# Identification of priority areas in the water resource management of the watershed of the La Villa River in Panama

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## 1.0 INTRODUCTION

Panama is rich in water and the population at the national and global levels greatly uses this finite resource. The availability of enough water of good quality is very important for a country and can determine the potential economic growth since it allows a diversification of activity (Sanchez, 2002). The national economy relies greatly on water resources; indeed, up to 80% of Panama's Gross Domestic Product comes from the tertiary sector, including the Canal and maritime services, and the remaining 20% comes from agriculture and fisheries sector as well as industry and manufacturing sector, all which rely heavily on water. In Panama, the overall water availability is approximately 144120 $km^3$ per year (ANAM, 2004). This amount is generally sufficient to respond to the user demand; however, there are problems of availability during the dry season. There are also issues related to water quality for the parts of the river system that flow through populated areas. Like in most developing countries, Panama suffers from various social and economical issues and inequities, which are reflected in the state of the environment (Tremblay-Boyer and Ross, 2007)

Water conservation is an important issue and will be an even more significant in the coming years due to climate change and the growing imbalance between freshwater supply, distribution and consumption (Espinosa et al., 1997). Many parts of the world are already subject to water limitation in amount and quality, especially in Europe and Africa (Jackson et al. 2001). The availability of water depends on preservation of the sources. Limited water availability is an important issue as well as water quality deterioration. Contamination and sedimentation are problems related to water quality. Soil degradation, deforestation, forest fragmentation, land-use change and inadequate water extraction all affect the quality and quantity of water resources (Sanchez, 2002). The conservation of water resources brings many ecological services vital for the society; one of the ways to protect those ecological services is by protecting and managing the resource at the watershed scale. Indeed, there are close connections between land use and water quality and quantity (Dudley and Stolton, 2005).

Management and conservation strategies have to take multiple factors into account such as the type of processes involved in water management, the competence and capacities of the managing institutions as well as the socio-political conditions of the area and country (Biswas, 2008). Integrated water resource management is a concept that takes into account that the many different uses of water are interdependent. It is a complex management strategy that considers socio-economic and environmental factors for sustainable land and water development as well as allocation and monitoring of water resource use. Biswas (2008) evaluates the concept and its pertinence and discusses the problems related to such strategy for water management. Fishhendler (2008) realized a project in IWRM in Israeli and defined the concept of integrated water resource management as a strategy that emphasizes the watershed as a management unit, integrating both, land and water in management practices and calling for an integrated planning process that consists of flexible allocation systems which unifies water uses and users to create a joint management framework. Integrated water resource management has been greatly documented and implemented in many parts of the world, but little projects in Panama have used the strategy. Ibanez and his team did a study on the land cover and the Panama Canal watershed and concluded that changes in policies related to forest conservation and pollution control are necessary for the protection of the water resources

(Ibanez et al. 2002). This study is most likely not the only project realized in Panama, but it is one of the few ones published.

Many geophysical and social criteria need to be taken into account when evaluating water resource issues in order to plan a water management strategy. This evaluation can be performed with a Multi-Criteria Analysis (MCA) and the help of Geographic Information Systems (GIS). A MCA is a complex technique that allows analysis of the opinion and knowledge of various experts about the quantitative importance of each criterion. This method is very useful for a wide range of fields to support the decision-making processes when a lot of criteria are involved. GIS is a powerful tool that can be used to evaluate the special location of problems and to represent them graphically, to help in decision-making processes, to store, organize and create data and to make models in order to analyze spatial information and to create maps. A methodology using Geographic Information Systems to do a Multi-Criteria Analysis (MCA) can be applied in a range of projects, from evaluating policies to modeling physical processes (Sanchez, 2002). Sanchez (2002) did a MCA to find priority areas for water resource management in the watershed of the Sarapiqui River in Costa Rica. Another very similar study has been realized in Brazil where a workshop was organized to allow experts to weight the different thematic maps used to find the appropriate locations for the creation of greenway to protect hydrological resources. GIS was used as the tool analyzing the results of the MCA (Giordano and Riedel, 2008). In this project, the use of GIS for MC analysis is beneficial since it will enhance the precision of the information and results, and make the evaluation process easier and faster. Nevertheless, it has the disadvantage of increasing the sources of errors due to technical mistakes.

Most of the water management efforts in Panama focus on the protection of the Panama Canal watershed because of its economical and political importance. Indeed, 20% of Panama's gross domestic product is directly related to canal operations, and a temporary loss of canal operations would cause serious financial losses for the country and the world trading community. The U.S. Agency for International Development, the Smithsonian Tropical Research Institute, and the Panamanian government's Environmental Authority are some of the many groups doing research, management and monitoring the Panama Canal watershed (Ibanez et al. 2002). Indeed, studies and research are usually done for the Panama Canal or the area of interests for hydroelectricity development. Other rivers are also very important for Panama. Indeed, the Changre, the Chiriqui and La Villa rivers and watersheds are vital for the people and the economy of the country (Espinosa et al., 1997). Some projects have been realized in these watersheds. Indeed, Panama has effective conservation groups that focus on environmental education and extension programs. Two such organizations are TecnoServe and the Union de Campesinos del Lago Alajuela, which have succeeded in persuading indigenous communities along the Chagres River to abandon traditional slash-and-burn farming for more sustainable land use techniques. Moreover, the group ANCON works with small-scale farmers in the same watershed to replace cattle with subsistence farming growing fruit and nut orchards as well as doing iguana farming (Greenquist, 1996). Espinosa and her team (1997) did a study on the possible impacts of climate changes in the water resources in the Changre, the Chiriqui and the La Villa rivers.

Very few other studies have been realized on La Villa River. Next to a non-published document realized by CATHALAC, the Water Centre for the Humid Tropics of Latin America and the Caribbean, there has been a pilot project done by ANAM in 2002 concerning the water quality of the La Villa River (ANAM, 2002). This river is poorly monitored and interests in making management efforts started only recently. The watershed is experiencing significant environmental degradation because of inappropriate land use and management practices. Deforestation, slash-and-burn agriculture and intensive cultivation and cattle ranching have negative impacts on the soil (ANAM, 2002). La Villa River's watershed is part of an area called the Arco Seco ('dry arc') of Panama (Ashton et al., 1999) which is very hot and dry, therefore requiring serious water management. This region is very important for the local and national economy because it is one of the main areas for agricultural and industrial activities in the country.

The purpose of this project is to identify critical areas that should be prioritized in the integrated water resource management and conservation of the river La Villa in order to secure a sustainable use of the water for a long term availability of quality water. More specifically, the objectives are 1) to identify and characterize the principal users of water resources, 2) to propose and validate the criteria that will allow the identification of critical areas to manage and 3) to identify areas of high priority for water resource management in the watershed of La Villa River.

This study is part of a long-term project developed by CATHALAC that aims at identifying priority areas for integrated water resource management in the Republic of

Panama (CATHALAC, pers. Comm.). The methodology developed and the criteria identified will be used as a basis for the CATHALAC's project that will be implemented in the studied area, La Villa River watershed, as well as in other watersheds in the country. The identification of criteria will allow the experts in water management to know which data they need to collect in order to prioritize areas. Once critical areas are found using the methodology developed in this project, it will be used as a tool for environmental and political policy making as well as water resource management planning. Indeed, it can be used to allow a more efficient distribution of work efforts and funds for integrated water resource management, which will ensure a more continuous and sustainable use of quality water.

## 2.0 STUDY SITE AND HOST INSTITUTION

### 2.1 La Villa River watershed.

The La Villa River watershed is part of the Azuero Peninsula, which is considered as the most arid region of the country. The watershed belongs to "Arco Seco" which mainly consists of the provinces of Coclé, Herrera, Los Santos and Veraguas (ANAM 2002). The watershed of La Villa River is located in between the geographic coordinates 7° 30' and 8° 00' of latitude north

and 80° 12' and 80° 50' of longitude east and covers a drainage area of 1,284 $km^2$ (Espinosa 1997, CATHALAC). The main river is 125 km long, and the river network in the watershed adds up to 300 small rivers and creeks. The elevation of the watershed averages 135 meters above sea level, the highest point being El Manguillo at 918 meters above sea level (CATHALAC). The region is has been deforested for centuries and the land is mainly used for subsistence and intensive agricultural and livestock grazing activity. The climate of this region is typical of tropical savannas with annual precipitations of 1.200 mm which are irregularly distributed, most of them taking place in the rain season that lasts from May to November (Gil, 2002). The main annual temperature is 27° C, but during the dry season, between December and April, the temperatures rise as high as 42° C (CATHALAC). The watershed is significant in the national economy since it is an important area for agricultural and industrial areas.


*Figure 1 Map of the study site*

**2.2 CATHALAC**.

The Water Centre for the Humid Tropics of Latin America and the Caribbean (CATHALAC) is a non-profit organization promoting sustainable human development by providing tools, technology and education and applied research. CATHALAC focuses on water resources and the environment in order to improve living standards in Latin America and the Caribbean. CATHALAC works to improve public knowledge as well as to provide decision makers with scientific information for environmentally friendly policies.

The supervisor for this project is Noel Trejos, specialist in integrated water resource management (IWRM) and in community development for CATHALAC.

## 3.0 OBJECTIVES

### 3.1 General Objective

The general objective of this project is to develop a methodology to identify critical areas to prioritize for integrated water resource management in order to secure a sustainable and continuous use of water resources of good and constant quality in the watershed of La Villa River.

### 3.2 Specific Objectives

There are three specific objectives that guide this study. The first specific objective aims at identifying and characterizing the principal users of water resources. More specifically, the identification of the users and beneficiaries of water means to obtain the geographic location of the water extraction points and the characterization is to obtain information about water withdrawal from the watershed by each of the users. The second specific objective is to propose and validate the criteria that will allow the identification of critical areas in the watershed to prioritize the water resource management. The established criteria will allow the evaluation of critical and vulnerable areas within the watershed of La Villa River. The criteria of prioritization for management of water quality and quantity are determined by taking into account biophysical, economical, social and administrative information. Finally, the third specific objective of the project is to identify areas of high priority for water resource management in the watershed of La Villa River. The data related to the criteria identified will be analyzed using the MCA and the GIS to find and locate the critical areas that need to be prioritized for management of quality and quantity of water resources.

# 4.0 METHODOLOGY AND ACTIVITIES

## 4.1 Collection of Data

The collection of information has been done by visiting different national governmental and non-governmental institutions as well as by doing an extensive literature review on integrated water resource management and previous studies done on river systems. Data were available at the Autoridad Nacional del Ambiente (ANAM), the host institution of the project CATHALAC, the Empresa de Transmisión Eléctrica S.A. (ETESA), the Instituto de Acueductos y Alcantarillados Nacionales (IDAAN), the Ministerio del Desarrollo Agropecuario (MIDA) and the Ministerio de Salud (MINSA). Table 1 presents the information that has been collected from each institution. Data was collected in Panama City for all six institutions as well as at the local branches of ANAM, IDAAN, MIDA and MINSA in the districts of the study area including Chitre, Las Tablas and Los Santos in the provinces of Herrera and Los Santos .

**Table 1. Institutions visited in the data recollection process**

| **Institution** | **Data** |
|---|---|
| ANAM | Concessions and temporal permits for industrial and agro-industrial use |
| CATHALAC | Biophysical data, river network, cities and villages, municipalities, districts, land use, soil texture, digital elevation model (DEM) |
| ETESA | Precipitation |
| IDAAN | Urban human water consumption |
| MIDA | Wells for agricultural purposes |
| MINSA | Potable water (rural) |

The information obtained was in digital and paper format.  The data were gathered and compared and a database of all the data was created. The data that were not in map format were geo-referenced and transformed in map format.

## 4.2 Multi-Criteria Analysis (MCA)

### 4.2.1 Multi-Criteria Analysis (MCA) as a decision-making tool in the evaluation process of environmental problems

The method of Multi-Criteria Analysis (MCA) was developed to find solutions for complex problems. Since environmental problems are always influenced and caused by multiple factors, they should be addressed in a multidisciplinary approach. Finding a good solution or management decision then becomes a very difficult process since decision makers with different scientific backgrounds are often not in complete agreement about the approaches that have to be taken or the instruments that should be used. With the aid of MCA it is possible to include a range of different criteria into the decision-making process. Furthermore, different opinions about the weight of those criteria can be included which helps finding a consensus between different experts and lowers the probability of developing a wrong solution (Mendoza and Macoun, 1999).

Nevertheless, defining the criteria as the first step is a crucial part of MCA and determines the final result. Therefore, multiple experts from different fields should be included already in the first step of deciding which criteria to use in order to find the best management strategies.

Once the criteria are identified, different experts give their opinions on the relative importance of those criteria by applying a percentage to each criterion. All criteria should in the end add up to 100%. Since every expert decides about the importance of every criterion by himself there is no need of finding an agreement between different experts. Instead, analytical methods like ranking and rating are applied in order to find a consensus. MCA is used for instance in the context of forest certification by the Center for International Forestry Research (CIFOR, 1999)

### 4.2.2 Multi-Criteria Analysis as a tool to identify areas that need to be prioritized in the water management of the watershed of La Villa River

The first step in applying MCA to this project was to find the different criteria that are crucial in evaluating the need for prioritized management within the watershed of La Villa River. Normally these criteria are found by arranging a work shop in which experts from different fields discuss the relevance of criteria that seem to be important in evaluating the need of management in the watershed. Due to limited time, the criteria were found based on literature review and consultation with supervisor Noel Trejos from CATHALAC. As a result, eight criteria were identified for the management of water quality while six criteria were found for the quantity of water.

Those criteria consist of biophysical aspects like precipitation, pedagogical and geological factors like soil texture and slope, socio-economic characteristics like population density and the proximities of the river to roads and industries. Special attention was furthermore given to the uses of the watershed and the area around it by including the criteria of land use and water extraction.

