Review article

Pesticides in Libya: Health Impacts, Regulatory Gaps, and Pathways to Sustainable Management

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Abstract
Libya's agricultural sector is growing in importance, but pesticide misuse threatens both public health and the environment. This review examines the status of pesticides used in Libya. This review synthesizes data from existing Libyan studies on pesticide residues in food and groundwater, farmers' safety practices, and clinical data. A review of studies showed significant levels of pesticide contamination in different food and groundwater samples. This suggests that human health in Libya could be affected. Farmers in Libya exhibit low adherence to safety practices. However, regulatory enforcement in Libya remains weak because of political instability and limited resources, leaving farmers and consumers unprotected. Pesticide contamination is prevalent in Libya, and the chronic exposure to certain herbicides is raising, endangering human health. In addition, there is a lack of hospital records of pesticide-exposed cases; therefore, it is recommended to have firmer monitoring, more farmer education programs, and alignment with international standards. It also highlights the necessity of hospital records of pesticide-related illnesses.
Keywords. Libya, Pesticide, Health Hazard, Environmental Contamination, Occupational Exposure.

Introduction
Agriculture is vital to Libya's economy, but the country's dry climate limits arable land to coastal and oasis regions [1]. To increase production, farmers rely heavily on pesticides; insecticides alone account for 47% of total use in eastern Libya, and herbicides for 34%. That widespread use has created health hazards [2]. Pesticides do help farmers economically, but they are toxic. They carry real risks to human health and ecological stability. In Libya, these risks are made worse by factors common in developing countries: improper spraying techniques, poorly maintained equipment, and the dangerous practice of reusing pesticide containers to store food and water [3]. Despite existing regulations (e.g., Law No. 94 of 2012), enforcement is inconsistent, and farmer awareness remains low. This paper brings together current data on pesticide use in Libya, the health impacts, and the policy gaps, then proposes actionable solutions for better pesticide management.

Pesticide Use Patterns in Libya: A Regional Story of Risk and Misuse
Libya's agricultural landscape includes coastal farms, desert oases, and scattered greenhouses, each with its own pesticide use, risks, and consequences. The problem of pesticide use here is not uniform; it shifts from the olive groves of the northwest to the vegetable fields of the southeast, revealing a troubling pattern of over-reliance, mismanagement, and unintended harm.

Eastern Libya
According to Abdullah et al. (2024), the most frequently used pesticides in the Beir Bullerjam (Suluq) area in 2024 were insecticides (47%), followed by herbicides (34%), acaricides (18%), and fungicides (2%). Furthermore, farmers in this survey used the following brand names: Dursban 48 (organophosphates)., Roundup (glyphosate), Oscar wp® 50 Azoxystrobin 120 G/L + Tebuconazole 240), Permethrin, Vertimec Abamectin (Abamectin), Cyberkill 25 (Cypermethrin), Voliam Targo (Abamectin + Chlorantraniliprole). and Strike (Atrazine 50% WP). as seen in (figure_1) [1].
In 2015, near Derna, El-Awami et al found that 2.81% of fruits and vegetables exceeded the Maximum Residue Limits (MRLs), with carbofuran and oxamyl, which are two highly toxic insecticides posing a great risk [2]. The consequences extend beyond these fields. In nearby Benghazi, Samira et al. (2016) reported 113 cases of accidental pesticide poisoning in children over four years, many from families who stored pesticides in soda bottles, an upsetting error in an area where this mistake is minimal, and learning opportunities are even more limited [4]. Additional research conducted in northeast Libya, where groundwater samples were collected, showed that DDT, DDE, and heptachlor, long-banned organochlorines, were detected in 74% of surface water samples. Even more alarming, 26.98% of groundwater exceeded the WHO safety limits, a legacy of decades of runoff from farms and improper waste disposal [5].

