Conception of a Geodatabase for the Monitoring of Groundwater Quality in Watershed of Ehania, Southeast of Côte d'Ivoire

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Abstract

In the watershed of Ehania, we are seeing an increase of the industries in the agricultural field. Therefore, agriculture has increased and even modernized with a high use of fertilizers, accompanied by a growth of households. The characteristic of this watershed will not remain without negative impacts on water resources and the environment. For this purpose, these negative aspects could therefore have an effect on the health of people in the long run. It therefore appears necessary to set up a monitoring system of groundwater based on geodatabase model. The aim of this study is to develop a decision support tool for monitoring and evaluating the risks of underground water pollution of this agro-industrial region. The tool developed in this study revolves around links database-GIS. It has been of great benefit to this community and is a starting point for the development of effective management tools. The result of this work is an interface that facilitates the entry and the implementation of the tables as well as querying the database for a better management of information relevant to decision making. Statistical analyzes revealed very high levels of certain pollutants. Risk zones are observed in the north and in the southwestern part of this region. This information system provides managers the tools for analysis and decision support for monitoring of agro industrial activities in the region.

Keywords: Data modeling, GIS, agro industrial plantations, groundwater quality, Ehania

1. Introduction

Water resources occupy a prominent place in the development of various sectors of the economy of a country (Mehanned et al, 2014). The degradation of the natural environment, including the aquifer has gradually become a global concern (Abdelbaki and Boukli Hacene, 2007). In Côte d'Ivoire, the main source of satisfaction of the demand for water remains underground water for safety reasons. The high population growth and modernization of agriculture cause a big problem of deterioration of the quality of this resource. Several studies have identified the impact of industrial exploitations on water resources in general and particularly on groundwater (Dibi et al, 2007; Bouqdaoui El et al, 2009; Kouamé et al, 2012). Also, problems of water qualities primarily related to health risks in the long-term need to be considered essential for populations (Kolokytha et al, 2002; Youmbi et al, 2013). This concern is currently a priority for development actors that require sustainable management of water resources. At the watershed Ehania, intensification of agriculture, coupled with a greater use of water resources, could be the cause of the deterioration of some quality parameters of groundwater (Doumouya et al, 2012).

Studies conducted in the region by Dibi et al (2007; 2013) were limited to the assessment of vulnerability to pollution that identifies risk areas and sometimes potential sources of pollution of the earth. The mechanism of groundwater pollution is an evolutionary process in space and time, so hardly controllable. Thus, to understand these problems, identify risk areas and find appropriate solutions for sustainable resource management, monitoring and oversight of the quality of soil and groundwater are found necessary. Geographic information systems (GIS) can perform spatial analysis in order to have summary maps to identify the groundwater quality in the area of digital support to assist in decision making. The interest in having a geographic information system is its flexibility in modeling of space objects to meet specific requirements of users. The aim of this study is to develop a decision support tool for monitoring and evaluating the risks of underground water pollution of this agro-industrial region. Given the spatial data, the approach is based on a geodatabase that will then offer the ability to quickly extract the necessary information and the respondent's clearly defined goals (Barazzuoli et al, 1999).

2. Materials and Methods

2.1. Study Area

The study area selected for this research project (Figure 1) is located in south-eastern Côte d'Ivoire, precisely in the region of South-Comoé. It is located between Western longitudes 2°45′W and 3°05′W and Northern latitudes 5°10′N and 5°45′N. It covers about 342 km^2. The area is in the tropical climate characterized by four seasons with two dry (large and small) and two wet (large and small). The geological formations are varied from shale in the northern part to the sedimentary formations in the South. These different types of geological formations indicate the existence of different aquifers that are aquifers in sedimentary formations (Quaternary and Tertiary), weather aquifers and fractured. Concerning topographic, relief is very rugged with elevations generally ranging from 100 to 200 m up to 400 m. The hydrographic network which is an indicator of recharge is very dense in the north and less dense in the South where we have sedimentary formations. Soils consist of reworked soil and sometimes indurated throughout with some portions of hydromorphic soil and gley pseudogley especially along the river Ehania.