This approach assumes that chosen criteria that might not be very important for the management of the watershed will not be given high values by experts. Nevertheless, it harbors a risk of missing criteria that might have been important for the evaluation process.

1. *Description of the criteria and categories used to identify areas that need to be prioritized in the water management of the watershed of La Villa River*

**i. Land Use**

Agricultural and cattle ranching activities account for the most important use of the land with 780 $km^2$ (37.7%) of total land area within the watershed of La Villa River.

Disturbed forests (Bosque Intervenido) represent the predominant land coverage in the watershed of La Villa River next to cattle ranching and agricultural activities with 30% of the total area. The largest continuously covered area with this type of forest accounts for 99 $km^2$. Of the total area, 1.8% is covered by pioneer forest (Bosque Pionero), the biggest plot being only 34 $km^2$ big. The total area covered by subsistence agriculture accounts for 339 $km^2$ which represents 16.4% of the watershed. Only 61.8 $km^2$ (4.3%) are covered by mature forests (Bosques maduros) while the size of continuous mature forests varies between 3 $km^2$ to 32 $km^2$. Less than 0.5% (5.6 $km^2$) within the watershed is covered by mangroves. The area covered by industrial or urban areas represents a region of 26.4 $km^2$ (1.8%) while the sizes of the areas vary between 10 $m^2$ and 11.3 $km^2$. Only two areas are covered with floodable vegetation (vegetacion baja inundable). Taken together, these two areas make up only 1.5 $km^2$ of the watershed which equals 0.08 % of the total area of the watershed. Based on the previous information, the criterion of land use was divided into eight categories, namely: disturbed forest (Bosque Intervenido), mature forest (Bosque Maduro), pioneer forest (Bosque Pionero), mangroves (Manglares), intensive agricultural and cattle activities (Uso Agropecuario intensivo), subsistence agriculture (Uso Agropecuario de Subsistencia), floodable vegetation (Vegetacion baja inundable) and other uses which include urban and industrial uses (otros usos).

## II. Slope

The values for the slopes in the watershed of Rio La Villa vary between 0 and 64 degrees. Most of the terrain in the region is flat; in fact, the mean slope value is 12.8 degrees. The majority of the slopes in the region vary between 0 and 30 degrees. Based on this information it was decided to use six categories within the criterion of slope. After consultation with experts from CATHALAC and the University of Panama the decision was made to use the conventional ranges established by the Ministry of Agriculture and Cattle in Costa Rica (MAG, 1995). Therefore the maximum of the last category is 75 degrees although the highest value within the watershed is 64 degrees. Therefore, the following categories were established: 0-3 degrees, 3-8 degrees, 8-15 degrees, 15-30 degrees, 30-50 degrees and 50-75 degrees.

### iii. Proximity to river

The closer a point is to the river, the bigger its impact is on the watershed – be it positive or negative. Since the impact of the vegetation cover was valued with the criterion of land use, the criterion of ‘proximity to the river’ gives a value in terms of the impact of every point on the map concerning its proximity to the river. Therefore, a mature forest is rated 1 in the land use section because it does not have a negative impact on the watershed. However, when this forest is close to the river than it has a bigger positive impact on the water quality than when it is further way from the river (Dudley and Stolton, 2005). Thus, a close forest is given a high value because it is more important to conserve this area than an area of forest that is further away. The same reasoning is applied to negative impacts, for instance those caused by intensive agriculture since its impacts are bigger the closer the agricultural land is to the river. Therefore, for this criterion, six buffers around the river have been created with the following attributes:

*Table 2*

| Categories | Attributes (in meters) |
|---|---|
| 1 | 0 – 50 |
| 2 | 50 - 100 |
| 3 | 100 - 300 |
| 4 | 300 - 500 |
| 5 | 500 - 1000 |
| 6 | 1000 - 5000 |

**iv. Proximity of the river to roads**

For this criterion the same reasoning applies as for the ‘proximity to the rivers’ since roads have a higher negative impact due to contamination the closer they are to the river. Since roads are not included in any of the layers, a separate criterion had to be established by creating a map of the road network and buffers around them. There is a total of 425 kilometers of road to be found within the area of the watershed which is mainly concentrated around the largest town Chitré. The largest distance between a road and the river within the watershed is shorter than 2000 meters. Thus, six buffers have been created, the first one covering an area of 50 meters around the roads, the second one covering the next 50 meters, while the third covers the next 200 meters up to 300 meters around the river. The fourth category reaches from 300 to 500 meters around the roads, the fifth one from 500 to 1000 meters and finally the last one from 1000 to 2000 meters

**v. Proximity of the river to industries/agro-industries**

*Table 3 Attributes for Prox.of river to industries*

| Categories | Atributes (in meters) |
|---|---|
| 1 | 0 – 50 |
| 2 | 50 – 100 |
| 3 | 100 – 500 |
| 4 | 500 – 1000 |
| 5 | 1000 - 3000 |

For this criterion the same data has been used as for the criterion of water extraction. Thus, 125 extraction points have been used. Since it was assumed that industries, like roads, will affect the watershed much more the closer they are to the river, five buffers have been created around the industries to evaluate the impact depending on the distances between the river and the industries. The first category therefore ranges from 0 to 50 meters, the second from 50 to 100 meters, the third from 100 to 500 meters, the fourth from 500 to 1000 meters and the last category covers 1000 to 3000 meters around the industries.

**vi. Population**

There are 313 towns and villages within the area of the watershed of La Villa River of which most of them are small. In fact, the mean value of inhabitants amounts to only 225 people. For the biggest town, Chitre, there were 20529 people counted in the last national census in 2000 (Contraloria General de laRepública, 2000). . One hundred inhabitants or less live in 222 out of 313 villages and cities. Based on this information it was decided to divide the criterion of population into seven categories. Although this number of categories is quite big, it gives the advantage of making a better differentiation, especially in between the small villages, which are more abundant in the watershed than larger cities. The ranges in between the categories were found with the natural break 'Jenks' classification in ArcGIS 9.2., using seven classes and finally rounding up the values.

This application groups the most similar values and finds breakpoints between the classes so that the differences inherent in the data are maximized. Therefore the boundaries are set where big gaps in the data set are encountered (ESRI, 2007).

Thus, the first category is 0-75 people, the second goes from 75 to 250, the third from 250 to 500 people. The fourth category covers 500 to 775 people, the fifth from 775 to 1500, the sixth from 1500 to 5000 and the last category spans 5000 to 20000 inhabitants.

*Table 4: 7 Categories for the criterion of population*

| | |
|---|---|
| 1 | 0 – 75 |
| 2 | 75 – 250 |
| 3 | 250 – 500 |
| 4 | 500 – 775 |
| 5 | 775 – 1500 |
| 6 | 1500 – 5000 |
| 7 | 5000 – 20000 |

**vii. Soil texture**

The main type of soil texture encountered in the region is fine clay (Arcillosa fine). It covers almost 80% of the watershed. Clay soil is found all over the study area. Close to the coast, a line of marine clay (Esqueleto arcilloso) covering 10.5 % of the watershed can be found. An area of approximately 0.28% of the total area is covered by loamy soil (Franco grueso), 0.97 % is sandy soil (Arenosa), less than 0.61 % is sandy loam (Franco arenosa) and 0.02 % is covered by very fine clay soil (Arcillosa muy fina). According to the six different soil types found within the area of the watershed we divided this criterion into six categories.

**viii. Precipitation**

The mean annual precipitation varies within the watershed between 1276.2 mm per year to 3535 mm per year with greater amounts found further away from the coast in the southern areas of the watershed. The mean annual precipitation in the entire watershed is 1888.1

mm/year.

The data used for this criterion was obtained from ETESA (Empresa de Transmisión Eléctrica S. A.) for university purposes. It contains values for the precipitation that are averages of the last 30 years. The categories were found using the Natural break 'Jenks' classification in ArcGIS 9.2. The ranges were obtained using five classes and a final round-up of the values. However, the final ranges were confirmed by ETESA. Thus the first category ranges from 1275 mm per year to 1500 mm per year while the second starts at 1500 mm per year and ends at 1775 mm per year. The third category spans from 1775 mm per year to 2000 mm per year. For the fourth category the interval is bigger so that it ranges from 2000 mm per year to 2500 mm per year. Finally, the interval is again doubled for the last category which ranges from 2500 mm per year to 3500 mm per year. The growing of the intervals within the last two categories is due to a decreasing negative impact with higher precipitation. Therefore it is much more important to obtain more accuracy for low values of precipitation, reflected by categories one to four.

### ix. Water extraction

In total, 125 points of extraction of surface water and groundwater have been used for the study. The amount of water that is withdrawn there varies greatly between 3840 and approximately 3 million liters per day assuming the user withdraws water for eight hours per day. Most of the wells are used for agricultural and cattle farming purposes and 28 water extraction points are for industrial use. The points collected might not represent the real situation because there were no data available for the lower part of the watershed. According to the data the criterion was divided into six categories of water taken out from the watershed in liters per day (see table 4).

*Table 5 : Categories of water extraction*

| Categories | Attributes in l/day |
|---|---|
| 1 | 10.000 – 50.000 |
| 2 | 50.000 – 0.1 million |
| 3 | 0.1 – 0.5 million |
| 4 | 0.5 – 1 million |
| 5 | 1 – 5 million |
| 6 | 5 – 10 million |

Of those nine criteria, eight were used to identify those areas that need prior management in terms of water quality and six criteria were used for water quantity.

*Table 6: Criteria used to prioritize critical areas for water resources management in La Villa River watershed, Panama in terms of water quality and water quantity*

| Criteria (Layers of information) | Use of criteria | |
|---|---|---|
| | Quality | Quantity |
| Land Use | X | x |
| Slope (in degrees) | X | x |
| Proximity to river (in m) | X | |
| Proximity of the river to roads (in m) | X | |
| Proximity of the river to industries/agro-industries (in m) | X | |
| Population (individuals) | X | X |
| Soil texture | X | X |
| Precipitation (in mm/year) | X | X |
| Water extraction (agricultural and industrial) (in l/day) | | X |

**I. Water quality**

For the objective of prioritizing areas in terms of water quality, eight of the nine criteria were used, namely: land use, slope, proximity to the river, proximity of the river to roads, proximity of the river to industries/agro-industries, population, soil texture and precipitation. The use of the land is considered important since it determines the input of chemicals (fertilizers, pesticides) and litter depending on the abundance of agricultural or urban use compared, for instance, to very low impacts occurring when the area is covered in mangroves. Moreover, there is a close connection between forests and water quality (Dudley and Stolton, 2005). Slopes are very important concerning soil degradation and following increased sedimentation rates in rivers depending on the steepness of the slope (ANAM, 2002). The criterion proximity to the river was used since it describes the importance of the impact of every point in the area of the watershed. Thus, a forest is more important for the quality of the water if it is closer to the river and has less impact the further it is away. In contrast, a town that is located directly next to the river has a much bigger negative impact on the quality of the water than one that is one kilometer way from the bank of the river. A similar reasoning is applied to the criteria 'proximity of the rivers to roads' and 'proximity of the river to industries/agro-industries,' since roads and industries have more negative impacts like contamination of the water if they are in very short distance to the river. As for the criterion of population it is assumed that there is more pressure on the water quality if there are more people living in an area. Moreover, with a certain amount of people, the environment becomes more developed in terms of infrastructure and economic activity, thereby increasing the impacts on water quality. The texture of the soil is important concerning two aspects. The first and more important one is the infiltration rate of the soil and the second is the erosiveness of the soil type since this will have an impact on the sedimentation rate which will then affect water quality

Finally the amount of precipitation is important for water quality since the ecosystem can withstand contamination better if there is more water available in terms of dilution processes.

**II. Water quantity**

For the objective of water quantity, six criteria were used; namely land use, slope, water extraction, population, soil texture and precipitation. The use of the land is important in terms of water quantity because it describes the vegetation cover which can have a great impact depending on the type of cover. For instance, a forest cover is important in terms of infiltration rates of the soil and therefore influences the amount of water that is available in the watershed (Dudley and Stolton, 2005). The criteria of slope and soil texture are also essential factors to be included in terms of infiltration rates. Moreover they are important in terms of the run-off because that influences the recharge capacities of the watershed (Sánchez-Campos, 2002). In terms of human influences on the watershed, the amount of water taken out of for industrial and agricultural uses is a central criterion to evaluate the need for management in terms of water quantity. Similarly, the number of people living in the area influences the amount of water taken out for human consumption and determines the state of development which, in turn, might affect the establishment of new industries in the area. Finally, the criterion of precipitation is used as the basic source of water recharge within the watershed because the water balance for this region is not available.

### 4.2.3 Applying the MCA methodology in order to evaluate the criteria

Rating is next to Ranking one of the simplest MCA methodologies. These two methodologies are very similar. Based on the perceived importance of one criterion in relevance to the remaining criteria a rank or a percentage is given to it.

In this case, Rating was used to assign percentages between 0 and 100 to each criterion. In the end all percentages have to add up to a hundred percent - once in terms of the eight criteria for the quality of water and once in terms of the six criteria for the quantity of water. Thereby, giving a high percentage to one criterion means at the same time that another criterion is valued less. This rating will be done by different experts so that the final percentages will be derived by taking the total average of all opinions.

As a second step every criterion is divided into different categories depending on the characteristics of the watershed.

Normally those categories are then evaluated by experts as well so that every expert gives two weights: one for the criterion and one for each category (CIFOR, 1999). In this study, due to time limits, the categories are given values that had previously been determined on the basis of literature review and through interviews with experts from different fields such as employees of ETESA or professors of the University of Panama.

