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Review

Are Adult Mosquito Control Products (Adulticides) Harmful? A Review of the Potential Human Health Impacts from Exposure to Naled and Dichlorvos (DDVP)

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Abstract: We performed a thorough systematic review of published literature to determine potential links between human health impacts and naled, a registered adult mosquito control product (adulticide), and its major degradate, dichlorvos (DDVP). A search query was performed on 8 September 2023, capturing all articles published up to that date on the Scopus and PubMed databases. Inclusion criteria were the presence of either pesticide and a measured or modeled human health outcome or risk. The search string resulted in 382 articles; however, 354 articles were excluded, resulting in only 28 articles that met the inclusion criteria. The studies that directly relate to aerosolized ultra-low volume (ULV) mosquito control applications did not report any associated deleterious human health outcomes. Results from the reviewed papers displayed no negative health effects or led to inconclusive results. No studies showed adverse health effects from aerial ULV applications for mosquito management. Our findings are congruent with the United States Environmental Protection Agency and Centers for Disease Control and Prevention recommendations that aerial applications of naled, following label parameters, do not pose an adverse risk exposure to humans, wildlife, and the environment.

Keywords: naled; dibrom; dichlorvos; DDVP; ultra-low volume; pesticides; aerial applications; mosquito control; adulticiding; human health

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1. Introduction

1.1. Motivation

The Food and Agriculture Organization of the United Nations and the World Health Organization are currently in the final drafting phases for the 2022 Guidance for Aerial Application of Pesticides [1]. The guidance for agricultural aerial pesticide application is Conventional (625 to 4168 or more mL/ha) and ultra-low volume (ULV) (less than 125 mL/ha) by volume of the active ingredient. The recommended ULV aerial pesticide application rate for adult mosquito control (adulticiding) is between 32 and 65 mL/ha by volume of the active ingredient. This guidance results in mosquito ULV application rates, which are 0.008–0.1% of conventional aerial agricultural applications by municipal mosquito control programs, such as the Salt Lake City Mosquito Abatement District (SLCMAD). The SLCMAD has jurisdictional boundaries over 285 square kilometers (110 square miles) in Salt Lake City, Utah, United States, and is tasked with quality-of-life enhancement and public health protection from mosquitoes and mosquito-borne pathogens. The district proactively conducts research in excess of federal and state requirements, to ensure continuing safety and efficacy of products and methods used for mosquito suppression.

Aerial, truck, and manual backpack treatments are the most common ULV delivery methods of adult mosquito control; however, the organophosphate naled (the primary adult mosquito control product in SLCMAD) is only used in aerial applications for mosquito management. The SLCMAD performs, on average, 17 annual aerial ULV naled applications for mosquito management during the active mosquito season (June–September), distributed across several treatment blocks of approximately 20 square kilometers (~5000 acres) each after sunset in relatively rural and remote areas near the outskirts of the Great Salt Lake. Although the positive health impacts of mosquito control are well-documented (reductions in pathogen-carrying mosquitoes, nuisance bites, secondary infections from bites, and allergic reactions), there is public interest in understanding whether adverse health impacts associated with ULV naled applications also exist. For example, as recently as 2016, the governor of Puerto Rico decided not to perform aerial ULV naled treatments during a Zika virus outbreak on the island due to criticism or concern from the public regarding the safety of naled applications [2].

1.2. Pesticide Registration

The United States Environmental Protection Agency (USEPA) evaluates the potential for health, biological, and ecological effects of pesticides through its risk assessment program [3]. Pesticides undergo a thorough registration process [4], which includes established test guidelines [5] conducted according to good laboratory practice (GLP) standards [6]. Furthermore, there is a clearly defined human health [7] and ecological [8] risk assessment guidance that must also be performed and presented for evaluation. The intensive registration process for an active ingredient may take decades of evaluations, with costs approaching hundreds of millions of dollars (USD) to ensure the efficacy and safety of these products by end users for the benefit of the public. The goal of the registration (and re-evaluation) process by the USEPA is to ensure that when pesticide products are used according to label directions, they will not harm people, wildlife, domestic pets, non-target organisms, or the environment.

