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Assessment and spatial modeling of diffuse pollution pesticide risk from cocoa-growing areas: case of the Houda upstream watershed, Côte d'Ivoire

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Abstract

The phytosanitary pressures exerted in the cocoa growing areas of the watershed upstream of Houda threaten their water resources. Simple tools are used to evaluate the aspiring risk of pollution from pesticides. Then, a method was proposed to assess the spatial variability of pollution risk on upstream watershed Houda. This method proceeds in four steps: (1) investigating on the planters and their practices, (2) determining the frequency use and pesticide load for most field, (3) establishing an indicator of dangerousness based on the toxicity, mobility, solubility, and persistence of each molecule, and (4) spatializing the indicator. The results showed that 19 active ingredients are used in cocoa orchards belonging to 09 pesticide families identified during the survey. These belong to the families of pyrethroids (38%), carbamates (17%), neonicotinoids (15%) in large amounts and some families such as organophosphates, chloroamines, benzurulées, cianniques, stobilins, pyridines, in little proportions. Using geographical information system, the very high threat risk areas were Gbrizokro and Kouadiobakro, while Boboukouamekro, Kramokro, N'guessankankro and Brunokro were simply high-risk. In contrast, the localities of Tourekro and Tottokoffikro were moderate and low risk, respectively. This study could be a way to prevent and minimize the contamination risks within the cocoa loop in Côte d'Ivoire.

1. Introduction

The development of the Ivorian economy is mainly based on agriculture. The country has produced significant results due to growing agricultural development, particularly through the export of these main crops. Thus, Côte d'Ivoire ranks first among cocoa producers in the world, i.e. with more than 40 % of world production. Indeed, coffee and cocoa alone occupy 2/3 of the cultivated land with a predominance for cocoa [1]. Currently, cocoa alone represents 30 % of Ivorian export products and therefore provides significant economic support to the state of Côte d'Ivoire [2]. Soaring selling prices in the cocoa sector sparked growing interest in cocoa cultivation. To increase and/or maintain the production yield, the farmers have resorted to pesticides. Unfortunately, we often see an irrational and uncontrolled use of these products. Despite the positive role of pesticides in crop protection, their misuse has a direct impact on the ecosystem, as well as on the population [3]. In fact, environmental pollution caused by pesticides largely depends on the cultivation techniques used which are sometimes unsuitable [4]. The impact of pesticides on the environment today poses a serious threat to the quality of water resources (i.e., surface and groundwater), air and soil. According to WHO (2008), 23 % of deaths within Africa in rural areas are attributable to environmental deterioration by pesticides. In most developed countries, attention to point pollution has helped to resolve this phenomenon [3]. In the case of water pollution by pesticides, there is a major problem regarding the scales from which data is acquired and assessment is carried out. Diffuse pollution is difficult to identify and therefore to control because it concerns large areas with imprecise outlines and is generated by various practices which mainly include the use of pesticides. Consequently, all these factors interfere in a complex way with the ground and the meteorological hazards [5]. For example, data acquisition is often done at the plot level, where farmers' practices take place, but the vulnerability of natural resources needs to be determined for the watershed. There is therefore a problem of moving up-scaling from the plot at the scale of the farm. Faced with the state of degradation of the ecosystem and the exposure of the population to public health problems, it appears imperative to find a more effective management or prevention method to minimize the risks of contamination linked to the pesticides use. Tools such as geographic information systems (GIS) capable of combining information from different sources and different spatial scales into a single database [6-8]. They can represent thematic maps using spatially complex information on practices. For this, indicators are helpful because they permit to consider several data in a single variable, e. g. poor agricultural practices and their impact on water. To further act, the spatial modeling of certain complex phenomena, as well as diffuse pollution could be a means of preventing and minimizing the risks of contamination. However, several previous modeling studies led to a better understanding of the processes and dynamics of pesticide transfers [9-12]. These investigations were obtained from the study of the contaminant behavior in relation to agricultural practices and developments and on nested watersheds of various types in several countries. However, this method remains little exploited in the sub watersheds of Côte d'Ivoire like within the department of Sinfra being a cocoa growing area, whose phytosanitary products would be used intensively there for the protection of the orchard. Thus, the upstream part of the Houda watershed located in this department could be affected by this diffuse pollution. This study aims to identify areas at contamination risk of surface water in the Houda upstream watershed by pesticides based on a multi-criteria spatial analysis. Specifically, it proposes to: (i) assess the phytosanitary pressure in the Houda upstream watershed, (ii) map the sensibilities of Houda upstream watershed to spreading pollution by pesticides in the surface water, (iii) identify the areas at risk of contamination of surface water by the pesticides' runoff in the Houda upstream watershed.

2. Study area localisation

This study was performed in the upstream part of the Houda watershed which is included in that of Sassandra. This part is located between latitudes 711,000 - 758,000 North and longitudes 30 N 150,000 - 185,000 Est, with an area of 763.45 km² [13]. It brings together some localities in the department of Sinfra and the Marahoué administrative region which are the sub-prefectures of Zaguiéta, Bonon, Gadouan, Kouétinfla, Bayota (See **Figure 1**). Its exit, named Batta, is in the Kouetinfla sub-prefecture nearly the Grizokro village. Moreover, the Houda watershed owns altitudes between 182 and 321 meters from digital terrain model (DTM). Thus, the highest altitudes are observed in the Zaguiéta area and the lowest off Kouétinfla. Its climate is of Baoulean type and characterized by two long seasons (*i.e.* from December to the end of February for the dry season and from March to June for rainy season) alternated by two small seasons (*i.e.* from July to August for the dry season and September to November for wet season). The precipitation and temperature annual average range between 1,800 and 2,000 mm and 25 to 30 °C, respectively [14]. Finally, the Houda geological watershed is represented by 80 % of heterogeneous biotite granitoids. However, a formation of shales and grawackes has been observed in the Zaguiéta region, while that of the Kouetinfla area revealed formations of migmatites which are generally embrichitic in some places [15].

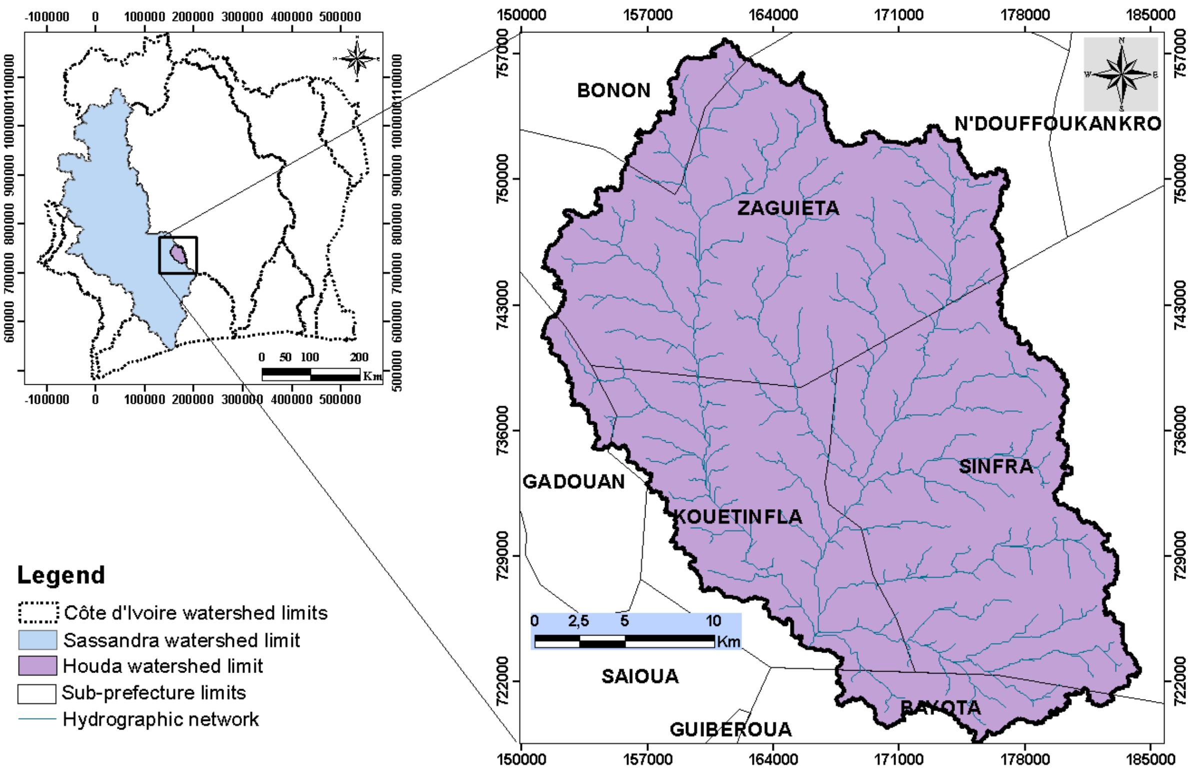

Figure 1. Map of study area.