In order to rate the different criteria found, a survey had to be developed which could be completed by experts with different scientific backgrounds. This survey (see Appendix 3) consists of two main tables, one for the evaluation in terms of water quality and one for water quantity. An introduction sheet explains the reason of the study and the methodology used.  The tables consists of the different criteria used, their separation into the different categories with the corresponding attributes and their values. The respondents are asked to give a percentage to each criterion depending on their opinion in terms of the weight of this criterion compared to the other ones. The sum of all percentages has to be a hundred per cent; once for the objective of water quality and also in terms of water quantity. The survey still leaves the option for changing one of the values based on an explanation for the change by the expert. All interviews are conducted following the McGill code of ethics.

## 4.3 Geographic Information Systems (GIS)

### 4.3.1 GIS as a tool to transform digital data and create a database

The secondary information collected in different institutions that was not yet in digital format has been digitized and then transformed into map format using the Geographic Information System ArcGIS 9.2. The land use, digital elevation model (DEM), river network, roads network, cities and villages, soil texture and precipitation data were already in map format. The slope map was created with the Slope function of the Raster Surface Analysis tool in the ArcToolbox application of the ArcGIS program. The slope function calculates the maximum rate of change between each cell of a digital elevation model (DEM) and its neighbors. The proximity to the river data was calculated using the river network dataset and the Buffer function of the Proximity toolset in the Analysis toolbox. The Buffer function creates area features at a specific distance, previously specified, around the input features. The same process has been used to create the Proximity of the river to the road layer. The Water extraction dataset has been created using the paper and digital data collected about the concessions and temporary permits of water withdrawal permits for industrial and agro-industrial uses, and the data of the wells used for agricultural purposes. All the data were compiled and put in an excel file. Then, the file was transformed into a database format and a map was created by using the Create Feature Class from Database option of ArcCatalog application. This layer was used to create the Proximity of the river to the industries and agro-industries dataset. The Multiple Rings Buffer functions of the Proximity toolset in the Analysis toolbox of the ArcToolbox application.

### 4.3.2 Prioritization of the critical areas for integrated water resource management using GIS

With the criteria defined previously, based on primarily literature review and knowledge of experts, a GIS analysis was performed to determinate the areas to prioritize for integrated water resource management. Once the criteria were proposed, validated and divided into categories, and the criteria and categories were weighted, the Multi-Criteria Analysis was performed using the ArcMap application of the ArcGIS 9.2 program. Each criterion is a layer of information. Each layer of information was transformed into raster image. The Slope and the Precipitation data were the only two datasets that were already in raster image. The other layers were feature data that were converted into a raster dataset format using the Feature to Raster tool from the To Raster toolset of the ArcToolbox application. All the raster were created with the same image resolution. The resolution of the precipitation image, which has a coarser resolution, was used; therefore, the resolution of all the images is 90m x 90m.

The criteria for quality and quantity of water were analyzed using the Model Builder of ArcGIS 9.2, which is a tool of the ArcToolbox application. The Model Builder allows relating, superposing and analyzing the different layers of information. Two distinct models were created: one considering the prioritization of critical areas for management of quality of water and one that consider areas to manage in order to allow a continuous and sustainable water supply in the future. To create the model for water quality, eight criteria in form of images were included, while six image datasets were used in the model for water quantity. For each criterion, the attributes were reclassified using the values of the categories explained previously. The Reclass function is part of the Raster Reclass toolset and it allows replacing input cell values with new output cell values. Then, all the image datasets were connected together using a Weighted Overlay, which is a function of the Overlay Spatial Analyst toolset. This function allows overlaying several raster images using a common measurement scale, from 1 to 5 in this case, and weights each according to its importance. Then, the model was run and the final map was created by the program. Those steps were realized separately for the two models and the results of the spatial analysis using the Model Builder were two maps: one shows the areas to prioritize for quality water management and the other one the areas for quantity water management. Finally, a final Weighted Overlay was performed to combine the two maps with results of quality and quantity. The same weight was applied to the two maps and the result was a final map showing areas to prioritize for the management of water to ensure the long term continuous supply of quality water.

## 5.0 RESULTS

### 5.1 Valuation of the criteria of prioritization of critical areas for the management of water resources in watershed of the La Villa River

*Table 7 Survey participants*

| | Institution | Scientific background/experience |
|---|---|---|
| 1 | Universidad de Panama | Ph.D., specialist in Soil |
| 2 | CATHALAC | Specialist in Integrated water resource management |
| 3 | CATHALAC | Senior scientist |
| 4 | McGill University | Student: water management |
| 5 | McGill University | Student: soil management |
| 6 | CATIE 1 | GIS; water resource management |
| 7 | CATIE 2 | Water resource management |
| 8 | CATHALAC | Specialist for renewable energy |
| 9 | ETESA | Hydro-meteorologist |
| 10 | CATHALAC | GIS, Remote Sensors and Land-Use Planning Specialist |
| 11 | ANAM | Land-use and conservation |
| 12 | ANAM | Conservation and water management |
| 13 | CATHALAC | Geospatial scientist |
| 14 | Universidad Tecnologica de Panama | Engineer: Geotechnics |
| 15 | McGill | Teaching assistant; M.Sc Candidate in Water Resources Management |
| 16 | CATHALAC | Weather and Climate Technology Spezialist |
| 17 | CATHALAC | Knowledge Management Spezialist |

After distributing approximately 30 surveys, 17 have been completed in time to be included in the Multi-Criteria Analysis. The people interviewed have different scientific backgrounds, including students, university scientists and employees of private companies (see complete list in table …). As the most important criteria in terms of water quality the criterion of ‘Land use’ and ‘Proximity of the river to industries/agro-industries’ have been chosen with an average value of 19.4 per cent (Standard deviation: 6.76 per cent) and 19.1 per cent (5.88 per cent). The criterion that was rated less important was the criterion of ‘slope’ with 7.6 per cent (3.29 per cent), followed by ‘Proximity of the river to roads’ with 8.4 per cent (4.55 per cent) and ‘Soil texture’ with 8.7 per cent (4.41 per cent). In terms of water quantity the most important criterion was found to be ‘precipitation’ with 27.5 per cent (9.05 per cent), followed by ‘water extraction’ with 17.0 per cent (7.96 per cent). ‘Soil texture’ was rated as the least important criterion with 11.7 per cent (6.74 per cent), followed by ‘Slope’ with 13.4 per cent (7.76 per cent). In all cases the standard deviation was at least half as much as the actual value.

*Table 8: Criteria to prioritize critical areas for water resources management in La Villa river watershed, Panama and their final weights*

| Criteria (Layers of information) | Weight with standard deviation (%) of the criteria | | | |
|---|---|---|---|---|
| | Quality | St.-Dev. | Quantity | St.-Dev. |
| Land Use | 19.4 | 6.76 | 15.4 | 5.31 |
| Slope (in degrees) | 7.6 | 3.29 | 13.4 | 7.76 |
| Proximity to river (in m) | 9.5 | 7.21 | - | - |
| Proximity of the river to roads (in m) | 8.4 | 4.55 | - | - |
| Proximity of the river to industries/agro-industries (in m) | 19.1 | 5.88 | - | - |
| Population (personas) | 17.8 | 7.48 | 15.7 | 8.95 |
| Soil texture | 8.7 | 4.41 | 11.7 | 6.74 |
| Precipitation (in mm/year) | 10.3 | 5.83 | 27.5 | 9.05 |
| Water extraction (agricultural and industrial) (in l/day) | - | | 17.0 | 7.96 |

### 5.2 Values of the attributes of each criterion for the quality and quantity analysis

#### 5.2.1 Water quality

#### I. Land use

Areas that are covered with mature forests and mangroves were rated as very low priority areas since they affect the ecosystem in a positive way by increasing the infiltration rate.

Table 9 : Valuation of the Land use criterion

| Categories | Attributes | Values |
|---|---|---|
| 1 | Disturbed forest | 3 |
| 2 | Mature forest | 1 |
| 3 | Mangroves | 1 |
| 4 | Other uses (urban; industrial) | 5 |
| 5 | Pioneer forest | 2 |
| 6 | Intensive agricultural use | 5 |
| 7 | Subsistential agricultural use | 3 |
| 8 | Floodable Vegetation | 2 |

Moreover, where there is natural cover there is no or very low contamination which means that those areas do not need to be prioritized for conservation. The areas of floodable vegetation and pioneer forests were rated with a low priority. Areas of subsistence agriculture have been cleared of natural vegetation and are treated with chemicals regularly. They were rated as priority areas while the category of intensive agriculture has been rated as very high priority area since there are more chemicals applied and the soil is being degraded faster due to the regular outtake of nutrients in the form of agricultural products. The category of ‘other uses’ which includes urban and industrial areas has been rated as very high priority as well since those areas have big impacts concerning the contamination of the river due to industrial and urban waste.

**II. Slope**

Steep slopes highly affect the run-off and the sedimentation rates in rivers and thereby the water quality (MAC, 1977). Therefore slopes between 15 and 30 degrees have been rated as high (4) and slopes over 30 degrees as very high (5) priority areas.

Table 10 : Valuation of the criterion of slope

| Categories | Attributes (in degrees) | Values |
|---|---|---|
| 1 | 0 – 3 | 1 |
| 2 | 3 – 8 | 1 |
| 3 | 8 – 15 | 3 |
| 4 | 15 – 30 | 4 |
| 5 | 30 – 50 | 5 |
| 6 | 50 – 75 | 5 |

Slopes with a smaller angle signify that the speed of run-off is slower and sedimentation rates smaller. Thus the impact on the ecosystem decreases which was expressed in giving slopes between eight and fifteen degrees a value of 3 and slopes smaller than that a value of 1.

**III. Proximity to the river**

Table 11: Valuation of the criterion of Proximity to the river

| Categories | Attributes (in meters) | Values |
|---|---|---|
| 1 | 0 – 50 | 5 |
| 2 | 50 – 100 | 4 |
| 3 | 100 – 300 | 4 |
| 4 | 300 – 500 | 3 |
| 5 | 500 – 1000 | 2 |

The river banks are very sensitive areas concerning the condition of a watershed as an ecosystem and its water quality in particular (Decamps, 1993).

Therefore, a very high prioritization value was given to the first category which spans the first 50 meters around the river. A slightly smaller impact was assumed for the area between 50 and 100 meters from the river since that area extends further than the river banks. Therefore, a high prioritization value of 4 was given to the second category. There were values given to the next four categories as well, but unfortunately it was not possible to create the last four buffers so that this criterion was used with only two buffers, spanning 100 meters around the river thereby covering the most sensitive areas in terms of water resource management (Decamps, 1993).

**IV. Proximity of the river to the road**

For the same reasons that applied to the previous criterion of proximity to the river, the first category was given the highest prioritization value. Moreover, the next category was also rated with the same value since it was assumed that roads still have a big impact on the river in 50 to 100 meters distance due to emissions and road side use. From 100 meters on up to 500 meters a high prioritization value was given because a road is still seen as a big disturbance of an ecosystem and the watershed even half a kilometer way from the bank since it opens up the region for human development.

Table 12: Valuation of the criterion of Proximity of the river to the road

| Categories | Attributes | Values |
|---|---|---|
| 1 | 0 – 50 | 5 |
| 2 | 50 – 100 | 5 |
| 3 | 100 – 300 | 4 |
| 4 | 300 – 500 | 4 |
| 5 | 500 – 1000 | 3 |
| 6 | 1000 – 2000 | 1 |

Finally the impact decreases within the buffer of 500 to 1000 meters but was still given a value of 3 while the impact within a distance of 1000 to 2000 meters was rated as very low.

**V. Proximity of the river to industries/agro-industries**

Table 13: Valuation of the Proximity of the river to industries/ agro-industries criterion

| Categories | Atributes (in meters) | Values |
|---|---|---|
| 1 | 0 – 50 | 5 |
| 2 | 50 – 100 | 5 |
| 3 | 100 – 500 | 4 |
| 4 | 500 – 1000 | 2 |
| 5 | 1000 – 3000 | 1 |

The valuation within this criterion is very similar to the one for ‘proximity of the river to the road. The first two categories were again rated as very high prioritization assuming that industries have a similar or even higher impact on the watershed compared to rivers. Similarly the third category of 100 to 500 meters was given a value of 4 since the impact decreases with distance but is still big in 500 meters due to emissions and the release of waste water into the watershed. Finally the last two categories of 500 to 1000 meters and 1000 to 3000 meters were rated as low and very low impact areas.

### VI. Population

Table 14: Valuation of the criterion of Population

| Categories | Attributes | Values |
|---|---|---|
| 1 | 0 – 75 | 1 |
| 2 | 75 – 250 | 2 |
| 3 | 250 – 500 | 2 |
| 4 | 500 – 775 | 3 |
| 5 | 775 – 1500 | 3 |
| 6 | 1500 – 5000 | 4 |
| 7 | 5000 – 20000 | 5 |

Small villages of 75 inhabitants were rated as very low impact areas while a village seize of 75 to 500 people was rated with a low impact value of 2. The higher the number of people in a village or a town the bigger is the pressure on the watershed due to a higher take of water, pollution and the increasing development in the region. Therefore, a value o three, meaning that the area is a prioritization area, was given to categories number four and five which span 500 to 1500 people. A high prioritization area was assumed for 1500 to 5000 inhabitants while the areas with more than 5000 people and up to 20000 people were rated as very high prioritization areas.

**VII. Soil texture**

In terms of water quality the texture of the soil is important in terms of the infiltration rate, but also because of the erosiveness of the soil since this influences the sedimentation rate. Sandy textures have a better infiltration rate, but since they are a lot more erosive and contain smaller and loose particles.