Naled is registered as a mosquito adulticide (an insecticide that targets adult flying mosquitoes in an outdoor space application), as well as an agricultural insecticide that may be used in greenhouses [9]. Naled and its major degradate, dichlorvos (DDVP), have undergone substantial toxicological exposure and risk reviews as part of their required registration review process [10], including risks associated with mosquito control. Although DDVP is also a pesticide used in some insect control applications, it is not a product used directly for mosquito control outside of insecticidal coils in a few countries. Naled is currently undergoing a regulatory review process by the USEPA, as required by law to occur every 15 years, in conjunction with the Food Quality Protection Act. Although these reviews are periodic, the USEPA retains the authority to remove any product through a special review process whenever a critical health concern is determined. Naled has been registered in the United States since 1959, and through all regulatory reviews and evaluations with updated methods and analysis, the USEPA has maintained its use in the market.

Naled has been in commercial use for over 60 years and has been studied both during the initial registration process and multiple re-registrations. Improved knowledge concerning exposure from the use of the chemical has led to label changes that further reduce public exposure potential. These efforts include industry initiatives and stewardship programs. For naled, this has meant defining nozzles, application parameters, and aircraft configurations to address different environmental, climatological, and application conditions [11]. As an adulticide, this effort is directed at ensuring that the applied chemical remains in the air column where mosquitoes are likely to be flying to achieve maximum efficacy, which also limits other terrestrial, aquatic, and non-target exposure.

Naled is used in peridomestic environments for several reasons. Exposure is reduced as most of the airborne droplets never reach the ground; instead, they are intercepted by buildings and trees. Those droplets that penetrate near the ground layer quickly degrade, as well as the droplets that are intercepted by buildings and vegetation. This has been demonstrated in a series of field studies that have been submitted to USEPA. These studies clearly show that initial low-level residues on turf grass following applications are no longer measurable within just a few hours because of the quick degradation rate [12]. Furthermore, adult mosquito control applications have been shown to decrease the risk of exposure and infection to West Nile virus and other mosquito-borne pathogens and that human health risks from exposure to the insecticide are below thresholds set by the USEPA [13]. Additionally, applications of adult mosquito control products have not been associated with population-level increases in public hospital emergency department visit rates for respiratory (asthma), gastrointestinal, skin, eye, and neurologic complaints, even within peridomestic environments where naled applications are routinely carried out by professional mosquito control districts, such as in California and Florida [14,15].

1.3. Exposure Thresholds

The USEPA is also the regulatory agency responsible for establishing exposure thresholds for naled and DDVP. These thresholds are reviewed during the registration and registration review process and updated if necessary [10]. As part of the registration process, the USEPA Office of Pesticide Programs (OPP) evaluates the toxicological and exposure data to conduct dietary, occupational, and residential exposure assessments, as needed, to estimate the risk to human health that may result from the currently registered uses of pesticides [9]. The result of the toxicological assessment evaluations is the reference dose (RfD). The RfD (mg/kg body weight/unit time) is a dose that is the regulatory acceptable daily exposure. The USEPA takes several factors into consideration when establishing no observed adverse effect levels (NOAEL), including specific dermal and inhalation toxicity studies. The NOAEL (mg/kg body weight) is an exposure or dose that produces no observed toxicity. The RfD is calculated as the NOAEL divided by a safety factor (SF). The NOAEL for naled is 1.0 mg/kg (body weight)/day, and the SF is 100 (a 10× factor for interspecific variability multiplied by a 10× factor for intraspecific variability), resulting in a RfD for naled of 0.01 mg/kg/day. Estimated—and sometimes actual—exposures are then compared to the RfD, often using a risk quotient (RQ), which is the ratio of exposure to RfD. The RQ (ratio of exposure to effect threshold) is an effect threshold (e.g., RfD) divided into an estimate of exposure or the actual exposure.