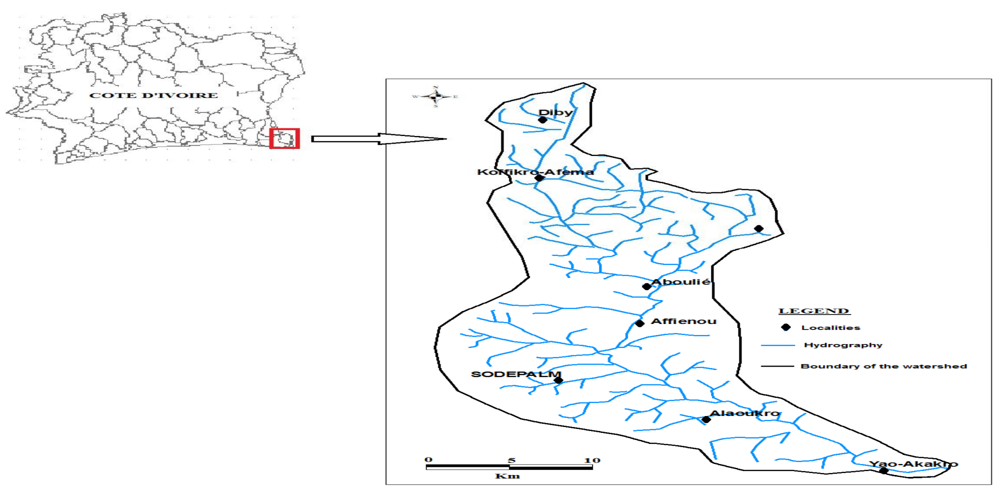

Figure 1: Study Area

2.2. Data

The design of the GIS required the use of a topographic map at 1/200 000, provided by the Centre of Cartography and Remote Sensing (CCRS) of Abidjan and a Landsat TM satellite image acquired in 2000. Descriptive data concerning physico-chemical parameters collected during a mission to collect water samples conducted at 32 sites during the year 2013. They are split over the entire watershed and were stored at 5 ° C in a cool box for analysis in the laboratory of the Centre for Oceanographic Research (COR). Others attribute data such as GPS coordinates of boreholes and wells, statistical data were also added.

2.3. Design of the Geodatabase

GIS developed during this study focuses on a databases management system (DBMS) with semantic data and GIS software including graphical data (Figure 2).

Semantic data in the DBMS can be classified into two categories: those relating to the management and monitoring of projects on the one hand and those who are described as useful to be spatialized on other hand. They are actually all potentially spatialisables, but only the second category contains useful information for the development of thematic maps. These attribute data are related to the graphic data through the geodatabase. The methodology adopted for the development of DBMS is inspired by relational database method. From this work, a prototype DBMS has been developed and tested, allowing adapting and changing. Geodatabases have the functionality of relational databases while integrating spatial data (Courtney, 2005; Wojda et al, 2010; Sami et al, 2013). They thus offer the possibility of treating both spatial and descriptive information in a single application. The success of the geodatabase necessarily involves data modeling.

