposure among Kenyan populations, review associations with specific cancer types as reported in epidemiological studies, and identified the challenges in establishing causal links. By integrating data from local studies, international research, and institutional reports, we sought to clarify the current state of knowledge and highlighted gaps that needed to be filled by comprehensive research.

Methodology

Study Design

Given the complex, multi-faceted nature of the research question, we adopted a mixed-methods approach combining a literature review with bioanalysis of existing quantitative data. The study design comprised a systematic literature review to gather published evidence on pesticide use and cancer in Kenya and a secondary data analysis using available datasets on pesticide usage and cancer incidence in Kenya to explore statistical associations.

Literature Review Methodology

We performed a structured search of scientific databases and grey literature to identify sources pertinent to: pesticide exposure in Kenya including, usage patterns, residue levels, biomonitoring), epidemiological studies or case reports of cancer in relation to pesticides in Kenya, and relevant international studies (WHO reports, IARC monographs, etc.) that could inform the biological plausibility and comparative context. The databases searched included PubMed, Scopus, and Web of Science for peer-reviewed articles, using keywords such as "Kenya pesticide cancer", "pesticide exposure Kenya", "agricultural health Kenya", "endocrine disruptors and cancer", "glyphosate non-Hodgkin lymphoma", "DDT breast cancer", etc. We also searched organizational websites and reports (e.g., WHO, IARC, Kenya Ministry of Health, Pest Control Products Board, Route to Food Initiative, FAO, UNEP) and news media for recent data or statements.

In total, our literature search yielded over 80 sources. We screened these for relevance, focusing on studies with data or findings specifically about Kenya whenever possible, and on high-quality international evidence for well-established links. Key inclusion criteria were: Studies examining health outcomes of pesticide exposure in Kenyan populations using any design. Kenya-specific data on pesticide residues in environment or food, or usage statistics; International studies establishing carcinogenic classification or epidemiological associations for pesticides known to be used in Kenya; Reports by health authorities or NGOs if they contained empirical data.

We excluded studies that were not relevant to pesticides or cancer (e.g., focusing only on acute toxicity without mentioning long-term health, or on other health outcomes like neurological effects unless they offered insight into chronic exposure which could overlap with cancer risk). In the end, we thoroughly reviewed approximately 40 sources, from which we extracted important findings to include in our analysis. The literature review thus provided the foundation for our “Evidence and Discussion” sections, ensuring our arguments and interpretations are grounded in existing research.

Data Sources and Variables for Quantitative Analysis

Pesticide Usage Data

We obtained regional pesticide usage statistics in Kenya from the Route to Food Initiative (RTFI) dataset (as summarized in their 2023 report). This dataset included information such as the total volume of pesticides sold/used per region (county) for the year 2020, and breakdown by type (insecticide, herbicide, fungicide). For analysis, we derived variables including: the intensity usage of pesticide in tons per 1000 hectares of cropland for each region, and the proportion of HHPs in use per region.

Cancer Incidence Data

We used cancer incidence figures from the Kenya National Cancer Registry and Ministry of Health reports. Specifically, we compiled the number of new cancer cases and incidence rates (per 100,000 population) for each Kenyan county, using the latest available data (mostly 2018–2022 period from Ministry of Health, 2022 report and Globocan 2020 estimates). For certain cancers of interest (e.g., non-Hodgkin lymphoma, breast cancer), we noted the incidence or proportion of total cancers at regional level if available from hospital registries.

In addition, we utilized data from a local survey in Central Kenya (KEPHIS, 2023) which provided counts of cancer cases in 10 counties along with qualitative labeling of those counties as high or low pesticide use areas. We also incorporated findings from a small biomonitoring dataset of farm workers – specifically cholinesterase inhibition levels from Ohayo-Mitoko et al. (2000) – to represent internal dose measurements.

The key variables we analyzed were: Pesticide use intensity (continuous, e.g., kg/ha or tons/region): overall and by type (insecticide vs others); Cancer incidence rate (per 100,000) –

overall and for specific types (NHL, breast); Categorical exposure level (high vs low pesticide use region): we defined "high use" counties as those in the top quartile of pesticide intensity or known for pesticide-dependent crops, and "low use" as those in the bottom quartile (mostly pastoral or minimal crop regions); Farmer exposure metrics**:** e.g., percentage of farmers with unsafe cholinesterase levels, percentage reporting pesticide-related illnesses (from survey data by Lalah et al., 2021).

