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Dietary risk assessment of drinking water and fish from cultivated wetlands of Ndop

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ABSTRACT

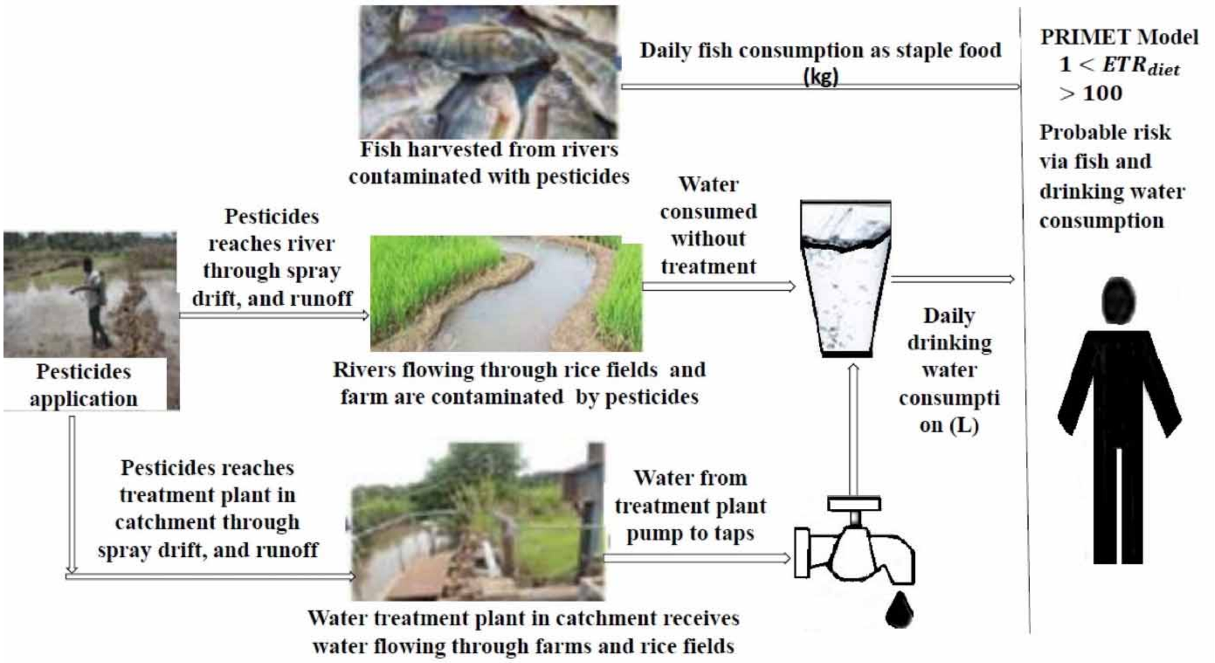
This study evaluated pesticide exposure practices, and the potential health risks of drinking water and consuming fish from the cultivated wetlands of Ndop, Cameroon. Six hundred and twenty-six questionnaires were conveniently administered to farmers ($\geq$ 26 years old) in a cross-sectional study to assess exposure practices and dietary risks. The Chi-square and Pearson correlation coefficients were used to establish relationships between variables. The PRIMET model was used to predict a worst-case dietary risk. The pesticide handling practices of 90% of farmers were inadequate. Chlorpyriphos, lambda-cyhalothrin, fipronil, and paraquat dichloride posed a possible dietary risk at recommended and applied doses, with chlorpyrifos having the highest exposure toxicity ratio ($ETR_{diet} = 36.72$). Paraquat dichloride, fipronil, and lambda-cyhalothrin posed a possible dietary risk at 26.3%, 58.3%, and 62.2% of their recommended concentrations, respectively. Remarkably, the dietary risk for cypermethrin was acceptable at 5.8 times its recommended dose ($ETR_{dietR} = 0.29$). The significant positive correlation ($p = 0.000$) between PEC_{fish} and ETR_{diet}, suggests a possible health risk of consuming fish and drinking water harvested from the wetlands, thus the need for replacing pesticides posing possible risks at lower or recommended concentrations with less toxic alternatives and to train farmers on pesticide application practices.

Key words: cypermethrin, exposure toxicity ratio, PRIMET model, recommended doses, worst-case scenario

HIGHLIGHTS

- Most developing countries do not include dietary risk assessment in the pesticide authorization process because it is expensive.
- The PRIMET model uses unsophisticated equipment to establish dietary risk in a worst-case scenario.
- Many studies have explored the model to assess risk to aquatic life, terrestrial life, non-target organisms, and bees.
- Limited data exist on its use in dietary risk assessment, and this research seeks to explore this.

GRAPHICAL ABSTRACT



INTRODUCTION

The annual estimate of global pesticide usage by the year 2020 might have increased from 2 million to 3.5 million tons (Sharma *et al.* 2019), with extensive usage posing severe consequences to human and environmental health because pesticides remain the most effective and economical pest control method that can substantially contribute to a steady supply of affordable quality food and consequently increase farmers' income (Antonini & Argilés-Bosch 2017). Global pesticide usage and dependency are high, even on low-value staple food crops, and pesticide-related illnesses are raising public health concerns (Udeigwe *et al.* 2015). For instance, in sub-Saharan Africa, the aid for pesticide-related sicknesses between 2005 and 2020 was estimated at $90bn, exceeding the total amount of international aid allocated for health services for the region, excluding HIV/AIDS (UNEP 2012). The oral route is the primary exposure route to pesticides, and oral/dietary exposure is the function of pesticide residue levels in food and the consumption rate of the food (Zarn & O'Brien 2018).

