

Demarcation of Surface Water Protection Perimeters by Using GIS: Case of Gagnoa Reservoir in West Central of Côte d'Ivoire

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Abstract-The water retention Gagnoa built on a sub-tributary of the river Sassandra named Guéri. It drains a catchment area of approximately 700 km² with a storage capacity of 2,336,000 m³ of water. This water retention which serves drinking water to the city of Gagnoa and its surroundings is subject to frequent pollution from domestic and agricultural degrading the quality of this resource. Indeed, several source of pollution were identified in the reservoir basin. The latters have led to the damage of resource the quality. Thus, seen its usefulness for the population, it appear important to fit a management tool through protective perimeters. These will allow reducing the risk of pollution, preserve and protect this surface water resource intended for drinking water. The methodological approach employs a spatial analysis model integrating several previously parameters defined such as slope, land use, soil type, drainage density and run off. They will be prioritized and weighted and then integrated into a geographic information system (GIS). Our study allowed delineating three protection zones around the reservoir through the cartography of vulnerabilities areas. Certain activities are regulated or prohibited inside of areas. These areas are defined:

- Zone I or immediate protection perimeter has limited to a radius of 100 m around the reservoir;
- Zone II or close protection perimeter was defined taking into account of water direction and areas influencing strongly on reservoir vulnerability;
- Zone III or distant protection perimeter covers the most part of basin taking account diffuse pollution.

Index Terms- Gagnoa, GIS, multicriteria analysis, pollution, Protection perimeter, vulnerability, water retention



1. INTRODUCTION

General pollution of water, whether punctual, accidental or diffuse is currently a widespread problem involving several actors among which the scientific community, civil society and policy [1]. This pollution is much taken seriously that water resources become scarcer following the years [1]. It is so important that these water resources require a more precise management to minimize the losses and non-productive uses. Such management requires a more detailed knowledge of the resources, their spatial and temporal distribution, their quality and losses, as all anthropogenic activities that can affect their quality [2].

In Côte d'Ivoire, the hydrogeological context is particularly bound to geological ground nature which is composed of 97.5% of the crystalline basement and cristallophyllienne. Thus, according to this fact the major part of its water comes from aquifers base [3]. Nevertheless, the low overall productivity of aquifers and the growing of population favor the use of surface water as an alternative source or main water supply by regions

These waters are often picked up in natural or artificial reservoirs built for this purpose.

The Land use for urban agriculture and industry around the surface water contributes to enhancement of potential for contamination of the latter and in some cases, a real deterioration of their quality. To avoid or minimize these problems of contamination, it is essential to take all measures to ensure the quality of surface water intended for drinking water [4]. The achievement of protection perimeters around these water resources is an important tool to achieve this goal [5].

In fact, in Côte d'Ivoire, to make up for the vulnerability problems of water resources, the establishment of perimeters were taken. But only groundwater, have benefitted of several studies and protection; no surface water has yet gotten protective perimeters. This study is one of the first in this field. The purpose of this study is to determine protection perimeters around surface water resource using GIS to reduce the risk of pollution of this one.

This study is a contribution to better management of surface water intended for consumption.

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2. PRESENTATION OF STUDY AREA

The study area belongs to Gagnoa's region. It is a forest zone which concentrates several populations of different origins. This is a sub-basin of Sassandra great basin. The latter has five main sub-basins that are Daloa, Man, Odienné and Gagnoa. These sub-basins include several reservoirs such, the reservoir of Gagnoa's city exploited by SODECI (Water Distribution Company of Côte d'Ivoire) [6]. Gagnoa basin is located between longitudes 5°56 and 6°1 W and latitudes 6°6 and 6°12 N and occupies an area of approximately 700 km² (Fig. 1).