3. Material and methods

3.1. Material

Using a digital camera and a Garmin ETREX 30 GPS receiver, field observations and recording of agricultural parcel coordinates as well as the determination of the planting extent were performed, respectively. Then, the alphanumeric data used are linked to the values of the parameters got from the toxicity, mobility, persistence, and solubility of the pesticides identified. These data were collected in the Footprint database (2007). From the 2015 phytosanitary index of the Ministry in charge of Agriculture in Côte d'Ivoire, the active ingredients of these phytosanitary products have been obtained [14]. The spatial data used hail from a Landsat 8 ETM+ image with the scene (197-55) from August 2016 which fully covers the Houda watershed while the geological map is made from the pedological sketch of the Côte d'Ivoire on 1/2,000,000 established by ORSTOM-SODEMI [16] and the geological sketch established by [15]. Finally, a digital terrain model (DTM) of the ASTGTGM 2 image with a resolution of 30 meters was used to determine the altitudes and the slope thresholds of the study area.

3.2. Methods

3.2.1. Data acquisition

In order to properly conduct this study, a survey was carried out among producers concerning their intellectual level, their state of health, the age of the plantation as well as the inputs used (*i.e.* phytosanitary products), their method of packaging management, the frequency of insecticides, fungicides, and herbicides use. Before that, a random sampling method has been used to select the producers to interview in collaboration with the ANADER agents. On the basis of the above criteria, 08 villages, Brunokro (BN), Boboukouamekro (BB), Gbrizokro (GB), Kouadiobakro (KD), Kramokro (KR), N'guessankankro (NG), Tottokoffikro (TT), Tourekro (TO) and 112 planters were selected from two main areas, namely the Sinfra and Kouétinfla sub-prefecture areas.

3.2.2. Data treatment

The data collected from the survey were first codified. Then, the information collected were grouped versus locality and criteria. The frequency of each criterion was calculated in relation to the number of growers interviewed according to the following relationship:

$$\mathbf{F} = \frac{\mathbf{X}}{\mathbf{Y}} \times \mathbf{100} \qquad (1)$$

Where,

F: Frequency (%);

X: Modality sum (number of planters by locality and by criterion);

Y: Total number of planters surveyed by locality.

Then, the criteria were estimated from the arithmetic mean of the information received according to **equation 2**:

$$\overline{\mathbf{X}} = \frac{1}{n}\sum_{i=0}^{n} x_i \qquad (2)$$

Where, $\overline{X}$: Estimated average. x_i: Quantity indicated by planters and n: Number of planters.

3.2.3. Dangerousness index of active matters

The danger index of the active matters was determined by summing the coasts of the different toxicity, solubility, mobility, and persistence indices for each molecule (**equation 3**) [17]. Indeed, these indices are rated according to the criteria previously defined in table 1. Based on this table, the sum of the different ratings of these indices is therefore established between 4 (low danger) and 16 (very high level of danger) (See **Table 1**).

$$\mathbf{AmD} = \sum \mathbf{Ti} + \mathbf{Si} + \mathbf{Mi} + \mathbf{Ri} \qquad (3)$$

Where, AmD : Active matter dangerousness; Ti : Toxicity index coast ; Si : Solubility index coast ; Mi : Mobility index coast ; Ri : Persistence index coast.

Table 1. Rating of the indexes of the dangerousness of active ingredients

	Toxicity classes (mg kg^{-1})			
	< 100 Harmless	100 – 1000 Slightly toxic	> 1000 Toxic	> 10000 Very toxic
Coast	**1**	**2**	**3**	**4**
	Solubility classes (mg L^{-1})			
	< 0,01 Insoluble	< 1 Slightly soluble	1 - 100 Soluble	> 100 Very soluble
Coast	**1**	**2**	**3**	**4**
	Mobility classes (mg L^{-1})			
	> 5000 Immobile	1000 - 5000 Slightly mobile	100 - 1000 Mobile	< 100 Very mobile
Coast	**1**	**2**	**3**	**4**
	Persistence classes (DT50 in days)			
	< 10 Not Persistent	10 - 30 Slightly Persistent	30 - 100 Persistent	> 100 Very Persistent
Coast	**1**	**2**	**3**	**4**
	Active ingredients dangerousness			
	[4 - 6] Low	[7 - 9] Moderate	[10 - 12] High	[13 - 15] Very high
Coast	**1**	**2**	**3**	**4**

3.2.4. Frequency index of molecules use

The frequency of use of the molecules is a determining parameter for the calculation of the diffuse pollution of active matters. It represents the percentage of the active matter use by the planters. Then, the frequencies were codified, and classified according to the compounds and the localities as indicated in **Table 2**.

Table 2. Classification of the citation frequency

Citation frequency per molecule				
Classes	[2- 22]	[23 - 43]	[44 - 64]	[65 - 85]
Coast	1	2	3	4
Citation frequency per locality				
Classes	[19 - 21]	[22 - 24]	[25 - 27	[28 - 30]
Coast	1	2	3	4

3.2.5. Specific load determination

The specific charge of active matter in pesticides was evaluated considering their concentrations on the phytosanitary products' technical sheets used by planters. Indeed, it was estimated according to **equation (4)** using the volume of commercial products per hectare for each season obtained from the surveys:

$$\mathbf{SC(g) = Vp_{com} \times C} \qquad (4)$$

Where, SC (g): Specific load of active matter (g/ha/an); Vp com: Volume of commercial products used (L/ha/an); C: Concentration of active matter in the product (g L^{-1}).

Table 3. Specific load Classification

	Specific load per active molecule			
Classes	[25 - 469]	[470- 914]	[915 - 1359]	[1360 - 1804]
Coast	1	2	3	4
	Specific load per locality			
Classes	[24 – 24.75]	[24.76- 25.51]	[25.52 – 26.27]	[26.28 – 27.03]
Coast	1	2	3	4

3.2.6. Phytosanitary pressure index

The phytosanitary pressure index was obtained by summing the danger indices, the use frequency, and the specific charge of the active matter above determined, as indicated in equation 5:

$$\textbf{Phyto IP} = \sum \textbf{AmD} + \textbf{FIc} + \textbf{SC} \qquad (5)$$

Where, Phyto IP: Phytosanitary pressure index coast; AmD : Active matter dangerousness index coast; FIc : Frequency index of molecule use coast; SC: Specific charge index coast.

3.3. Multi-criteria analysis method for developing sensitivity indicators for the transfer of pesticides into surface water

The multicriteria analysis method is carried out using several parameters shown below. This approach of building the database is denoted in Figure 2.