Table 15 : Valuation of the criterion of Soil texture

| Categories | Attributes | Values |
|---|---|---|
| 1 | Loamy soil | 3 |
| 2 | Sandy loam | 3 |
| 3 | Sandy | 3 |
| 4 | Marine clay | 2 |
| 5 | Fine clay | 2 |
| 6 | Very fine clay | 2 |

The group of sandy soil types was rated with a value of three. That means for the watershed that those areas need to be prioritized concerning the management of the water quality. In contrast, the group of clay soil, which is made up by the categories 4 to 6, was given a value of two which stands for areas of low prioritization. Therefore the experts saw the sedimentation rate as more important concerning the water quality than the infiltration rate.

**VIII. Precipitation**

Precipitation is in general very low in the watershed of Rio La Villa. Therefore, the first category that ranges from 1275 to 1500 mm per year was rated with a value of 5 which stands for very high prioritization area.

Table 16 : Valuation of the criterion of Precipitation

| Categories | Attributes (mm/year) | Values |
|---|---|---|
| 1 | 1275 – 1500 | 5 |
| 2 | 1500 – 1775 | 4 |
| 3 | 1775 – 2000 | 3 |
| 4 | 2000 – 2500 | 3 |
| 5 | 2500 – 3500 | 2 |

A slightly higher precipitation of 1500 to 1775 mm per year was seen as having a little less impact than the first one and was therefore given a value of 4. Categories 3 and 4 range from 1775 to 2500 mm per year and were still seen as factors that demand a prioritized management of the area in terms of water quality. An area with a precipitation more than 2500 and up to 3500 mm per year was seen as being an area of low prioritization.

### 5.2.1 Water quantity

#### I. Land use

Mature forests and mangroves have been rated very low priority areas in terms of water quantity due to their low impact on the watershed since they are still covered in their natural vegetation and therefore have positive impacts on the infiltration rate of the soil. Pioneer forests, floodable vegetation and disturbed forests have been rated as low priority areas due, for instance, to the removal of their natural vegetation cover.

Table 17 : Valuation of the criterion of Land use

| Categories | Attributes | Values |
|---|---|---|
| 1 | Disturbed forest | 2 |
| 2 | Mature forest | 1 |
| 3 | Mangroves | 1 |
| 4 | Other uses (urban; industrial) | 5 |
| 5 | Pioneer forest | 2 |
| 6 | Intensive agricultural use | 4 |
| 7 | Subsistence agricultural use | 3 |
| 8 | Floodable Vegetation | 2 |

Prioritized management is seen as necessary in areas of subsistence agriculture while the impacts of intensive agriculture and cattle ranching as well as the urban and industrial use of the area are rated as being of very high importance in terms of identifying prioritized areas. According to an expert, the loss of natural vegetation and an additional compaction of the soil caused by intensive use worsen the infiltration rate which in turn affects the water quantity.

### II. Slope

Table 18 : Valuation of the slope criterion

| Categories | Attributes | Values |
|---|---|---|
| 1 | 0 – 3 | 1 |
| 2 | 3 – 8 | 1 |
| 3 | 8 – 15 | 2 |
| 4 | 15 – 30 | 4 |
| 5 | 30 – 50 | 5 |
| 6 | 50 – 75 | 5 |

The values for the quantity of water are almost the same as the ones given for the quality of water. This is due to the fact that the same factors that influence the water quality also influence the water quantity.

Therefore, a steep slope affects the run-off, as well as the sedimentation- and infiltration rates and results in less water availability within the watershed. Thus, the categories 4 to 6 (15 to 75 degrees) have been valued as areas of high, respectively very high management priority while a slope smaller than 15 degrees has been rated as being of low and very low priority.

### III. Water extraction

For this criterion, solely areas falling into the category number six and therefore covering the extraction of 1 to 3 million liters of water per day were rated as priority areas. Categories 1 to 5 all fell into the same group of low prioritization.

Table 19 : Valuation of the water extraction criterion

| Categories | Attributes (liters/day) | Values |
|---|---|---|
| 1 | 0 – 50000 | 2 |
| 2 | 50000 – 0.1 million | 2 |
| 3 | 0.1 – 0.25 million | 2 |
| 4 | 0.25 – 0.50 million | 2 |
| 5 | 0.50 – 1 millions | 2 |
| 6 | 1– 3 millions | 3 |

The evaluation of this criterion was mainly done with the support of ETESA.

**IV. Population**

The evaluation of the attributes in terms of water quantity is exactly the same as the one for water quality since the loss of water due to extraction affects the quality as well as the quantity of water.

Table 20 : Valuation of the population criterion

| Categories | Attributes (personas) | Values |
|---|---|---|
| 1 | 0 – 75 | 1 |
| 2 | 75 – 250 | 2 |
| 3 | 250 – 500 | 2 |
| 4 | 500 – 775 | 3 |
| 5 | 775 – 1500 | 3 |
| 6 | 1500 – 5000 | 4 |
| 7 | 5000 – 20000 | 5 |

Therefore, the impact is much bigger in area where the population seize ranges from 5000 to 20000 people per village or town. Thus, categories 6 and 7 have been rated as having a high and very high impact on the water quality. Categories 4 and 5 also require prioritized management, while categories 1 to 3 (0 to 500 people) have been rated as having a very low, respectively low, impact.

**V. Soil texture**

The texture of the soil is very important in terms of the infiltration rate. Sandy textures allow for a better infiltration rate than clay textures (Sánchez-Campos, 2002). Therefore the sandy textures (categories 1, 2, 3) were given the value 2 for low priority by the experts consulted.

Table 21 : Valuation of the soil texture criterion

| Categories | Attributes | Values |
|---|---|---|
| 1 | Loamy soil | 2 |
| 2 | Sandy loam | 2 |
| 3 | Sandy | 2 |
| 4 | Marine clay | 3 |
| 5 | Fine clay | 3 |
| 6 | Very fine clay | 3 |

In contrast, the clay textures need to be more prioritized and thus were given the value 3. In between the categories 1 to 3 for sandy textures there are no differences in terms of infiltration according to the experts. Similarly there was no difference made in between the ‘clay texture’ categories 3 to 6.

### VI. Precipitation

Table 22 : Valuation of the Precipitation criterion

| Categories | Attributes (in mm/year) | Values |
|---|---|---|
| 1 | 1275 – 1500 | 5 |
| 2 | 1500 – 1775 | 4 |
| 3 | 1775 – 2000 | 4 |
| 4 | 2000 – 2500 | 3 |
| 5 | 2500 – 3500 | 2 |

The values given to the different attributes concerning the quantity of water are almost the same given for the quality of water. While category number three was given a value of three in terms of water quality, it received a four concerning the quantity since the precipitation is the main source of recharge in terms of water availability within the watershed. A value of three was given to category number four which finally means that all areas with a precipitation ranging from 1275mm per year to 2500 mm per year should be prioritized in the management of the watershed. In contrast, category number 5 which ranges from 2500 to 3500 mm per year was considered to have a low impact.

## 5.2 Models of spatial analysis to prioritize critical areas for water resources management

The results of the definition and valuation of the criteria of prioritization were used to identify critical areas for water resources management in the watershed with respect to quality and quantity using models of spatial analysis developed with a Geographic Information System. With the Model Builder, which is a tool of the ArcToolbox application of ArcGIS program, a Multi-Criteria Analysis was performed. The next section will present those results. Figure 2 and 3 present the diagrams of the models created and used in the analysis using the Model Builder.

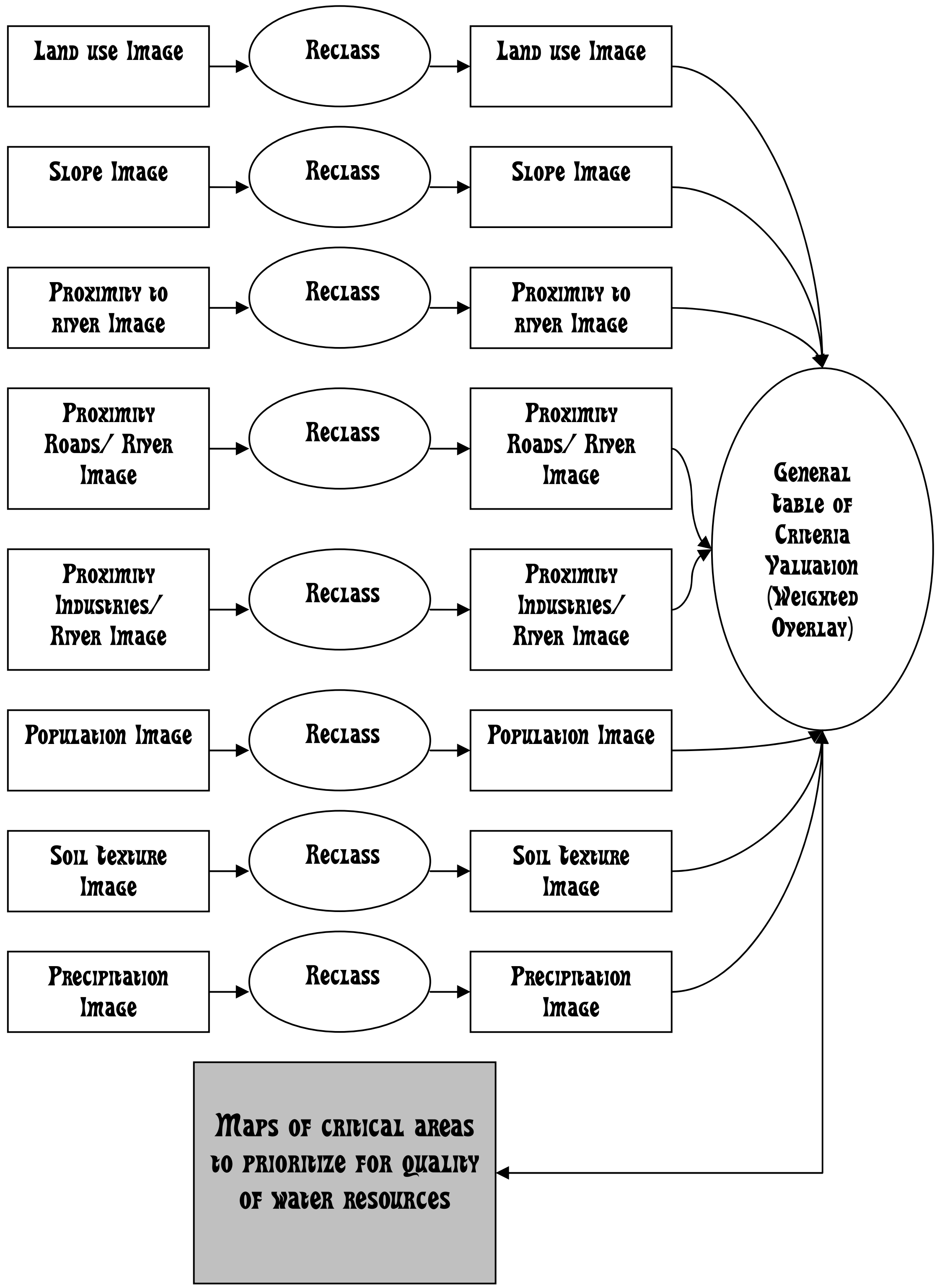



Figure 2 : Diagram of the model used to identify the critical areas to prioritize quality water resources

management

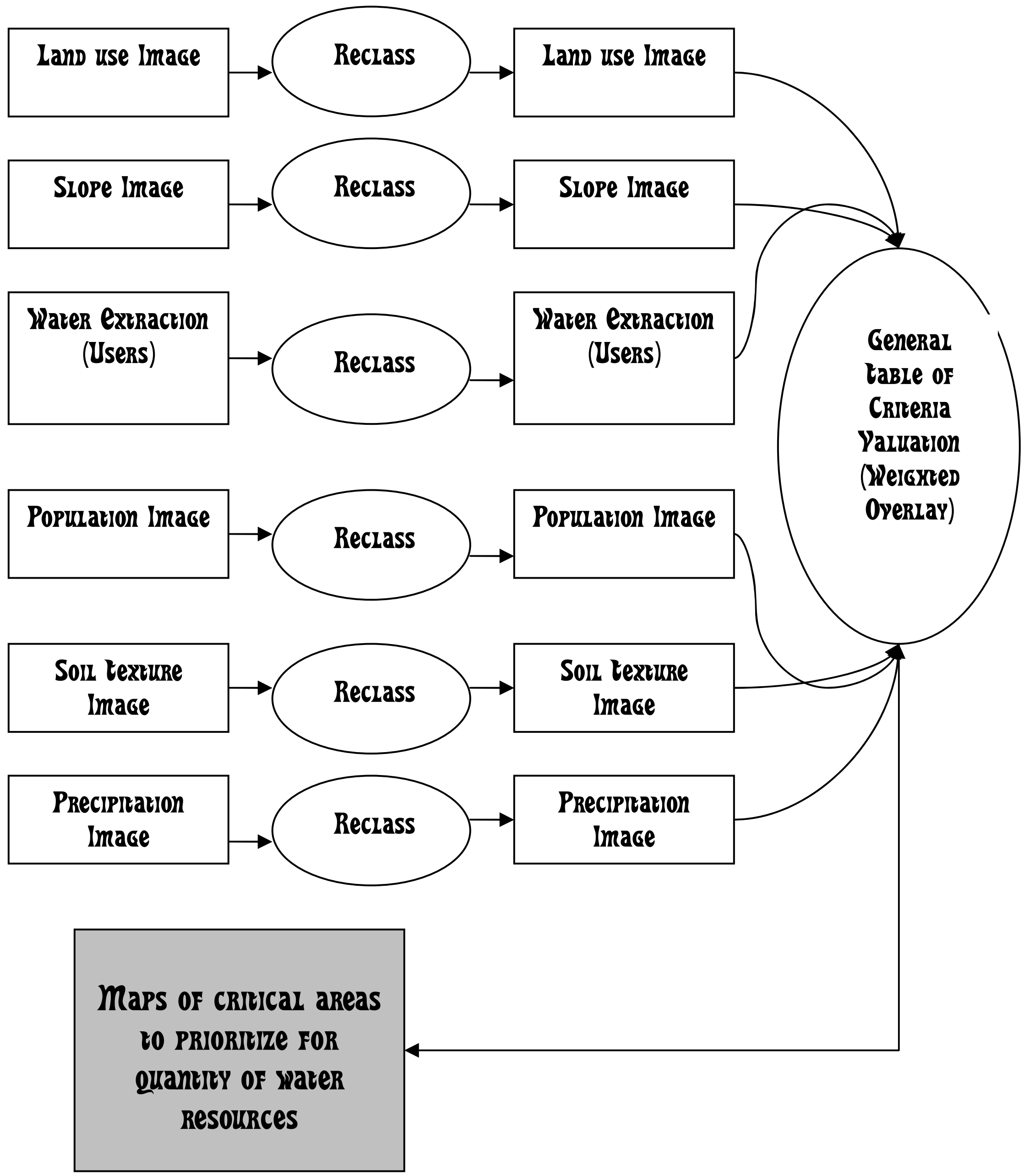



Figure 3 : Diagram of the model used to identify the critical areas to prioritize quality water resources management

After running the digital models, images of the study areas with the score of every pixel were created. Therefore, the results of the Multi-Criteria Analysis using the Model Builder are two maps, one for the quality and one for the quantity.