1.4. Significance and Novelty of This Work

In this study, we performed a thorough literature scoping review of peer-reviewed published manuscripts linking naled and DDVP exposure with potential health impacts. Our specific research question was: "Does the published literature show adverse health outcomes associated with the use of naled or its degradate, DDVP"? Since naled has been in commercial use for more than half a century, this has allowed the chemical to be studied by a large body of independent researchers. This assessment of what data exist on exposure and health effects in the scientific literature for naled and DDVP can be informative and provide insight into the safety of the product. To our knowledge, no previous study has focused on human health outcomes from exposure to naled and DDVP; thus, this paper will provide valuable information on the topic and may be used to inform practitioners, regulatory agencies, public health stewards, advocacy/environmental groups, and the public.

2. Materials and Methods

This is a systematic review, and we have adhered to the PRISMA statement (Figure 1) through our review process. A search query was performed on 8 September 2023, capturing all peer-reviewed articles published up to that date on the PubMed [16] and Scopus [17] databases. The search string used was as follows:

"(Naled OR dichlorvos OR DDVP) exposure AND (health outcomes OR neurological OR pulmonary OR cardiovascular OR public health)".

Our interest was in both naled and DDVP exposure and included "dichlorvos", as it is an analogous term to DDVP. We chose to use the general terms "health outcomes" and "public health" to capture as broad a spectrum as possible. We explicitly searched for three common and specific health effects ("neurological", "pulmonary", and "cardiovascular") to capture possible specific outcomes. Our use of the Scopus and PubMed databases ensured we only included peer-reviewed literature in accredited scientific journals and excluded gray literature (information produced on all levels of government, academia, and private industry, which is not controlled by commercial publishing).

The search string resulted in 305 articles identified via PubMed and 103 in Scopus. Because there were 26 articles identified in both databases, the total number of unique articles was 382.

The intent was to capture all peer-reviewed literature pertaining to human health outcomes associated with verified or potential exposure from applications of naled or DDVP. Inclusion criteria were the presence of either pesticide and a measured or modeled human health outcome or risk. Exclusion criteria were animal or cell/molecular results, non-specific or compound pesticides (i.e., a combination of multiple organophosphates), lack of a clear health outcome, use of naled or DDVP for accidental or intentional poisoning, safety equipment analysis, article not found, article not in English, review article, laboratory experiment, and op-ed articles.