Western Libya
In the west, near Tripoli, the pesticide profile changes significantly. Here, the distribution was more balanced: 22% insecticides, 21% herbicides, 21% fungicides, 19% rodenticides, and 17% acaricides. However, balance does not imply safety. In the capital's markets, pesticides are sold as household products. A 2024 survey conducted by Sleik et al. revealed that 79% of sellers had no agricultural training, and 72% could not explain the dangers of the products they sold [6]. In

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western Libya Lagili et al. also reported that farmers generally followed good pesticide safety practices, such as wearing protective clothing, washing PPE after use, and bathing with soap and water after spraying. However, risky behaviors persist, such as drinking water during spraying, taking protective clothing home, and washing protective clothing together with personal clothes [7].

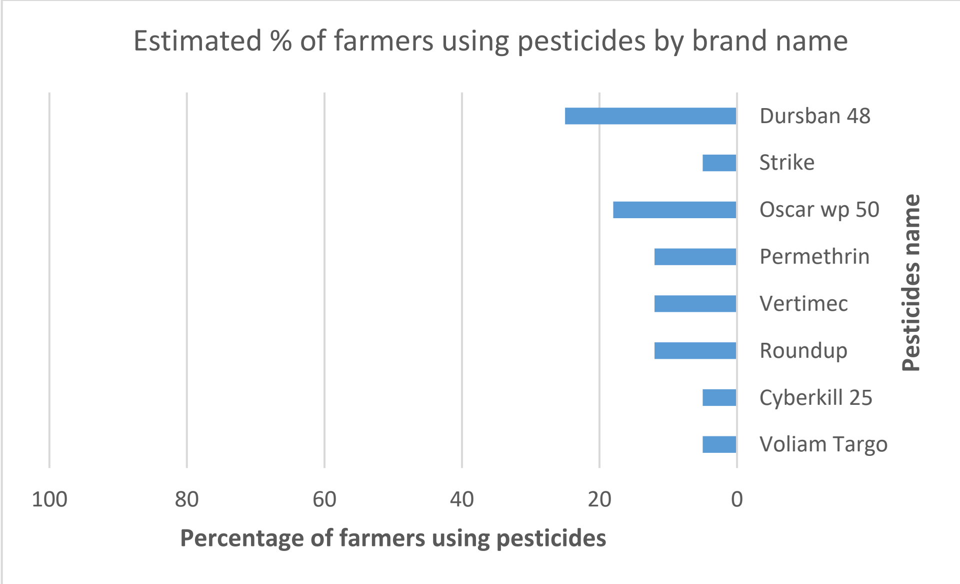

Figure 1. Ratio of pesticides consumed by farmers in Suluq using its brand name. Adapted from El-Awami et al. (2015, p. 45) [1].

Southern Libya: Greenhouses and Hidden Dangers

Further south, in the dry regions of Ubari and Wadi Alshatti, agriculture survives under plastic greenhouse covers. where farmers depend on cypermethrin and abamectin, often applying extra doses "just to be sure. "Testing revealed eggplants contaminated with 4.71 µg/g of cypermethrin, which is three times the safe limit, and 1.65 µg/g of abamectin, a neurotoxin harmful to humans and bees alike [8].

The Human Factor: Knowledge Without Action

In developing countries, farmers frequently withstand substandard levels of education and they do not have adequate training to minimize their risk from contact with pesticides. For that, a large portion of these workers either do not know about personal protective equipment (PPE) or fail to use it, and many of them misunderstand the symbols on pesticide labels [9]. On the other hand, in Libya, some farmers know the risks, but they don't have good alternatives. A study in West Tripoli found that most farmers understood how dangerous pesticides are. Yet many still dumped extra chemicals onto empty land, where those chemicals seeped into the groundwater. They also reused empty pesticide containers to store water or food meaning traces of poison ended up right in their homes, and they washed their protective gear together with the family laundry, exposing their own children to pesticide residues [6].

Health Hazards of Pesticides: Exposure Pathways and Toxicological Consequences

Pesticide regulation is a complex process that extends beyond the consumption of contaminated food and contaminated water with pesticides. It also involves food imported from neighboring countries. In fact, due to the globalized nature of agriculture, defects in the regulatory system and the enforcement of restrictions on certain pesticides are often masked. In the absence of proper regulation, foods consumed daily may be treated with excessive amounts of pesticides. Subsequently, pesticide residues can accumulate in the human body, leading to long-term health risks to the population [10].