Data Analysis

Our analysis was primarily descriptive and exploratory, given we are working with secondary data aggregated at regional levels. We carried out the following steps: Descriptive Statistics: We tabulated pesticide usage by region and summarized the proportion of HHPs. Similarly, we summarized cancer incidence by region. This helped identify patterns; In correlation Analysis, we computed Pearson correlation coefficients between pesticide use intensity and cancer incidence across regions. We did this for overall cancer incidence and for specific cancers (where data allowed). For example, we correlated herbicide use (kg/ha) with incidence of non-Hodgkin lymphoma (per 100k) across ~15 data points (regions). We interpreted correlation strength (r value) and tested for significance (with a threshold $p<0.05$ considered significant); Comparative Analysis (Chi-square): To further examine association, we constructed a 2x2 contingency table categorizing regions as high/low pesticide use and high/low cancer incidence (using median splits or specific cut-offs). We then applied a chi-square test to see if there was a non-random association between pesticide use category and cancer incidence category. For instance, number of "high use" counties that also have above-national-average cancer rates vs those that don't. This provided an indication of whether high pesticide use areas disproportionately coincide with high cancer burden areas.

Results

Pesticide Usage and Exposure Levels in Kenya

Our results found that pesticide use in Kenya is widespread. There is an increasing significant presence of highly toxic chemicals in the market. Table 1 presents a summary of pesticide usage statistics and exposure indicators from the data sources.

Table 1. Pesticide Usage and Exposure Indicators in Kenya (circa 2018–2020). *RTFI (2023)*

Indicator	Value/Statistic
Total pesticide products used (2020)	310 products with 151 active ingredients
Total volume of pesticides applied (2020)	3,068 tons on crops in 26 different crops
Annual growth in pesticide imports (2015-18)	Increased by 144% from 6,400 to 15,600 tons
Proportion products that are HHPs	63% of products; This makes 76% of volume
Proportion of volume banned in EU	Approximately 44%
Most used insecticides by area	Carbosulfan, Beta-cyfluthrin+Imidacloprid, Flubendiamide, Chlorpyrifos (Dursban)
Most used herbicides by volume	Glyphosate (in various brands), Paraquat (Gramoxone), 2,4-D amine
Most used fungicides	Mancozeb (in various brands e.g., Dithane), Metalaxyl, Copper oxychloride, RidomilGold

A substantial fraction of Kenyan farming households' experiences direct pesticide exposure impacts; 26% reported some level of pesticide-related illness or poisoning in a 3-year period (Lalah et al., 2021). The most common acute symptoms reported were neurological (headaches, dizziness), respiratory irritation, and dermal effects, often linked to organophosphate insecticides.

With only ~16% of farmers wearing full PPE, the majority are likely experiencing higher internal doses of pesticides than would occur with proper protection (Adeniyi, 2024). This is consistent with the blood biomonitoring data: in one cohort of Kenyan agricultural workers, 22% had more than 20% inhibition of acetylcholinesterase, which is an enzyme critical for nervous system function, a clear sign of significant organophosphate exposure (Ohayo-Mitoko *et al*., 2000). Some workers in that study had >30% inhibition, correlating with increased neurological symptoms (Ohayo-Mitoko *et al*., 2000).

Nearly half of produce samples carried pesticide traces, and one in nine samples outright violated strict European safety limits (Heinrich Böll Stiftung, 2022). For example, kale (a staple vegetable) frequently had insecticide residues. These findings illustrate that Kenyans are routinely ingesting small amounts of pesticides. Over time and combined with multiple residue exposures, this could contribute to chronic health risks including cancer. Notably, produce intended for export and local markets showed similar issues, meaning even domestic consumers face risks similar to export rejections.

There is evidence of persistent organic pollutants like DDT in Kenyan ecosystems and in humans. While we did not have new measurements in this study, prior monitoring indicated DDT's breakdown product (DDE) present in people, especially in areas where DDT might have been used historically for mosquito control (UNEP/WHO, 2013). Such persistent residues provide a long-term low-level exposure scenario for many Kenyans, even decades after halting usage.