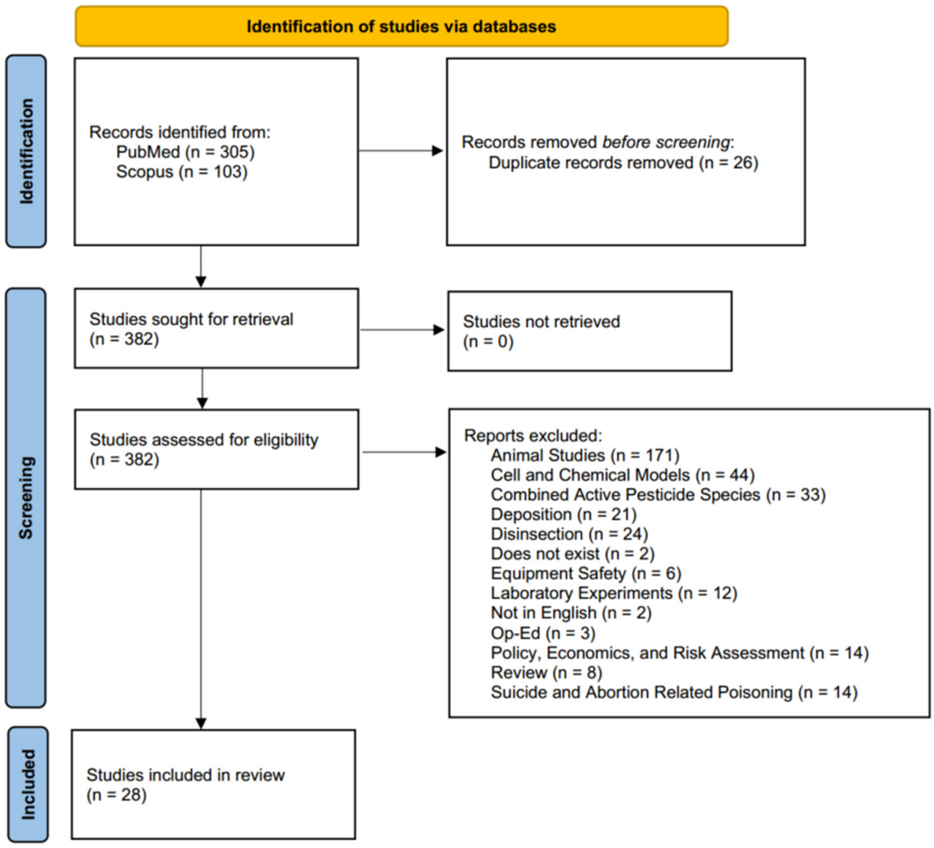

Figure 1. PRISMA flow diagram of systematic review performed in this study [18].

3. Results

3.1. Excluded Articles

There was a total of 354 excluded articles, and the rationale for their exclusion is shown in Table 1 and Figure 1. More details can also be found in the Supplementary Information Section (SI).

Table 1. Counts of excluded articles by reason.

Reason for Exclusion	Number of Articles Excluded
Animal Studies	171
Cell and Chemical Models	44
Combined Active Pesticide Species	33
Deposition	21
Disinsection	24
Does Not Exist	2
Equipment Safety	6
Laboratory Experiments	12
Not in English	2
Op-Ed	3
Policy, Economics, and Risk Assessment	14
Review	8
Suicide- and Abortion-Related Poisoning	14
Total	354

3.2. Included Articles

There were 28 articles that were included in the study. The results are stratified into five categories: Search Engine, Pesticide, Country, Application Purpose, and Health Outcome. Each category was further subdivided into sub-groups. The countries where studies took place are shown in Figure 2.

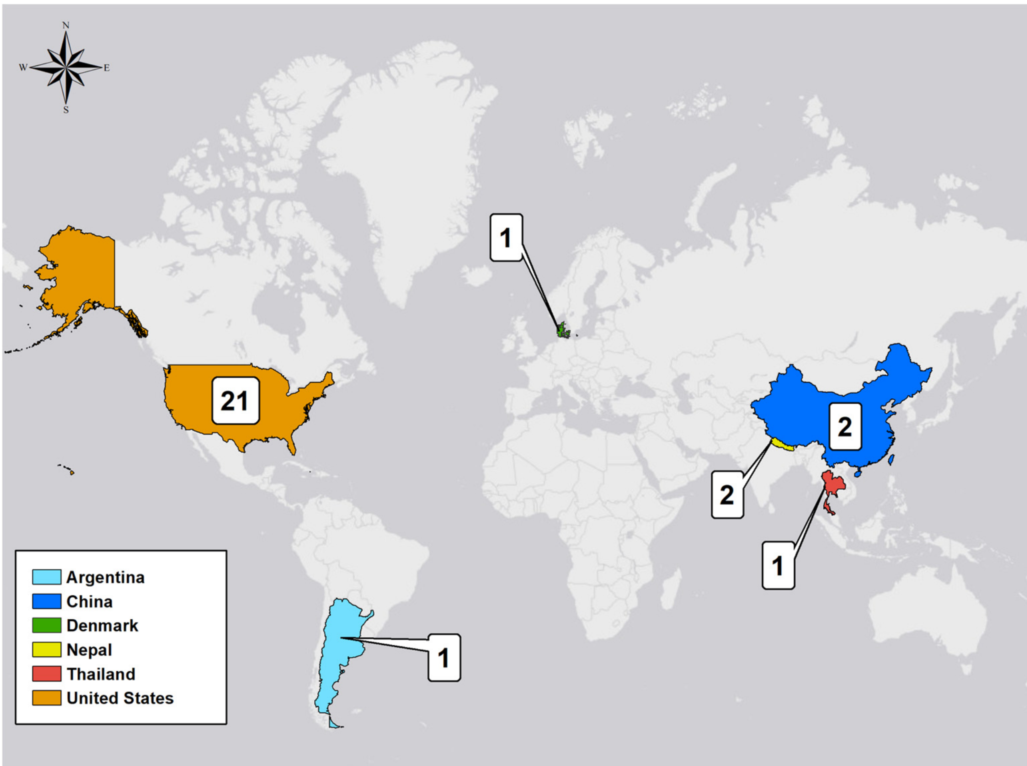

Figure 2. Map showing location of included peer-reviewed articles in this study [19]. The number of articles based on each country are listed on the map.