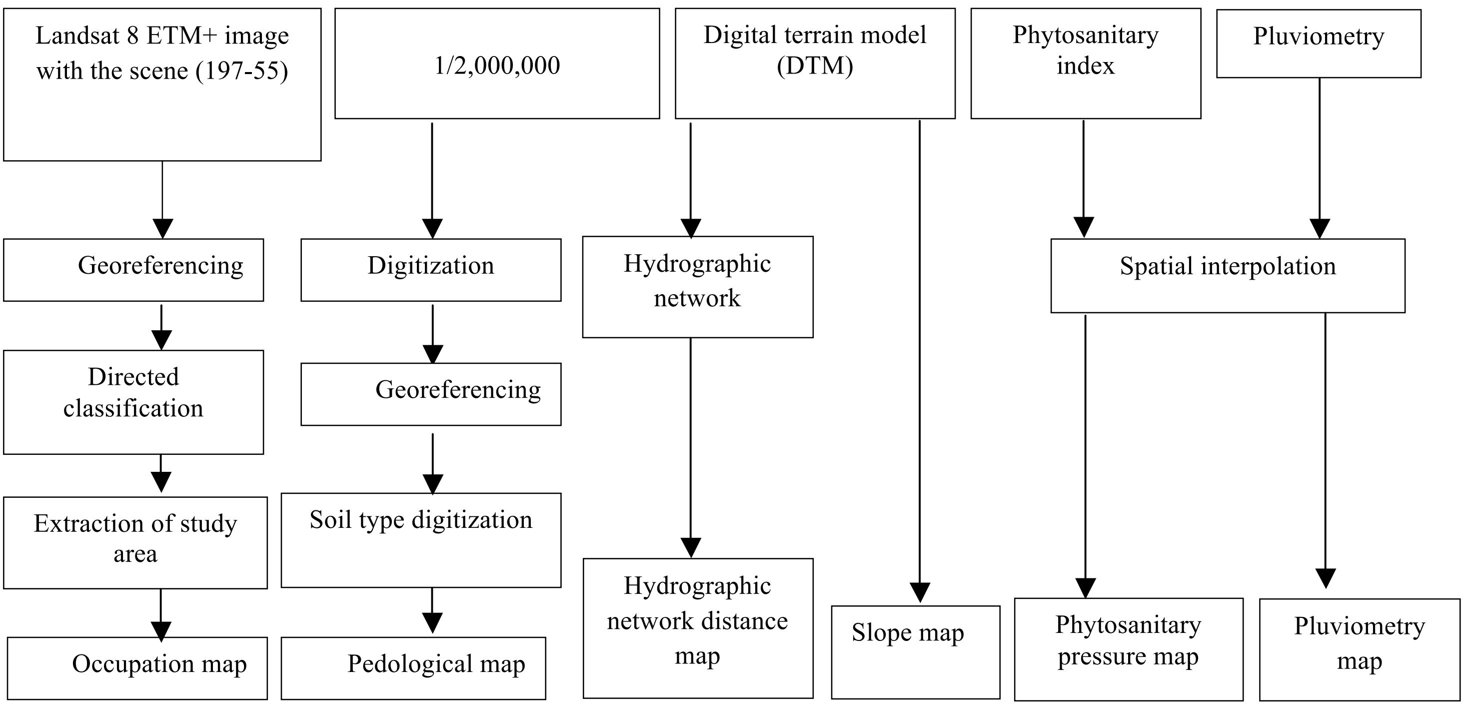

Figure 2. Diagram of the parameters involved in the Geographic Information System (GIS).

3.4. Modeling and mapping of surface water diffuse pollution potential risk from pesticides

To properly model and map the potential risks of surface water diffuse pollution, all combinations were made in "RASTER" mode using the "Raster Calculator" tool from the "Spatial Analyst" module of ArcGIS. To do this, a model was established according to **equation (6)**:

$$Rp = [\alpha + dh + Pedo] \times [Pphy] \times [Ocs] \times [Plu] \quad \textbf{(6)}$$

Where,

Rp : Potential risk of pollution indicator ;
α : Slope indicator ;
$\mathbf{d_h}$: Hydrographic network distance indicator ;
$\mathbf{P_{edo}}$: Pedological indicator ;
$\mathbf{P_{phy}}$: Phytosanitary pressure indicator ;
$\mathbf{O_{cs}}$: Soil occupation ;
$\mathbf{P_{lu}}$: Pluviometry indicator.

4. Results and Discussion

4.1. Phytosanitary pressure in the Houda upstream watershed

4.1.1. Ecotoxicological risk analysis relative work planters' conditions

The surveys on the use of protective equipment, pesticide storage places and management of empty packaging, performed on 112 growers in the study area, shown that more than 90 % of planters had no personal protective equipment (PPE), with the exception of those from Gbrizokro (GB) representing 50 %. In addition, more than 75 % of planters keep their phytosanitary products at home, excluding those from Boboukouamekro who keep them in the stores, while after their use, more than 70 % of the packaging empties are discharged into the environment and 5% is reused as a household container. These practices cause several diseases, the most common of which (~ 50 %) are skin and eye problems. According to [18] and [19], frequent contact with pesticides and improper handling can in the short-term cause ailments such as diseases above-mentioned. All of this could be explained in part by the high illiteracy rate (almost 60 %) or the low level of education (~ 40 %) of producers and the non-training of planters in the use of phytosanitary products. According to [20], the illiteracy represents a real risk due to the ignorance by planters of the rules for the proper use of plant protection products. To properly use these products, growers must know how to read, understand, and be able to apply manufacturers' instructions in accordance with the doses prescribed for environmental conservation [21].

4.1.2. Biological families of phytosanitary products used

Three types of pesticides are generally used by planters, namely insecticides, fungicides, and herbicides, corresponding to 60, 20, and 20 % of their use, respectively (**Figure 3-a**). Yet, the most widely used active matter concerning herbicides was glyphosate. This active matter is highly prized by growers because it is an effective herbicide that would apply to all crops [22]. According to [23], fungicides and herbicides are very toxic, and their uses are no longer authorized in order to promote sustainable cocoa cultivation. **Figure 3-b** exhibits the percentage of herbicide use. Indeed, the planters interviewed use phytosanitary products for the protection of the orchard. However, the choice of pesticides is not made under expert advice. In addition, manual weeding of the fields has decreased at the expense of chemical weeding involving the dumping of active matters in high doses into the environment. In fact, more than 50 % of planters use herbicides for weeding, regardless of the village, except those of N'guessankankro (NG) (10 %). This could be explained by the lack of skilled labor, the cleaning of plantations without providing physical effort, and ridding agricultural species of the most harmful weeds [24-25]. However, 10 % of herbicide use by N'Guessankankro growers could be due to the fact that they have a better understanding of the risks associated with chemicals [26]. Indeed, this village has initiated a certification program in cocoa cultivation which involves retraining of mentalities for good agricultural practices.

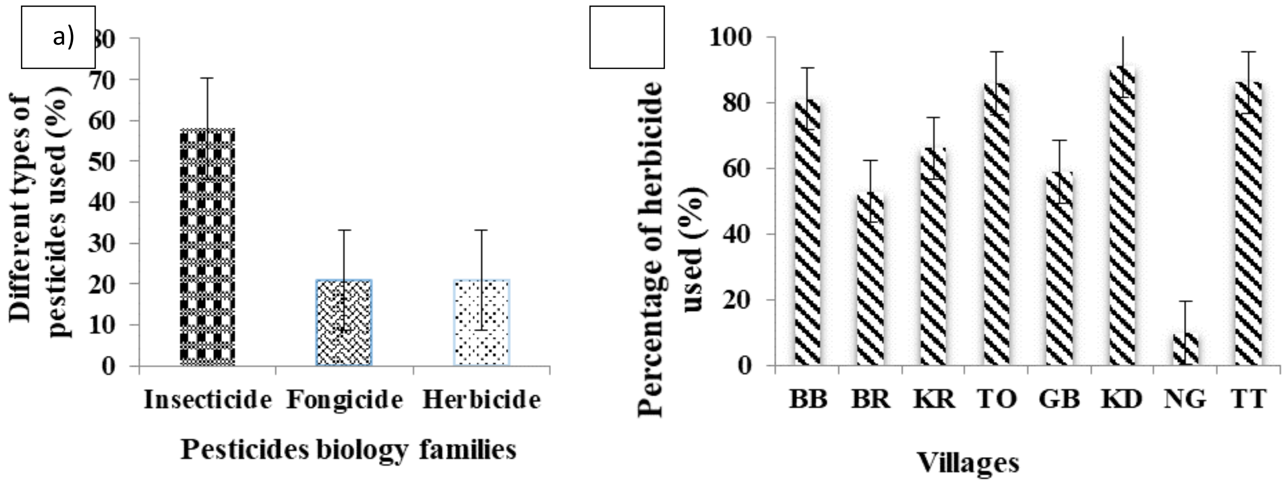

Figure 3. The different types of pesticides (a) and percentage of herbicides used by the growers in each village (b).

