Review Article

Systematic review on detection of Chlorpyrifos Herbicide Residues in Water resources, soil and Vegetable matrices: Remediation techniques.

ABSTACT

The presence of widely used Chlorpyrifos pesticide residues in the environment increases concerns owing to its associated adverse effects on human health and the ecosystem. The present study reports the comprehensive analysis of published papers concerning the detection of Chlorpyrifos herbicide residues in water resources, vegetables and soil matrices.The results showed that Chlorpyrifos residues were frequently found in water resources, plants, and soil matrices in excess, beyond permissible levels. The results collected, point to possible hazards to the aquatic ecosystem and human beings in general due to pollution of drinking water, exposure to pesticide residues through edible crops, and long-term effects on soil quality and crop growth. The study emphasizes the urgent need for remediation alternative actions, such as ceasing or restricting the use of Chlorpyrifos, improving water treatment techniques and implementing best agricultural management practices.

Keywords: Chlorpyrifos, Water resources, Ecosystem, Remediation, Vegetables, Soil, Environment.

1. INTRODUCTION

Environmental pollution with synthetic chemical contaminants in natural waters has emerged a global issue owing to their extensive application in several sectors, such as industry, agriculture and municipal activities [1]. Pesticides chemical substances are widely used in agriculture fields to safeguard crops from pests and promote bumper yields. However, these chemical substances have resulted into pollution of water resources and soil but also food contamination in some cases [2]. Recently, pesticides have remarkably attracted environmentalists’ attention due to their potential toxicity and special physicochemical characteristics associated with the active ingredients they possess that allow them to interact with other chemical substances making them to have high motility and persistence. This has made pesticides to be regarded as of special environmental concern [3]. Further, the ecology and biodiversity of aquatic systems are greatly affected by the presence of hazardous pesticides chemical substances. They can negatively impact aquatic health and other biological characteristics, as well as the quality of soil and productivity of the water bodies [4]. Despite all these environmental issues pesticides are continuously being released beyond allowable limits into the vicinity of water resources, vegetables, fruits and soil sediments [5].

Published reports and papers have indicated detection of pesticides residues in an environment. This has been associated with frequency of usage, application patterns, rainfall, and irrigation techniques that influence their distribution in the soil and water [6]. Pesticide solubility, mobility, adsorption, absorption, n-Octanol-water partition coefficient (*KoW*), and other physical, chemical, and biological processes all play a part in the breakdown of pesticide residues [7]. Therefore, monitoring of pesticides residues in an environment such as, water resources, soil and other aspects has attracted attention of many researchers in all parts of the world, predominantly those with scarce water supplies and increasing demand [8].

Chlorpyrifos is an organophosphate insecticide that is widely used in agriculture and at household level to control a variety of pests (Hossain *et al*., 2022). These herbicides have unique properties and remains the most preferred choice amongst farmers and also considered as the most effective herbicides in safeguarding crops for a wide range of pests such as aphids, caterpillars and beetles (Hossain *et al.*, 2015). The Chlorpyrifos chemical structure and physicochemical properties are presented on **Figure 1** and **Table 1**, respectively.

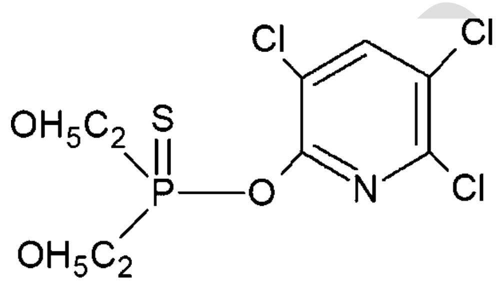

Figure 1. Chemical structure of Chlorpyrifos pesticide.

Table 1. Physicochemical properties of Chlorpyrifos.