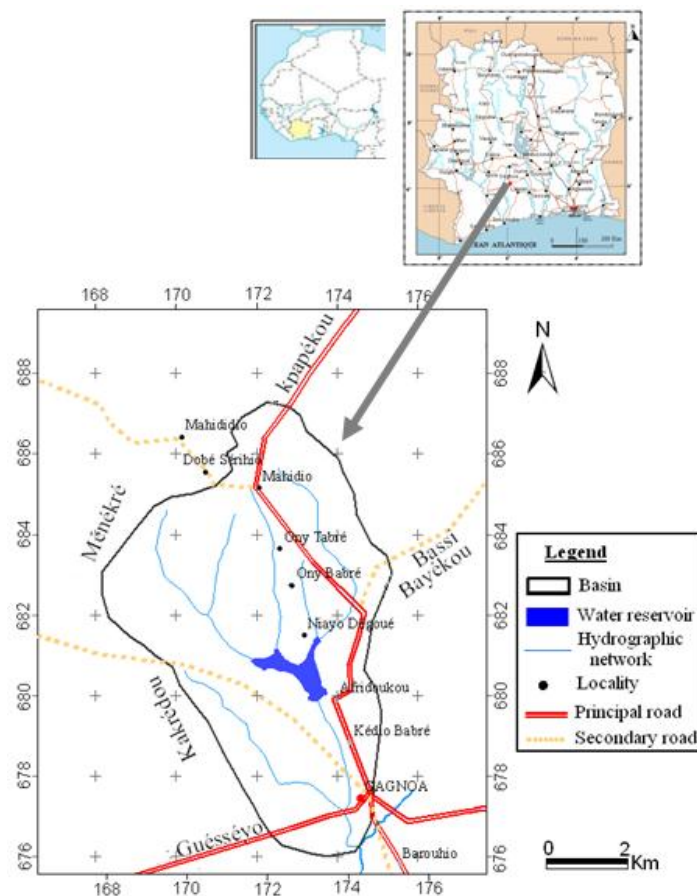


Fig.1. Location of study zone

Water retention of this study has been created after a dam building on the Guéri which is a sub-tributary of Sassandra River. This reservoir has a water storage capacity of approximately 2.336000 m³ and enables the drinking water supply of population. However, it is subject to much pollution related to human activities that are developed in its surrounding.

On the lithological plan, geological formations of the Gagnoa region belong to the domain of Proterozoic, regrouping two types of rock formations: Eburnean formations and Eburnean post-formations. These are

formed by plutonic formations, the base granite-gneissic, volcanic complex or volcano-sedimentary and complex flyschoid [7]. At the study area scale, two type of rock are identified: métagranodiorites biotite and, or hornblende and métagranites biotite and dominant muscovite [8]. The high alteration of these formations provides important alterite thickness of reddish color that show both sides, horizons leached with fine ferruginous gravel and horizons with abundant kaolinite and spotted. On the hydrological and hydrogeological plan, this area is well watered and drained by several rivers fed-batch or continuous depending on the season. Found there as in all areas of the base, three types of reservoirs formed reservoirs alterites often very low permeability, cracks and a reservoir in the rock traversed by large tectonic fractures[9].

3. METHODOLOGICAL

3.1. Principle of protection perimeters running

Protection areas generally aimed at strengthening the protection of the resource for consumption. In fact, the pollution of water resources decreases as one moves away [5].

In Côte d'Ivoire, according to Article 38 of the water Code Law n°98-755 of 23th December 1998, the scope of protection as a public healthiness measure is mandatory. There are three types: the immediate scope of protection (zone I), the close protection perimeter (zone II) and the scope of protection away (zone III).

In zone I, it is question of prohibiting access to the sampling point and treatment facilities, and to protect them vis-à-vis acts of malice. According to Garouani and Merzouk [5], the size of this area should allow intervening properly in case of accidents, removing each human influence and implementing a vegetation zone oriented protective.

Zone II, is intended to maintain the quality of water at the approach to the outlet. The longitudinal extension of the perimeter must also provide a response time for the operator in case of accidental pollution and its lateral extension should help reduce runoff and reduce or eliminate the risk of pollution from these activities on slopes of the basin of the lake [10].

Finally, zone III is a possible extension of zone II. It must ensure the protection of waters against extensive damage, especially pollution or persistent and difficult to remove chemical or radioactive pollution [11].

3.2. Approach

This work, the territorial unit used is the watershed. Therefore, only the factors identified in this scale will be used for the determination of protection zones.