4.1.3. Chemical families of pesticides encountered

The different chemical families of pesticides used in the study area are presented in **Figure 4**. Nineteen (19) active molecules have been identified and classified into nine (09) families. The active matter of the pyrethroid family were the most used (38 %), followed by carbamates (17 %) then neonicotinoids (15 %) unlike organophosphates (5 %), chloroamines (5 %), benzurulates (5 %), cianniques (5 %), stobilins (5 %), pyridines (5 %). The high use of pyrethroids (*i.e.* Alpha cypermethrin, Bifenthrin, Cypermethrin, Deltamethrin, Lambdacyhalothrin) in cocoa orchards could be explained by the low toxicity of these active ingredients compared to other compounds (e.g. organochlorines (Endosulfan) and organophosphates (Chlorpyrifos)) [27]. On the other hand, some studies shown a high use of organochlorines in certain regions or countries [28]. These authors demonstrated that the toxic effect of organochlorines is due to incorrect dosage or poor conditioning in relation to use. In addition, these products are mainly used in July, August, September, and December, depending on the type of treatment. This could be explained by the fact that the climatic conditions during these periods are suitable for the growth and proliferation of some pests which could develop resistance to one or other of the active matters of pesticides [29].

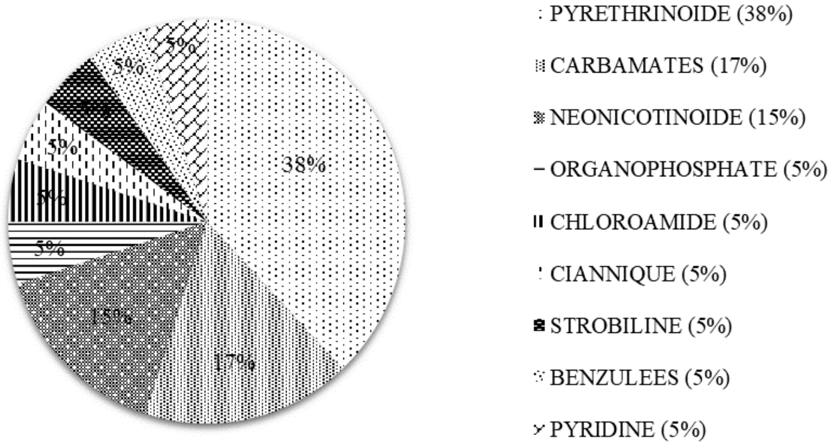

Figure 4. Chemical families encountered in the Houda sub-watershed.

4.1.4. Phytosanitary contamination index

4.1.4.1. Dangerousness index

Based on **Equation 3**, the dangerousness index of the active matters is determined (**Figure 5**). Indeed, the danger index enables to classify the active substances according to their capacity to be dangerous for the environment. Thus, Imidacloprid, Thiamethoxam, Triclopyr, and Propoxur were very high dangerousness, whereas 2,4 D Amine salt, Acetamiprid, Propanil, Lambdacyhalothrin, Dimethomorph, Diazinon, Bifenthrin, α-Cypermethrin presented high dangerousness (See **Figure 5**). Unlike both previous groups, glyphosate, diethofencarb, deltamethrin, cypermethrin, carbendazin, pyraclostrobin were moderately high in dangerousness, while only teflubenzuron was slightly dangerous (**Figure 5**).

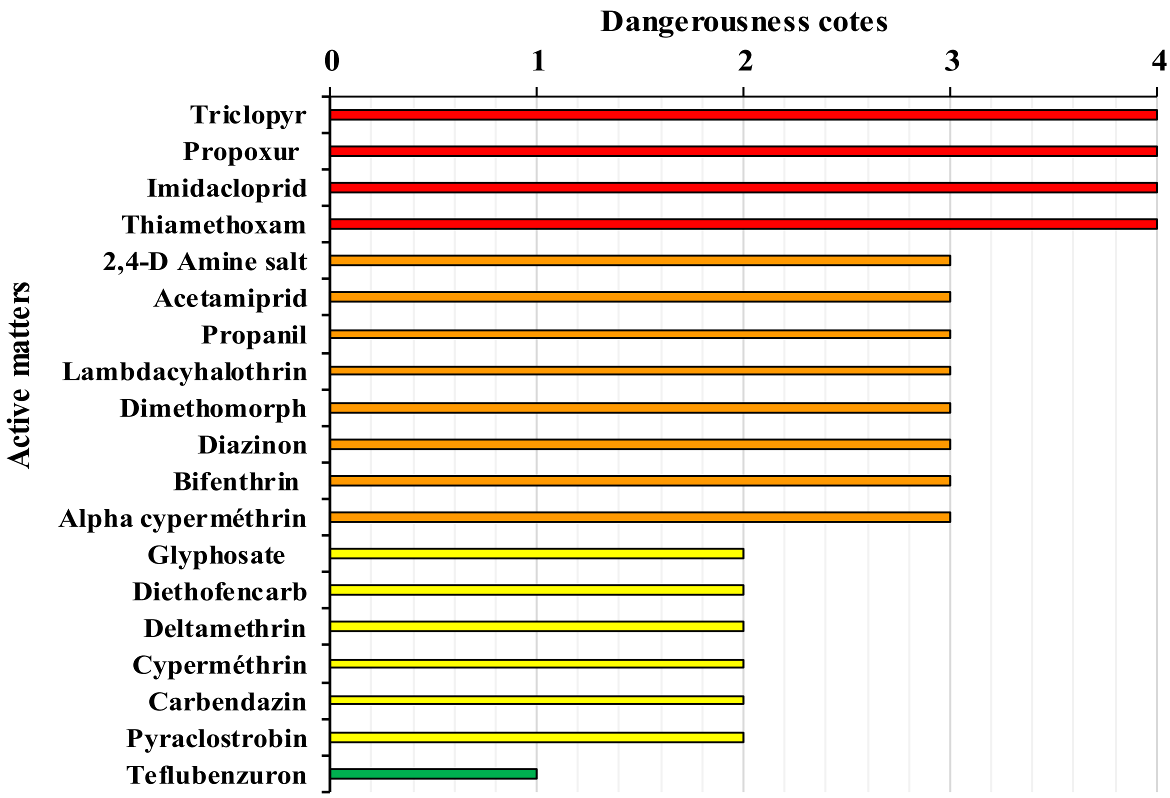

Figure 5. Active matter dangerousness indexes.