Understanding how dangerous pesticides are for people is not easy. It is often just a rough estimation. There are reasons for that, the people can be exposed to pesticides for a different period, and the exposure can also be different, mild or strong. Moreover, different pesticides have different harmful effects. Also, the environment can play a role. Wind, heat, and the local area affect how pesticides spread and reach people. So, making an accurate exposure risk assessment is very difficult [3].

Exposure Pathways

Pesticides enter the human body through multiple routes; each associated with distinct risk factors.

Ingestion

Ingestion represents a major route of herbicide exposure, occurring accidentally, particularly among children, or

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intentionally in cases of self-poisoning. Additional sources include residues from water. During agricultural application, excess herbicides may leach through the soil and into freshwater sources. Thereby, contamination of soil and water will expose the population to pesticide-related chronic health hazards. Contaminated food was documented in different research conducted in Libya, Elawami et al., said pesticide residues exceeded Maximum Residue Limits (MRLs) in 2.81% of food samples [particularly carbofuran (carbamate)] and 26.98% of groundwater sources. carbofuran detected in 2.81% of Libyan fruits and vegetables and water; however, these results raise the possibility of human exposure to this pesticide through ingestion. Furthermore, detectable residues of (cypermethrin and Imidacloprid) in peach samples from the Al-Marj region. Indeed, cypermethrin and Imidacloprid were identified as Highly Hazardous Pesticides. In addition, Salah Hasan et, al. was recorded the improper storage of pesticides in beverage containers were exposed children in Bengazi to pesticides through accidental consumption [2,4,11,12].

Inhalation

(Bradman et al., 2007) demonstrated that inhalation of pesticides is a major route of exposure, which could be occupational during spraying of pesticides, as farmers are exposed to highly hazardous pesticides (e.g., organophosphates) which include some neurotoxicants. Similarly, the presence of indoor pesticide-laden dust in homes was correlated with pesticide exposure in the general population. In Libya, 77% of farmers lack consistent PPE use, making inhalation and dermal routes important routes of exposure [6,13].

Dermal Absorption

Compromised skin barriers (e.g., sweat and cuts) enhance the uptake of herbicides, such as paraquat. In addition to a lack of regular PPE use, Libyan farmers frequently mix protective gear with household laundry, leading to significant secondary dermal exposure [6].

Transplacental and Lactational Transfer

Bouwman et al. (2012) conducted a study in South Africa, where DDT is still used for malaria control, and showed the presence of DDT in breast milk at high levels. In China, Wickerham et al. (2012) showed an association between pesticides and fetal growth disruption among newborns in rural China. In Libya, specifically in El-Gabal Al-khdar, organochlorine pesticide residues in human milk [heptachlor] were detected at levels higher than the Maximum Residue Limit (MRL). This underscores the significant exposure risk for Libyan infants [14,15,16].

Acute Toxicity

Different authors have described the acute toxic effects of pesticides, with acute exposure leading to the manifestation of symptoms within hours, which vary by chemical class. Organophosphate compounds are widely used as insecticides. In Libya, it is a commonly used compound. OP compounds phosphorylate the active site of acetylcholinesterase, leading to enzyme inactivation and elevation of acetylcholine levels. This accumulation stimulates nicotinic and muscarinic receptors, causing a cholinergic toxidrome that manifests as nausea, vomiting, diarrhea, urinary incontinence, blurred vision, salivation, lacrimation, bronchorrhea, bradycardia, hypotension, muscle paralysis, fasciculation, confusion, seizures, coma, and respiratory failure [17].

Carbamates and organophosphate pesticides are structurally similar and have similar toxic mechanisms. Exposure to carbamates leads to the carbamylation of acetylcholinesterase at neuronal synapses and neuromuscular junctions. This leads to the inactivation of the enzyme, resulting in the accumulation of acetylcholine. They have similar clinical symptoms, except for the duration of toxicity, which is typically less than 24 h in carbamate poisoning [18]. Accidental ingestion of glyphosate [Roundup®] is usually nontoxic, with minor gastrointestinal corrosive effects on the mouth, throat, and esophagus. Renal and hepatic impairments can occur in high-concentration formulations. Respiratory distress, impaired consciousness, and metabolic acidosis can occur in severe cases. Dermatitis and superficial corneal injury are also possible due to local exposure to glyphosate [19]. Another dangerous pesticide is organochlorines, which can cause long-term health problems in humans. Organochlorines act as endocrine-disrupting chemicals (EDCs) by interfering with the body's hormone system [12]. The most common manifestations are neurological, although multiple organ failure can be associated. Moses et al. reported that generalized seizures occur in (75%) of acute intentional toxicity cases [20]. Moreover, some organochlorines are identified as carcinogens, neurotoxic, and destructive to reproduction.