Property	Value
Chemical formula	$C_9H_{11}Cl_3NO_3PS$
Molecular Weight	350.6 g/moL
Physical Appearance	Colorless to light brown liquid
OdourMild, ester-like odor	
Melting point	42-43°C (107-109°F)
Boiling point	153-155°C (307-311°F)
Solubility	Insoluble in water
Soluble in organic solvents	
Density	1.42 g/cm^3
Vapour Pressure	2.3 × 10^(-5) mmHg at 25°C

Pesticide residual levels on crop products should be considerably below regulatory limits by the time fresh produce reaches markets or retail establishments if pesticides are applied in compliance with fundamental good agricultural practices. Farmers must adhere to the recommended application rates, which are listed on the pesticide labels and include withholding intervals before harvest, in order to prevent exceeding minimum residual limits (MRLs). Several research studies have revealed pesticide residual levels that are higher than those permitted by laws [11]. However, concerns have been raised regarding the potential adverse health effects associated with Chlorpyrifos exposure on human health, ecology and the environment as it has been summarised in **Table 2**[12].

Table 2. The Human health, ecology and environmental effects of Chlorpyrifos

Effects	Human health	Ecosystem	Environment	Animals
Neurotoxicity	Reduced IQ and cognitive Development in Children	Disruption of aquatic ecosystems	Water pollution	Harm to non-target organisms
Respiratory Effects	Coughing, wheezing and shortness of breath	Harm to beneficial insects	Air pollution	Potential harm to birds and mammals
Skin and Eye Irritation	Skin irritation and redness	Soil contamination	Non-target species impact	Impact on food chain
Reproductive And Development Effects	Development delays Reduced birth weight	Disruption on food chains	Loss of biodiversity	
Endocrine Disruption	Disruption of hormone function			
Toxicity to Aquatic life		Disruptions of aquatic ecosystems		
Soil Contamination		Soil contamination		
Water Contamination		Water contamination		
Air Pollution		Air pollution		
Loss of biodiversity		Loss of biodiversity		

In view of the stated facts, this paper therefore aimed at reviewing the Chlorpyrifos pesticide residues in water resources, vegetables and soils to allow analysis and compilation of existing knowledge on the subject matter. By thoroughly reviewing and synthesizing published studies, reports, and relevant literature the study provides a comprehensive overview of the current state of knowledge regarding Chlorpyrifos contamination in these aforementioned matrices. This approach helps identify research gaps, inconsistences and emerging trends, facilitating a deeper understanding and possible remediation procedures on the subject matter.

2. METHODOLOGY

The study used the literature survey approach. This methodology allows inclusion of studies conducted in different geographical regions, allowing for a broader and more diverse perspective on Chlorpyrifos contamination. Many countries may have different regulatory frameworks, agricultural practices and environmental conditions that affect the presence and distribution of Chlorpyrifos residues in the ecosystem. By examining these studies from multiple locations, the study can provide a global perspective on the issue, identify regional differences and highlight potential hotspots and problem areas. Several papers were downloaded from various scientific databases such as PubMed, googlescholar, Google.com and Sciencedirect by searching keywords such as "Chlorpyrifos residues, water resources, vegetables and soil contaminants". Downloaded articles were critically analyzed and reviewed.

3. RESULTS AND DISCUSSIONS

3.1 CHLORPYRIFOS RESIDUES IN WATER RESOURCES

There has been several studies that have detected Chlorpyrifos in water resources in relation to defined standards. In one study the author collected surface water samples from the Ankobra River in Ghana and found Chlorpyrifos residues levels ranging from 0.01 to 0.27 µg/L, which exceeded the WHO guidelines for drinking water quality (0.03 µg/L) [6]. Another study by Atabila*et al.,*[13], analyzed water samples from the Densu River in the Greater Accra Region also found Chlorpyrifos levels which surpassed recommended levels for drinking water established by EPA's with concentration of 0.01 to 0.19 µg/L. Water samples from the Pra River in the Central Region of Ghana also indicated Chlorpyrifos contamination with levels ranging from 0.01 to 0.05 µg/L, which were below the WHO guidelines but exceeded the EPA's MCL for drinking water[14]. Samples collected from Oti river region in Ghana showed the Chlorpyrifos levels ranging from 0.01 to 0.08 µg/L, which were below both the WHO guidelines and the EPA's MCL for drinking water [15].