4.1.4.2. Citation frequency index of pesticide active ingredients used

Figure 6 exhibits the spatialization of the frequency index of active ingredients' use in villages. This index is the outcome of the practice frequency and the dangerousness of the active ingredients of pesticides. Indeed, the use rates of glyphosate, imidacloprid and bifenthrin are very high in the villages of Kramokro, corresponding to 90 %, 65 % and 45 % respectively, while in Kouadiobakro, lambdacyhalothrin and bifenthrin are the most used with 45 % each in cocoa orchards. On the other hand, Boboukouamékro, Gbrizokro, N'guessankankro and Brunokro inhabitants used these active ingredients with a high rate of between 30 and 45. In fact, other active ingredients (i.e., Cypermethrin, Deltamethrin, Alpha cypermethrin, Carbendazin) are moderately used in the localities of Tourekro and Kouetinfla with proportions varying between 20 and 30 %. Finally, these active ingredients and others (i.e., Carbamates, Diethofencarb, Propoxur and Carbendazin) are weakly used Totokoffikro with rates ranging from 10 to 20 %. It worthy be noted that the localities of Kramokro and Kouadiobakro owned the highest frequency index of pesticide use, whereas the lowest was observed Tottokoffikro. The high rates at Kramokro and Kouadiobakro could be explained by the lack of skilled labor, as well as by the willingness of producers to clean their plantations without providing physical effort and to rid agricultural species of the most harmful weeds [24-25].

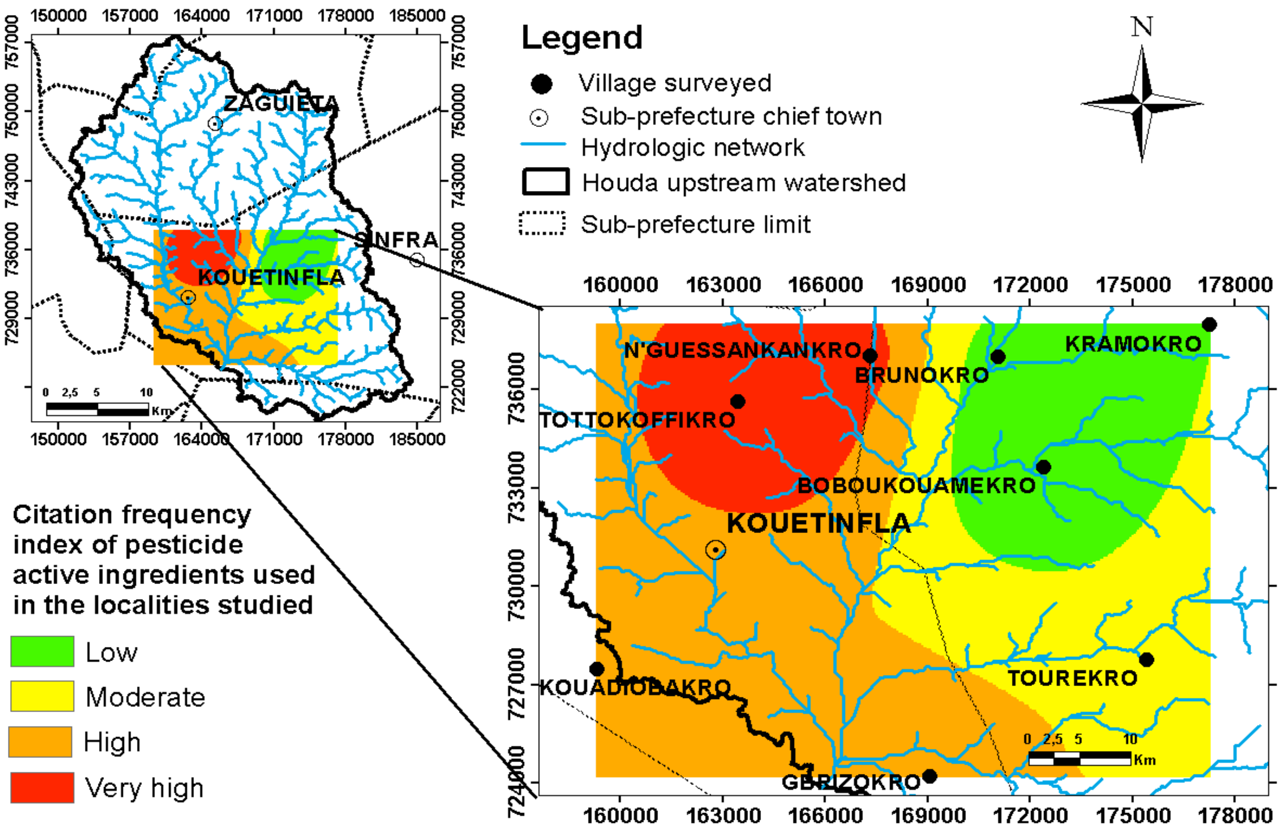

Figure 6. Mapping of the frequency of pesticide use within the villages.

4.1.4.3. Specific load index of pesticide active ingredients used

The mapping of the specific load index is presented in **Figure 7**. The specific load index is the result of the codification of the specific load of the active ingredients. Regarding herbicides, the highest loads exceeding one kilogram per hectare per year, corresponding to Glyphosate (1.8 kg ha^{-1}) and 2-4 D Amine salt (1.5 kg ha^{-1}). The highest load lower concerns Triclopyr with 0.61 kg ha^{-1}. In contrast, the highest specific load for fungicides was teflubenzuron (0.103 kg ha^{-1}), while propoxur was the lowest (0.21 g ha^{-1}). Among the insecticides, the highest load was that of cypermethrin (0.72 g ha^{-1}) and the lowest was that of Dianizon (0.29 g ha^{-1}). From the codification of these loads above, the lowest specific loads are obtained in the locality of Kramokro, unlike the other localities, thereby underscoring a very high risk of specific load for these other localities. This is due to the high use frequencies of active ingredients in these localities. According to [30], a high use frequency of active ingredients of pesticides with a high level of danger could seriously damage the environment of the study area.