Chronic Health Effects

Long-term exposure is implicated in multisystem pathologies:

Carcinogenicity

In a study of 276 legally marketed pesticides in Europe, 51 were categorized as carcinogenic by the EPA, whereas eight were classified as carcinogenic by the International Agency for Research on Cancer (IARC). Furthermore, evaluations by the Swedish Chemical Agency (KEMI) identified seven active substances, including herbicides, fungicides, and insecticides, that met the "cut-off" criteria because they were identified as carcinogenic, mutagenic, or toxic to reproduction [3]. Tarazona et al. supported the association between cancer and pesticide exposure, and the International Agency for

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Research on Cancer (IARC) considered the chronic toxicity of glyphosate to be probably carcinogenic in humans [21].

Neurotoxicity

Tanner et al. said that paraquat users were 2.5 times more likely to develop Parkinson's disease than those who did not use it, especially if they were smokers [22]. In addition, pyrethroid pesticides, which are commonly used in Libya, can lead to neurotoxicity; it crosses the blood-brain barrier and keep the sodium channels open, leading to hyper-excitation of the central nervous system. After repeated exposure, cypermethrin can lead to neurodegeneration [23]. In addition, Lagili et al. suggested that organophosphates may be related to increased cognitive deficits in Libyan farmers [7].

Endocrine Disruption

Chronic exposure to high doses of pesticides results in a wide range of endocrine disruptions, especially in children, including reduced learning ability, low birth weight, and growth retardation. It also produces toxicity to the testes in the form of reduced sperm counts and motility, and atrazine exposure leads to complete feminization of genetically male frogs; therefore, toxicity in human reproduction is suspected [24,25].

Pulmonary and Hepatic Damage

Paraquat can cause renal failure, irreversible lung fibrosis ("paraquat lung"), and elevated AST/ALT levels in animal models. Toxic reactive oxygen species are formed after the ingestion of concentrated paraquat, which accumulates in lung or renal cells. This leads to renal tubular necrosis and acute alveolitis, which subsequently results in pulmonary fibrosis [26].

Regulatory Framework for Pesticides in Libya: Structures, Gaps, and International Commitments

The regulatory framework for pesticides in Libya is established through a comprehensive set of regulations governing their registration, import, manufacture, labeling, and use in Libya. This framework is designed to ensure that only pesticides considered safe for human health, animals, and the environment are permitted for use in accordance with international standards.

Institutional Governance

In Libya, the Ministry of Agriculture and Livestock (MoAL) hold primary regulatory authority, overseeing pesticide registration (pre-market approval), licensing of distributors and applicators, and safety enforcement (e.g., protective equipment mandates). The National Center for Protection and Agricultural Quarantine (NCPAQ) supports MoAL.

Registration Protocol

The mandatory registration process is the framework's cornerstone. The Libyan registration process (Law No. 94, 2012) requires manufacturers to submit an application for registration or re-registration to the Agricultural Pesticides Registration Committee. with the following important documents:

•A certificate of registration from the country of origin, authenticated by the Libyan embassy.
•Quality assurance and analytical certificates from the manufacturer.
•Toxicological and ecotoxicological studies (e.g., carcinogenicity, mammalian toxicity).
•Efficacy trial reports and environmental fate studies (e.g., soil half-life).
•Approved methods for analyzing the pesticide and its residues.
•The proposed package labels in Arabic and English include safety precautions, first-aid measures, and disposal instructions.
•Physical samples of the pesticide and its active ingredient for analysis and field trials.

The Committee evaluates this report and can recommend approval or refusal based on criteria such as incomplete data, excessive toxicity, inefficacy, or the availability of safer alternatives. The registration is valid for five years and can be renewed upon application [27].

