Gina-Lee Moreira

Licenciada em Ciências de Engenharia e do Ambiente

Fluvial System Restoration – Case Study: River *Tua*

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Abstract

The purpose of this thesis is to provide river basin managers with a framework for river restoration. To that end, it presents and discusses the relevant information on the current condition of the river *Tua,* in northern Portugal, and establishes what can be done to restore the river basin in order to protect the most important **drainage basin's functions** and ecosystems. It is intended that this thesis will serve as an example of the application of current knowledge on **freshwater restoration** which can be emulated by future managers in their efforts to restore this, or any water body they wish to.

To this purpose, the thesis analyzes **demographic data** on the municipalities of the *Tua* drainage basin. It discusses literature and research on the subject of river restoration and important river processes in the following chapter, so as to introduce important theory concepts to have in mind when designing any restoration efforts.

In its methodology, the techniques and data assessment tools used in the process of evaluating the river basin's conditions are described and defined, allowing interested managers to review and adapt to the specific needs of drainage basins anywhere.

Finally, it presents a practical point-of-view intended to be applied on other freshwater bodies. The thesis includes the realization of an assessment physical characteristics and status of the ***Tua* river reach**, it splits up the drainage basin into several different **sub-basins**, for individual study, and, after a discussion of the conclusions drawn from the assessment for the whole drainage basin, it presents arguments for choosing the sub-sections which present the highest risk to the drainage basin and, as such, require priority action. This section also includes a presentation of the arguments in support of **specific techniques** to be put into place, given the specific needs of the sub-basin and the restoration goals for the entire drainage basin.

Keywords: freshwater; restoration; vegetation; geomorphology; climate; *Tua*.

Resumo

Pretende-se com o presente trabalho recolher informação e analisar o estado da bacia hidrográfica do rio *Tua* e estabelecer o que deverá ser feito para restaurar o rio e proteger as **funções e processos da bacia hidrográfica** essenciais. A intenção é a de que esta tese sirva como exemplo e ponto de partida para a aplicação do conhecimento atual referente ao tópico de **restauro de água superficial** e que possa ser utilizada por futuros gestores nos seus esforços de restauração de este ou outros corpos de água.

Para este propósito, a tese apresenta e discute **dados demográficos** para os municípios da bacia hidrográfica do *Tua*, que precede uma revisão teórica da literatura sobre o tema da restauração de corpos de água, com o objetivo de dar a conhecer o conhecimento técnico e teórico mais recente no campo da gestão e restauração de corpos de água.

Na metodologia procede-se à enumeração e definição das ferramentas técnicas utilizadas na avaliação da bacia hidrográfica do Tua, possibilitando ao leitor que escolha e adapte as mesmas a qualquer outro corpo de água.

Finalmente, apresenta uma aplicação prática que pode ser aplicada a outras bacias hidrográficas. A tese inclui a realização de uma avaliação à bacia hidrográfica do *Tua* que inclui a separação da bacia hidrográfica em subsecções que são estudadas individualmente e, depois de apresentadas e discutidas as conclusões da avaliação da bacia hidrográfica, apresenta os argumentos que levam à escolha das subsecções que apresentam um maior risco para a bacia hidrográfica e que portanto requerem ações restaurativas. Esta última secção discute os argumentos que apoiam uma **seleção de técnicas específicas**, a ser utilizadas de acordo com as necessidades de cada sub-bacia e de acordo com os objetivos de restauração da bacia hidrográfica.

Palavras-Chave: rio; restauro; vegetação; geomorfologia; clima; Tua

Table of Contents

List of Figures

List of Tables

1. Introduction

Restoring a river to a functional state or even just acting to protect its current conditions requires a thorough analysis of drainage basin control processes, a successful communication between managers and stakeholders and decision makers, design a plan and objective that all parties can agree to and finally, apply the gathered information, support and knowledge into actions that will interact with river processes and require years of maintenance and close watch. River restoration is not a simple subject, and it may require a hefty amount of resources to take it to end.

What this thesis attempts to achieve is a contribution to the science of river restoration, by applying the concept to a particular Portuguese river, the river Tua, in northern Portugal, collecting the relevant information, developing the analytical tools necessary to the assessment of the drainage basin, discussing the most recent available literature in the subject and finally, identifying priority areas and ideal restoration practices to achieve the final goal: the protection of Tua's fauna and flora and the maximization of the river's services to residents with the drainage basin under study.

1.1 - Case Study Framework

The river *Tua* is a tributary to River *Douro*, one of the largest drainage basins in continental Portugal and the third longest river in the Iberian Peninsula. Figure 1 displays the location of the drainage basin of river *Tua* within the Iberian Peninsula.