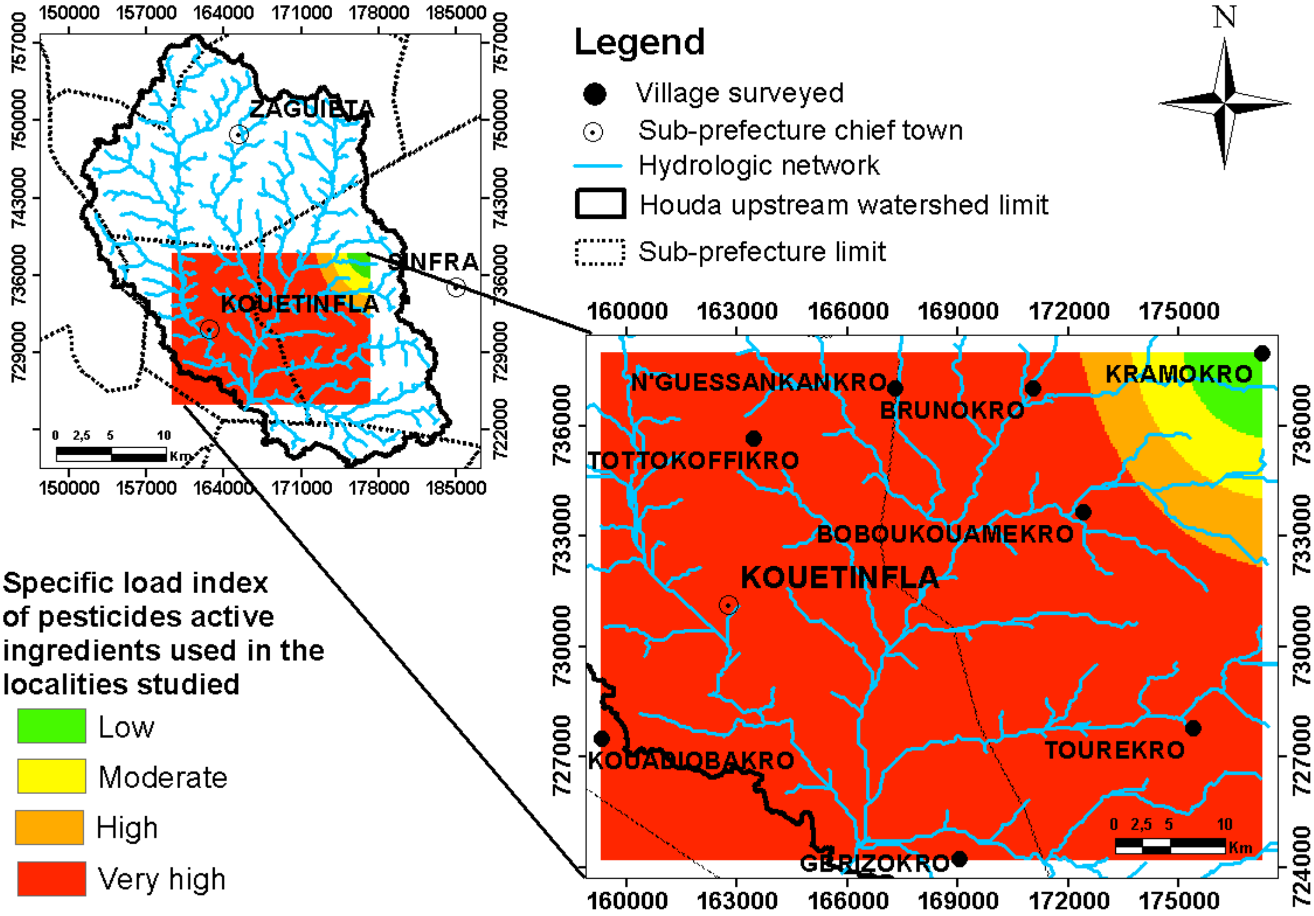

Figure 7. Specific load index map of pesticides active ingredients.

4.1.4.4. Phytosanitary Pressure Index

Figure 8 represents the phytosanitary pressure index which is the consequence of the dangerousness index of the active ingredients, the citation frequency index of the molecule and the load specific index. This one represents the pressure exerted by phytosanitary products on a given area. The results showed that the locality of Kouadiobakro possessed a very high phytosanitary pressure, while those of Boboukouamekro, Gbrizokro and Kramokro were at high pressure. On the other hand, Brunokro and Tourekro localities owned an average phytosanitary pressure, unlike that of Tottokoffikro, which was a low. These results corroborate with those of the indices of use frequency of active ingredients and their dangerousness explained above.

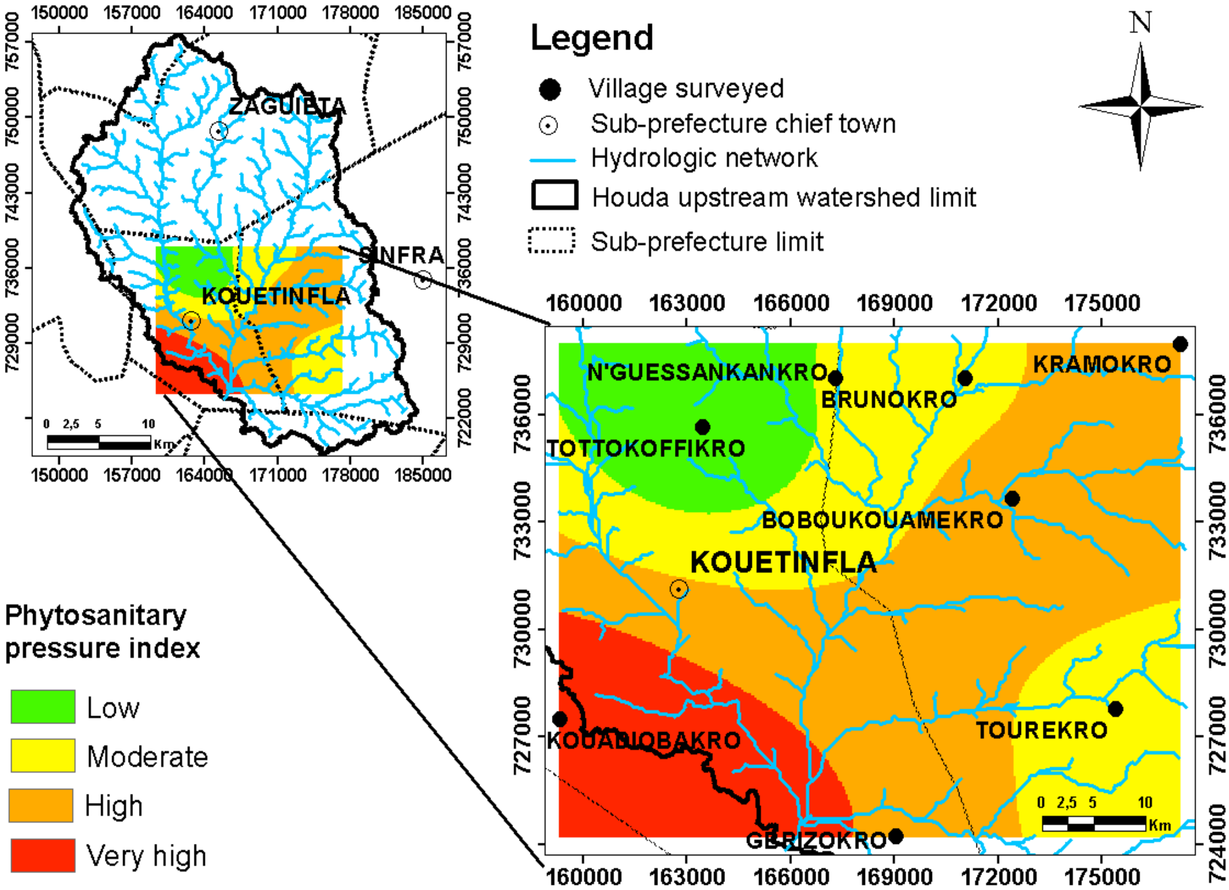

Figure 8. Phytosanitary pressure index map.

4.2. Surface water of Houda upstream watershed diffuse pollution sensibility indicators

4.2.1. Slope and pedology indicators

Figure 9 exhibited the slope indicator map that is generated from the digital terrain model (DTM) and pedology indicator map. The results showed that the steepest slopes of the basin are around the rivers. However, in the villages of Tottokoffikro, Gbrizokro and Kramokro, the weak slopes are observed, while the slopes are very strong in the villages of Boboukouamekro, Brunokro, N'guessankankro and Tourekro (**Figure 9-a**). As shown in the **Figure 9-b**, the whole area that is the subject of this investigation is essentially composed of reworked overlapping soil. This type of soil is characterized by an average sensitivity to the transfer of pesticides into the soil.

4.2.2. Proximity indicator to rivers and rainfall

The maps the proximity indicator of rivers and the rainfall of the study area are shown in **Figure 10**. The localities of Brunokro, Boboukouamekro, N'guessankankro and Tourekro are very close to the rivers and present very high risks. On the other hand, Gbrizokro being close also cause high risks, while Gbrizokro being very distant exhibits a low risk (See **Figure 10-a**). On the other hand, average rainfall was observed whatever the locality, except in Gbrizokro which owned a high rainfall (See **Figure 10-b**).