Studies conducted in Switzerland indicated contamination of water resources with Chlorpyrifos herbicides. The presence of Chlorpyrifos residues were studied in Swiss water resources and detected [16]. Water samples collected from one of the rivers detected Chlorpyrifos herbicide levels ranging from 0.005 to 0.25 µg/L, the reported results exceeded the Swiss Water Protection Ordinance's limit value for surface waters pegged at 0.1 µg/L [17]. In a separate study which investigated the occurrence of Chlorpyrifos pesticides in groundwater resources indicated that out of 54 samples analysed the herbicide was detected in 3 samples with concentrations ranging from 0.009 to 0.032 µg/L. However, reported concentrations were below the established standards for Swiss Drinking Water Ordinance's limit value for individual pesticides of 0.1 µg/L. [18]. Similar studies collected surface water samples from different regions across Switzerland and found that the levels of the herbicides were within the range of 0.02 to 0.16 µg/L, which were higher compared to the Swiss Water Protection Ordinance's limit value for surface waters resources [19]. These studies suggest that Chlorpyrifos contamination in Swiss water resources is a concern and that levels of Chlorpyrifos can sometimes exceed defined standards. However, the extent of contamination and the associated risks may vary depending on the location and type of water resource [20].

Similarly, studies were also conducted in New Zealand to determine the effects of Agriculture sector on water resources. The investigation which analyzed water samples from the major River Manawatu located at New Zealand's North Island recorded the Chlorpyrifos herbicide levels ranging from 0.01 to 0.1 µg/L. However, the results reported were below established permissible standards for the New Zealand drinking water of pesticides at 0.5 µg/L [21]. Similar studies by [22] examined the occurrence of Chlorpyrifos and other pesticides in groundwater resources around Canterbury region located at South Island. In a total of 71 samples which were collected, Chlorpyrifos herbicide were detected in only 1 sample with concentration of 0.0002 µg/L which was below defined permissible standard for New Zealand Drinking Water Standards. Separate investigations which focused on analysing surface water samples from different regions indicated levels of the herbicide ranging below detection limit to 0.005 µg/L [23], suggesting non-existence of the herbicide in the water resources across studied regions. Overall, these studies suggest that Chlorpyrifos contamination in New Zealand water resources is generally low and does not pose a significant risk to human health or the environment. However, continued monitoring is necessary to ensure compliance with defined standards and to identify any potential risks.

Similar investigations were also reported in Tanzania as this herbicide iscommonly used to safeguard crops against weeds. Several studies have reported the levels of Chlorpyrifos in Tanzania's water resources which assessed its compliance with defined standards [24]. In another study researchers analyzed water samples from three agricultural areas in Tanzania. The detected levels of Chlorpyrifos ranged from 0.11 to 1.48 µg/L, which were above the defined permissible limits for World Health Organization's (WHO) value for individual pesticides 0.1 µg/L [25]. Furthermore, the study indicated that concentrations of the Chlorpyrifos were much higher during the rainy season compared to summer, suggesting that run off from agricultural fields contribute to the contamination. The presence of Chlorpyrifos from an important water resource in Mara region thus river Mara was examined. The results recorded that concentration of the herbicide ranged from below detection limit to 3.23 µg/L [26]. These results surpassed the WHO's maximum acceptable value for individual pesticides. Further, Water samples from vicinity of agricultural field had recorded far much higher levels when compared to those from non-agricultural fields.

In a related study, researchers collected surface water samples from Kilombero River a major river in Tanzania around Morogoro region. The findings indicated that levels ranged from below detection limit to l0.27 µg/L [27]. The attained values were above the established WHO maximum acceptable value for individual pesticides in water resources. The concentrations of the herbicide were dominated by samples taken during rainy season compared with dry reason which suggest that runoff from agricultural field may have promoted contamination. In general, these studies suggest that Chlorpyrifos contamination in Tanzania's water resources is a significant issue, with levels exceeding the WHO's maximum acceptable value for individual pesticides. The findings also suggest that agricultural activities may be a major contributor to the contamination, particularly during the rainy season [24]. Continued monitoring and enforcement of regulations are necessary to address this issue and ensure compliance with defined standards.