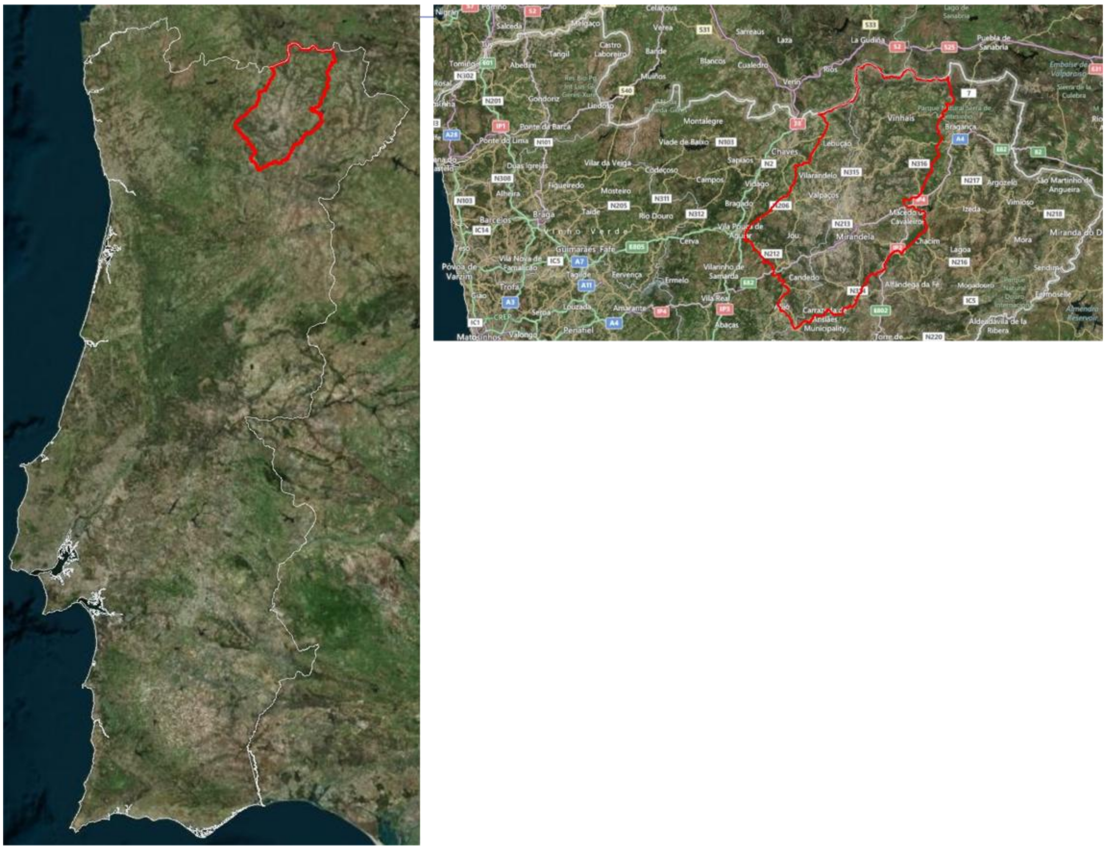

Figure 1. Location of the drainage basin under study (adapted from the Basemap component of ArcGIS (ESRI, 2013)).

River *Tua* is located in the northwestern region of Portugal, perpendicular to River *Douro* with a dominant North-South orientation. The river's drainage basin has a total dimension of 3123 km^2, with the *Rabaçal*, *Tuela* and *Tinhela* rivers as its main tributaries.

The longest waterway in the drainage basin is formed by the conjoining of river *Rabaçal* with river *Tua,* which starts a drainage with a basin length of 200 km. Furthermore the average width of the drainage basin is 44km.

The stream order of the drainage basin, valued at 4 and represented in figure 2, corresponds to a medium sized stream. As a basis for comparison, the Mississippi river, in the United States of America, for example, has a stream order of 10 (Sharp, 1970; Strahler, 1954).

The drainage basin is located within a mountainous region with a plateau at the centre of the basin. It has an average height of 509 meters.

There are a grand total of 12 counties that intercept the drainage basin. Figure 3indicates the location of the counties aforementioned. The biggest counties, in terms of occupied area, are *Vinhais*, *Mirandela* and *Valpaços* each smaller than the previous one and respectively occupying 23%, 21% and 17% of the drainage basin.