Oral exposure may result in health risks and varies with active ingredient toxicity, concentration, time of exposure, and individual health status (Debnath & Khan 2017). A dietary risk assessment (DRA) study establishes the health risks of pesticides via oral exposure. It is used for setting legally enforceable limits for pesticides in food (maximum residue levels). It is an integral part of the authorization process for plant protection products (Zarn & Geiser 2019). However, in countries with limited resources, DRA is rarely included in the pesticide authorization process because most dietary risk models necessitate the use of sophisticated equipment (Nougadère *et al.* 2012; Hlihor *et al.* 2016; Galani *et al.* 2021), which are unavailable or expensive to procure.

However, the PRIMET model (Pesticides RIsks in the tropics to Man, Environment and Trade) is a decision support system that can potentially address these difficulties by establishing a dietary risk in a worst-case scenario using limited input data generated by unsophisticated equipment (van den Brink *et al.* 2005). The PRIMET model was developed to assess risks due to pesticides to groundwater, aquatic and terrestrial ecosystems, bees, nontarget arthropods, and the human diet (van den Brink *et al.* 2005), and several studies have demonstrated its validity in the risks assessment of aquatic, terrestrial, bee, and nontarget organism (Malherbe *et al.* 2013; Kenko & Ngameni 2022; Kenko *et al.* 2022, 2023). However, its use in DRA of pesticides remains unexploited. The inhabitants of the Ndop wetlands source drinking water from the wells or rivers that flow through the farms and rice fields. Besides, their drinking water catchment and treatment plant is located downstream and receives water flowing through farms and rice fields. Catfish (*Clarias gariepinus*) and tilapia (*Oreochromis niloticus*) are harvested from the wetlands and consumed daily by the inhabitants (Fai *et al.* 2019; Ncheuveu *et al.* 2021).

Therefore, the current study aimed to assess pesticide exposure practices, and health risks of drinking water and fish from the cultivated wetlands of Ndop. This research will allow regulatory authorities in developing countries with limited resources to include a first-tier dietary risks assessment in their pesticide registration/authorization process.

METHODOLOGY

Study site

The Ndop flood plain in Cameroon is a rice and vegetable cultivation zone with an estimated population of over 200,000 inhabitants (Wirmvem *et al.* 2015) (Figure 1). The floodplain stretches from latitudes 5°42° and 6°10° N to longitudes 10° 11° and 10°40° E, with an annual average temperature of 26 °C and an annual average rainfall of 1,540 mm/year (Wirmvem *et al.* 2013; Ndzeidze *et al.* 2016). The wetlands have a short dry season (mid-November to mid-Match) and a long subequatorial monsoon-type rainy season (mid-March to mid –November), and approximately 3,000 ha of the wetlands are under rain-fed rice cultivation during the rainy season and seasonal vegetable production in both seasons (Table 2). The Ndop wetland is the second-largest rice-producing area in Cameroon. The use of pesticides to control crop pests in the Ndop wetlands dates back to the 1990s, when The Upper Noun Development Authority (UNVDA), a parastatal that supervises rice production in the Ndop wetlands, introduced pesticides (especially herbicides) to improve rice productivity in the country. Later, in the early 2000s, intensive vegetable production with the use of pesticides started in the wetlands to meet the increasing food demands in the urban cities in Cameroon. Vegetable farmers used herbicides, fungicides, and insecticides with different active ingredients to control crop pests during production (Table 1). To date, the use of pesticides in rice and vegetable production in the wetlands is intensive because of the wetland's agricultural endowment and increasing food demands.