The approach is based on the assessment of vulnerability to pollution of the resource. In fact, all factors that can contribute to the evaluations of vulnerability to pollution are identified. These factors are then selected hierarchical, weighted according to their importance in the process of

delineation of protection zones and then integrated into a GIS. According to Garouani and al.[12], there exists in the literature, a variety of methods for delineating protection perimeters, however, the most relevant are those that allow the integration of topographic, geological and hydrological. However, these factors are selected based on their availability and the limits of capacity and performance of the method.

3.2.1. Choice of parameters or factors

In this study, the work of [5], on the dam Hachef Morocco and those made by [13], have served as a guide in the choice of data. Depending on the availability of data, five (05) parameters were selected: the land, the slope of the surface topography, drainage density, soil type and runoff.

Slope of the surface topography (P)

Surface slope is one of the most important parameters in determining the perimeters of protection (PDP) because it influences the vulnerability of water resources of surface inclination. More its inclination increases, its steep slopes over the ability of the flow is high and the risk of pollution of surface water increases. But if the inclination decreases (lower slopes), we will see a dominance of infiltration. The slope map was made from a Digital Elevation Model (DEM) curves generated from topographic study area (Fig. 2).

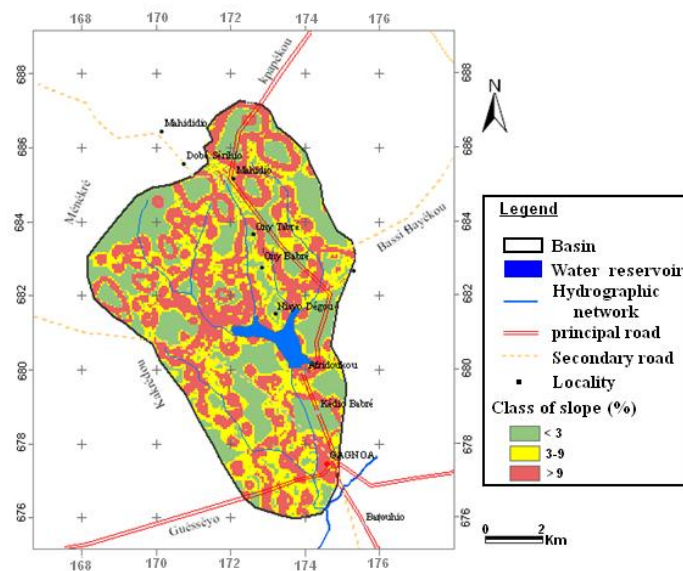


Fig.2. Slope Map of study area

Land use (OS)

Chery [14], defined land use as the cover of the biophysical land surface. Its importance in this study is that it has the most activities in the area studied. Activities that alter the vegetation of the area are urbanization, roads and crops using fertilizers or not. This modification of the natural process of functioning ecosystem, increases water pollution.

Also, the situation may be aggravated when it is poor drainage of domestic sewage or industrial highly urbanized [10]. In addition, an area with well cover slows or prevents soil erosion. This coverage is therefore a natural protection against pollution to surface waters.

This map is derived from the image processing Landsat ETM+ in 2003 (Fig. 3). After processing and obtaining the land use map of ENVI4.5, it was transferred to 9.3 for ArcGis to be rasterized in order to make it usable in the GIS.

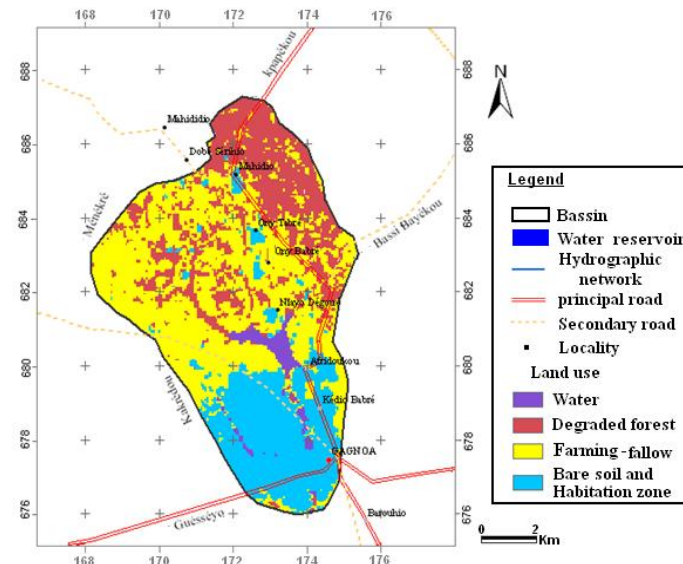


Fig.3. Land use Map study area

Soil type(S)