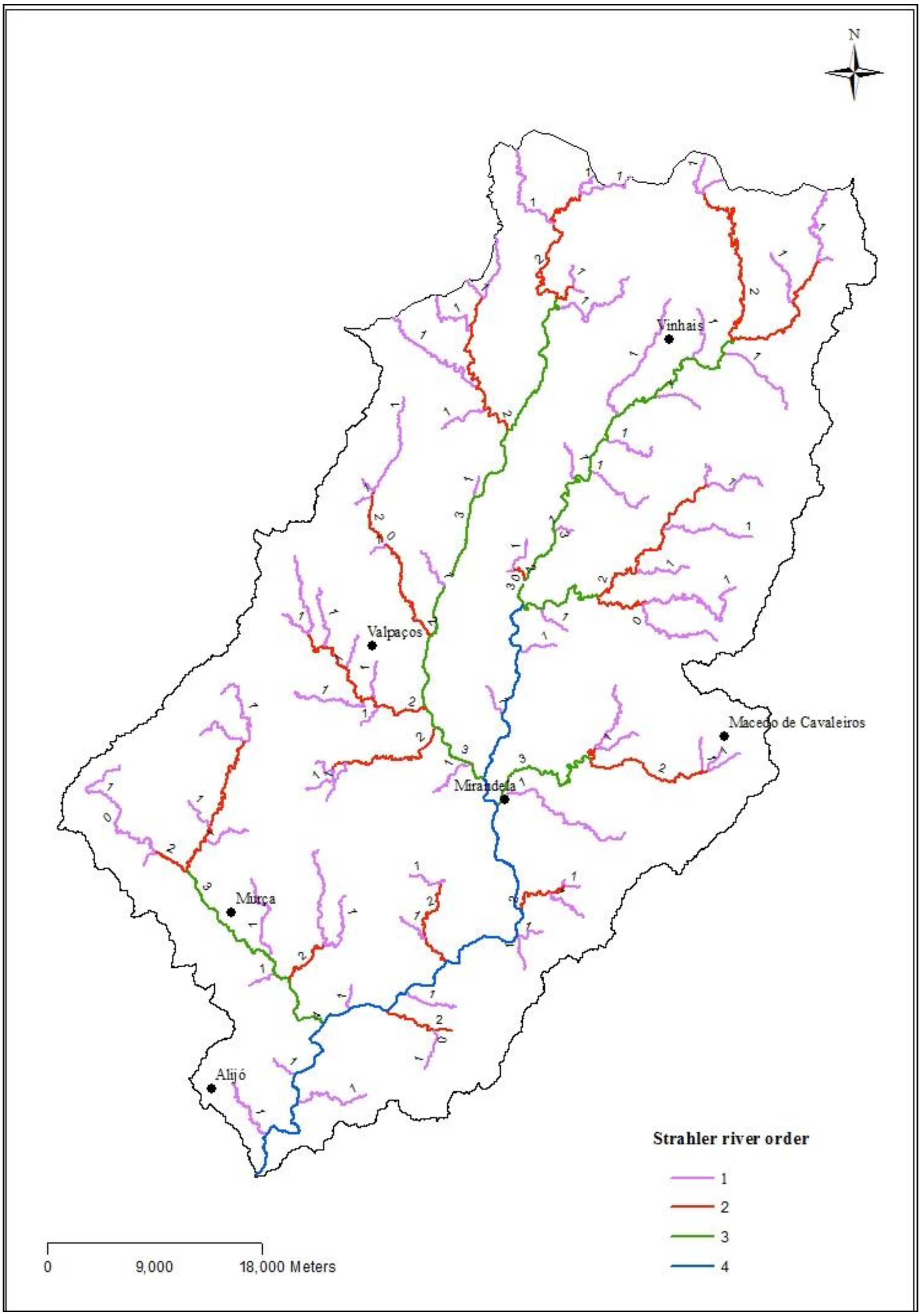

Figure 2. Strahler's order of the waterways throughout the drainage basin (adapted from SNIRH (2013) by application of ArcGIS (ESRI, 2013)).