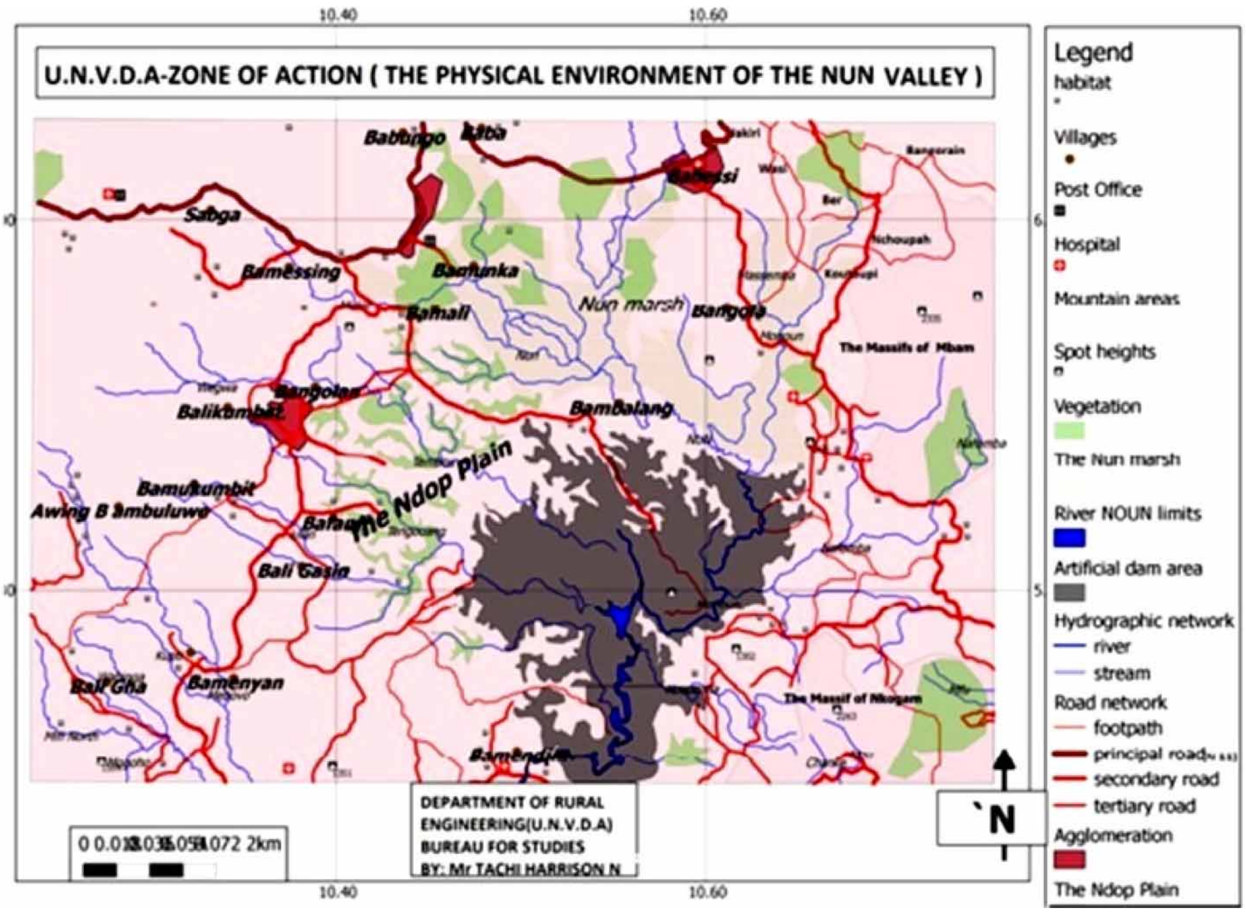


Figure 1 | Map of the study area in Ndop floodplain, North West Region, Cameroon created by UNDA, 2016. *Source:* Ncheuveu *et al.* 2021

Table 1 | Pesticide application scheme physiochemical properties of pesticide used by farmers in the Ndop floodplains

Active ingredient	Single application dose of pesticide (a.i.g/ha)	Recommended dose of pesticide (a.i.g/ha) (MINADER 2013)	Number of applications per cropping cycle	Molecular mass (g/mol)	Saturated vapor pressure (Pa)	Solubility (mg/ℓ)	DT50/half-life-water (days)	DT50 – sediment (days)	Kom (ℓ/kg)	Octanal-water partitioning coefficient (log Kow)
Carbendazim	94.4	200	16	191.2	0.09	15.5	0.2	0.065	144.8	3.02×10^{01}
Chlorothalonil	1036.8	1,008	16	265.9	0.0762	0.81	0.1	15.7	500	8.71×10^{02}
Mancozeb	868.0	1,600	16	271.3	13.3	16.19	0.5	0.1	586	2.00×10^{02}
Maneb	544.0	1,600	16	265.3	0.014	7.267	7	0.15	321.6	3.55×10^{-01}
Metalaxyl	96.0	240	16	279.3	0.3397	7,445	24.9	38.06	95.75	5.62×10^{01}
Potassium Phosphite	515.25	n. a.	16							
Copper oxide	329.47	n. a.	16		0.01		9.7	1.00E + 05	−1.00E + 06	
Acétamipride	10.0	20	16	222.7	0.001	2.95	4.7	2.6	62.6	6.31×10^{00}
Chlorpyriphos	600	480.0	16	350.6	1.49	0.7802	1.958	76.8	7,768	5.01×10^{04}
Cypermethrin	201.6	36	16	416.3	0.00023	0.009	3	68	5.03E + 04	3.55×10^{05}
Fipronil	17.5	30	16	437.2	0.00032	1.9	54	142	428	5.62×10^{03}
Imidacloprid	28.0	20	16	255.7	0.0002	510	79	179	843	3.72×10^{00}
ʎ-cyhalothrin	28.0	45	16	449.9	0.0002	0.01045	0.335	57	4.74E + 06	3.16×10^{05}
2, 4 D amine	1,080	720	2	221	0.00987	1.88E + 04	4.544	4.544	101.8	1.51×10^{-01}
Glyphosate	1,536	1,440	2	169.1	0.0068	10.2	3.6	17.63	6.09	5.25×10^{-07}
Paraquat dichloride	210.0	800	2	257.2	5.19E + 06	6.20E + 05	10,000	3,000	5.80E + 04	3.16×10^{-05}

Source: Research and PRIMET database and field data (Fai *et al.* 2019).

Study design and sample population

The study population included rice and vegetable farmers (age ≥26 years) in a cross-sectional study. A convenience sampling technique was used to obtain information from rice and vegetable farmers actively involved in farming. Some of these farmers also fish from canals and streams/rivers adjacent to paddy fields and in flooded paddy fields during the rice growing season.