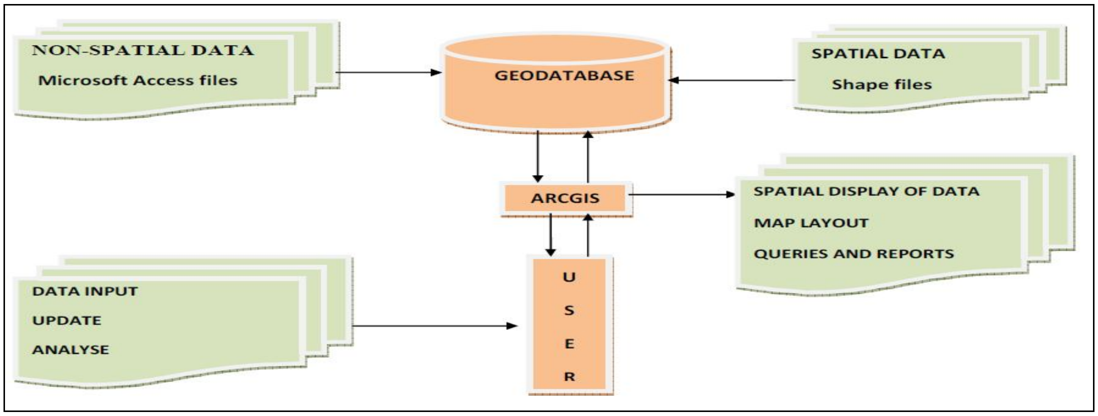

Figure 2: Conceptual Design of the Information System

2.3.1 Data Modeling

Modeling is an essential prerequisite in the context of a development or the study of computer applications. This is true with geographic databases which are also organized and structured. A model is a representation of reality used to simulate a process, predict an outcome or analyze a problem.

Conceptual Model

The Conceptual Data Model (CDM) has defined geometry, attributes and logical relationships (spatial and temporal) between the objects studied. Thus, the entities have been determined taking into account the contents of the geodatabase that can distinguish objects in the real world as entities having two types of attributes: alphanumeric attributes and graphical attributes. The conceptual model has been designed according to the Entity-Relationship formalism. A first approach to the work has an inventory of existing data being acquired and available on each region of the country. Only relevant and existing data to develop a database management system (DBMS) on the topic concerned but likely to be collected were retained.

Logical Model

The logical data model (LDM) organizes data in tables, while allowing keeping existing relationships. The most common logical structures are hierarchical models, networks, relational and in recent years, the object-oriented model. Among the four basic logic models listed above, the relational was chosen as the most appropriate for the purposes of the geodatabase (Kaimaris et al, 2011). The table "borehole" is the central element of the database management system which are associated useful data to the management and monitoring of the boreholes.

Development of a Prototype

The final step in the design of the database is integration of tables in a Relational Database Management System (RDBMS). So, after defining the overall system using modeling, a prototype is proposed. This is an exploratory system involving a limited set of analysis functions. Using a prototype is an efficient way which helped to clarify concepts, test and make strategic choices. The prototype was crucial to see the possibilities and limitations of the model and the selected software. It implements various usage scenarios of the information system. The prototype has been built on the Microsoft Access software. It is a tool easy to handle, which forms allow a quick and clear data entry. Data retrieval is also a focal point for users.

2.3.2 Integration of Spatial Data

Geographic information is composed of geometric, topological and descriptive information. Its integration goes through georeferencing and digitization. In this sense, we used ArcGIS environment to implement a spatial database by georeferencing, digitizing, and the development of a number of layers of information from topographic maps and boreholes data. Indeed, for the creation of the reference and maps, the corresponding topographic map were digitized, projected, transformed and corrected. For purpose of this study, the projection used is the WGS 84 system, zone 29N. It ensures the compatibility of the geodatabase with other data that can be added. Four layers were digitized: the localities, the limit of study area, the drainage network, and the layer of the sample points. The analysis data about the quality of waters were stored in the geodatabase that is constructed for the study area. It is processing these informations allowing understanding the structure and functional relationships of objects distributed geographically, that will emerge summary maps.

3. Results

3.1 Presentation of the Interface

For efficient operation of the database, we propose its use via a friendly interface with the basic menu consisting of several modules that allow consulting, editing and updating of GIS data (Figure 3).