The soil is another parameter in the process of pollution of surface water. It plays a significant role in the passage of water and consequently in time transfer of pollutants from the soil surface to water [15]. Indeed, the vulnerability of the means transfer of pesticide to water depends on the characteristics of the soil that is the receiver of these products. Also, the characteristics of the soil determine the partition of rainwater between infiltration and runoff by taking into account the slope.

The study area has only a pedologic unit (Fig. 4), that is revised ferralitic soil more or less denatured [16].

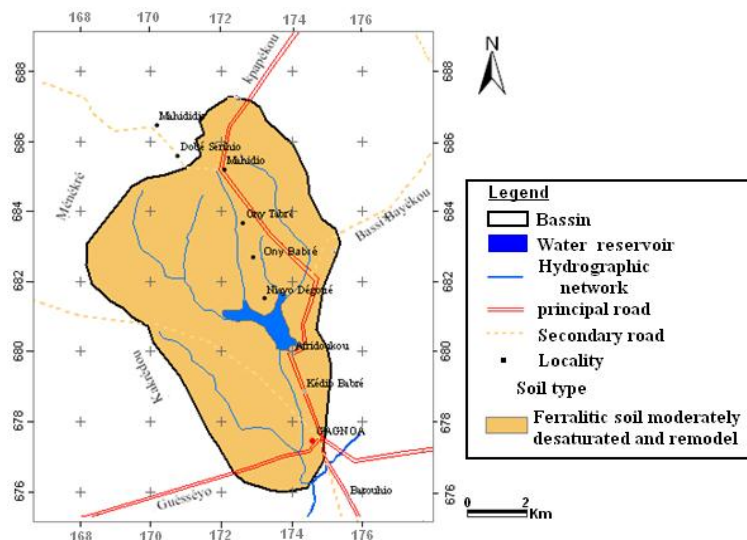


Fig.4. Soil map of study area

Drainage Density (DD)

Pollution of surface water (lakes, dams, rivers etc..) is related to the density of the river network that underlies these resources. Indeed, the river network collects all the drainage water from the same pond with the possibility of contamination by pollutants to convey to the outlet built sometimes as in this restraint case. More by the hydrographic network management unit is dense, vulnerability to pollution of the resource is high [13].

It is this parameter to evaluate the drainage density of the basin drainage. Density map drainage area has been derived from a map of the drainage treated Linwin software which measures the number density drain gridded (Fig. 5). It was then rasterized through software Arcgis 9.3.

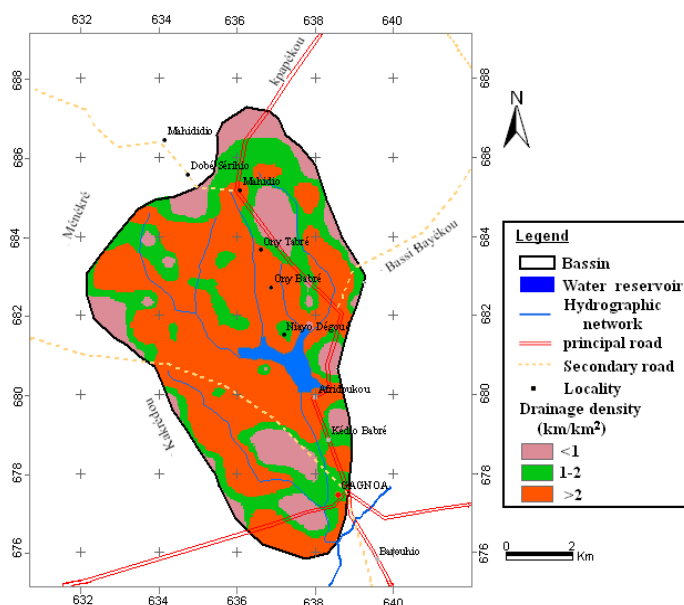


Fig.5. Drainage density Map of study area

Runoff (rainfall) (R)

Rainfall is also a key parameter in the process of assessing vulnerability to pollution of surface water. Indeed, the intensity of rainfall influences the runoff water fraction fell [13]. For these authors, the duration and the amount of rainfall determine the onset of runoff when the soil has reached the maximum infiltration capacity.