Furthermore, Nigerian investigators have reported Chlorpyrifos in water resources for as it is commonly used in agricultural sector. The presence of the Chlorpyrifos in surface water in four selected areas around Delta state region was examined. The findings revealed that the concentrations of Chlorpyrifos ranged from 0.3 to 5.5 µg/L. The established results were much higher compared to the defined standards established by WHO guide for Chlorpyrifos in drinking water of 0.03 µg/L [25]. The study concluded that the presence of Chlorpyrifos in surface water in Delta State poses a possible risk to human health. Furthermore, water samples collected from Lagos Lagoon were analysed for the presence of the herbicide Chlorpyrifos and the findings indicated that for all samples analysed the levels ranged from 0.013 to 0.560 µg/L. The concentrations recorded were higher than defined by European Union (EU) maximum allowable concentration of 0.1 µg/L in drinking water [18]. The results suggested that Lagos Lagoon was polluted with Chlorpyrifos and that there is a need for regular monitoring to ensure compliance with regulatory limits [28].

The existence of Chlorpyrifos in surface water and groundwater in Ibadan were also examined. The results from the assessment found that Chlorpyrifos were detected and ranged from 0.20 to 1.97 µg/L [29]. The obtained results were far much higher compared with the EU maximum allowable concentration of 0.1 µg/L in drinking water. The results suggested that human health and environment around Ibadan region could be at risk due to presence of Chlorpyrifos in surface water and groundwater [30]. Another independent investigation determined the levels of Chlorpyrifos in selected boreholes in Abeokutu region and the results showed that levels of the herbicide ranged from 0.012 to 0.067 µg/L[2]. The reached concentrations of herbicide Chlorpyrifos were below than the EU maximum permissible concentration of 0.1 µg/L in drinking water. The study indicated that the levels of the herbicide in the selected boreholes were relatively low, but regular monitoring is imperative to prevent contamination. Overall, the results obtained in water resources for possible contamination of Chlorpyrifos in Nigeria has indicated that some water resources had higher concentrations surpassing defined standards posing a potential risk to human health and environment while in other locations Chlorpyrifos detected. Practices in the no-detected provenances would be a benchmark to prevent contamination.

There are several studies which have detected and reported environmental issue of water resource contamination by Chlorpyrifos herbicide in China. Surface water samples collected from Liao river basin in north eastern China were analysed for the herbicide. The findings from the study showed that the levels ranged from 0.001 to 1.033 µg/L. The attained concentrations were high compared with the Chinese National Standards for Drinking Water Quality (GB 5749-2006), which sets the maximum tolerable concentration for Chlorpyrifos at 0.1 µg/L [31]. Similarly, the study by [32] detected Chlorpyrifos in surface water samples taken from the Taihu Lake Basin in eastern China. The recorded levels of Chlorpyrifos ranged from 0.02 to 0.76 µg/L. The concentrations surpassed the Environmental Quality Standards for Surface Water (GB 3838-2002), which sets the maximum acceptable concentration for Chlorpyrifos at 0.02 µg/L.

Surface water taken from Pearl River Delta in southern China detected Chlorpyrifos herbicide also. The concentrations of Chlorpyrifos reported in the study ranged from 0.0005 to 0.2 µg/L [33]. The levels of concentrations recorded were higher than the defined levels by the National Surface Water Environmental Quality Standards (GB 3838-2002), which established the maximum acceptable concentration for Chlorpyrifos at 0.02 µg/L. In addition to these, studies on ground water in China has also reported Chlorpyrifos herbicide in ground water sources. Ground water samples collected from Chengdu plain in south western region of china were analysed for the occurrence of the herbicide. The levels recorded were in the range of 0.01 to 0.36 µg/L [34] The gotten results were above permissible limits for Chlorpyrifos of 0.1 µg/L established by the Chinese National Groundwater Quality Standards (GB/T 14848-2017). The presence of Chlorpyrifos herbicide in water resources in china is mainly attributed to improper use of pesticides, lack of regulation and enforcement as well as inadequate treatment of wastewater [35].