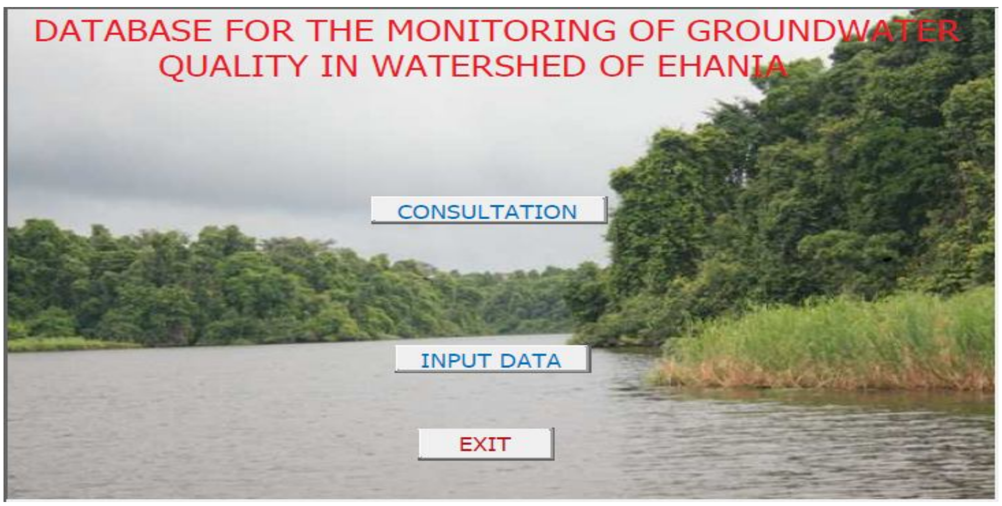

Figure 3: User Display of the Groundwater Database

The application offers two distinct modes of inquiry: the "Input data" mode and the "Consultation" mode. Only staff trained by the administrator can enter new data in the application. The consultation is not restrictive and is read-only.

The "consultation" mode allows querying the database in three distinct components namely interrogation by "Location" to " hydrochemical parameters " or by "water use".

* The "Location" pane allows you to make requests concerning sampling sites, dates of sampling, the condition of structures.
* The "parameters hydrochemical" component allows querying the database on the status of water points, and the static water table levels, the flow of operations and the quality of data.
* The "Water use" component enables the formulation of queries on the water needs of the population, the consumption of agriculture, agricultural practices.

In order to maximize the data, many requests can be made and viewed from the ArcMap module of ArcGIS software. Another complementary approach conducted on the database has achieved a spatial analysis of the quality parameters of the water. Thus, spatial analyzes illustrate the ability of GIS to support access to geographic information.

3.2 Spatial Analysis Related to Water Quality Data

The quality parameters which are subject to monitoring were defined on the basis of degradation processes identified in the watershed and the probable risk of water degradation due to human activities conducted in the region.

A precise analysis of this spatial information on GIS allows evaluating water quality of the study area in terms of environmental concerns. Evaluation of the chemical quality of drinking water is based on the comparison between the results of the qualitative analysis and recommended by the World Health Organization (WHO) guideline values.

In terms of physical parameters, we see first the case of pH. Indeed, a pH between 4.2 and 6.70 (Figure 4) with 84% of samples having a value lower than 6.5, recommended by WHO standard. These values indicate the overall acidity of these waters.

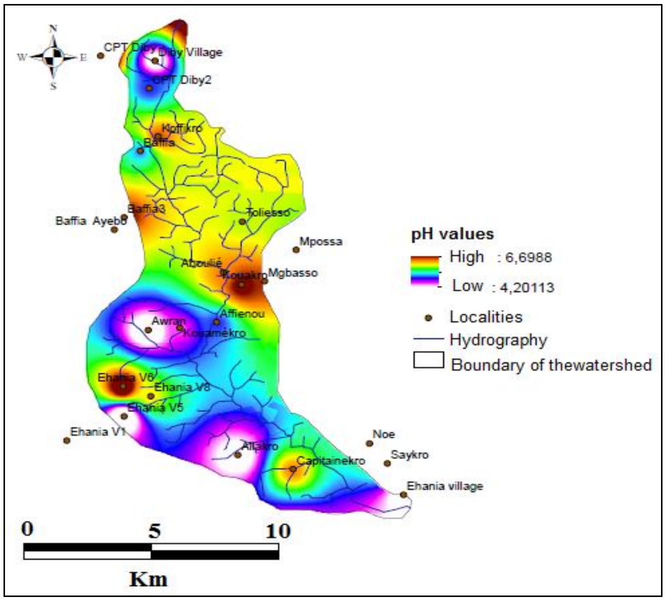

Figure 4: Spatial distribution of PH

In terms of conductivity (Figure 5), it indicates the degree of mineralization of waters. Thus, the higher the conductivity, the higher are the mineralized water. Low conductivity values are stored in the following locations: Diby Village, Baffia, Baffia Ayebo, Mpossa, Abolie, Mgbasso, Kouamékro, Affienou, EhaniaV1, V5 and V8, Noe, and Allakro Capitainekro. This represents 43.75% of the water samples. For other locations which represent 56.25% of the samples, the conductivities remain in compliance with WHO standards despite the maxima observed at Campement Diby, Koffikro and Kouakro.