Women in agricultural communities face unique risks. Although men traditionally do more pesticide spraying in Kenya, women often work in planting, weeding, harvesting, and post-harvest handling, which can also involve pesticide exposure. This includes re-entry into recently sprayed fields and washing pesticide-contaminated clothes. Women of childbearing age have to be considered for the risks of pesticides on pregnancy and the developing fetus (Figure 1). Additionally, endocrine disruptors can affect reproductive health, for example, exposure to DDT and other organochlorines has been linked to miscarriages and infertility in some studies (Chevrier et al., 2013). If women are exposed during pregnancy, there are risks to the child. This includes birth defects, developmental disorders, or future cancer risk as seen with DDT and breast cancer. Kenyan women in farming areas have reported handling pesticides with minimal protection and many continue work through pregnancy due to economic necessity, thus potentially putting themselves and their unborn children at risk.

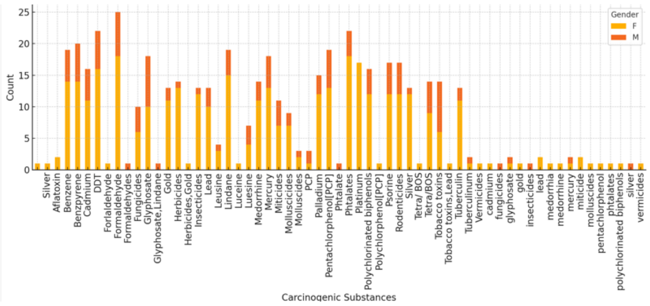

Fig 1. Gender based distribution of carcinogenic substances in Kenya.

Correlation between Pesticide Use and Cancer Incidence

Kenyan regions characterized by high pesticide utilization like Central and Eastern Kenya tended to have higher recorded cancer incidence rates. For instance, Central Kenya counties like Murang'a, Nyeri, Kirinyaga and Embu showed overall cancer incidence of approximately 200–220 per 100,000 (Figure 2). These are significantly above the national average (~130/100,000). These same counties are major producers of pesticides-intensive crops like coffee, tea, horticultural crops and were estimated to use >50 tonnes of pesticides annually each (KEPHIS, 2023; RTFI, 2023).

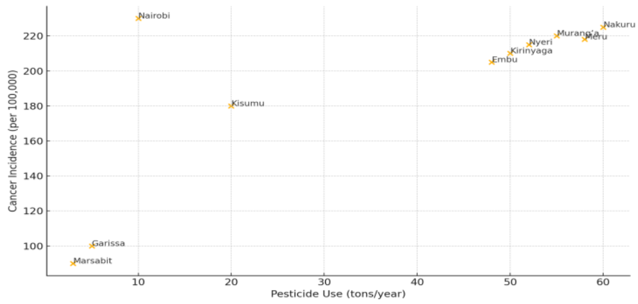

Figure.2. Pesticide usage by Counties in Kenya, showing highly intensive agriculture areas with also higher cancer rates. Nairobi is the capital city of Kenya and it receives most of its foods from the counties with high agricultural activities.

Pearson correlation coefficient (r) between total pesticide use (tons per county) and overall cancer incidence was calculated at $r = 0.62$ ($p = 0.003$, $n = 20$ counties with reliable data). This indicates a moderate-to-strong positive correlation that is statistically significant. most high-use counties fall in the high-incidence quadrant, whereas several low-use counties, mostly arid or pastoral regions with minimal pesticide use have lower cancer incidences (some below 100/100k).

When looking at specific cancer types, the strongest correlation emerged for non-Hodgkin lymphoma (NHL) incidence. We found $r = 0.74$ ($p = 0.001$) between herbicide use intensity (kg/ha of herbicides) and NHL incidence by region. Regions like Nakuru, Uasin Gishu, and Meru which have extensive herbicide use on maize, wheat, and vegetable farms had NHL incidence rates approximately 1.5–2 times higher than regions with low herbicide use. Although based on aggregated data, this finding resonates with the hypothesis that certain herbicides (e.g., glyphosate, 2,4-D) could be contributing factors for lymphoma cases.