Compliance Mechanisms

Regulatory compliance is monitored by various governmental agencies, emphasizing the need for farmers and pesticide applicators to adhere to guidelines concerning application rates, timing, and necessary protective equipment. Random inspections and monitoring of agricultural practices are conducted to ensure compliance with existing regulations [27].

Legislative Instruments

Although Libya's agricultural legislation has faced challenges since the political upheaval, certain laws remain in effect.

- Law No. 94 of 2012: This law governs the use and trade of pesticides to protect human health and the environment. It outlines the protocols for registering and approving pesticides.
- Legislation No. 362 of 2024: This law controls the import of pesticides; only pesticides registered with the Ministry of Agriculture may be imported, and only by licensed public or private companies. Import licenses are valid for six months, and pesticides must be imported directly from the original manufacturers. The sale of agricultural products with residue levels not exceeding the established Maximum Residue Limits (MRLs), which are based on the FAO food and Agriculture

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Organization, WHO Health Organization, and the EU standards [27, 28].

Prohibitions

The foundation of the regulatory system is the strict prohibition of pesticides banned or severely restricted by major international organizations. This includes pesticides recommended for prohibition by the Food and Agriculture Organization (FAO), World Health Organization (WHO), U.S. Environmental Protection Agency (EPA), European Commission, and international conventions ratified by Libya, such as the Stockholm, Rotterdam, and Basel Conventions.

International Commitments

Libya has signed several international agreements that govern pesticide use. Two of the most relevant are the Stockholm Convention and the Rotterdam Convention. The Stockholm Convention focuses on getting rid of—or at least strictly limiting—persistent organic pollutants (POPs), which include certain harmful pesticides that don't break down easily in the environment. The Rotterdam Convention, on the other hand, works through a "prior informed consent" procedure. This basically means that before a country receives certain pesticides or chemicals, it has to be told about their potential hazards up front [27].

Discussion

Various organizations are involved in herbicide management, such as the Codex Alimentarius Commission (CAC), European Commission (EC), and national governments in many countries, which set maximum residual limits (MRLs) [29]. The EPA controls the sales, distribution, and use of pesticides. The EPA evaluates applications for new products and decides whether to approve their registration for use [30]. Despite that pesticides contamination is still worldwide problem. 89 Highly hazardous pesticides (HHPs) remain widely used in Near East and North Africa (NENA) countries, posing significant risks to human health and the environment due to weak pesticide management capacities [12]. In Tunisia, Toumi et al. isolated several pesticides from surface and groundwater, as well as from soil, with different concentrations. This indicates widespread contamination like the situation in Libya. Toumi et al. stated that inadequate management of pesticides could also have a role [31]. Other research conducted in Egypt revealed that raw bovine milk samples contained high levels of pesticide residues [32]. This food contamination in Tunisia and Egypt is reaching consumer in Libya. Moreover, Libya's pesticide regulatory system is affected by profound systemic challenges that weaken its regulatory framework. Capacity deficits represent a critical weakness, with an insufficient number of personnel to monitor approximately 1.2 million hectares of farmland. This operational deficiency is accompanied by significant awareness gaps among users; surveys indicate that most farmers cannot accurately interpret pesticide labels, leading to improper and hazardous application practices. Furthermore, there is a lack of research data that can reflect the effect on the Libyan population and chronic political instability, which has actively destroyed essential enforcement infrastructure. Together, these interconnected challenges, inadequate institutional capacity, low user education, and weak enforcement mechanisms, reduce the effectiveness of policies, exposing human health and the environment to significant risks.

Conclusion and Future Directions

Theoretically, Libya's pesticide regulations are extensive and line up with international standards. But really it doesn't work in a good way. It depends entirely on whether the authorities can implement, monitor, and enforce them—and right now, farmers use pesticides unsafely, and the regulatory system is largely inactive. Therefore, it is recommended that all hospitals across the country should start tracking pesticide exposure and health impacts more carefully, provide proper farmer education, and enhance monitoring of pesticide residues in food and water.

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Conflicts of Interest. The authors declare that they have no affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript

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