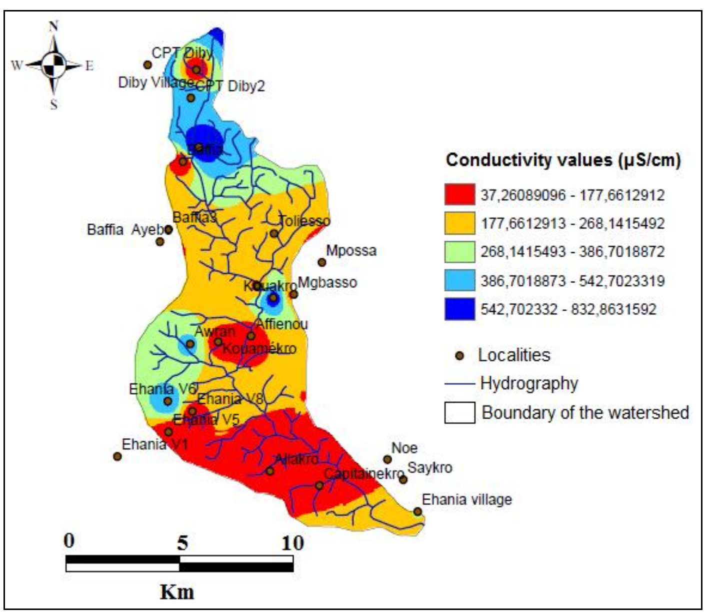

Figure 5: Spatial Distribution of Conductivity

Chemical analyzes performed on certain parameters (iron, nitrate, sulfate, magnesium, chloride, potassium, sodium and manganese) from samples show a variable composition between different water sources (Figure 6). There are some particularities corresponding to well water from localities of Baffia and Mpossa that contain high levels of iron and manganese; wells and boreholes from Campement Diby, Ehoua-Village, Awran, Toliesso, Kouakro and Koffikro are characterized by high levels of Cl^-, SO_4^{2-} and NO_3^-. Samples from Ehoua V6 Affenou, Abolie, Baffia 3, Capitainekro, Mpossa and Mgbasso are rather rich in Ca^{2+} and Mg^{2+}.

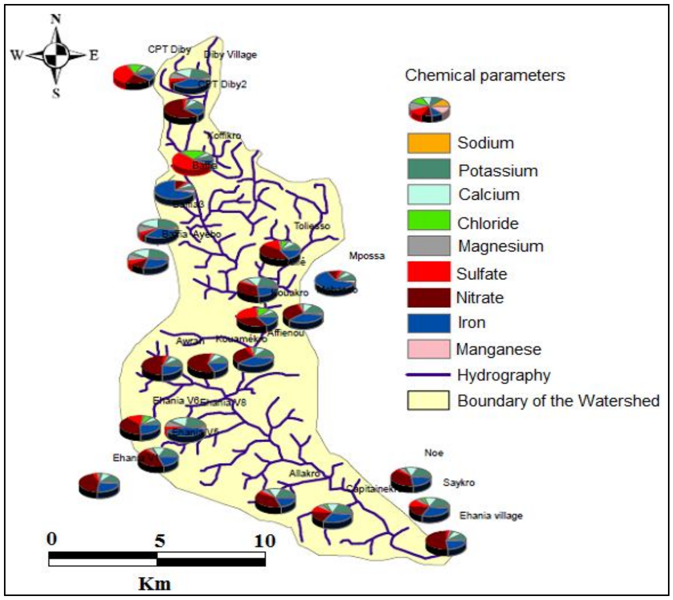

Figure 6: Proportion of Chemical Parameters

Within the parameters analyzed, the chemical characteristics shows that the levels of the major particularly cations (Na^+, K^+, Mg^{2+}, Ca^{2+}, Mn^{2+}, Fe^{2+}) are generally lower than the guide values defined by the World Health Organization (WHO).