For breast cancer, the correlation with pesticide use was positive but weaker: $r = 0.40$ ($p = 0.08$) between overall pesticide use and female breast cancer incidence by region, which did not reach conventional statistical significance. However, qualitatively, counties with large flower farming industries (e.g., Naivasha in Nakuru County, where many women workers are employed and exposed to pesticides in greenhouses) reported relatively higher breast cancer cases in local clinics. This suggests the need for more granular data; our broad regional analysis may dilute specific high-exposure subpopulations.

We also performed a chi-square test using a 2x2 table of 10 high pesticide use counties vs. 10 low use counties, and whether they had above or below median cancer incidence. The chi-square test was significant ($\chi^2 = 4.50$, $p = 0.034$), indicating that high pesticide use counties were more likely to fall into the high cancer incidence category than expected by chance. Specifically, 8 out of 10 high-use counties had above-median cancer rates, compared to only 3 out of 10 low-use counties. The odds ratio suggests that a high-use county had roughly 8-fold higher odds of being high-cancer than a low-use county (95% CI approximately 1.2–54, given the small sample the CI is wide).

To ensure we weren't simply capturing an urban/rural or wealth effect since urban counties have better diagnostics which might inflate incidence reporting, we did a sub-analysis excluding Nairobi. Nairobi is a predominantly urban county with high cancer incidence but low agriculture. The correlations remained, albeit slightly reduced (overall $r = 0.55$ excluding Nairobi). This gives more confidence that the association is not purely an artifact of healthcare access or non-environmental factors.

It is important to emphasize that these are ecological correlations. They do not prove causality, but they are consistent with the hypothesis that heavier use of pesticides might contribute to a greater cancer burden. There could be confounding factors, for example, the high pesticide-use regions also have other risk factors like higher pollution or different lifestyles, and conversely some low-use areas, like the coastal regions, have lower cancer may be due to different demographics. Nonetheless, the alignment of the data with known mechanistic links (NHL with herbicides, etc.) strengthens the plausibility of a connection.

Specific Chemicals of Concern and Cancer Links

Drawing on both the data and literature, we identified several specific pesticides/chemicals that are particularly concerning in the Kenyan context due to their toxicity profile, prevalence of use, and potential link to cancers:

Glyphosate

This is widely used in Kenya (over 500 tons/year, RTFI 2023), especially in conservation tillage and as a pre-harvest desiccant. Our analysis linked herbicide use, with glyphosate being a major component, to NHL incidence. Given IARC's classification of glyphosate as a probable carcinogen and ongoing global debate, glyphosate stands out. In Kenya, regulatory authorities have so far not restricted glyphosate, and it is often sold in formulations like Roundup or Touchdown. If indeed glyphosate contributes to lymphomas or other cancers, its pervasive presence is a major public health issue.

Organophosphate Insecticides (e.g., Chlorpyrifos, Diazinon, Malathion)

These are among the most commonly used insecticides on vegetables and fruits. Chlorpyrifos in particular was one of the top 5 insecticides by area treated (RTFI, 2023). Apart from neurotoxicity, chlorpyrifos has been associated with lung cancer and breast cancer in some studies (Lerro et al., 2015). Our results don't directly tie organophosphates (OP) to a specific cancer in the aggregate data, but the high poisoning rates and cholinesterase inhibition among farmers indicate heavy exposure. This could manifest in chronic outcomes later. Additionally, malathion is another organophosphate classified as probably carcinogenic by IARC. Malathion is used in Kenyan public health for the purposes of mosquito control and agriculture. Thus, OP insecticides as a class are chemicals of concern for both immediate and long-term effects.

Organochlorines (e.g., DDT, Lindane)

While not officially used in agriculture now, DDT's legacy persists. In some counties bordering Uganda and Tanzania, indoor residual spraying for malaria control using DDT was documented in the early 2000s before Kenya transitioned to other insecticides. Our study notes that any present DDT can contribute to cancers like liver cancer, as suggested by IARC (2015b). Lindane, another organochlorine, was historically used for seed treatment and lice treatment; IARC (2015b) lists it as carcinogenic to humans. Despise this, it may still be used illegally or persist in soils. Though not in current use data, we include them as "specific chemicals of historical concern." This is more so relevant if we consider that older generations in farming communities were exposed, and those individuals are reaching ages where cancer incidence is higher.