The overall results from several studied areas in china suggest that Chlorpyrifos contamination of water resources is a significant environmental problem. The detected concentrations of Chlorpyrifos exceeded the defined standards posing a risk to human health and the environment [36]

3.2 CHLORPYRIFOS RESIDUES IN VEGETABLES AND FRUITS

Some studies have reported the levels of Chlorpyrifos in vegetables and fruits in Tanzania. The studies done by [28] reported Chlorpyrifos concentrations in tomatoes, cucumbers and bell peppers. The concentration ranged from 0.004 to 0.032 mg/kg, 0.002 to 0.012 mg/kg, and 0.006 to 0.048 mg/kg, respectively. However, the attained levels were below the maximum residue limit (MRL) of 0.1 mg/kg recommended by the European Union (EU) and the Codex Alimentarius Commission (CAC) for these vegetables. Further, the levels of Chlorpyrifos in applied apples and grapes in Tanzania ranged from 0.006 to 0.038 mg/kg and 0.002 to 0.012 mg/kg, respectively[29]. These levels were also below the MRL of 0.1 mg/kg established by the EU and the CAC for these fruits. Another separate study by [37] reported higher levels of Chlorpyrifos in strawberries and raspberries in Ukraine. The levels of Chlorpyrifos in strawberries ranged from 0.08 to 0.3 mg/kg, while the levels in raspberries ranged from 0.01 to 0.04 mg/kg. The concentration levels in strawberries are above the MRL of 0.05 mg/kg established by the EU and the CAC while raspberries concentration ranges were below the established standards.The results of the studies reviewed in this paper suggest that the levels of Chlorpyrifos in vegetables and fruits in sub-Saharan Africa are generally below the MRLs established by the EU and the CAC. The results suggest that the consumers of these products may not be at risk of exposure to Chlorpyrifos through consumption of fruits and vegetables.

Furthermore, another study was carried out in Ukraine on Chlorpyrifos herbicide concentration in strawberries and raspberries. The findings revealed that concentration of herbicide residues were high compared to the established permissible limits by EU and CAC which suggest that there could be a risk of exposure to Chlorpyrifos herbicide through consumption of these fruits [38].Similar research studies carried out in China have also reported detection of herbicide in vegetables and soils. A study on vegetables that measured the levels of Chlorpyrifos sampled in six provinces in China found that the levels of Chlorpyrifos ranged from 0.004 to 0.57 mg/kg [39]. The maximum and lowest levels of herbicide were found in spinach and lettuce, respectively. Nevertheless, the obtained levels in vegetables were lower than defined maximum residue limit (MRL) set by the Chinese government. In a similar research conducted by [40] the levels of herbicide residues were assessed in peaches and carrots sold at a market in Beijing. The levels ranged from 0.002 to 0.207 mg/kg, with the highest and lowest levels of herbicides residues recorded in peaches and carrots, respectively. The obtained results from study were lower compared with regulatory permissible standards for Chinese government.

The levels of Chlorpyrifos in cherry tomatoes and potatoes sold in a Hangzhou market were evaluated. The obtained results ranged from 0.001 mg/kg to 0.058 mg/kg [41]. The maximum and lowest levels were found in cherry tomatoes and potatoes respectively. The attained results were generally lower compared to the established permissible limits for Chinese government. Furthermore, green beans and peaches sold at Shanghai market were sampled and studied for the presence for the herbicide [42]. The results ranged from 0.002 to 0.149 mg/kg and the highest and lowest levels of Chlorpyrifos were found in peaches and green beans respectively. However, the results recorded were much lower when compared to allowable limits set by Chinese government. The results obtained from these series of investigations suggest that that the levels of the herbicide in fruits and vegetables in China are generally lower than the MRL set by the Chinese government. However, monitoring of concentrations of this chemical herbicide in fruits and vegetables is important to minimise the risk of contamination which might cause direct health hazards to individuals, despite that the attained results from several studies revealed generally lower levels than the MRL set by the Chinese government [43].