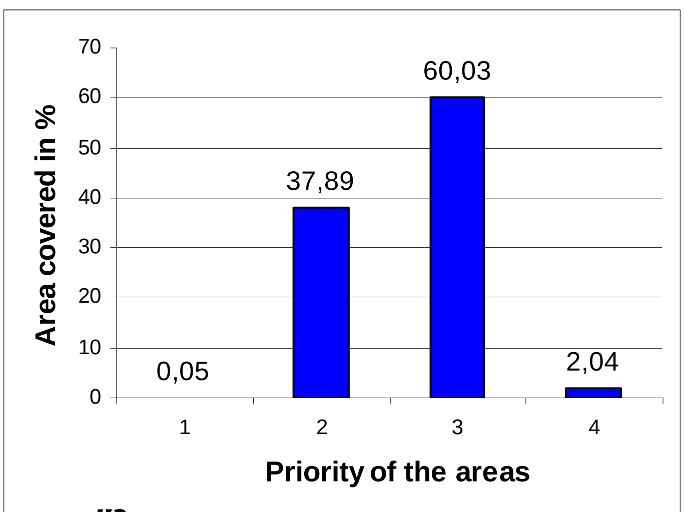
### 5.3 Analysis of the results of the model of prioritization of critical areas for water resource management

Since the reclassification of the attributes was on a scale of 1 to 5, the results given by this Multi-Criteria Analysis using the Model Builder are also with the same scale. The higher the score, the higher is the priority in the area. Therefore, the categories are (1) very low priority area, (2) low priority area, (3) intermediate priority area, (4) high priority area and (5) very high priority area. Areas in category 3 to 5 are considered as critical areas to prioritize for water resources management. Indeed, areas in intermediate priority are the areas most likely to become high priority areas in the future.

#### 5.3.1 Water Quality

The results obtained by using the model to prioritize critical areas in the management of the quality of water resources in the watershed of La Villa River show very few areas that have very low priority. Those regions are comprised in a national park and the integrity of the bio-physical factors is most likely conserved. Approximately 40% of the watershed is qualified as low

Table 23 : Relative distribution of the priority areas for the management of the quality of the water resources



priority. The category where most of the area falls into is the intermediate priority category. Finally, only 2% of the watershed are high priority areas. The areas considered as critical and that need to be prioritized for management of the quality of water resources represent over 60% of the total area of the watershed. The results are presented on a graphical form in Table 22 and as images in Figure 4.

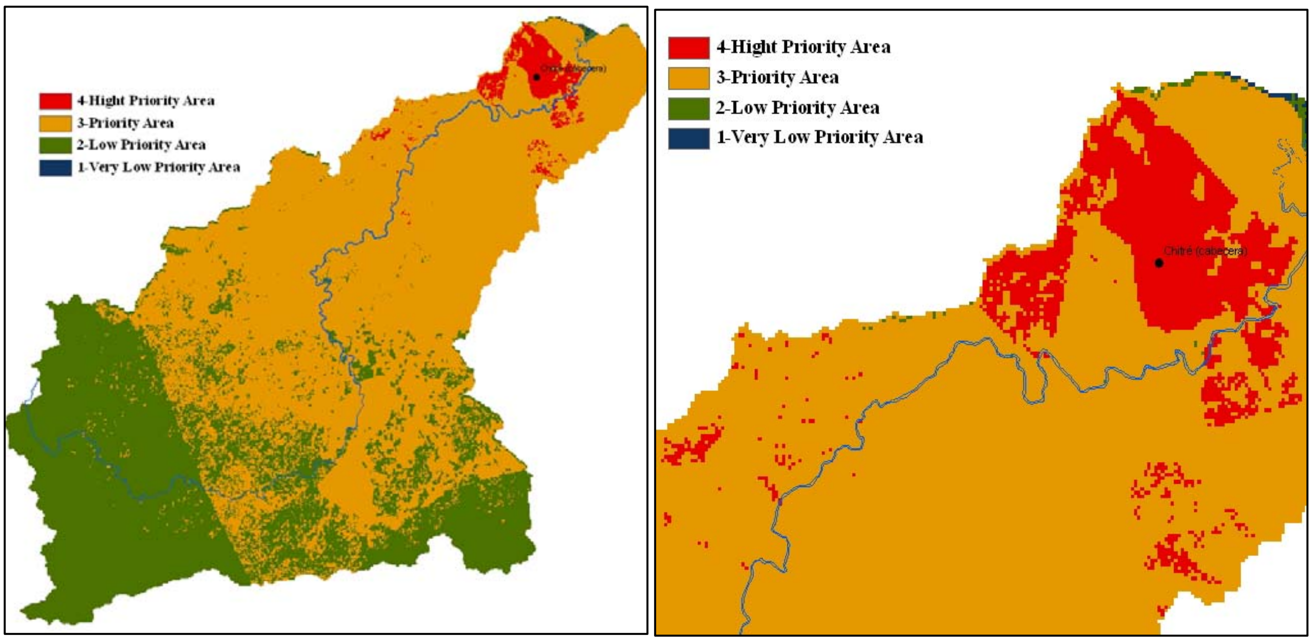
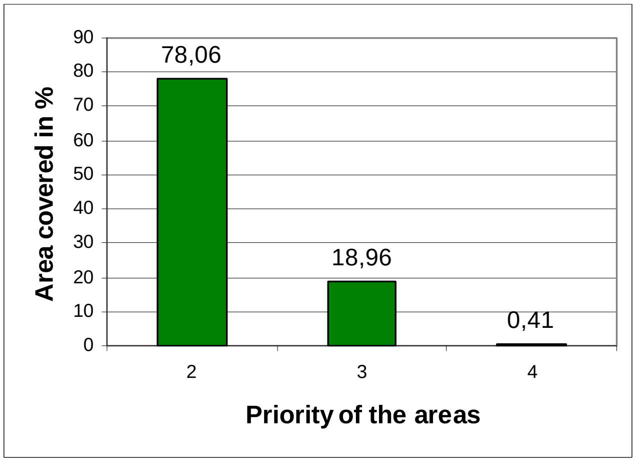



Figure 4 : Priority areas for the management of quality of water in the watershed of La Villa River

### 5.3.2 Water Quantity

Table 24 : Relative distribution of the priority areas for the management of the quantity of the water resources




The results obtained for the analysis of the priority areas for the management quantity of water resources in the watershed of La Villa River show quite different results. In this analysis, no areas have been identified as very low priority. Most of the watershed is characterized as low priority areas; indeed, this category is in over 60% of the watershed. Less than 20% of the watershed is qualified as intermediate priority areas and the percentage of areas of high priority to be managed is very small. The results are presented on a graphical form in Table 23 and as images in Figure 5.

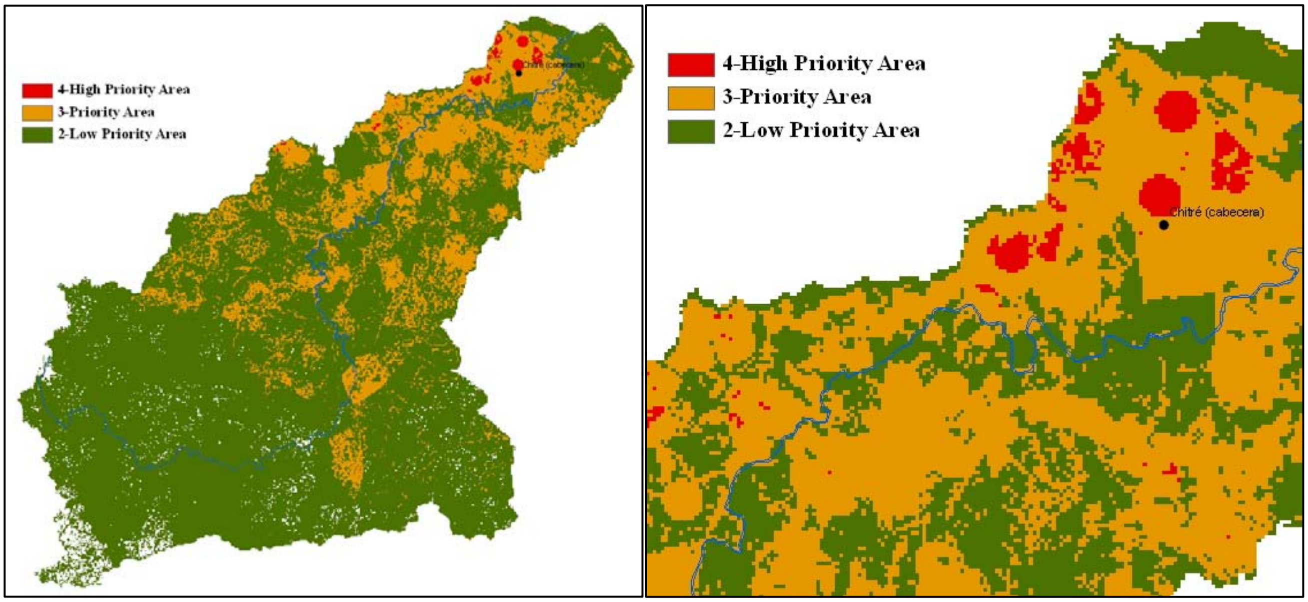
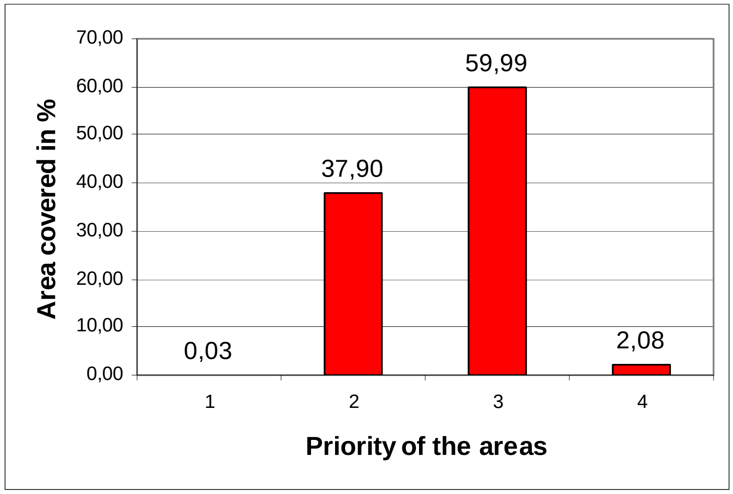



Figure 4 : Priority areas for the management of quantity of water in the watershed of La Villa River

### 5.3.3 Final result

The last step of the analysis was the overlay of the map of areas to prioritize for management of quality water resources and quantity water resources. The final results are presented in Table 24 and Figure 4. In the watershed of La Villa River, over 60% of the area should be considered as critical areas that need to be prioritized for water resource management in order to ensure a continuous supply of quality water in the present and in the future.