Determination of sample size

The sample size of rice and vegetable farmers was determined as follows (Amin 2005):

$$n = \frac{(z^2 \times p \times q \times N)}{e^2(N-1) + z^2 \times p \times q}$$

where n = sample size; z = Std variate at a given confidence limit (1.96 at 95%); p = sample proportion = 0.5; $q = (1–p) = 0.5$; N = size of population = 13,123; and e = maximum error = 0.05.

$$n = \frac{1.96^2\,(0.5)(0.5)(13{,}123)}{0.05^2(13{,}123 - 1) + 1.96^2(0.5)(0.5)} = 381.51$$

Since the expected response rate was 80%, 381 was divided by 0.8 to have a minimum of approximately 476 participants. Since the two groups of farmers were not mutually exclusive, 526 rice farmers and 100 vegetable farmers were interviewed separately using questionnaires.

Data collection

Assessment of farmers' pesticides exposure practices and health effects

Field observations and household interviews using semistructured questionnaires with open- and close-ended questions were pretested and administered to farmers (age ≥ 26 years) in a cross-sectional study using a convenient sampling technique in 2023. The questionnaire comprised four categories of questions based on (i) pesticide exposure practices (i.e., pesticide exposure practices during mixing, application, storage, use of personal protective equipment (PPE) and disposal, etc.) and (ii) consumption of aquatic resources and drinking water harvested from the wetlands, and (iii) dietary risk data (body weight (kg), daily intake of fish (kg), and drinking water (kg) for the PRIMET model. The researcher visited farmers' fields to observe farmers' pesticide exposure practices (practices during mixing, application, storage, use of PPE and disposal, etc.).

Dietary exposure assessment

The model uses the average daily drinking water (kg), fish (kg), and aquatic macrophytes/vegetable (kg) consumption values obtained from household interviews or the standard World Health Organization values (WHO 2003) in case the inhabitants cannot give a reliable estimate.

Estimating daily fish consumption

Dried fish samples (catfish and tilapia) from the wetlands were classified into 'small, medium, or large' sizes based on the weight and length of the fish. A representative sample of each fish size was carried alongside questionnaires to the field so that each farmer could identify the fish size and the number they consume daily. Fifty tilapia/catfish samples in each size category were randomly selected, oven dried, and weighed with an electronic balance to obtain the average weight of each fish size category. The average daily fish consumption of the inhabitants was calculated as follows:

$$\begin{aligned}&\text{Daily fish consumption (kg/day)}\\&= \text{Average weight of fish in each category or class} \times \text{Corresponding average number of fish consumed daily}\end{aligned} \tag{1}$$

Estimating daily water consumption

The estimated daily intake (EDI) of drinking water was obtained through a household interview [10]. The average quantity of water (l) consumed by the inhabitants was used in the PRIMET model to obtain the EDI for drinking water (van den Brink *et al.* 2005). This study considered only fish and drinking water since the inhabitants do not consume aquatic macrophytes.

Dietary effects assessment

The PRIMET model predicts risks based on the physicochemical properties (octanal-water partitioning coefficient (log Kow) and solubility (mg/l) of the substance in water at a reference temperature of 20 °C, half-life in water (days), half-life in sediments (days), organic carbon-water partition coefficient (l/kg) molecular mass (g/mol), saturated vapor pressure (Pa), farmers' dosage of pesticide (Table 1), and toxicity data (acceptable daily intake (ADI), bioconcentration factor (BF), and the no-observed adverse-effect level (NOAEL)) (Table 2) of individual pesticides. The toxicity and physiochemical data of the various pesticides were obtained from the PRIMET database or the Pesticide Properties DataBase (Lewis *et al.* 2016).

Data analysis

All data on farmers' dosage of pesticides, the average body weight (farmers $\geq$ 26 years), and daily intake of water (kg) and fish(kg) were input into Microsoft Excel©, and their means ($\pm$SD) were calculated and used in the PRIMET model software. The dietary exposure to pesticides through fish and water intake was determined from the EDI for fish (EDI_{fish}) and water (EDI water) using the following equations:

Calculation of the EDI_{water}

$$EDI_{water} = \frac{PEC_{gw} \text{ x } Conc_{water}}{bw \text{ x } 1000} \quad (2)$$

where PEC_{gw} is the annual average pesticide concentration leaching from the soil profile at 1 m depth (μg/l) and $Conc_{water}$ is the daily drinking water consumption (l/d). Farmers' average daily drinking water consumption was 2.1 l/day (Table 3); bw is the body weight (kg); and 1,000 is a factor to correct from μg/l to mg/l. The value for PEC_{gw} used in Equation (2) is based on the assumption that people drink groundwater pumped up from 1 m depth. The PEC_{gw} was obtained from the default value generated by the PRIMET model for the groundwater assessment scenario in Ndop.