USA studies on the herbicide in bell papers have detected herbicide [44]. The levels were found to be below the MRL of 0.01 mg/kg. Similarly, apples collected from Washington state by Heller [45] reported that the levels of Chlorpyrifos were also below the MRL of 0.01 mg/kg. However, the assessment report on apples from Virginia found Chlorpyrifos concentration to be above the MRL [46]. Furthermore, the levels of Chlorpyrifos in green beans from Florida were 0.01 mg/kg which was on the mark of MRL [47].

Herbicide contamination levels were examined on spinach sampled from California and were found to be above the MRL[48]. Similarly the herbicide concentrations were found to be high in tomatoes collected from Florida exceeding permissible standard for vegetables [49]. The results showed that most European countries indicated high levels of Chlorpyrifos herbicide in fruits and vegetables, compared to Sub-Saharan African countries, depending on the location and type of produce [50]. On the other hand, some studies reported levels below the MRL set by the EPA, others reported levels above the MRL [51]. The results obtained from these review studies suggest that the pesticides residues may pose harm to human health in those areas where the concentrations are higher than the MRL set standards. Moreover, studies have suggested that even low levels of exposure to Chlorpyrifos can have adverse health effects, especially in children. Therefore, it is important to continue monitoring levels of Chlorpyrifos in fruits and vegetables and take necessary steps to reduce exposure [52].

3.3 CHLORPYRIFOS RESIDUES IN SOILS

There are several studies that have been conducted and have reported Chlorpyrifos herbicide in soils, which have resulted in its pollution. Most recent investigations across Canada have also detected the herbicide in the studied soil samples. One study by Tejada *et al*., [53] recorded Chlorpyrifos in soil samples from three agricultural areas around Alberta in Canada. The levels in the soil samples ranged from 0.003 to 0.14 mg/kg. Investigators indicated that the levels detected in the soil samples were below the maximum residue limits (MRLs) established by Health Canada. Likewise, a study conducted by Trujillo *et al.,*[54] detected Chlorpyrifos in soil samples from agricultural fields in Ontario, Canada. They found that Chlorpyrifos levels in the studied soil samples ranged from 0.001 to 0.014 mg/kg. The obtained levels in the soil samples were also below the MRLs established by Health Canada.

Still more, other studies have detected Chlorpyrifos levels in soil samples that exceed the MRLs established by Health Canada. This was confirmed in soil samples from agricultural fields in Quebec [55]. The concentrations levels in the soil samples ranged from 0.04 to 0.79 mg/kg. The obtained results were higher than permissible limits for pesticides residues established by Health Canada. Chlorpyrifos residues in soil samples from potato fields in Manitoba in Canada were examined [56]. The study found that Chlorpyrifos levels in the soil samples ranged from 0.16 to 0.64 mg/kg. The levels attained in the soil samples were above the MRLs established by Health Canada. As observed, the investigations that determined herbicide in soil samples collected from agricultural fields in Canada found the levels which were below the MRLs established by Health Canada while others found levels above the MRLs [57]. The results suggest that there is a need for continued monitoring of Chlorpyrifos levels in soil samples to ensure that they remain below the MRLs established by Health Canada.

Several studies have detected Chlorpyrifos in soil samples from different parts of Egypt [9]. The Chlorpyrifos in soil samples from agricultural areas in the Gaza Strip were determined and ranged from 0.1 to 2.2 mg/kg [58]. The Chlorpyrifos residues in soil samples collected from different agricultural fields were analysed and the levels ranged from 0.4 to 4.5 mg/kg [59]. The attained results were higher exceeding permissible limit for Chlorpyrifos in soil samples pegged at 0.2 mg/kg [60]. These results show that the concentration of the studied herbicide in soil samples from Egyptian soils were high compared with results reported elsewhere.
In general the studied herbicide is highly toxic pesticide that has been found to be harmful to human health and the environment [61]. Studies have shown that the pesticide is associated with several health issues as it can contaminate groundwater and surface water [55]. The use of Chlorpyrifos in many countries has proven to have significant implications for human health and the environment [62]. Therefore there is a high need to search and develop better and convenient options to reduce but also help to de-contaminate the herbicide through adoption of the proposed remediation strategies.