3.3. Search Engine

3.3.1. PubMed: 22

The articles returned by PubMed include [20–41].

3.3.2. Scopus: 16

The articles returned by Scopus include [20–29,42–47].

3.4. Pesticide

3.4.1. Naled: 8

The studies that focused on naled include [23,27,29,34,37,41,46,47].

3.4.2. Dichlorvos: 21

The studies that focused on dichlorvos or DDVP include [20–22,24–26,28,30–33,35–40,42–45].

3.5. Country

3.5.1. United States: 21

The studies that took place in the United States are [20,25–29,31–42,45–47].

3.5.2. Outside of United States: 7

The studies that took place outside of the United States are [21–24,30,43,44].

3.6. Application Purpose

3.6.1. Agriculture: 24

The studies that involved farmer pesticide applicators include [20,25,26,28,31–33,35,36,38,39,42,45].

The studies that involve pesticide residue in agricultural soil include [43] and in agricultural products [21–24,30,34,41,44].

Two studies focus on bystander exposure from agricultural applications: [37,40].

3.6.2. Mosquito Management: 4

The studies that involve mosquito management include [27,29,46,47].

3.7. Health Outcome

3.7.1. Neurological: 4

A study found a substantial increase in Parkinson's Disease outcomes in both private applicators and their non-applicator spouses at the highest levels of DDVP use (>1134 Intensity Weighted Lifetime Days—IWLD) compared to lower levels of use (>0 and <1134 IWLD) [20]. The purpose of the study was to estimate the risk to both the applicator and their family through contamination pathways such as clothing and wearing of personal protective equipment, including gloves [20].

One study examined the amount of organophosphates, including naled, in umbilical cord blood in a cohort of Chinese infants whose mothers were exposed to organophosphates (OPs) from agricultural product consumption [23]. However, the source of exposure is unknown and cannot be assumed to be exclusively from this pathway. This study found that prenatal naled concentrations were associated with decreased 9-month motor function. Female children were also found to be more sensitive to these effects [23]. However, follow-up studies that attempted to replicate the results from Silver, Shao, Zhu, Chen, Xia, Kaciroti, Lozoff and Meeker [23] were not successful, and a conclusion was made that naled may have been misidentified in the initial study [34,41].

3.7.2. Sensory: 1

One study found a modest increase in self-reported olfactory impairment in a cohort of private pesticide applicators using DDVP [42]. Olfactory deficit has been associated with increased mortality in older adults and may negatively impact safety, diet, nutrition, and overall quality of life [42].

3.7.3. Risk Quotient: 2

A study found that the risk quotient (RQ) (the ratio of estimated exposure to reference dose) using reasonable worst-case assumptions for the use of naled for mosquito management to prevent outbreaks of West Nile virus (WNV) are well below 1.0 for all subgroups [47]. The acute RQ values ranged from 0.15 to 0.47, and the subchronic RQ values ranged from 0.026 to 0.17 for the study groups spanning adult males to infants [47]. In a refined risk assessment using probabilistic techniques, Schleier, Macedo, Davis, Shama and Peterson [46] estimated that RQs associated with the use of naled ranged from 0.017 to 0.035 for the study groups spanning adult males to infants.

3.7.4. Urine Metabolites: 2

A study involving exposure to naled in Mississippi, North Carolina, and Virginia found no statistically significant differences in the urine concentrations of naled metabolites before and after spraying following mosquito control applications [27]. Similarly, Duprey, Rivers, Luber, Becker, Blackmore, Barr, Weerasekera, Kieszak, Flanders and Rubin [29] found no increase in naled metabolite levels following a spray event at 12 h after the event and every 8 h up to 40 h. There were also no statistically significant increases in reported symptoms associated with potential pesticide exposure, pre- and post-spraying [29].