Table 2 | Toxicity data for dietary effects assessment and field measurements for dietary risk scenarios

S/N	Active ingredient (a.i)	Crops	ADI (mg/kg/d)	$NOAEL_{mammal}$ (mg/kg/d)	Bioconcentration factor (l/k g)	Bodyweight adults (bw)(kg)	Daily fish consumption ($Cons_{Fish}$) kg/d	Daily drinking water consumption ($Cons_{water}$)
1	Carbendazim	Vegetables	0.003	10	3.758	60.2	0.117	2.1
2	Chlorothalonil	Vegetables	0.015	10	62.89	60.2	0.117	2.1
3	Mancozeb	Vegetables	0.05	55	1,316	60.2	0.117	2.1
4	Maneb	Vegetables	0.05	5	0.3958	60.2	0.117	2.1
5	Metalaxyl	Vegetables	0.08	8	5.559	60.2	0.117	2.1
6	Copper oxide	Vegetables	-	-	-	60.2	0.117	2.1
7	Potassium phosphite	Vegetables	-	-	-	60.2	0.117	2.1
8	Acétamipride	Vegetables	0.07	15	0.9538	60.2	0.117	2.1
9	Chlorpyriphos		0.001	1	2,495	60.2	0.117	2.1
10	Cypermethrin	Vegetables	0.05	10	9,441	60.2	0.117	2.1
11	Fipronil	Vegetables	0.0002	0.35	501.2	60.2	0.117	2.1
12	Imidacloprid	Vegetables	0.057	13	0.6081	60.2	0.117	2.1
13	Lambda-cyhalothrin	Vegetables	0.005	0.7	1.78E + 05	60.2	0.117	2.1
14	2,4 D Amine	Grains (rice)	0.01	1	39.36	60.2	0.117	2.1
15	Glyphosate	Weeds	0.3	31	0.0003802	60.2	0.117	2.1
16	Paraquat dichloride	Weeds	0.004	0.45	2.99E-05	60.2	0.117	2.1

Source: PRIMET database, literature and field data.

Table 3 | Pesticide handling practices that can result in oral exposure

Pesticide handling practices	Yes (%)	No (%)
Store pesticides at home (ceiling, kitchen, bedroom) among other items	75.7	24.3
Storage of pesticides separate from other items (farms)	24.3	75.7
Reuse of pesticide containers for drinking water or storing food items	3.2	96.8
Disposal of empty containers by burying, burning, or throwing them in open fields	80.5	19.5
Disposal of empty containers in thrash houses constructed by UNVDA	16.3	83.7
Repeat clothing after pesticides application	93.6	6.4
Washed and rinsed Knapsacks in water bodies	100.0	0.00
Deep their Knapsack sprayers to collect water	78.2	21.8
Read pesticide label before mixing and application	42.6	57.4
Mix pesticides near water bodies	89.7	10.3
Use protective equipment during mixing and application	85.6	14.4
Renter farms to harvest immediately or a few days after pesticide application	76.2	23.8
Mix two pesticides before application	95.9	4.1
Respect pesticide doses during application	87.1	12.9
Spray at any time of the day regardless of weather conditions	100	0.0

Calculation of the EDI_{fish}

$$EDI_{fish} = \frac{PEC_{fish} \times Conc_{fish}}{bw} \quad (3)$$

where PEC_{fish} is the concentration of pesticides in fish (mg pesticide/kg fish); $Conc_{fish}$ is daily fish consumption (kg/d); and bw is body weight (kg). The average daily fish consumption (tilapia and catfish) was 117.44 g/d (Table 2). The average body weight of farmers (adults ≥26 years) in Ndop was 60.2 kg (Table 2). The concentrations of pesticides in fish are estimated from Equation (4):

$$PEC_{fish} = \frac{PEC^{n}_{water} \times BCF}{1,000} \quad (4)$$

PEC^{n}_{water} is momentary water concentration from multiple (n) applications. This value was obtained from the computed value generated by the PRIMET model for the aquatic risks assessment scenario; BCF is the Bio-concentration Factor for each pesticide (Table 2). BCF was obtained from various online databases, particularly the Pesticide Properties DataBase (PPDB). 1,000 is a factor to correct from μg/l to mg/l. The EDI used for DRA of each pesticide was determined as follows:

$$\text{EDI of each pesticide} = EDI_{fish} + EDI_{water} \quad (5)$$

Dietary effects assessment

The PRIMET model estimates dietary effects based on the ADI or tolerable daily intake. The ADI used in the current study was obtained from PRIMET Database and the literature (Table 2).

Dietary risk characterization

The risk assessment is the exposure toxicity ratio (ETR), which is the ratio of the exposure (EDI) and safe (ADI) concentrations. ETR is calculated as follows:

$$ETR = \frac{\text{Estimated daily intake (EDI)}}{\text{Tolerable daily intake (TDI)}} \quad (6)$$

ETR < 1 indicates that the exposure level is less than the safe concentration or risk is acceptable when 1 < ETR < 100, and it implies that the exposure level is slightly higher than the safe concentration or risk is probable, and if ETR > 100, the exposure level is greater than the safe concentration or risk is definite (van den Brink *et al.* 2005). The IBM Statistics SPSS version 21.0 (SPSS, Chicago, USA) was used to establish the relationship between ETR variables (Pearson's correlation) and the distribution of ETR values (Kruskal–Wallis's test).

A Chi-square test (χ^2) at a *p*-value $\leq$0.05, significant level, was performed to determine the association between variables on pesticide exposure practices and health effects.