Runoff is a senior transfer of pollutants to surface waters [17]. More runoff in large quantity, the risk of contamination sources is high. The study area with only one hydrométéoric station, runoff was obtained by applying the runoff coefficient of the area to the average annual rainfall. A value of runoff 171.028 mm is obtained, a side of 3 is assigned to the entire study area.

Table I summarizes the different parameters and their classes, and the various ratings assigned to these classes. Indeed, the different classes and grades assigned to them were determined by referring to the work of [13] one hand, on the assessment of the vulnerability of surface waters and on the other hand on the author's appreciation of this study. However, the parameter "Rain efficient" used by these authors was replaced by the by the runoff in this study according to our assessment of the parameters used.

Table I: Parameters, classes and ratings of the various parameters

Parameters	Class	Notes
Slope (%)	<3	1
	3-9	2
	>9	3
Land use	Water	0
	Degraded forests	1
	Farming-fallow	2
	Bare Sol – habitation zone	3
Rainfall	Runoff >0	3
Soil type	Ferrallitic soil	3
Drainage density (Km / Km ²)	<1	1
	1-2	2
	>2	3

3.2.2. Prioritization and weighting parameters

3.2.2.1. Prioritization and development of the square matrix

In this study, the method developed by [18], used by [19] and [20] has been exploited. It is a method of pear wise comparison by the Analytic Hierarchy Process (Analytical Hierarchy Process: AHP). This is to compare the relative importance of all the parameters used taken in pairs to set up a reciprocal square matrix. This comparison is based on a numerical scale of 9 steps [18], pair wise comparisons. When two parameters have the same importance in the studied phenomenon, the scale of Saaty gives these two parameters the value "1". However, if a parameter is more

important than the other then it takes a higher value between 1 and 10 and the other the inverse of this value. This method allows the production of standardized weights whose sum is equal to "1". Matrix resulting from the pair wise comparison of parameters summarized in table II.

Table II: Matrix after comparing various parameters (original matrix)

	P	O.S	R	S	D.D
P	1	2	4	5	5
O.S	1/2	1	3	4	5
R	1/3	1/3	1	3	4
S	1/4	1/4	1/3	2	2
D.D	1/5	1/5	1/4	1/2	1
$\sum a_i$	2.28	3.78	7.58	12.5	17

This square matrix after prioritization will allow for combinations for determination of weight. The letters are an abbreviation used different parameters (each parameter above), with the sum $\sum a_i$ parameters by column.

3.2.2.2. Determination of different weights

The weight of an element expresses the size there of relative to one another [18]. It corresponds to the intensity of its impact on the study of the vulnerability of water resources. Determination of these weight amounts to calculating the weighting coefficient for each item. This coefficient is calculated from the following formula:

$$C_p = V_p / \sum V_p \tag{1}$$

V_p is the proper vector of each compared element. It is calculated as following:

$$V_p = \sqrt[k]{w_1 X \dots \dots \dots X w_k} \tag{2}$$

Before the determination of different weights, it is verified that the base matrix prepared (table II) is coherent. We will calculate the ratio of coherence (RC) which serves as a reference for judging the consistency of the matrix. Logical coherence or consistency ratio (CR), compared to 10% can judge the consistency of the matrix [18]. It is calculated as the ratio of the consistency index (CI) and the Random Index (AI). The formula is as follows:

$$RC = CI / AI \tag{3}$$

$$CI = \frac{\lambda_{max} - \text{Nombre d'éléments comparés}}{\text{Nombre d'éléments comparés} - 1} \tag{4}$$

CI is the consistency index, AI Index random and λ_{max} the maximum Eigen value.

-if $RC \leq 10$, then the matrix is called coherent

-if $RC > 10\%$ then the matrix is inconsistent and should be revise Le calculating λ_{max} will be explained below. In addition, the indexes values are random data based on the number of parameters compared and are shown in Table III. In this work, the number of parameters is 5, as a result, the Index random used is 1.12 (Table III).