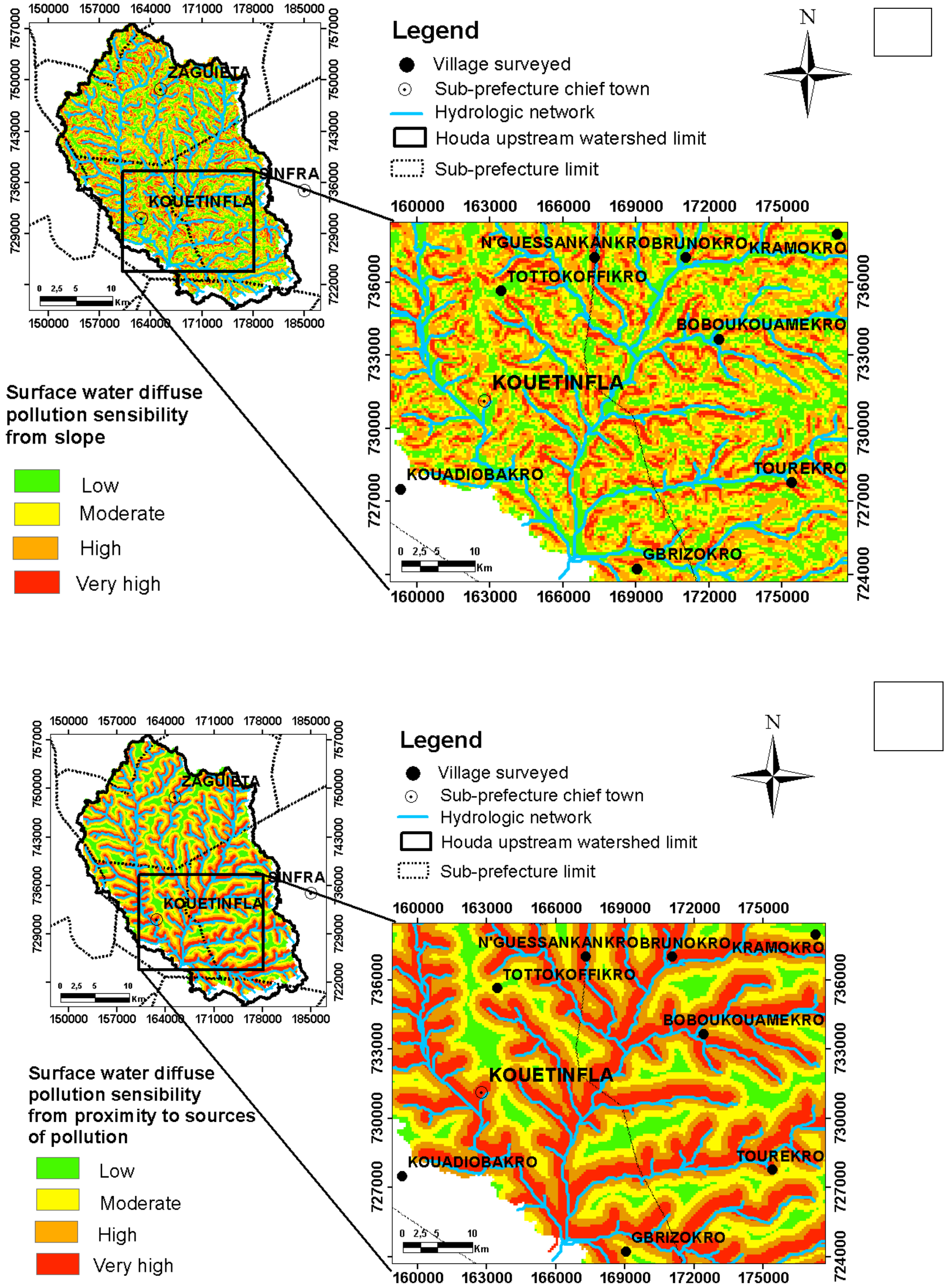

Figure 9. Slope and pedology indicator map: (a): Surface water diffuse pollution sensibility from slope, and (b): from proximity to sources of pollution.

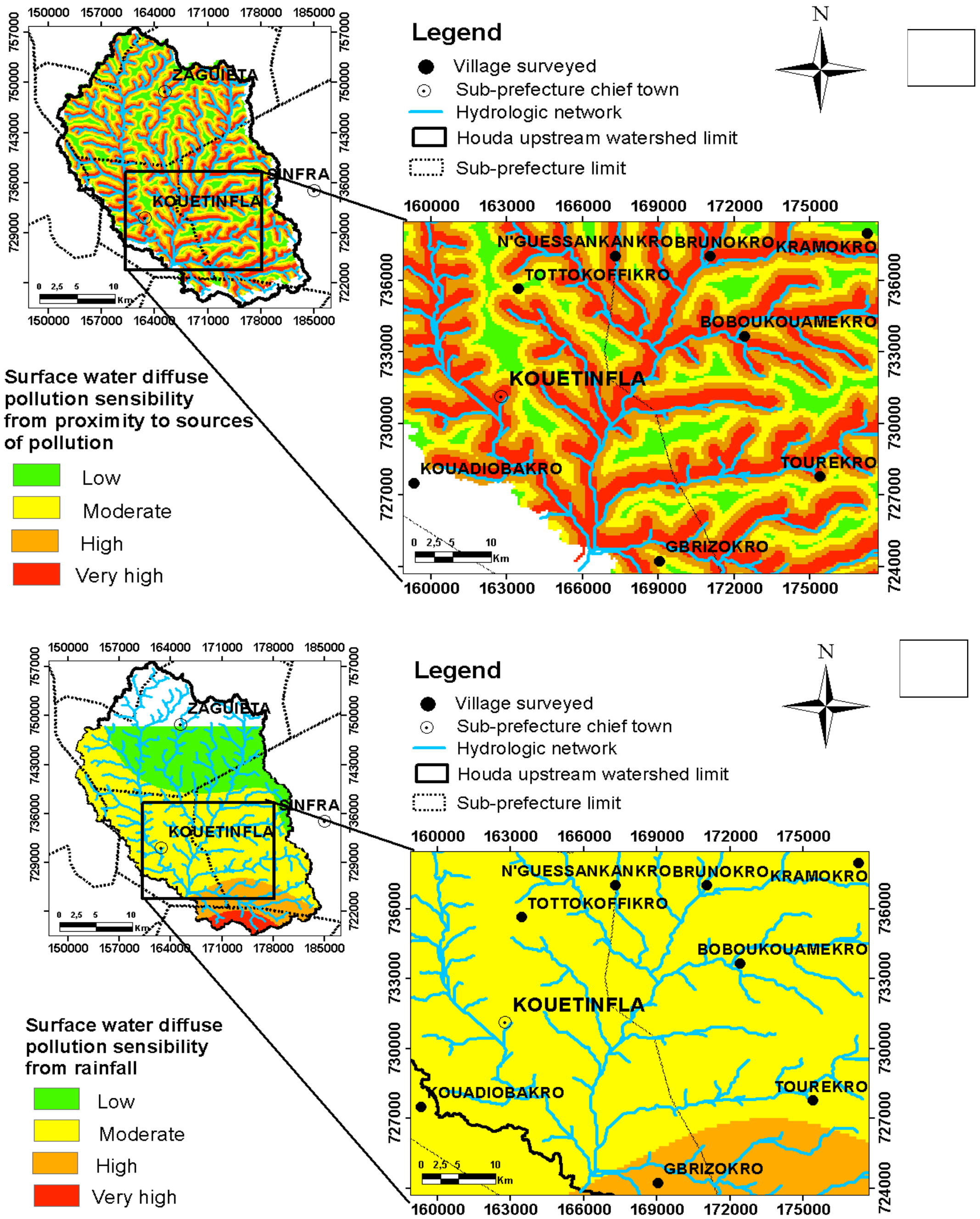

Figure 10. Map of the indicator proximity to water course (a) and rainfall (b).

4.2.3. Land use indicator

The sensitivity map linked to land use resulting from the classification of the Landsat 8 ETM + image of July 27, 2016 is represented by **Figure 11**. This map displays 04 large land use areas with low sensitivities (i.e, rivers), moderate (i.e, Forest), high (i.e, Crops and Fallow land) and very high (Bare soil and Inhabited area). It can be seen that forest and bare or inhabited soils occupy most of the basin's surface.

4.3. Surface water potential diffuse pollution risk

Figure 12 exhibits the map of the potential risk of surface water contamination by pesticides. In fact, the low risk was observed at Tottokoffikro locality, whereas the locality of Tourekro exposed an average risk. Moreover, the localities of N'guessankankro, Brunokro, Boboukouamekro, and

Kramokro shown high risks. Finally, the locality of Kouadiobakro and that of Gbrizokro present a very high risk of surface water contamination.