3.4 REMEDIATION

It is crucial to take the proper corrective action to reduce any potential dangers to human health and the natural environment when Chlorpyrifos pesticide residues are found in water supplies, plants, and soils. Outlined are a few potential corrective measures:

3.4.1 CEASE OR RESTRICT CHLORPYRIFOS USE: Implementing regulations or guidelines to restrict or ban the use of Chlorpyrifos can prevent further contamination and reduce the overall presence of the herbicide in the environment [63].

3.4.2 IMPROVE WATER TREATMENT METHODS: Improve water treatment processes to remove or reduce Chlorpyrifos residues. This can include using activated carbon filtration[64], [65], advanced oxidation processes, or other appropriate treatment technologies specifically designed for pesticide removal.

3.4.3 IMPLEMENT BEST MANAGEMENT PRACTICES (BMPS) IN AGRICULTURE: Encourage the adoption of BMPs by farmers and other agricultural stakeholders that reduce the use of pesticides, enhance application methods, and support sustainable farming practices. This could entail applying alternative pest control approaches, putting integrated pest management (IPM) plans into practice, or adopting precision farming technologies [66].

3.4.4 PROMOTE ORGANIC FARMING:Encourage the transition to organic farming methods, which prohibit the use of synthetic pesticides like Chlorpyrifos. Promoting organic agriculture helps reduce the introduction of Chlorpyrifos and other harmful pesticides into the environment.

3.4.5 SOIL REMEDIATION TECHNIQUES: Utilize soil remediation methods to lessen the persistence of Chlorpyrifos residues in polluted soils. Bioremediation, phytoremediation (using particular plants to absorb and degrade pollutants), and soil additives that promote microbial activity to break down the pesticide are some examples of these techniques[67].

3.4.6 PUBLIC AWARENESS AND EDUCATION: Spread knowledge about the potential hazards of Chlorpyrifos and the significance of effective pesticide management among the general public, farmers, and other stakeholders. Long-term contamination levels can be decreased by educating people about appropriate pesticide usage, disposal, and substitutes[68].

3.4.6 MONITORING AND ENFORCEMENT: Establish robust monitoring programs to regularly assess water resources, vegetables, and soils for Chlorpyrifos residues. Strict enforcement of regulations and penalties for non-compliance can act as deterrents and ensure compliance with pesticide usage guidelines[69].

3.4.7 RESEARCH AND DEVELOPMENT: Support research and development efforts to find safer alternatives to Chlorpyrifos and other potentially harmful pesticides. Encourage the development of innovative pest control technologies and methods that are effective, economically viable, and environmentally friendly [47].

It is crucial to implement a combination of these remediation options and tailor them to the specific context and severity of Chlorpyrifos contamination. Collaboration among government agencies, farmers, researchers, and communities is essential to effectively address the issue and protect water resources, vegetables, and soils from Chlorpyrifos residues and safeguard the health of humans and environment.

4. CONCLUSION

In summary, research has shown the prevalence of herbicide Chlorpyrifos residues in water, vegetable and soil sources, potentially posing risks to human health and the environment. These findings highlight the urgent need for corrective action to mitigate these risks and protect our ecosystem. The presence of Chlorpyrifos in water supplies necessitates the development of effective water treatment techniques and strict guidelines for its use. To reduce Chlorpyrifos contamination in soil and vegetables, it is essential to promote the use of best agricultural management practices, organic farming and soil treatments. Raising awareness of the risks associated with Chlorpyrifos and promoting responsible pesticide management practices can be done through public awareness and education initiatives. For long-term sustainable solutions, it is also necessary to support continuous monitoring systems, rigorous enforcement, and research and development of safer alternatives. We can strive to create a safer and better environment for present and future generations by putting these alternative sanitation solutions into practice and working together in all areas, to protect our invaluable water, crops and soils from Chlorpyrifos residues.

6.0 DATA AVAILABILITY

The data reported in the study is included in the manuscript itself.

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