Table III: Random indices bases on the number of elements compared [18]

Number of elements compared	2	3	4	5	6	7	8	9	10
IA	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

These steps are used to determine the weighting of the various parameters:

-Normalize the matrix by dividing each element in a column (I) by the sum of this column ($\sum a_i$). We obtain the new values normalized matrix denoted by [bi]:

$$[b_i] = \frac{a_i}{\sum a_i} \tag{5}$$

The sum of [bi] is denoted by line: [Bi].

-Identify priorities line is to calculate the average of each row: [Mi]

$$[M_i] = \frac{[B_i]}{k} \tag{6}$$

- Multiply each value (I) of the original matrix by its corresponding priority vector to determine the overall priority line [Gi]:

$$[G_i] = \sum [M_i] \times [a_i] \tag{7}$$

-Report to the global priority of each priority for each line. The values obtained are denoted E_i :

$$E_i = \frac{G_i}{M_i} \tag{8}$$

- Determine the maximum Eigen value of the elements being compared (λ_{max})

$$\lambda_{max} = \frac{\sum E_i}{k} \tag{9}$$

- Calculating the coherence index(IC):

$$IC = \frac{\lambda_{max} - k}{k - 1} \tag{10}$$

- Determination to Ratio of Coherence (RC) :

$$RC = \frac{IC}{IA} \tag{11}$$

Table IV summarizes the results obtained in the subsequent calculations. The ratio of coherence is obtained lower than 10% ($Rc = 4.46\%$).Therefore judgments awarded are good

Table IV: containing the results of various calculations above

	P	OS	R	S	DD	B _i	M _i	G _i	E _i	λ _{max}	IC	RC	V _p	C _p
P	0.44	0.52	0.39	0.32	0.3	1.98	0.4	2.11	5.32				2.60	0.4
OS	0.22	0.27	0.39	0.32	0.3	1.7	0.29	1.6	3.38				1.97	0.3
R	0.15	0.09	0.14	0.24	0.23	0.84	0.17	0.86	3.16	5.20	0.05	0.0446	1.06	0.16
S	0.11	0.07	0.04	0.08	0.12	0.41	0.08	0.43	5.05				0.33	0.08
DD	0.08	0.05	0.04	0.04	0.05	0.27	0.06	0.27	5.08				0.35	0.06
Σ	1	1	1	1	1	5	1	5.27	25.9				6.51	1

3.2.3. Using GIS for delineating protection perimeters

Following the hierarchy leading to intra-criterion weighting and allocation to different classes of notes determined, different parameters were incorporated into a GIS to derive the different scopes of protection. The method chosen for the layering approach, is the operational unique synthesis criterion of Roy [21], cited by [5]. It consists of adding the different layers of different parameters. The addition of layers is done through the software ArcGis 9.3. Fig.6 reflects the conceptual data model that allows the determination in the first instance vulnerability areas whose boundary intervals were fixed are based on the work of [22], and then the protection perimeters of retaining Gagnoa.

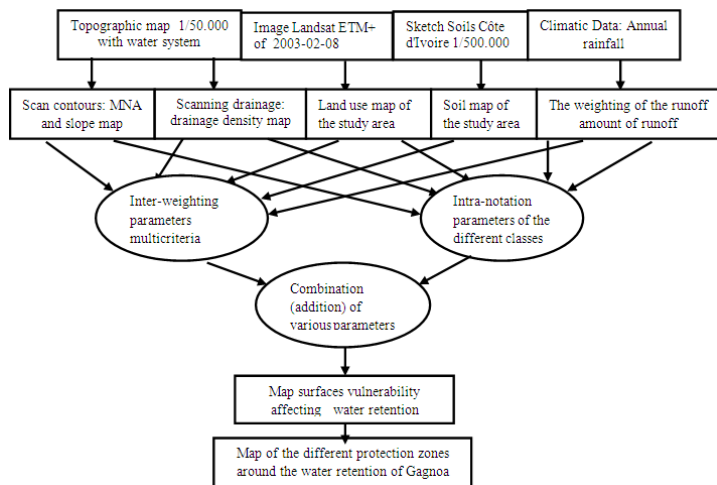


Fig 6: Flow diagram for the preparation of the map perimeter protection

4. RESULTS

The first result is a map of vulnerability to pollution in the reservoir. This map shows 5 classes of vulnerability ranging from "very low" to "very high" and include the values of the following indices:

- Index < 1.64: vulnerability "Very low";
- 1.64 < Index < 2.00: vulnerability "Low";
- 2.00 < Index < 2.30: vulnerability "Medium";
- 2.30 < Index < 2.70: vulnerability "high";
- Index > 2.70: vulnerability "Very High".

The figure 7 shows the result of this classification map.

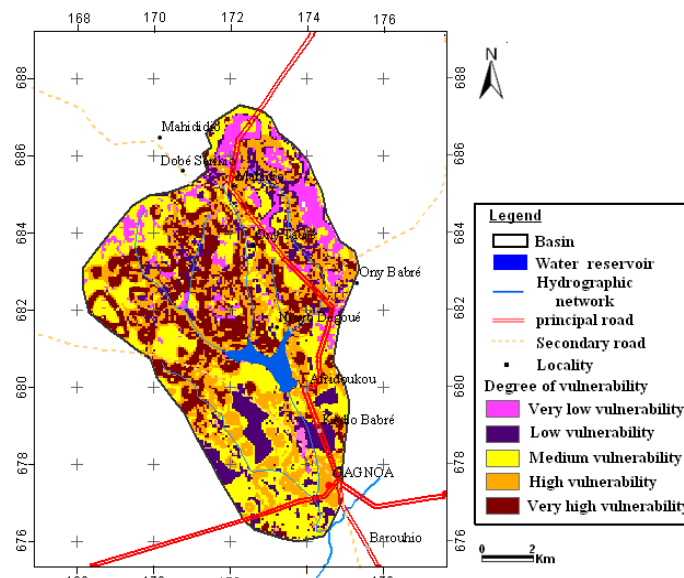


Fig.7. Vulnerability Map of Gagnoa's retention water

This map shows the levels of vulnerability to pollution of the water reservoir supply of the city of Gagnoa and its surroundings.

- Class "Very low" characterized by very low slopes and cultivated sun forest. Runoff in these areas to the reservoir is negligible;
- Class "Low" represented by areas mostly inhabited but where the same degraded forest is still present;
- Class "Medium" takes into account the areas inhabited, cultivated, slope more or less low and moderately low drainage density;
- Classes "Strong and Very Strong" cover the area around the reservoir surfaces especially upstream. These surfaces act strongly on the vulnerability of retention correspond to areas of steep, so a high activity of runoff. The forest is virtually nonexistent. These are areas with high agricultural activities sometimes using fertilizers for soil amendment or used directly on crops.

These different classes of vulnerability retention obtained as a result of the pollution of the little basin of Gagnoa are the combination of several natural parameters but also anthropogenic (dumps, agricultural practices, drainage water does not comply worn etc.). Taking into account these different classes of vulnerability, map different protection zones shown in fig. 8 was made. It has identified three areas of protection. Protection zone I, protection zone II and protection zone III.