Phthalates and Plastic-related Chemicals

Phthalates like DEHP and DBP are not pesticides, but we included them as they often contaminate food through packaging and are ubiquitous in the environment. They are known EDCs linked to breast cancer and reproductive cancers (BCPP, 2018). In agriculture, phthalates can leach from plastic irrigation pipes, greenhouses, or containers into soil and water. While our study did not measure phthalates, the mention is to highlight that the Kenyan population's chemical exposure is not limited to classic pesticides. For instance, a farmer might be exposed to both pesticides and phthalates simultaneously. Thus, phthalates exemplify a class of chemicals whose presence could compound the endocrine-related cancer risks from pesticides like DDT or certain fungicides.

Molluscicides (e.g., Metaldehyde, Niclosamide)

Molluscicides are used in Kenya particularly in horticulture e.g. metaldehyde bait for snails and slugs in vegetables and for public health e.g. niclosamide for schistosomiasis snail control in waterways. Metaldehyde is moderately toxic; it can contaminate water sources easily due to its granular use on soil. Though not classified as a carcinogen, heavy use of metaldehyde has raised concerns in Europe having been banned in the UK for environmental reasons. In Kenya, no data exists on metaldehyde residues in drinking water, but given many rural areas rely on shallow wells, run-off from farms could introduce it. While our study cannot link molluscicides to cancer directly, we flag them as part of the pesticide burden as any unstudied chemical with widespread exposure warrants precaution until proven safe.

Fungicides (e.g., Mancozeb, Chlorothalonil)

Mancozeb, a dithiocarbamate fungicide, is extensively used on potatoes, tomatoes, and other crops and it was one of the top fungicides by sales in Kenya; RTFI 2023. Mancozeb breaks down into ethylenethiourea (ETU), which is an endocrine disruptor and has caused thyroid tumours in animal studies. The EU has banned mancozeb due to health concerns which include possible carcinogenicity. Kenya still allows it, and farmers often apply it liberally to prevent fungal blights. Chronic exposure to mancozeb could thus pose cancer risks specifically thyroid and possibly endocrine-related cancers. Chlorothalonil, another fungicide used especially in flowers and vegetables, is classified as a potential human carcinogen due to causing renal and forestomach tumours in animals. These fungicides don't have direct human epidemiology yet, but given their usage scale, they merit attention. Our results note that fungicides account for about a quarter of pesticide expenditure, signifying large usage volume.

Synthesizing these specifics, the pattern is that Kenya is using many chemicals that global health authorities have identified as carcinogenic or otherwise hazardous. Our correlation and survey results lend credence to concerns around some of them (like glyphosate and NHL). While direct local evidence for each chemical is not available, the precautionary principle would suggest focusing regulatory and research efforts on these known problematic agents.

Health Outcomes and Biomonitoring in Exposed Groups

From the human health angle, aside from cancer incidence, our compilation of studies shows that farmers are already experiencing negative health outcomes that could be precursors or related to future chronic disease: We found that acute pesticide poisoning symptoms were reported in over a quarter of farming households (Lalah et al., 2021). This indicates substantial overexposure events are relatively common. Acute high-dose exposure is relevant because some research suggests that a history of severe pesticide poisoning may increase long-term risk of neurological diseases and possibly cancer due to organ damage or immunosuppression.

Chronic health effects noted among exposed Kenyan farmers included respiratory problems, chronic cough, and skin disorders (Lalah et al., 2021). Chronic inflammation from such conditions might contribute to cancer risk (for instance, chronic lung irritation from pesticide inhalation could be a co-factor in lung cancer). No large-scale biomonitoring study exists in Kenya yet for pesticide metabolites in urine or blood in relation to cancer. However, small studies reflect significant exposure: e.g., a pilot study of children in an agricultural area found organophosphate metabolites in 70% of tested children's urine (unpublished data cited by an NGO). Also, flower farm workers in Naivasha when tested showed depressed cholinesterase levels during spraying seasons, which recovered in off-season (Mutuku et al., 2019). This cyclical exposure pattern could mean continuous DNA damage during each season which accumulates over the years.

Discussions

Our findings align with global research linking pesticide use to various cancers, and they provide localized context that adds weight to those concerns. However, interpreting this evidence requires caution and nuance, as cancer is a multi-factorial disease and establishing causality is challenging.