Table 24 : Relative distribution of the priority areas for the management of the water quality and quantity



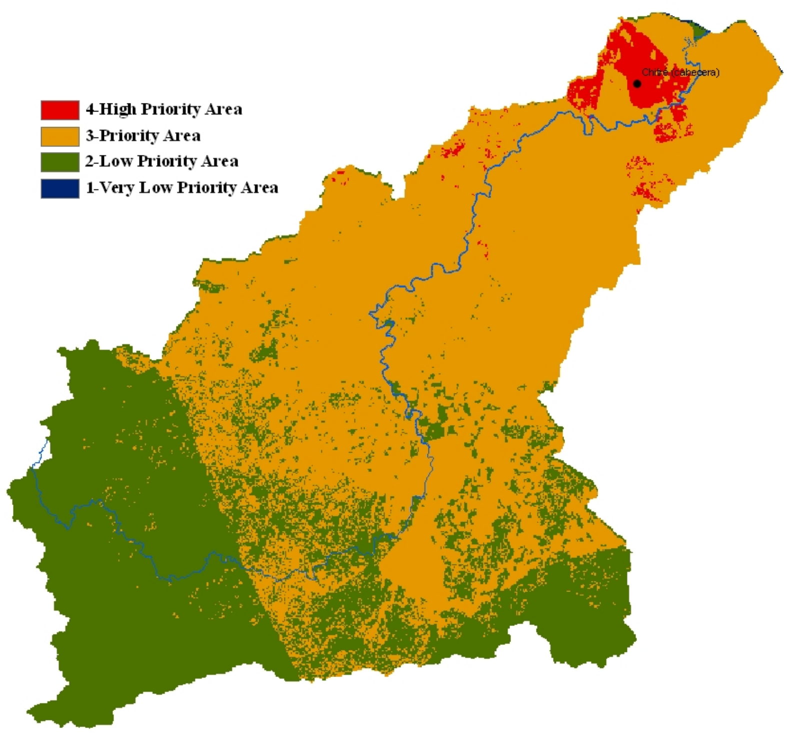




*Figure 5*: Priority areas for the management of water quality and quantity in the watershed of La Villa River

## 6.0 DISCUSSION

The most fundamental limitation encountered in developing and executing the project was the time factor. Different steps like information gathering, validation of the collected information, defining useful criteria, conducting surveys and finally creating maps had to be integrated into one project. That imposed the difficulty of uncertainty in the amount of time that was needed for each step, especially since the research was conducted in another country where processes and problems are handled in a different way. While it is common in North America to obtain information by email or phone, it was noticed that the personal contact is a crucial part in the information gathering process in Panama. For instance, none of the surveys that were sent to people which were not visited before were sent back. Therefore, much more time had to be scheduled in order to actually go to all the institutions in order to collect information and later conduct the survey. Therefore, defining our project, deciding which steps could actually be done and finally redefining certain parts of the project due, for instance, to lack of time or unavailability of data, took itself a large amount of the time that was actually available for the project. In fact, the unavailability and distribution of data over different institutions imposed the second largest limitation in executing the project. The data collection was mainly concerned with the extraction of water in the watershed. Concerning the distribution of data, information had to be collected at four different institutions, namely the Ministry of Health (MINSA), the Ministry of Development and Agriculture (MIDA), the Institute of Aqueducts and Drains (IDAAN) and the National Authority of the Environment (ANAM). The missing cooperation between those institutions, in between the different branches of one institution and even in between one single branch presented large impediments.

The unavailability of data was mainly due to missing monitoring by those institutions. According to employees this is due to a shortage of staff and financing by the government. Thus, there was data available for how many wells were made and how much water the owners were allowed to take out, but no data exists of the actual extraction of water. Moreover, according to the employees of MINSA and IDAAN in Chitre there is a huge amount of water taken illegally. This lack of information has influence on our final product since we do not know how much water is actually taken in which area so that the criterion of water extraction might be very inaccurate. Moreover, there was no data available concerning concessions for water and wells established for the Southern part of the watershed. Therefore, the results of low prioritization in this area could change when those data become available. Similarly, the criterion of 'Proximity of the river to industries/agro-industries' was affected by this lack of information. Nevertheless, there are two forest reserves located within the area of low prioritization which might be an indicator that the obtained results reflect the actual condition of the watershed.

Another important factor concerning the criterion of water extraction is that the chosen attributes were not very comprehensible for the experts interviewed. Instead of dividing the categories in terms of liter per day, a division into the percentages of water taken from the total amount available in the watershed would have been much easier to understand and would have made the evaluation process much more accurate. Unfortunately the water balance is not available for the watershed of La Villa River so that the total amount of water available in the watershed is not known.

Similarly, the criterion of run-off water is essential when analyzing the management needs of a watershed especially in terms of water quantity (ANAM, 2002). Unfortunately, the data for the run-off water within the watershed was obtained too late in order to include the run-off as one of the criteria for the survey. Since conducting the survey was very time-intensive it was not possible to repeat this process.

Another important criterion in terms of water quantity is evapotranspiration. Although this data was available in time to be included in the survey it was decided against since there were only differences of about 200 mm per year found in between the different areas within the watershed. Furthermore, no information was available concerning treatment facilities of water that goes back into the river. The different IDAAN branches within the watershed could only provide data concerning facilities that treat water that is taken out of the watershed in order to obtain drinking water. Moreover, there is no monitoring of the different sites where waste water goes back into the river. This information would have been very important in terms of quality of water. Thus it must be taken into account when interpreting our results that this important factor is missing.

Concerning the use of ArcGIS 9.2., some problems have been encountered.

One of the main difficulties was the application of the Model Builder, although using this program to realize the analysis is very advantageous since it allows to build a model in which the components can afterwards be revised and modified.

Moreover, technical problems like creating buffer zones around rivers due to their complex network represented an impediment in terms of the amount of time that had to be devoted. In fact, for the criterion of ‘proximity to the river’ only two buffers instead of six could be created. Nevertheless, the buffers created cover the more important area within 100 meters from the river so that at least those areas could be included into the evaluation process that had been valued as very high and high priority areas. Still, those areas that have been given a value of three are missing in the final maps obtained. A different result could therefore be possible after the creation of the missing buffers.

Moreover, the resolution of the data and the transformation into raster reduces the precision of the data which could also be a source of error.

Finally, the application of MCA has been proven to be very useful in terms of rating the different criteria since the standard deviations of every value were half as much as the actual percentage given. That means that the experts had very different opinions about the weights of different criteria which is the reason why MCA should be done rather than just using the evaluation of one single person or a small group of persons (CIFOR, 1999). Nevertheless, more people should probably be interviewed so that the standard deviation will eventually become smaller. Moreover, the survey should have been tested for a few people before it was sent out to all the interviewees in order to make sure that all the formulations are clear and the information complete. More specifically a descriptive section on the characteristics of every criterion should be included instead of assuming that local experts know the region. In the beginning it was assumed that such a section would have influenced people too much in their opinion formation, but with the benefit of hindsight it would have been useful in order to make the evaluation more precise.

Moreover, for the criterion of land use, problems have been encountered in the evaluation process. It was recommended by respondents to divide the category of 'agropecuario,' which includes cattle ranching and agriculture, as one attribute. The impacts of cattle ranching and agriculture are quite different from each other, especially in terms of the application of chemicals. However, even in between agricultural practices those differences assist because some crops are less chemical and input intensive than others. Unfortunately, in this study it had to be relied on the map of the land use available in GIS.

In terms of the final result of priority areas an assumption was made that might need some testing in order to apply the used methodology to other watersheds in Panama. For instance, the combination of the quantity and the quality map was done counting both maps as 50 per cent. This assumption might differ depending on the conservation objectives that are connected to a water resources management project. Thus, the improvement of water quality could be seen as more important than the quantity of water because there might be enough water available. In such a case the map for water quality had to be worth at least 60 or 70 per cent compared to the map of water quantity.

## 7.0 RECOMMENDATIONS

The experiences made in conducting the project showed that a better cooperation between the institutions, namely MIDA, MINSA, ANAM and IDAAN could facilitate the information collecting process for environmental management projects considerably.

At the moment there is almost no exchange of data taking place between the different institutions. Instead, data needed has to be purchased from one institution by another one.

Therefore, it is proposed here to establish a centralized information gathering facility to which every institution has access. Moreover, information that is collected by governmentally financed institutions should be accessible to every person in the country.

Considering the observed shortages in monitoring the extraction of water from the river and wells, more financial support of the responsible institutions by the government could probably highly improve this situation. That would, in turn, also make effective water management possible since it is difficult to find areas that need prioritized management if one of the most important factors, the actual water extraction, cannot be accurately estimated. For this reason, GPS mapping should be applied as part of the project since there is no data available about constructed wells in the South of the watershed. Moreover, an integrated water resource management approach should put more emphasis on social factors and people's needs.

Therefore, the social dimension should be considered more during the decision process of which criteria to use. Thus, the actual demand, that is the water which people need to maintain their families in terms of potable water and the water that is needed for irrigation and other agricultural and industrial uses, cannot be evaluated by obtaining information on the number of wells in the area. On one hand, that is due to the illegal take of water, but on the other hand, not having a well in the area can also mean that people do not have the money to pay for the construction of the well or are simply used to taking water directly out of the river. Therefore, an interrogation of the population of the area about their demand of water and the problems encountered within the watershed might help in establishing better and more suitable criteria that moreover integrate the local population into the process of management which might make them also more susceptible to the conservation of water within the area (Curtis et al., 2005). In conclusion, the choice of the criteria that will be used in the evaluation process is crucial in terms of the identification of prioritized areas. Many more criteria could have been used (see Sanchez, 2002) , but a decision had to be made. In order to find those criteria that are the most important within the watershed it might be beneficial to arrange a workshop where experts from different fields of studies come together and discuss the relevance and the valuation of those criteria.

Taking into account the illegal extraction of water, environmental education programs should be developed that inform people about the consequences of excessive take of water. Furthermore, education is needed in terms of contamination of waterways, especially caused by trash.

Based on the findings that there are no waste water treatment facilities within the watershed, money should be invested in establishing a suitable infrastructure in order to enhance the water quality and ensure a future use of the watershed.

Reforestation is another factor in enhancing water quality but also quantity. Since especially the areas close to the river are very vulnerable, reforestation projects along the banks could improve the state of the watershed (Sanchez, 2002).

In terms of the management of the watershed of La Villa River, it is proposed here to put special emphasis on the area around Chitre and further down to about two thirds of the watershed. All in all, about 60% of the area should be prioritized in terms of water resource management.

## 8.0 CONCLUSION

All in all, this study can be used first as an approach to the development of the proper methodology of how to find priority areas within watersheds in Panama. It turned out that the definition and the initial finding of the criteria is a crucial part of such a project. Thus, big effort should already be put in at the initial steps by consulting different experts in order to find suitable criteria. Moreover, the active collection of data in the field, probably involving GPS referencing, will probably form an integral part of such a project due to the unavailability of such data in Panama.

The priority areas found through the methodology applied, show results that had been expected before since the main areas of prioritization are found within the area of Chitre, the largest town of the watershed which is also the most developed with the biggest infrastructure. Thus, more than 60% of the watershed should be prioritized in terms of water resource management. This area reaches from the North of the watershed down to two thirds of the watershed. Within the area that was rated low priority area two forest reserves can be found so that these results seem to be reasonable.

## 9.0 ACKNOWLEDGEMENTS

First of all we would like to thank our supervisor Noel Trejos for providing us with the basic structure of this project. Especially we want to thank all the employees of CATHALAC that have been very helpful whenever their advice was needed. Moreover, we acknowledge the great participation concerning our survey. Without the help of students, University professors, employees of ANAM; MINSA, MIDA, IDAAN and ETESA this project could not have been realized. A special thank you goes to Ivan Jaramillo from ETESA who provided us with precious data of precipitation for the area of the watershed of La Villa River and was always available for consultation and advice. Another thank you goes to Engineer Camilo A. Caballero and his team for their hard work and warm welcome. Furthermore, we thank Senor Rincon and his colleagues who even managed to come to our final presentation.

Last but not least, we want to thank McGill University, especially our supervisor Roberto Ibanez and the teaching assistant Santiago Gonzalez for their helpful comments.

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# 11.0 APPENDICES

## 11.1 Appendix 1- Chronogram of Activitis

### Febrero/ February

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | 1 | 2 |
| 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| | Class | Class | Class | **GIS**<br>-Inventory of information given by Cathalac<br><br>**Internet** (what information we have access to?)<br>-Census<br>-Organizations (MIDA, ANAM, IDIAP, MINSA, CATHALAC) | **GIS**<br>- Merge point data given by Cathalac together<br>- Create one satellite image out of the 3 images<br><br>**Determine sub-basin** | **Lit Review**<br>-To identify criteria of priorization<br>- Vulnerability indices for rivers<br>- River impatcs by land-use/ water-use, - Integrated water resource management<br><br>**Work on Plan de trabajo** |
| 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| **Lit Review**<br><br>**Work on Plan de trabajo** | Class | Class | Class<br><br>**Plan de trabajo due** | **Determine sub-basin**<br><br>**Database**<br>- Add census data to the database (objective 1) | **Field Work preparation**<br>- Missing information<br>- Organization to visit<br><br>Discuss with Noël<br>- Criteria identified<br>- Plan de trabajo | **Lit Review**<br><br>**Identify criteria** |
| 24 | 25 | 26 | 27 | 28 | 29 | |
| | Class<br><br>**Discuss plan de trabajo with TA** | Class<br><br>**Adjust Plan de trabajo** | Class | **Campo with Noël**<br>- Visit the institutions<br>- Ask for missing data<br>- Verify and compare with available data<br>-GPS? | **Campo**<br>(objective 1) | |

**Marzo/ March**

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | 1 |
| 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| **Clearly identify criteria** | Class | Class | Class<br><br>(Paper and diary due in Geog- 498) | **Database**<br>- Verify/ Compare data<br>- Add data to the database (objective 1)<br>- Classify information (objective 2) | **Database**<br>- Add data to the database (objective 1)<br>- Classify information (objective 2)<br><br>**Identify what information is missing** | Field Trip preparation |
| 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Leave to area of study | **Campo**<br>- Visits of institutions<br>- Verify/ Compare information (objective 1) | **Campo**<br>-Visits of institutions<br>- Verify/ Compare information (objective 1)<br><br>Back to Panama city | **Database**<br>-Add data to the database (objective 1)<br>-Classify information (objective 2) | **Database**<br>-Add data to the database (objective 1)<br>-Classify information (objective 2)<br><br>**GIS**<br>**-** Create maps available data | **GIS**<br>- Map of water disponibility per months, per year and per corregimiento for the studied region<br>- Map of water demand (with available data and interpolation)<br>- Map of water scarcity | Going to Cathalac for GIS analysis if needed |
| 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| Prepare informal presentation | Class 3 | Class 3<br><br>Prepare informal presentation | Class 3<br>(out of city) | **Informal presentation**<br>(Comments from teachers and class about project) | no internship | Semana Santa |
| 23 | 24 | 25 | 26 | 27 | 28 | 29 |
| Semana Santa | Class 3<br>(out of city) | Class 3<br>(out of city) | Class 3<br>(out of city) | Class 3<br>(out of city) | Class 3<br>(out of city) | Class 3<br>(out of city) |
| 30 | 31 | | | | | |
| Class 3<br>(out of city) | Class 3 | | | | | |