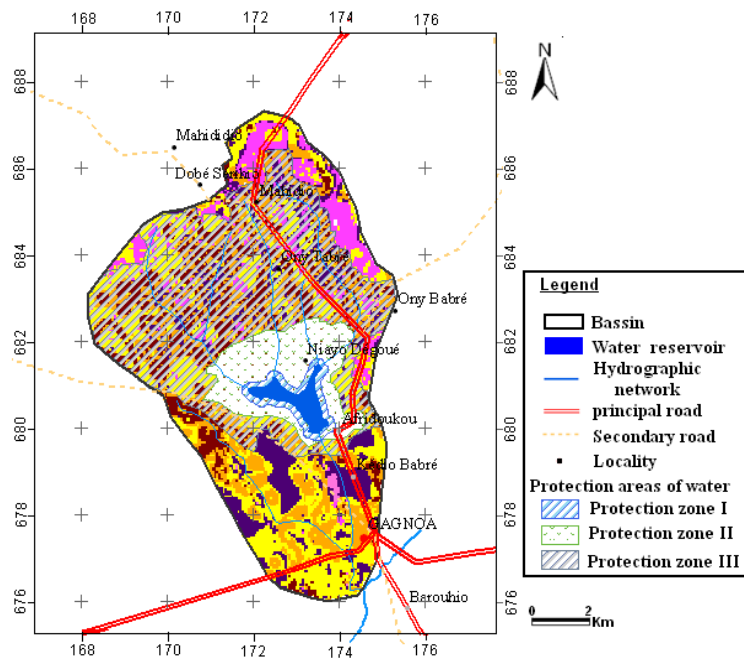


Fig.8. Protection zone of Gagnoa's retention water

Protection zone I or immediate perimeter protection (IPP)

It was limited to a radius of 100 m around the reservoir, because the surface of the reservoir is a small radius that can enable effective intervention. In addition, this area takes into account the immediate area of the reservoir which has a great influence on the vulnerability of restraint and should allow effective protection against pollution retaining said point.

This value has been advocated by several authors including [5]. And according [10], the size of this area should allow intervene properly in case of accidents related to the pollution of the reservoir.

Zone II protection or close protection perimeter (PPR)

Also called buffer zone, it has been defined by taking into account first the direction of flow of water in the basin and areas with very strong influence on the vulnerability of retention. Its size is limited to a distance of 1 Km maximum to the retention. At this distance, it is possible that dissolved pollution facing the retention can be caught or trapped in the favor of the presence of suitable vegetation. Garouani and Merzouk [19], rely more on the degree of slope to give the limits of this zone. However, they are not going beyond 1 Km. According to them, the zone II is bounded on lands bordering with a slope greater than 3 degrees, but the extent of this band does not exceed one kilometer wide. This opinion is also shared by [23]. These authors advocate an area between 100 m and 1km. This area was obtained by superimposing a surface of 1Km of radius with strong influences vulnerability on the retention.

Protection zone III or perimeter protection remote(PPE)

Some authors [23], it corresponds to a complementary regional zone. In this case, it covers substantially the entire surface of the tank located upstream of the reservoir. These surfaces have an impact on the vulnerability of retention. On the vulnerability map they correspond to areas of medium vulnerability to strong, although far from retention. These are mainly inhabited areas, where large plantations of coffee, cocoa, and rubber. That is why this area can be extended to the whole basin.

After delineation of protection zones, easements are formulated for each area for the regulation of different activities. These schemes have a role to participate in the preservation of the quality of the resource and in turn the health of populations.

Although different protection zones have been established at the end of this study, it is however to identify some difficulties. The subjectivity of weight and assigned to coastal settings in the application of multicriteria analysis is a limiting parameter. Similarly, the values of the parameters sometimes tend to overestimate or underestimate the degree of vulnerability of retention. This step can sometimes be made difficult when the knowledge is reduced and the subjectivity that implies. Also, the use of GIS for the determination of protection zones of surface water although apparently easier and less expensive, is more or less a theme that requires new knowledge in the field of GIS. However, the results obtained correspond to the reality on the ground. Garouani and Abdelaziz [5] used the same method to delineate protection zones around the dam Hachef Morocco and in fact led to the same conclusion. Therefore, the protection areas established are reliable and can be used for planning.

CONCLUSION

At the end of this work, the main objective is the delineation of protection zones around water retention Gagnoa whose quality is constantly tested by the various potential sources of pollution has been achieved. These schemes were established after assessing the vulnerability of the retention through the completion of a vulnerability map. Indeed, the method used is the coupling of multicriteria analysis which allowed the assignment of weights and coastlines parameters and GIS allowing their superposition. The resulting vulnerability map shows 5 classes of vulnerability: classes "very low", "low", "medium", "high" and "very high". The last two are the most represented on the map and correspond mainly to areas of high cultural activity. The map has three protected areas zones around the reservoir. It is the perimeter of immediate protection, close perimeter protection (PPR) and the scope of protection (PPE). Easements are available in all of these areas and proper compliance with these requirements will restore the quality of surface water resources. This study is therefore encouraging in the context of the use of GIS for

the management of water resources in general and in particular the protection of surface water intended for drinking water supply.

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