3.7.5. Cancer: 7

Two studies focusing on agricultural pesticide applicators found that there was no statistically significant association between DDVP exposure and the risk of total and aggressive prostate cancer and all cancers [38,45]. A 1992 study found a small but marginally significant increased risk of incidence of non-Hodgkin's lymphoma among male farmers who handled DDVP [28]. A study found statistically significant associations between male farmers who handled DDVP—either ever (OR = 2.0, 95% CI: 1.2–3.5) or at least 20 years before the 1990 study (OR = 2.4, 95% CI: 1.1–5.4), as well as an increased risk of leukemia [33]. Flower, Hoppin, Lynch, Blair, Knott, Shore and Sandler [32] found a non-statistically significant association (OR = 2.06, 95% CI: 0.86–4.90) between the parental use of DDVP and subsequent childhood cancer risk. A non-statistically significant association (OR = 1.35, 95% CI: 0.93–1.96) was found between the use of DDVP and increased risk of prostate cancer among Hispanic men who were members of a farm worker labor union in California [36]. Lee, McLaughlin, Harnly, Gunier and Kreutzer [37] studied the cancer risk associated with bystander exposure to both airborne naled and DDVP in California and found that neither species is present at sufficiently high concentrations compared to the RfD to cause increased cancer risk.

3.7.6. Respiratory: 4

Two studies examined the association between pesticides and wheezing among commercial pesticide applicators and found that DDVP exposure increased the odds of wheezing Odds Ratio: OR (OR = 2.48, 95% CI: 1.08–5.66) [25,26]. DDVP had the highest OR of 16 study insecticides (OR = 1.15, 95% CI: 1.03–1.28) of being associated with rhinitis among private pesticide applicators [31]. A study quantified the association between exposure to DDVP and chronic bronchitis among nonsmoking farm women who were not pesticide applicators and found a positive relationship (OR = 1.63, 95% CI: 1.01–2.61) [40].

3.7.7. Other Outcomes: 8

A study performed in Denmark identified that the overall risk using the hazard index (HI) method to estimate exposure to pesticides in 47 imported foods was on level with that of alcohol for a person consuming the equivalent of one glass of wine every seventh year [44]. One study that quantified the concentration and distribution of pesticide residues in soil found that the concentrations of DDVP were too low to pose any health risk [43]. Furthermore, soils from crop fields that employed integrated pest management fields had the lowest concentration of residues, including DDVP [43]. However, Bhandari, Zomer, Atreya, Mol, Yang and Geissen [21] found DDVP at levels above the recommended hazard quotient levels for chilies. Similarly, exposures above 100% RfD for DDVP were found in all four study clusters (6–23-month-old children, 2–5-year-old children, 10–49-year-old women, and pregnant women) due to dietary exposure [22]. In addition, a study performed in Thailand found levels of DDVP higher than the maximum residue limits (MRL) in durian

(*Durio zibethinus*) [24]. Zhang, Qin, Wang, Zhou, Feng, Ma and Zhu [30] found levels of DDVP well below the MRL in goji berries (*Lycium barbarum*) and concluded that there was no consumption risk. Montgomery, Kamel, Saldana, Alavanja and Sandler [35] studied the relationship between DDVP exposure and diabetes risk, finding inconclusive results among licensed pesticide applicators. This association remained consistent with both ever-use and cumulative-days-of-use models [35]. Shrestha, Parks, Goldner, Kamel, Umbach, Ward, Lerro, Koutros, Hofmann and Beane Freeman [39] found a statistically significant association between agricultural pesticide applicators using DDVP and increased risk of hypothyroidism (OR = 1.42, 95% CI: 1.17–1.72).

3.8. Summary of Included Articles

The complete list of included articles is shown in Table 2.

Table 2. Included articles. Search engine: P = PubMed, S = Scopus; pesticide: D = Dichlorvos, N = Naled; country of study: U = USA; O = Outside of USA; purpose: A = Agriculture, M = Mosquito Management. The table is organized by potential health outcome studied, listed in italics.