**Abril/ April**

| | | | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| | | Class 3 | Class 3<br>(out of city) | Adjust project with comments received from the informal presentation<br><br>Meeting with Noël to discuss adjustment and other concerns | **GIS analysis**<br>- Analysis of water quantity<br>- Analysis of water quality (is data are available)<br>- Map showing each criterias of priorization | Project report |
| 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Project report | **GIS analysis**<br>- Analysis of water quantity<br>- Analysis of water quality (is data are available)<br>- Map showing each criterias of priorization | **GIS analysis**<br>- Analysis of water quantity<br>- Analysis of water quality (is data are available)<br>- Map showing each criterias of priorization | **GIS analysis**<br>- Multivariable criteria analysis | **GIS analysis**<br>-Multivariable criteria analysis | **GIS analysis**<br>-Multivariable criteria analysis | Project report |
| 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| Project report | **GIS**<br>- Final results about criterias to priotize water management ar the studies region scale, whole river scale, arco seco scale and/or countru scale (depends on info found and time)<br>- Creating final maps (maps of areas to priotize) | **GIS**<br>- Final results<br>- Creating final maps | **GIS**<br>- Final results<br>- Creating final maps | **GIS**<br>- Final results<br>- Creating final maps | **Writing report/ Symposium Preparation** | **Writing report/ Symposium Preparation** |
| 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| **Writing report/ Symposium Preparation** | **Writing report/ Symposium Preparation**<br>- Powerpoint presentation preparation | **Symposium preparation**<br>- Powerpoint presentation preparation<br>- Presentacion practice | **Symposium and clausure ceremony** | **Report** | **Project report due** | |

### 11.2 Appendix 2- Budget

*Table 25 Budget for two persons in $*

| | Amount in $ |
|---|---|
| Accomodation | 48 |
| Transportation (Bus, Taxi) | 75 |
| Photocopies, Phonecards | 8 |
| Food | 55 |
| **TOTAL** | **186** |

### 11.3 Appendix 3- Survey

**Encuesta para valorar criterios que permiten la identificación de áreas criticas para el manejo del recurso hídrico en la cuenca del Rió La Villa, Panamá**

Kati Wenzel y Kim Gauthier Schampaert
En colaboración con CATHALAC, Panamá y McGill University, Canadá

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Esta encuesta es parte de una investigación para la identificación de áreas criticas para el manejo del recurso hídrico en la cuenca del rió La Villa. Este proyecto es para una pasantía que estamos realizando en colaboración con CATHALAC, el Centro del Agua del Trópico Húmedo para América Latina y el Caribe. Esta pasantía es parte de un semestre de campo en Panamá para los estudiantes de la universidad McGill en Canadá.

El estudio de identificación de áreas prioritarias de manejo del recurso hídrico en la cuenca del rió La Villa se realizara con la evaluación de ocho criterios para la calidad del agua y seis criterios para la cantidad aprovechable de agua en la cuenca.

Queremos poner una ponderación entre los criterios tomando en cuenta la opinión de personas con distintos conocimientos y trabajando en diferentes áreas. Nos gustaría si ustedes pueden poner un peso a cada criterio y validar los criterios de para priorizar áreas criticas. También se puede proponer criterios adicionales.

La valoración de los criterios se realiza asignando un porcentaje de 1 a 100 según la importancia de los criterios, donde el peso el más alto representa la mejor importancia para el manejo del recurso hídrico. Por ejemplo, si para usted la precipitación esta un criterio mas importante que la pendiente, se puede poner un peso de 45 % a la precipitación y un porcentaje menor a la pendiente, como 20 %. Lo importante es de llegar a un 100% cuando se adiciona los pesos de los criterios para la calidad del agua y lo mismo para la cantidad del agua.

La valoración de parámetros a dentro de cada criterio se realizó con número enteros de 1 a 5 donde el valor más bajo indica menor importancia en el manejo del recurso hídrico. Esta etapa ya esta hecha pero lo vamos a ajustar tomando sus consejos. Se puede validar los criterios y proponer criterios adicionales, o diferente ponderación.

Solicitamos su colaboración para completar el documento siguiente para valorar los criterios para priorizar áreas críticas. Pueden proponer cualquier cambio y exponer sus observaciones sobre el tema. Tomaremos todos los comentarios en cuenta. Para cualquier pregunta o comentario, y para devolver el formulario en formato electrónico, por favor de contactarnos vía e-mail.

Muchas Gracias.

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Kim Gauthier Schampaert (kim.gauthierschampaert@mail.mcgill.ca)

**Valoración de los criterios para priorizar áreas criticas para la calidad de agua en la cuenca Río La Villa**

| Criterios (Capa de información) | % | Categorías | Atributos | Valores |
|---|---|---|---|---|
| Uso de suelo | | 1 | Bosque Intervenido | 3 |
| | | 2 | Bosque Maduro | 1 |
| | | 3 | Manglar | 1 |
| | | 4 | Otros Usos (urbano; industrial) | 5 |
| | | 5 | Bosque Pionero | 2 |
| | | 6 | Uso Agropecuario intensivo | 5 |
| | | 7 | Uso Agropecuario de Subsistencia | 3 |
| | | 8 | Vegetación Baja Inundable | 2 |
| | | | | |
| Pendiente (en grados) | | 1 | 0 - 3 | 1 |
| | | 2 | 3 - 8 | 1 |
| | | 3 | 8 - 15 | 3 |
| | | 4 | 15 - 30 | 4 |
| | | 5 | 30 - 50 | 5 |
| | | 6 | 50 - 75 | 5 |
| | | | | |

| | | | | |
|---|---|---|---|---|
| Proximidad al río (en metros) | | 1 | 0 - 50 | 5 |
| | | 2 | 50 - 100 | 4 |
| | | 3 | 100 - 300 | 4 |
| | | 4 | 300 - 500 | 3 |
| | | 5 | 500 - 1000 | 2 |
| | | 6 | 1000 - 5000 | 1 |
| | | | | |
| Proximidad del río al camino (en metros) | | 1 | 0 - 50 | 5 |
| | | 2 | 50 - 100 | 5 |
| | | 3 | 100 - 300 | 4 |
| | | 4 | 300 - 500 | 4 |
| | | 5 | 500 - 1000 | 3 |
| | | 6 | 1000 - 2000 | 1 |
| | | | | |
| Proximidad del río a las industrias/ agro-industrias (en metros) | | 1 | 0 – 50 | 5 |
| | | 2 | 50 – 100 | 5 |
| | | 3 | 100 – 500 | 4 |
| | | 4 | 500 – 1000 | 2 |
| | | 5 | 1000 - 3000 | 1 |
| | | | | |
| Población (personas) | | 1 | 0 – 75 | 1 |
| | | 2 | 75 – 250 | 2 |
| | | 3 | 250 – 500 | 2 |
| | | 4 | 500 – 775 | 3 |
| | | 5 | 775 – 1500 | 3 |
| | | 6 | 1500 – 5000 | 4 |
| | | 7 | 5000 – 20000 | 5 |
| | | | | |
| Textura del suelo | | 1 | Franco grueso | 3 |
| | | 2 | Franco arenosa | 3 |
| | | 3 | Arenosa | 3 |
| | | 4 | Esqueleto arcilloso | 2 |
| | | 5 | Arcillosa fina | 2 |
| | | 6 | Arcillosa muy fina | 2 |
| | | | | |
| Precipitación (en mm/ano) | | 1 | 1275 – 1500 | 5 |
| | | 2 | 1500 – 1775 | 4 |
| | | 3 | 1775 – 2000 | 3 |
| | | 4 | 2000 – 2500 | 3 |
| | | 5 | 2500 – 3500 | 2 |

**Valoración de los criterios  para priorizar áreas criticas para la cantidad de agua en la cuenca Río La Villa**

| Criterios (Capa de información) | % | Categorías | Atributos | Valores |
|---|---|---|---|---|
| Pendiente (en grados) | | 1 | 0 - 3 | 1 |
| | | 2 | 3 - 8 | 1 |
| | | 3 | 8 - 15 | 2 |
| | | 4 | 15 - 30 | 4 |
| | | 5 | 30 - 50 | 5 |
| | | 6 | 50 - 75 | 5 |
| | | | | |
| Textura del suelo | | 1 | Franco grueso | 2 |
| | | 2 | Franco arenosa | 2 |
| | | 3 | Arenosa | 2 |
| | | 4 | Esqueleto arcilloso | 3 |
| | | 5 | Arcillosa fina | 3 |
| | | 6 | Arcillosa muy fina | 3 |
| | | | | |
| Toma de agua en litros/ dia (de todos los usos, incluido uso agropecuario, industrial) | | 1 | 10.000 – 50.000 | 2 |
| | | 2 | 50.000 – 0.1 milion | 2 |
| | | 3 | 0.1 – 0.5 milion | 2 |
| | | 4 | 0.5 – 1 milion | 2 |
| | | 5 | 1 – 5 miliones | 3 |
| | | 6 | 5 – 10 miliones | 3 |
| | | | | |
| Uso de suelo | | 1 | Bosque Intervenido | 2 |
| | | 2 | Bosque Maduro | 1 |
| | | 3 | Manglar | 1 |
| | | 4 | Otros Usos (urbano; industrial) | 5 |
| | | 5 | Bosque Pionero | 2 |
| | | 6 | Uso Agropecuario | 4 |
| | | 7 | Uso Agropecuario de Subsistencia | 3 |
| | | 8 | Vegetación Baja Inundable | 2 |
| | | | | |
| Precipitación (en mm/ano) | | 1 | 1275 – 1500 | 5 |
| | | 2 | 1500 – 1775 | 4 |
| | | 3 | 1775 – 2000 | 4 |
| | | 4 | 2000 – 2500 | 3 |
| | | 5 | 2500 – 3500 | 2 |
| | | | | |

| | | | | |
|---|---|---|---|---|
| Población (personas) | | 1 | 0 – 75 | 1 |
| | | 2 | 75 – 250 | 2 |
| | | 3 | 250 – 500 | 2 |
| | | 4 | 500 – 775 | 3 |
| | | 5 | 775 – 1500 | 3 |
| | | 6 | 1500 – 5000 | 4 |
| | | 7 | 5000 – 20000 | 5 |