Furthermore, the analyzes show that the concentrations of Cl^- et SO_4^{2-} remain low and below the WHO standards, despite the high rate obtained at Koffikro's sample (Figure 7). Overall it records the presence of nitrates in almost all samples. Also, the nitrate level is still higher than that of the chloride and sulphate.

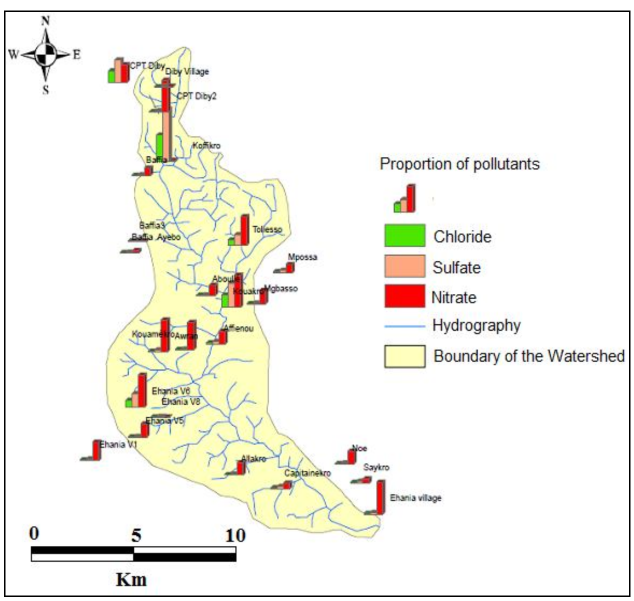

Figure 7: Proportion of Pollutants (NO_3^-, Cl^- and SO_4^{2-})

The nitrate levels vary from item to another with maximum values observed in some wells and boreholes. The limit value proposed by the WHO is 50 mg / L. In groundwater catchment basin of Ehania, levels of nitrates exceeding standards in some areas. Indeed, in the northern part (Figure 8), the localities of Koffikro, Ayebo, Diby Baffia and have respective levels of NO_3^- 114.7; 97.5; 114.7 and 66 mg / L. Similarly, in the southern part (Figure 8), water quality is also disrupted in the localities of Toliesso, Aboulie, Kouakro, Awran and Ehania V6 with respective levels of NO_3^- 113.8; 114.6; 114.7; 101.9 and 114.7 mg / L.

In general, the nitrate level is between 1.5 to 114.7 mg / L, with an average of 53.57 mg / L which remains above the WHO standard, and this corresponds to 37.5% of total samples.