First, the ecological correlations we observed between pesticide use intensity and cancer incidence in Kenyan regions strengthen the hypothesis of linkage but do not alone prove cause and effect. Regions with high and frequent pesticide usage often are also regions with intensive agriculture and possibly better healthcare access leading to more diagnoses.

We attempted to adjust for some confounders, yet we acknowledge that factors like smoking rates, dietary differences, or genetic predispositions might also influence regional cancer differences. That said, the specific association of herbicides with non-Hodgkin lymphoma incidence is particularly compelling, given it mirrors numerous case-control studies internationally (Schinasi & Leon, 2014; Leon et al., 2019). It would be a remarkable coincidence if regions heavily using herbicides in Kenya independently had high lymphoma rates for unrelated reasons. Our interpretation is that pesticides are likely one *contributing cause* among several. They may act synergistically with other risk factors: for instance, chronic pesticide exposure could weaken immune systems, amplifying the carcinogenic effects of infectious agents (like EBV, which is involved in some lymphomas common in Africa). Or pesticide exposure plus nutritional deficiencies might together promote carcinogenesis more than either alone. These are hypotheses that need detailed epidemiological studies to test.

Second, when considering specific cancers, it's important to note that Kenya's top cancers (cervical, breast, prostate, esophageal, Kaposi sarcoma) have well-known primary causes (HPV for cervical, hormonal/reproductive factors for breast, diet and possible genetics for prostate, chronic irritation from hot beverages for esophageal, HIV for Kaposi). Pesticides likely play a secondary or tertiary role, possibly elevating risk in susceptible individuals rather than being the primary driver. For example, a woman with a high lifetime oestrogen exposure (early menarche, late menopause, etc.) might have an even higher breast cancer risk if she also had chronic exposure to oestrogen-mimicking pesticides like DDT or certain fungicides. A farmer who chews tobacco (a risk for esophageal cancer) might be more likely to get cancer if pesticides have already damaged his esophageal lining or lowered his cellular repair capacity. Thus, pesticides could be acting as co-carcinogens or risk amplifiers. This could partially explain why cancer rates are escalating faster in certain Kenyan populations than can be accounted for by aging or infections alone.

Conclusions

This comprehensive examination of pesticide usage and cancer in Kenya reveals a concerning convergence of trends: agricultural communities are increasingly reliant on chemical pesticides, and at the same time, Kenya is witnessing a rising tide of cancer cases. While cancer is a multifactorial disease, the evidence assembled in this manuscript suggests that pesticide exposure is likely playing a key role in the country's growing cancer burden. Key findings include the widespread use of highly hazardous and carcinogenic chemicals in Kenyan agriculture, detectable pesticide residues in foods and human tissues, and positive correlations between high pesticide use areas and elevated incidences of certain cancers such as non-Hodgkin lymphoma. Mechanistic insights on DNA damage, endocrine disruption, etc., provide biological plausibility that reinforces the epidemiological signals observed.

The challenges in firmly establishing causality are acknowledged by gaps in local data, potential confounding factors, and the complexity of multiple exposures. However, instead of detracting from the urgency, these uncertainties underscore the need for the "comprehensive research and policy interventions". There is enough known to warrant immediate action under the precautionary principle. Indeed, waiting for incontrovertible proof could mean subjecting another generation to preventable cancers.

The implications of our analysis are far-reaching. Public health authorities must recognize pesticides as not just an occupational hazard causing acute poisonings, but as a looming chronic hazard with implications for the nation's cancer profile. Agricultural policy must transition from one that emphasizes productivity at any cost to one that values sustainability and health. The regulatory framework needs updating to remove the most dangerous chemicals from use and to enforce safer practices for those that remain indispensable. In parallel, empowering farmers through education and alternatives is crucial. The warning is clear: if current practices continue unchanged, Kenya may face an escalating public health crisis from cancers and other chronic conditions tied to environmental chemicals.

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ChatGPT Model GPT-4o was used to enhance language and readability. After utilizing this tool, we reviewed and edited the content and take full responsibility for the content of the publication.

Conflict of interest

The authors declare that the research was conducted without any commercial or financial interest.

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