## 11.4 Appendix 4 – Maps for each criterion

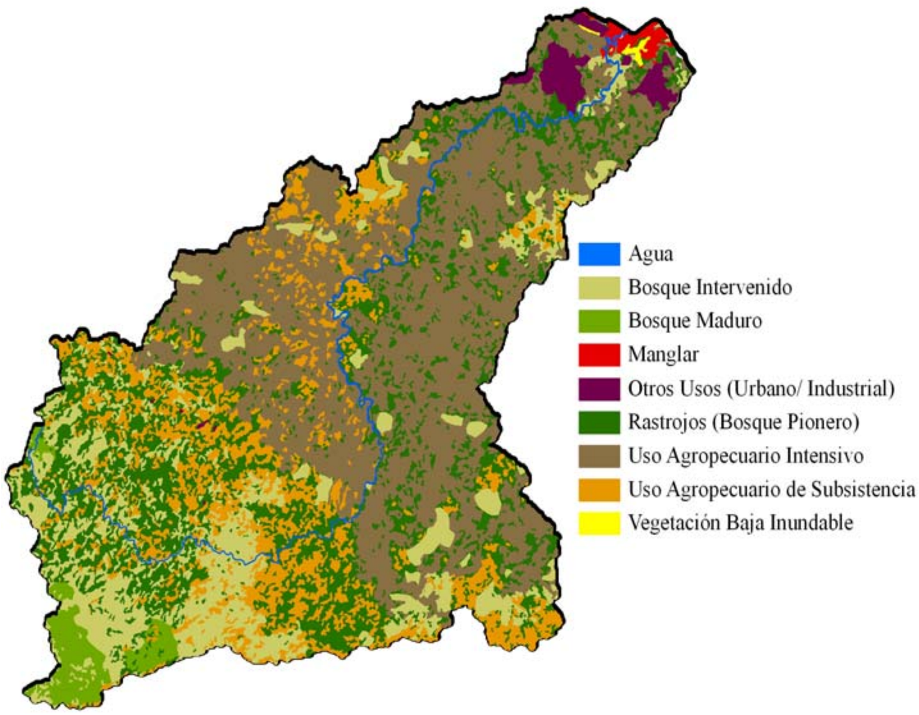


*Figure 6 Land use map*

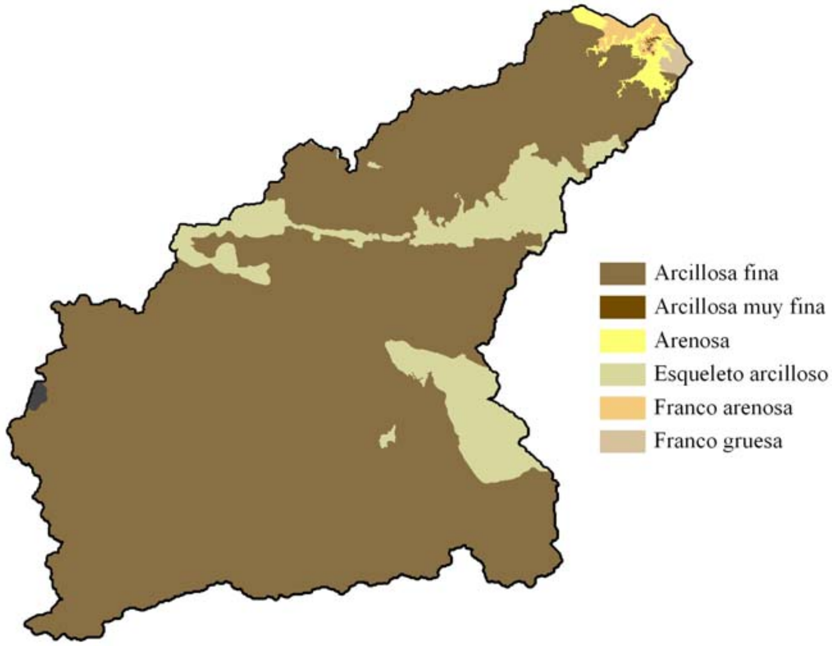


*Figure 7 Soil texture map*

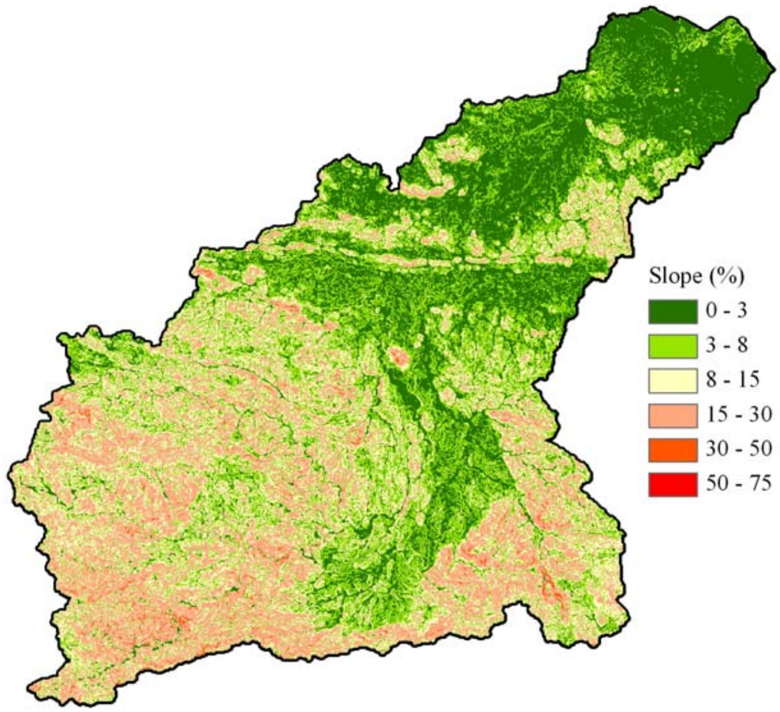


*Figure 8 Slope map*

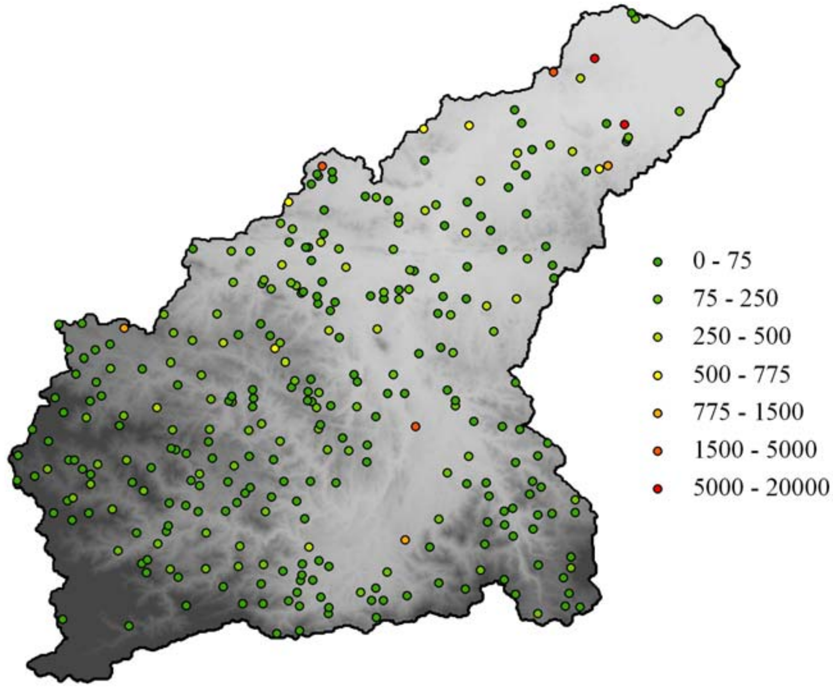


*Figure 9 Population*

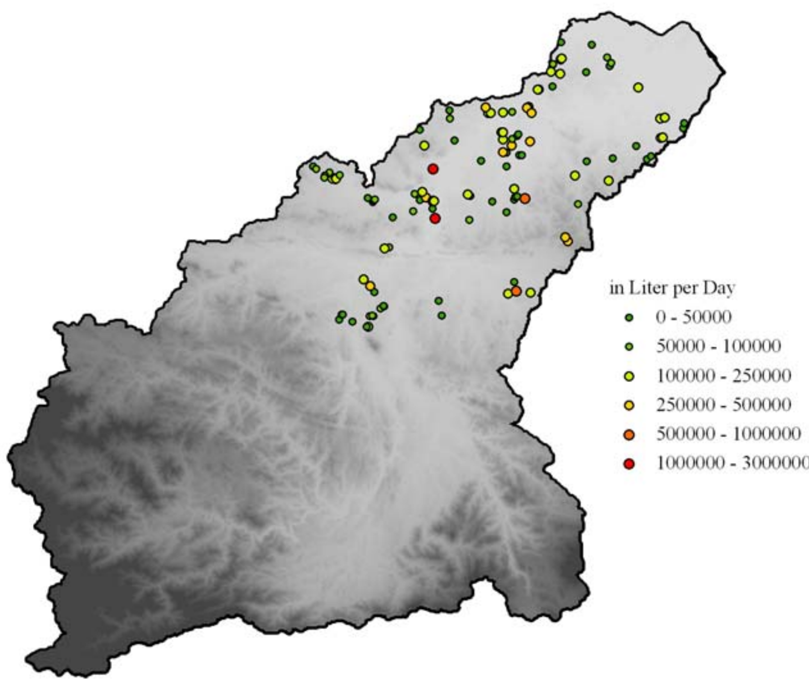


*Figure 10 Water extraction*

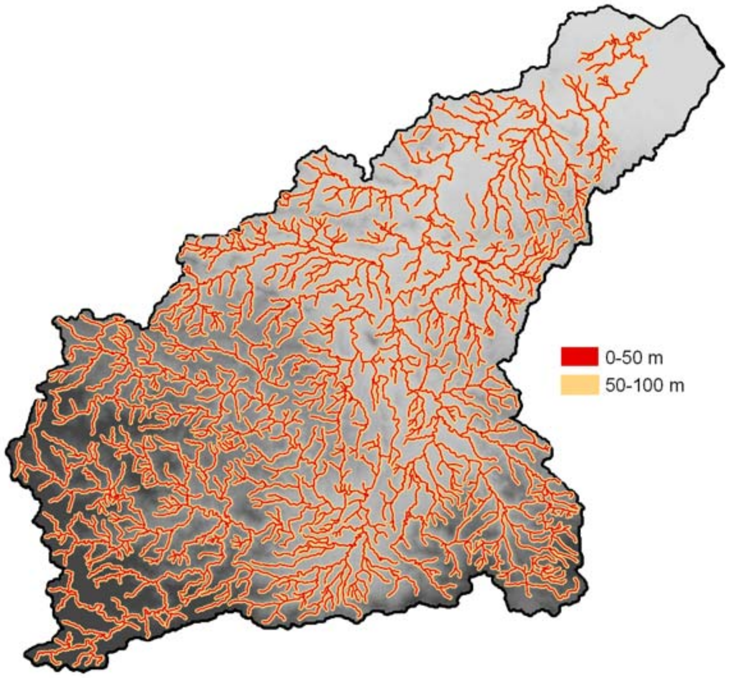


*Figure 11 Proximity to the river*

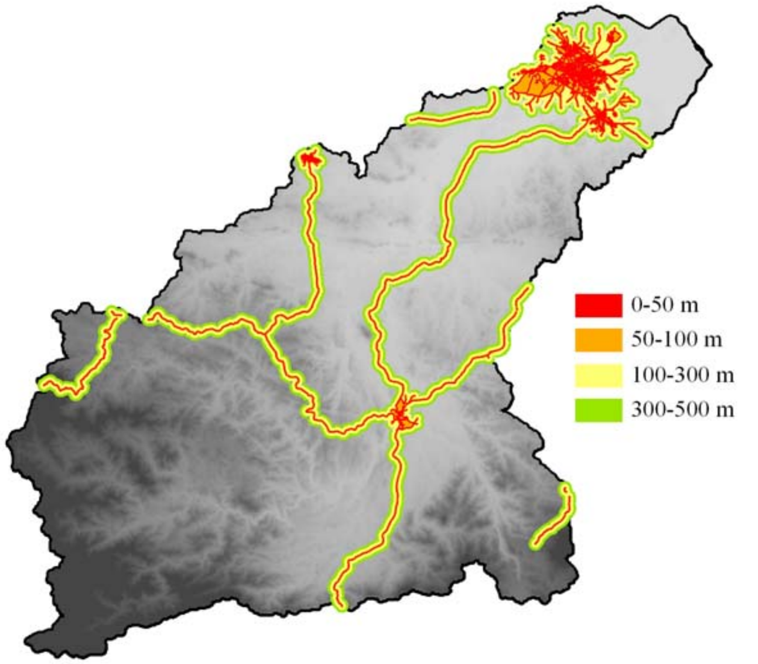


*Figure 12 Proximity of the river to roads*

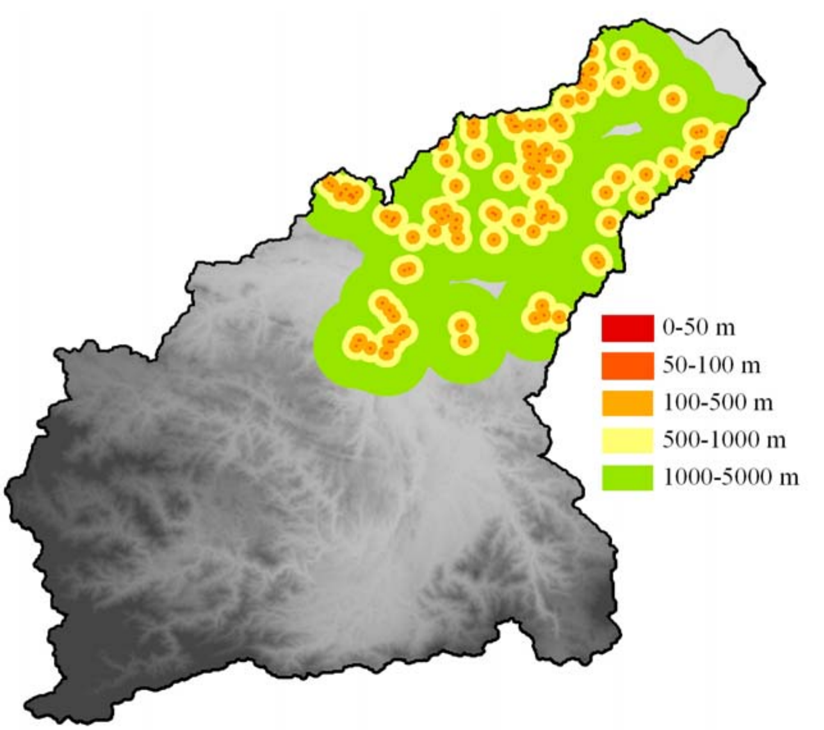


*Figure 13 Proximity of the river to industries/agro-industries*

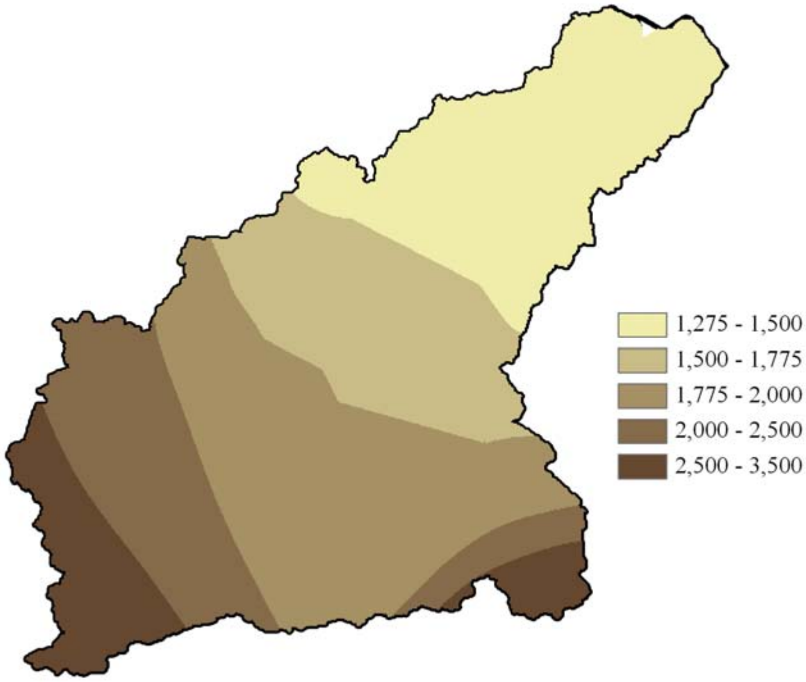


*Figure 14 Precipitation*