Author	Year	Title
Neurological		
Bhardwaj, Patterson II et al.	2018	Poor qualitative analysis of Naled necessarily leads to incorrect quantitative analysis [34] (P, N, U, A)
MacGregor	2018	Issues about the findings in the Silver et al. (2017) publication regarding Naled [41] (P, N, U, A)
Shrestha, Parks et al.	2020	Pesticide use and incident Parkinson's disease in a cohort of farmers and their spouses [20] (PS, D, U, A)
Silver, Shao et al.	2017	Prenatal naled and chlorpyrifos exposure is associated with deficits in infant motor function in a cohort of Chinese infants [23] (PS, N, O, A)
Sensory		
Shrestha, Umbach et al.	2021	Occupational pesticide use and self-reported olfactory impairment in US farmers [42] (S, D, U, A)
Risk Quotient		
Peterson, Macedo et al.	2006	A human-health risk assessment for West Nile virus and insecticides used in mosquito management [47] (S, N, U, M)
Schleier, Macedo et al.	2009	A two-dimensional probabilistic acute human-health risk assessment of insecticide exposure after adult mosquito management [46] (S, N, U, M)
Urine Metabolites		
Centers for Disease Control and Prevention	2005	Human exposure to mosquito-control pesticides—Mississippi, North Carolina, and Virginia, 2002 and 2003 [27] (PS, N, U, M)
Duprey, Rivers et al.	2008	Community aerial mosquito control and naled exposure [29] (PS, N, U, M)
Cancer		
Brown, Blair et al.	1990	Pesticide Exposures and Other Agricultural Risk Factors for Leukemia among Men in Iowa and Minnesota [33] (P, D, U, A)
Cantor, Blair et al.	1992	Pesticides and Other Agricultural Risk Factors for Non-Hodgkin's Lymphoma among Men in Iowa and Minnesota [28] (PS, D, U, A)
Flower, Hoppin et al.	2004	Cancer risk and parental pesticide application in children of Agricultural Health Study participants [32] (P, D, U, A)
Koutros, Beane Freeman et al.	2012	Risk of Total and Aggressive Prostate Cancer and Pesticide Use in the Agricultural Health Study [45] (S, D, U, A)
Koutros, Mahajan et al.	2008	Dichlorvos exposure and human cancer risk: results from the Agricultural Health Study [38] (P, D, U, A)
Lee, McLaughlin et al.	2002	Community exposures to airborne agricultural pesticides in California: ranking of inhalation risks [37] (P, DN, U, A)
Mills and Yang	2003	Prostate cancer risk in California farm workers [36] (P, D, U, A)
Respiratory		
Hoppin, Umbach et al.	2006	Pesticides and adult respiratory outcomes in the agricultural health study [26] (PS, D, U, A)
Hoppin, Umbach et al.	2006	Pesticides associated with Wheeze among Commercial Pesticide Applicators in the Agricultural Health Study [25] (PS, D, U, A)

Table 2. *Cont.*

Author	Year	Title
Slager, Simpson et al.	2010	Rhinitis associated with pesticide use among private pesticide applicators in the agricultural health study [31] (P, D, U, A)
Valcin, Henneberger et al.	2007	Chronic bronchitis among non-smoking farm women in the agricultural health study [40] (P, D, U, A)
Other Outcomes		
Bhandari, Atreya et al.	2020	Concentration and distribution of pesticide residues in soil: Non-dietary human health risk assessment [43] (S, D, O, A)
Bhandari Zomer et al.	2019	Pesticide residues in Nepalese vegetables and potential health risks [21] (PS, D, O, A)
Larsson, Sloth Nielsen et al.	2018	Refined assessment and perspectives on the cumulative risk resulting from the dietary exposure to pesticide residues in the Danish population [44] (S, D, O, A)
Maggioni, Signorini et al.	2017	Comprehensive estimate of the theoretical maximum daily intake of pesticide residues for chronic dietary risk assessment in Argentina [22] (PS, D, O, A)
Montgomery, Kamel et al.	2008	Incident diabetes and pesticide exposure among licensed pesticide applicators: Agricultural Health Study, 1993–2003 [35] (P, D, U, A)
Shrestha, Parks et al.	2018	Pesticide use and incident hypothyroidism in pesticide applicators in the agricultural health study [39] (P, D, U, A)
Wanwimorluk, Kanchanamayoon et al.	2015	Food safety in Thailand 1: it is safe to eat watermelon and durian in Thailand [24] (PS, D, O, A)
Zhang, Qin et al.	2022	Levels and health risk assessment of pesticides and metals in Lycium barbarum L. from different sources in Ningxia, China [30] (P, D, O, A)