RESULTS

Pesticide exposure practices

Table 3 presents farmers' pesticide exposure practices that can lead to dietary exposure. The majority of the farmers (75.7%) stored pesticides at home. Empty containers of pesticides were poorly disposed of by farmers (80.5%). From field observations, farmers disposed of empty pesticide containers in bushes and water canals or streams, farms/rice fields, and thrash houses. Some farmers (3.2%) reuse containers to store food items or drink water and palm wine. All farmers (100%) mixed pesticides at any time of the day regardless of the weather conditions. Most farmers (78.2%) used the Knapsack sprayers to collect water from streams, rivers, or canals to mix pesticides. Most farmers (89.7%) mixed pesticides near rivers, streams, or canals. From field observations, the nozzles of some Knapsack sprayers were in poor condition. Most farmers (87%) never used protective wear during application, and from field observations, no farmer used glasses, gloves, goggles, or masks during pesticide application, and most farmers wore regular dresses during application. All farmers (100%) washed and rinsed Knapsack sprayers in nearby water bodies. At least 93% of the farmers repeat their clothing after application. Less than half of them (42. 6%) read pesticide labels before mixing and application, while 87.1% did not respect standard recommended doses of pesticides. More than half of the vegetable farmers (76.2%) enter their farms to harvest vegetables a day or few days after spraying.

Consumption of water and aquatic resources

Oreochromis niloticus (44%) and *Clarias gariepinus* (56%) were the main fish species harvested from the paddy fields and consumed by rice (97.4%) and vegetable farmers (84.2%). Farmers consumed and sold fish catches from the rice fields and streams in the wetlands to the inhabitants. All farmers (100%) drink or use pesticide-contaminated flowing through farms. From observations, the primary water catchment is downstream and receives pesticide-contaminated water from farms.

Dietary risk characterization by the PRIMET model-based famers' application doses of pesticides

Table 4 depicts the exposure toxicity ratios (ETR_{dietF}) values of the various pesticides used by farmers. Four of 16 pesticides posed a possible dietary risk (lambda-cyhalothrin, $ETR_{dietF} = 34.62$ (pyrethroid), fipronil, $ETR_{dietF} = 13.17$ (neonicotinoid), chlorpyriphos, $ETR_{dietF} = 11.38$ (organophosphorus), and one herbicide (paraquat dichloride, $ETR_{dietF} = 2.48$ (bipyridylium) at farmers' concentrations). The possible dietary risk posed by lambda-cyhalothrin, fipronil, chlorpyriphos, and paraquat dichloride occurred at 62.22, 58.3, 80, and 26.25% of each recommended dose, respectively (Table 4). Interestingly cypermethrin did not pose risks at 5.6 times its recommended concentration. All fungicides (carbendazim, chlorothalonil, maneb, mancozeb, and metalaxyl), two herbicides (glyphosate and 2, 4 D amine), and three insecticides (imidacloprid, cypermethrin, and acetamiprid) applied by farmers posed an acceptable dietary risk ($ETR_{dietF} \leq 0$) and (Tables 1 and 4).

Dietary risk characterization by the PRIMET model based on the individual recommended doses of pesticides

Table 4 shows the dietary risks characterized by the PRIMET model based on the individual recommended doses of pesticides. The PRIMET model also predicted that possible dietary risks for chlorpyriphos scored the highest exposure toxicity ratio ($ETR_{dietR} = 34.72$), followed by Lambda-cyhalothrin ($ETR_{dietR} = 34.72$), fipronil ($ETR_{dietR} = 13.66$), and paraquat dichloride ($ETR_{dietR} = 2.48$). The ETR for paraquat dichloride at recommended (800 g a.i./ha) and applied (210.0 g a.i./ha) dose was remarkably the same ($ETR_{dietR} = 2.48$) (Table 4). The dietary risk for cypermethrin was acceptable at the recommended dose (36 g a.i./ha) and 5.8 times (210 g a.i./ha) its recommended dose. The ETR at individual recommended concentrations of chlorpyriphos, lambda-cyhalothrin, and fipronil was higher than at farmers' doses (Tables 1 and 4). All fungicides (carbendazim, chlorothalonil, maneb, mancozeb, and metalaxyl), two herbicides (glyphosate and 2, 4 D amine), and

Table 4 | Predicted effect concentration groundwater, aquatic scenario, and fish, estimated daily intake of drinking water and fish, and exposure toxicity ratio (ETR_{diet}) of pesticides using recommended and farmers' pesticide doses

S/N	Pesticide	PEC_{gw} (μg/l)	PECnw (μg/l)	PEC_{fish} (μg/l)	EDI_{fish} (mg/kg*d)	EDI_{dw} (mg/kg*d)	EDI (mg/kg*d)	ETR_{dietR} (mg/kg*d)	ETR_{dietF} (mg/kg*d)
Fungicides									
1	Carbendazim	1.026	2.662	0.01001	1.95E-05	3.58E-05	5.52E-05	0.003175	0.001841
2	Chlorothalonil	123.2	2.619	0.1647	0.0003201	0.004298	0.004618	0.2999	0.07706
3	Mancozeb	0.2919	2.608	3.433	0.006673	1.02E-05	0.006683	0.2666	0.1337
4	Maneb	7.362	2.64	0.001045	2.03E-06	0.0002568	0.0002588	0.1337	0.005177
5	Metalaxyl	11.75	2.668	0.01463	2.84E-05	0.000403	0.0004314	0.01317	0.005392
Insecticides									
6	Acétamipride	0.8341	2.672	0.002549	4.95E-06	2.91E-05	3.41E-05	0.001258	0.0004864
7	Chlorpyriphos	53.34	1.963	4.898	0.009519	0.001861	0.01138	**11.38**	**34.72**
8	Cypermethrin	11.97	0.7963	7.518	0.01461	0.0004176	0.01503	0.2938	0.3006
9	Fipronil	2.141	2.627	1.317	0.002559	7.47E-05	0.002634	**13.66**	**13.17**
10	Imidacloprid	11.55	2.578	0.001568	3.05E-06	0.0004091	0.0004121	0.001549	0.00723
11	Lambda- Cyhalothrin	0.7105	0.5008	89.06	0.1731	2.48E-05	0.1731	**34.62**	**34.62**
Herbicides									
12	2,4 D Amine	129.2	2.68	0.11	0.0002049	0.004508	0.004713	0.3209	0.4713
13	Glyphosate	188.3	2.68	1.02E-06	1.98E-09	0.006568	0.006568	0.02053	0.02189
14	Paraquat dichloride	86.15	2.668	3.557	0.006913	0.003005	0.009919	**2.48**	**2.48**