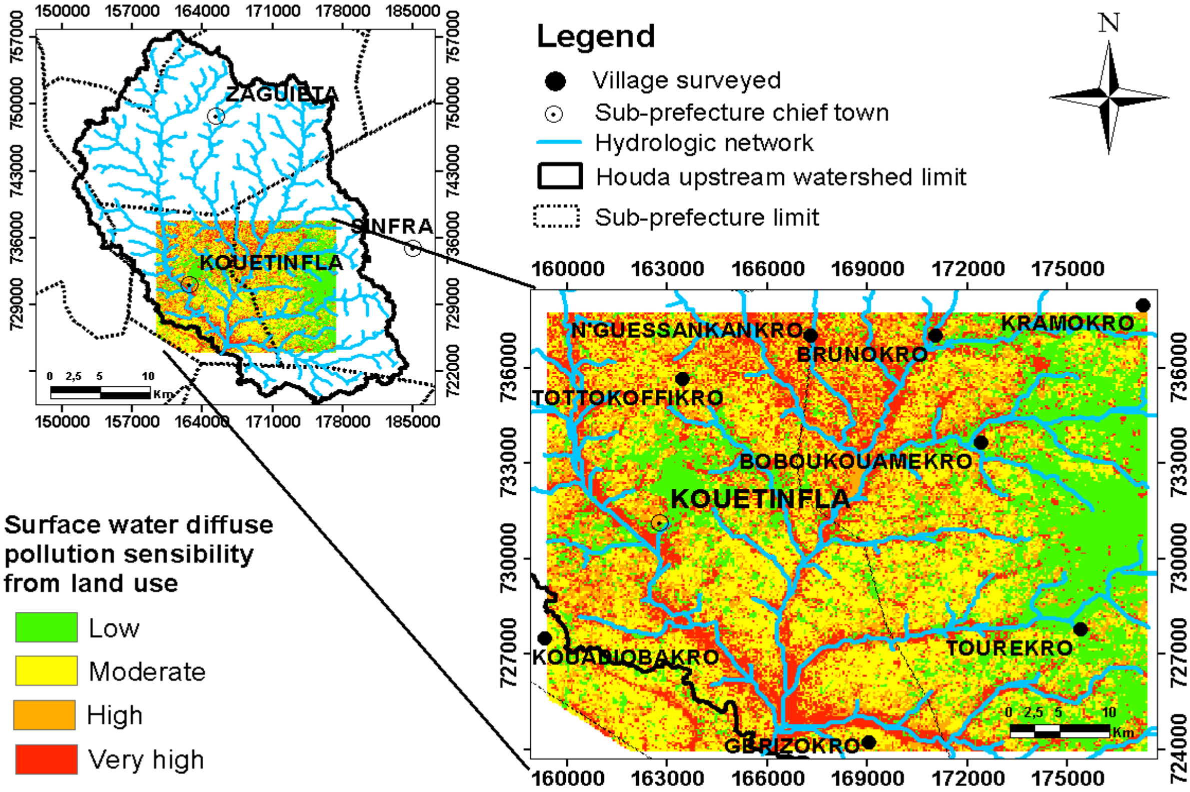

Figure 11. Map of the indicator land use.

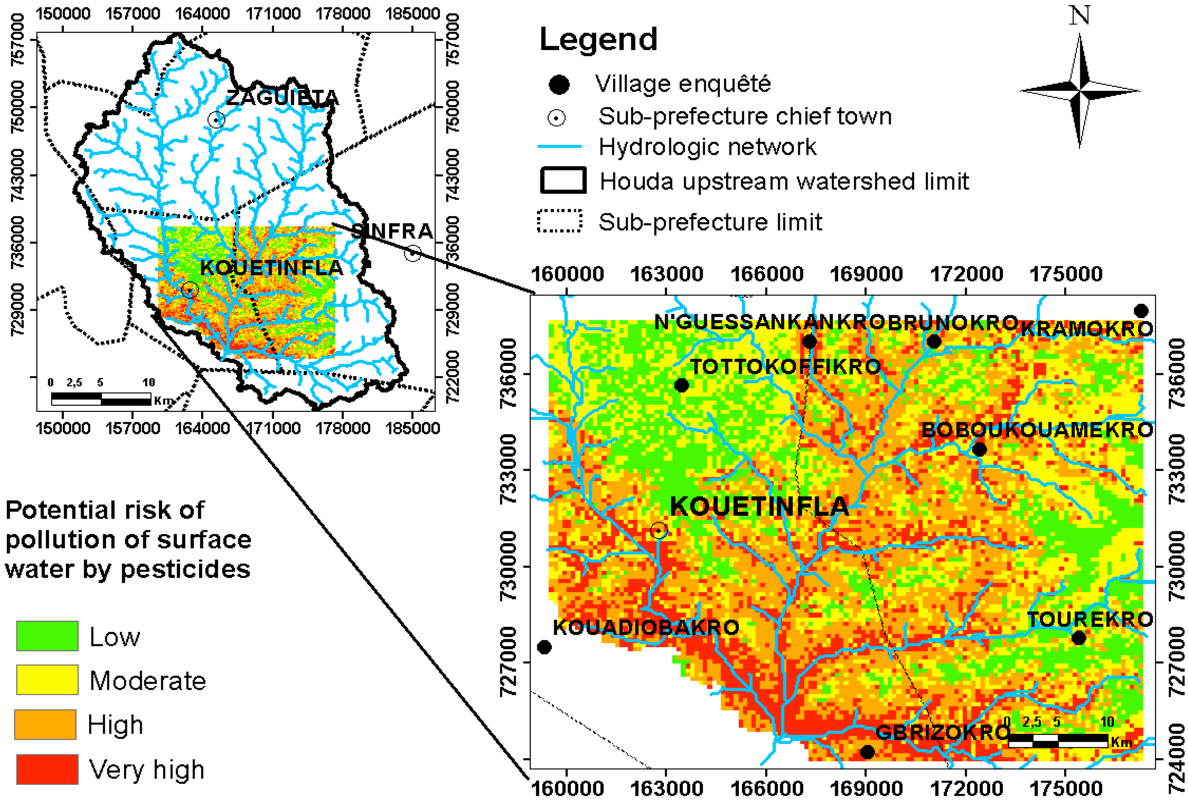

Figure 12. Potential risk map of surface water to pollution from pesticides.

Conclusion

As environmental remediation becomes a global concern, identifying diffuse pollution remains a major challenge. In this study, the active ingredients of the pesticides used in cocoa orchards were identified to characterize the phytosanitary pressure and to map areas at risk of surface water contamination of the Houda basin. Indeed, nineteen (19) active molecules were identified and classified into nine (09) families of pesticides. The active ingredients of the pyrethroid family were the most used (38 %), followed by carbamates (17 %) then neonicotinoids (15 %) contrary to organophosphates (5 %), chloroamines (5 %), benzurulates (5 %), cianniques (5 %), stobilins (5 %) and pyridines (5 %). However, the active ingredients are mostly insecticides, including fungicides and herbicides. It should be noted that the use frequencies and the pesticide dosages are carried out arbitrarily, thereby showing that their use does not respect good agricultural practices. In addition, the methods of storing and managing empty packaging are inadequate. Finally, Spatial modeling from indices (IDma, IFc, IQma, Slope Index, Pedological index, rainfall index, index of proximity to the watercourse) shown that the areas covering Gbrizokro and Kouadiobakro owned a very high potential diffuse pollution risk. In addition, the areas covering the localities of Boboukouamekro, Brunokro, Kramokro, and N'guessankankro had high potential diffuse pollution risk. On the other hand, the localities of Tourekro have an average vulnerability and the locality of Tottokoffikro possessed a low potential diffuse pollution risk.

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