4. Discussion

4.1. Study Findings

The literature found through both databases (Scopus and PubMed) is limited in terms of human health outcomes associated with exposure to naled and DDVP. There were only 28 total articles found that met the inclusion criteria. Of those, 8 focused on naled, 20 on DDVP, and only 1 focused on both. An overwhelming majority (24) were related to agricultural use, and only four studied outcomes related to mosquito management. Agricultural use is substantially more intensive and involves much higher volumes, amounts, and rates than ULV applications (both aerial and land-based) performed for mosquito control. Therefore, the health associations summarized in this review are generally associated with exposure levels not commensurate with mosquito control applications; this is reflected in the Section 3.7. All the studies that directly relate to ULV mosquito management applications were found to not have any associated deleterious health outcomes. The studies that involve agricultural operations, where the application rate was unclear or undetermined—whether that involves direct exposure from pesticide applicators (who belong in the occupational exposure and risk group), via consumption of food, or inhalation—have mixed results. Furthermore, one study [41] attempted to reproduce the results of a prior study showing an association between naled exposure and infant motor function [23] and discovered potential misidentification errors. Therefore, based on the published peer-reviewed literature, the health risks associated with naled or DDVP exposure are minimal or non-existent to human populations stemming from ULV mosquito control applications. Results from the reviewed papers generally showed either no negative health effects or inconclusive results, with a few exceptions, which were again associated with agricultural use exposure. However, because of the higher application rates used in agriculture, duration of exposure, location of applications, and lack of information on personal protection measures used by applicators, correlation with negative impacts is difficult to ascertain.

4.2. Limitations and Future Work

Although the USEPA has produced human health and ecological risk assessments for pesticides as part of their registration process, which dictate application rates, many of the studies presented here did not take place in the United States. The USEPA states that product label review is a part of the licensing and registration process for pesticides. Therefore, the label and instructions provide important and lawful information for proper use and to avoid harm to the environment and human health [46]. Therefore, future work should investigate whether studies presenting negative health outcomes are associated with mishandling or not following the label as required. Our investigations suggest that using naled, according to the product label, should not result in negative health outcomes. Consequently, education and enforcement of appropriate pesticide usage are of great importance and should be fortified for all pesticide applications.

5. Conclusions

The potential health impacts of naled and DDVP on human health were studied through a literature review. PubMed and Scopus were the 2 databases used for this study, and while 382 articles matched the search criteria, only 28 met the requirements, which included quantifiable exposure and direct human health outcomes. While a few studies showed adverse health effects, these were associated with exposure from agricultural use, which uses substantially greater amounts of pesticide (e.g., 250 to 10,000 times more per ha), and not aerial ULV applications for mosquito management. The published literature suggests that aerial applications of naled do not result in increased levels of naled in humans, provided the product is used according to label instructions. Furthermore, the USEPA requires manufacturers and mosquito abatement districts to follow strict guidelines during storing, handling, and field applications, parameters which may not be followed outside of the United States due to a lack of oversight and regulatory requirements. Our findings are in congruence with USEPA and United States Centers for Disease Control and Prevention (CDC) recommendations that aerial applications of naled, when applied according to label requirements, do not pose an adverse risk exposure to humans.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/pollutants3040039/s1.

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Abbreviations

ADI	Acceptable Daily Intake.
CDC	Centers for Disease Control and Prevention.
DDVP	2,2-dichlorovinyl dimethyl phosphate (dichlorvos).
GLP	Good Laboratory Practice.
HI	Hazard Index.
IWLD	Intensity Weighted Lifetime Days.
NOAEL	No Observed Adverse Effect Levels.

OP	Organophosphates.
OPP	Office of Pesticide Programs.
RfD	Reference Dose.
RQ	Risk Quotient.
SF	Safety Factor.
SLCMAD	Salt Lake City Mosquito Abatement District.
ULV	Ultra-Low Volume.
USEPA	United States Environmental Protection Agency.
WNV	West Nile Virus.

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