The bold values mean ETR values indicating risks.

three insecticides (imidacloprid, cypermethrin, and acetamiprid) applied by farmers posed an acceptable dietary risk ($ETR_{dietF} \leq 0$) and (Tables 1 and 4).

Relationship between variables input variables and exposure toxicity ratio

Table 5 shows Pearson's correlation between PRIMET input variables and the ETR at the recommended concentration (ETR2) and applied (ETR1) and at the standard recommended concentration (ETR2) of pesticides. There was a strong positive and significant relationship ($p = 0.000$) between pesticide concentration in fish (PEC_{fish}) and the ETR at applied (ETR1) and recommended doses (ETR2) of pesticides. Also, farmers' concentrations (Conc 1) correlated significantly ($p = 0.000$) with the annual average concentration of pesticides leaching from the soil profile at 1 m depth (PEC_{gw}). Also, the relationship between the standard recommended dose (Conc 2)/doses applied by farmers (Conc 1) and the momentary water concentration from *n*th applications (PEC_{nwater}) was strongly positive and significant ($p = 0.000$).

Distribution of ETR

Kruskal–Wallis test revealed an insignificant difference ($p \leq 0.05$) between the ETR values of fungicides, insecticides, and herbicides at farmers' and recommended concentrations. Also, the distribution of ETR across groups was the same.

DISCUSSION

Pesticide exposure practices and toxicity symptoms among farmers

The inhabitants in the current study were exposed orally to pesticide-related health symptoms through inappropriate handling practices during mixing, application, disposal, and storage and reuse of empty containers for storing food items or drinking water and palm wine. Earlier studies by Mattah *et al.* (2015), Mwabulambo *et al.* (2018), Bondori *et al.* (2019), Mequanint *et al.* (2019), and Matowo *et al.* (2020) also reported similar findings. However, in the current study, drinking water and fish intake were the primary sources of oral exposure to pesticides. The inappropriate pesticide practices exposed farmers to a broad range of pesticide symptoms, including pains in the lower limbs (probably due to exposure to pesticide-contaminated water in flooded rice fields). Lately, in Cameroon, pesticide-related illnesses are becoming a public health concern

Table 5 | Correlation between input parameters and exposure toxicity ratios

	PEC_{gw}	PEC_{nw}	PEC_{fish}	Conc 1	Conc 2	ETR1	ETR 2
PEC_{gw}	1						
PEC_{nw}	0.270 0.351	1					
PEC_{fish}	−0.221 0.448	−0.769** 0.001	1				
Conc 1	0.822** 0.000	0.287 0.320	−0.254 0.380	1			
Conc 2	0.469 0.091	0.384 0.176	−0.268 0.355	0.781** 0.001	1		
ETR 1	−0.238 0.414	−0.670** 0.009	0.902** 0.000	−0.317 0.269	−0.337 0.239	1	
ETR 2	−0.238 0.414	−0.670** 0.009	0.902** 0.000	−0.317 0.269	−0.337 0.239	1.000** 0.000	1

** means significance at 0.01 level.

(Pouokam *et al.* 2017). The significant difference ($p \leq 0.05$) between training, health awareness, and toxicity symptoms in this study indicates an urgent need to encourage farmers to use personal protective equipment during pesticide application and the need to raise awareness and sensitization through training programs.

Dietary risk assessment via intake of fish and drinking water

Generally, established standard recommended doses of pesticides are considered safe for the population. However, in this study, the PRIMET model predicted a possible dietary risk at applied and recommended concentrations of pesticides (Tables 2 and 4), indicating the need for their replacement with less toxic alternatives and the withdrawer of pesticides posing possible risks at lower or recommended doses. PEC_{fish} significantly correlated ($p = 0.000$) with ETR_{diet} at applied and recommended doses, signifying the high chances of oral exposure through the consumption of fish harvested from the wetlands. Biomagnification of pesticides in fish can result in human health risks. An earlier study in the wetlands by Fai *et al.* (2019) showed that chlorpyriphos, lambda-cyhalothrin, and paraquat dichloride posed a high aquatic risk due to high levels of exposure in the wetlands. Also, the significant correlation between farmers' pesticide doses (Conc 1) and PEC_{gw} (Table 5) indicate a probable groundwater contamination by pesticides since the wetlands have a shallow water table and permeable soils (Wirmvem *et al.* 2015).