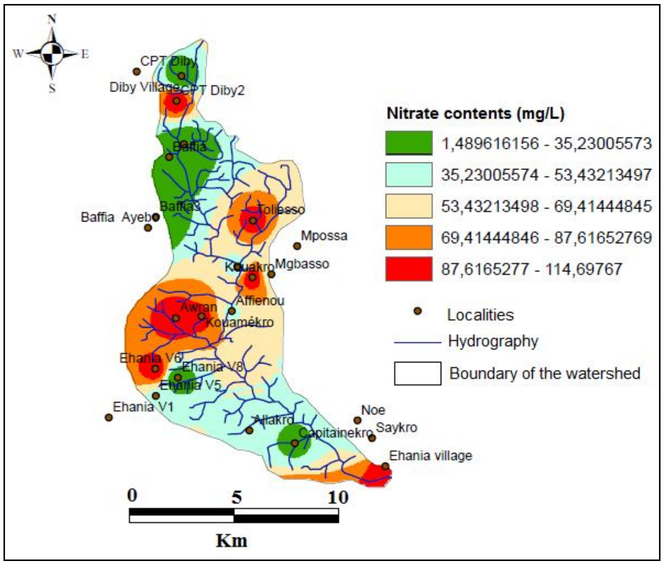

Figure 7: Spatial Distribution of Nitrates

4. Discussion

The information in the database can be viewed, sorted, handled, collected and printed in various ways and gives users the flexibility to get data in multiple formats. Query results should help users focus, review and abstract information without having to understand the complexities of individual tables. In addition, the system provides tools for editing and searching relevant information that will help them maintain documentation on the quality of water in this region. Regular field surveys are used to refine the compiled data and to complete certain themes that were not mentioned in the study. This ability to extract pieces of information based on criteria specified by the user makes the relational database management system an excellent computing technology of decision support. For this purpose, according to Martin et al (2004), construction of an effective database and combining the data relevant to the project as a single application reduces data redundancy, error, and the latency calculation. To the extent that priority research information related to the development and funding of programs to local markets, the different networks operating in the sector of water resources has increased substantially, the main challenge is to ensure the integrity between map data and relational data that are physically separated (Barbier, 2009). Quality parameters on which we focused in this study are the electrical conductivity, pH and nitrate content. From the data analysis of water quality, it appears that in most cases the water is more or less acid and the contents of the physico-chemical parameters are either lower, either conforms to WHO standards. With the exception of nitrates, where we observe the values which exceed the quality standards to the wells that capture the alterites aquifers and sedimentary formations. This could be explained by the presence of numerous plantations that use strong pesticides (Taylor and Townsend, 2010). Indeed, the spatial variation of nitrate depends on the variability of contributions related to the environmental context. For nitrate (NO_3^-) is a mineral form of soil nitrogen. Soluble in water, they find themselves naturally in low content (<10 mg / l) in surface and groundwater. Additional contributions can lead to a significant increase in nitrate levels in the water. These include, in agriculture, nitrogen fertilizer minerals brought to culture, mineralization of various organic products of crops (crop residues) or to the soil (livestock manure, sludge and various waste, etc.), but also atmospheric inputs by deposition or precipitation, and fixation by some symbiotic soil bacteria. These results confirm the impact of the intensification of agriculture and industrial discharges wastewater (El Hammoumi et al, 2012).

Furthermore, other factors seem nitrate accelerate infiltration to groundwater, including the thickness of the cover. The consequences for natural ecosystems and human health, the presence of pesticides in waters require alertness (Dubois de la Sablonière et al, 1999). By against in boreholes that capture the crystalline basement aquifers and cristallophylliens, nitrate levels are consistent with the standard for drinking water because of the depth of groundwater. In view of these analyzes, this tool will help tracking and monitoring water quality. For each of the follow-up samples will be collected for analysis. Data on test results and in-situ measurement can be integrated with GIS to develop maps. Thus, automation of analytical and visual processing of the periodic data for groundwater parameters of quality can be developed to meet the temporary and spatial requirements of data interpretation (Bitar et al, 2013). In short, the geodatabase is a real challenge for local development actors. The quality of water resources and in turn the quality of the lives of people can be mastered by a regular updating of data. Thus, a sustainable development of this region, that is to say, economically sound, environmentally responsible and socially acceptable, requires that the planning and decision-making are part of a spatial framework. This data updated regularly, will help to have information related to the degradation of groundwater quality in real time. In addition, elements of the database, with enhancements, can be easily introduced in the Internet network and a path consisting of data access. The various land managers can then insert data and search for information from their personal computers.

5. Conclusion

The geodatabase model was adopted in this study to facilitate the storage and management of geographic and descriptive data. The resulting application allows easy use of different data and has scalability for the integration of future studies. The form of the application is composed by two distinct modules namely: "Consultation" module and the "Input data" module that meet the requirements of management and monitoring of water resources. The results of physicochemical analyze show that the water of Ehania’s catchment are generally of good quality and meet drinking water standards, with the exception of a few water points. GIS has proven to be a tool that has helped create, manipulate and analyze, and produce decision support maps from temporal and physical data related to spatial reference. Agro-industrial plantations have been identified as sources of nitrate pollution in this watershed and as vulnerable areas. Map of concentrations of nitrates is an example of analysis and product provided by the GIS. Statistical analyzes revealed very high levels of NO_3^-, Cl^- and $SO4^{2-}$. Risk zones are observed in the north where there are industrial plantations of bananas and mainly in the southwestern part. The spatial reference will allow users to know the precise situation and context of each location in the region. The continuation of this work is to develop decision criteria based on quality indicators and selection of additional indicators such as soil quality parameters on water resources.

5. Acknowledgements

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