Risk predicted for herbicides

Glyphosate and 2, 4, D amine herbicides posed an acceptable dietary (Table 4) despite the higher concentrations applied by farmers, probably because their doses did not exceed threshold levels. Also, the short half-life of 2, 4, D amine (4.5 days) and glyphosate (3.6 days) probably reduced dietary risks via fish or water intake. However, this contradicted the findings by Watson (2014), who reported a high risk for 2, 4 D amine via dietary intake of fish and drinking water. Paraquat dichloride had the same ETR value at recommended doses and at doses approximately four times lower than the recommended dose (Tables 2 and 4), confirming it is highly toxic and can potentially pose health risks via oral exposure. This result is in line with the finding established by Watson (2014), who found paraquat dichloride to pose a dietary risk through drinking water consumption. This possible dietary risk of paraquat dichloride may be due to its very low ADI (0.004) and its long half-life in water (10,000 days), which increases the chances of fish and water contamination. Diarrhea and vomiting symptoms are symptoms of paraquat dichloride toxicity via oral exposure (Thundiyil *et al.* 2008; Yin *et al.* 2013). Farmers frequently experienced these symptoms in the current study though a serological test must confirm this assertion.

Risks predicted for insecticides

In the current study, acetamiprid, cypermethrin, and imidacloprid posed an acceptable/no risk (Tables 2 and 4), indicating that their recommended and applied concentrations did not exceed threshold levels. For instance, the dietary risk of cypermethrin (pyrethroid) at 5.6 times (201.6 g a.i./ha) its recommended dose (36 g a.i./ha) was acceptable, confirming its moderate toxicity via dietary intake. However, cypermethrin was reported to pose definite acute and chronic aquatic risks in the wetlands (Fai *et al.* 2019). The possible dietary risk posed by lambda-cyhalothrin (pyrethroid) at 62.2% (ETR = 36.62), its respective recommended dose (Tables 2 and 4), confirms that it is more toxic than cypermethrin, probably because it has a lower ADI (ADI = 0.005) compared to cypermethrin (ADI = 0.5). A similar study by Claeys *et al.* (2011) showed that lambda-cyhalothrin used in fruits and vegetables cultivation posed a dietary risk.

Chlorpyrifos residue is one of the most frequently detected pesticides in food (Kariathi *et al.* 2016). The high ETR of chlorpyrifos (ETR = 34.72) in this study may be attributed to its low ADI (ADI = 0.001), confirming findings established by Kariathi *et al.* (2016), Darko & Akoto (2008), and Zhang *et al.* (2010), though contradicts with findings by Hossain *et al.* (2013) via dietary intake of vegetables.

The possible dietary risks predicted for fipronil at recommended doses (30 g a.i./ha) and lower concentrations (17.5 g a.i./ha) (Table 2) may be due to its low ADI (ADI = 0.0002), BF in fish (575), and half-life in water (54 days). However, this result disagrees with the findings established by Zhang *et al.* (2010), who found a negligible acute and chronic risk for fipronil via dietary intake. Fipronil is very toxic and is on PAN international's list of highly hazardous pesticides for global phase-out because of its carcinogenicity (Pesticide Action Network 2012).

Risk predicted for fungicides

Fungicides posed an accepted dietary risk in the current study (Table 4), which may be because the recommended and applied concentrations did not exceed threshold levels. However, some dithiocarbamate fungicides and chlorothalonil have proven to pose unacceptably high chronic and cancer risks via dietary intake (Nougadère *et al.* 2012; Hlihor *et al.* 2016).

The PRIMET model is limited because it cannot predict the risks of pesticides with incomplete data on the toxicity and physiochemical characteristics of a pesticide. For instance, in the current study, the model could not predict the risk of copper oxide and potassium phosphide because of incomplete data on their toxicity and physiochemical properties. Also, the model predicts only the overall dietary risks (first tier) in a worst-case scenario.

CONCLUSION

From the current study, pesticide handling practices of 90% farmers were inadequate. The PRIMET model predicted a possible dietary risk (ETR_{diet}) at recommended and applied concentrations of chlorpyriphos, lambda-cyhalothrin, fipronil, and paraquat dichloride. The significant correlation between PEC_{fish} and ETR indicated a high level of oral exposure to pesticides via the intake of fish harvested from the wetlands. Remarkably cypermethrin posed an acceptable dietary risk at 5.8 times its recommended dose ($ETR_{dietF} = 0.30$). Paraquat dichloride, fipronil, and lambda-cyhalothrin posed a possible dietary risk at 26.3, 58.3, and 62.2% of their recommended concentration, respectively. Thus, regulatory authorities should prohibit or substitute pesticides that can pose a possible dietary risk at recommended or lower concentrations in a worst-case scenario with less toxic alternatives. Also, there is a need to train farmers in the wetlands on pesticide use practices to respect recommended doses of pesticides and reduce exposure in the wetlands. However, studies should be done to complete the physiochemical characteristics and toxicity data of most pesticides in the Pesticide Properties DataBase.

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AUTHOR STATEMENT

Each named author has contributed substantially to conducting and drafting the manuscript. N.T. Nkwatoh: conceptualization, collected data, formal analysis, methodology, and writing – original draft. P.B.A. Fai: visualization, data curation, supervision, and validation; N.M. Tchamba: visualization and supervision.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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