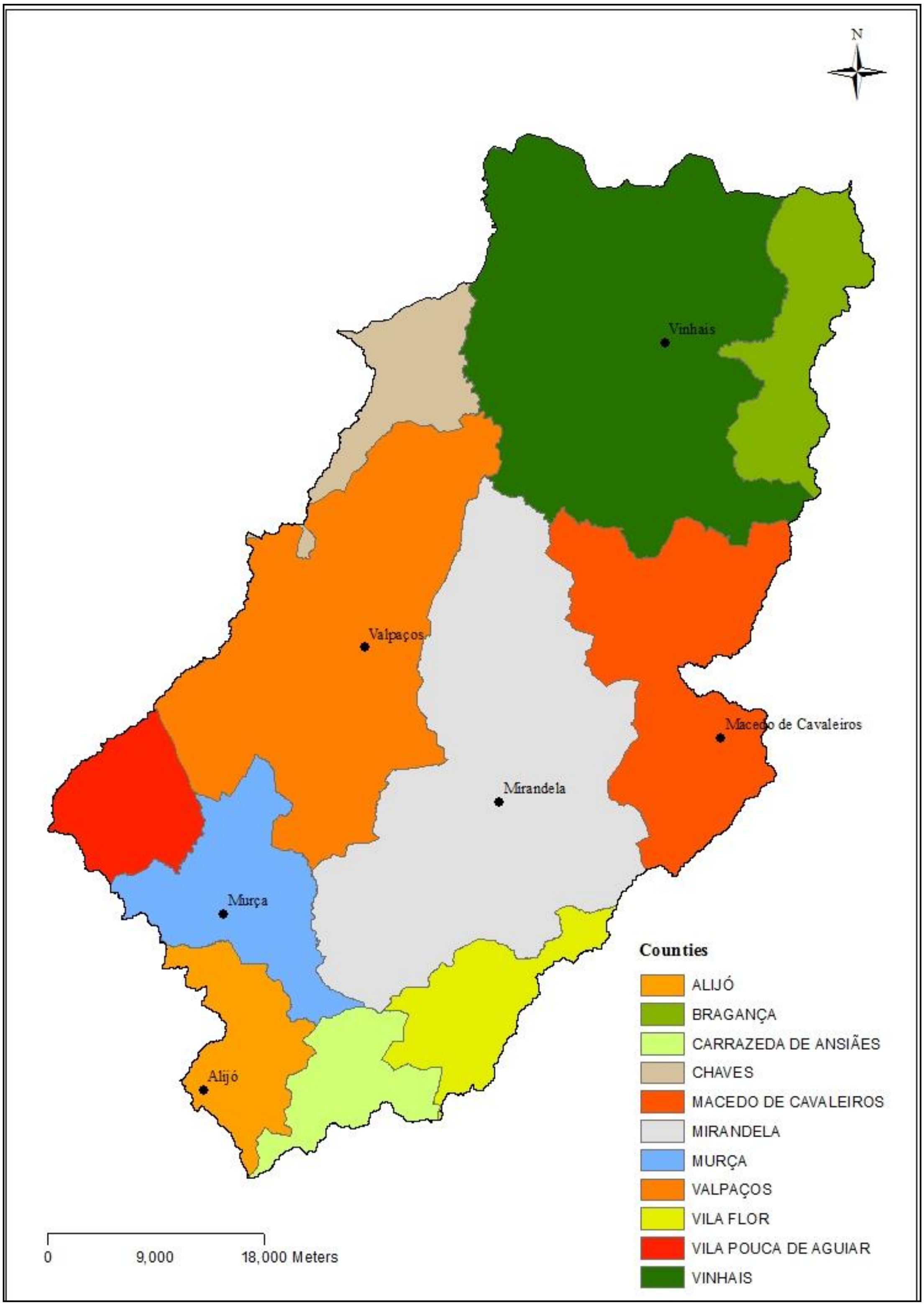

Figure 3. Counties that intercept the drainage basin (adapted from COS 2007).

1.2 - Relevance/Problem Definition

Current world trends of demographic and economic growth are increasing the pressure on natural resources, raising the importance of measures thought out to protect and restore important but threatened resources that have been explored unsustainably.

One such type of resource that has mismanagement and over-exploitation is freshwater, and although research on the restoration of this resource has been produced for decades, the process is so complex, time consuming and financially unattractive that not all projects are successful.

The pressure on freshwater is only expected to grow as time goes by, with more structures being build over it, more fisheries and agricultural land explored in its drainage basins and greater industrial and commercial activities expected to be performed on its margins. All of which adds to the importance of good freshwater management and the emergence of conservation and restoration frameworks that are both cheaper and more likely to provide results.

As such it is crucial to instill the debate and organize available knowledge and literature, as well as provide real case scenarios for a more comprehensive understanding of its applications, in the hope that the practice of freshwater restoration will move towards a more successful, practical and less financially demanding future.

1.3 - Aims and Goals

This thesis was elaborated with the objective of proving that an assessment of a given river's drainage basin's current state and the identification of the best restoration techniques for strategic sites that improve the overall health and sustainability of the river can be done without the need to obtain a large amounts of funding.

Furthermore it is expected that this thesis will encourage discussion about freshwater restoration, thusly invigorating a field that has so far suffered from a negative reputation but which could make an overwhelming difference, especially if present population growth and economic expansion trends continue to evolve at present rates.

The expectation is that this thesis will serve as an outline for future attempts at freshwater restoration interventions and will be used to consolidate knowledge within drainage basin managers seeking to deepen the debate and improve their practices.

1.4 - Thesis Outline

This thesis starts with the analysis of relevant publicly available information on demographic and economic variables involving the municipalities that contain the drainage basin of the river *Tua.*

This section is followed by the discussion of relevant literature and research on the topics of drainage basin assessment, with special consideration of the knowledge on geomorphology, vegetation and climate, as the controls on river processes, which precedes the discussion river restoration treatment techniques and considerations.

After the literary review, a section on the treatment of all relevant data regarding the *Tua* region ensues, presenting and commenting issues such as soil erosion, river flow speed and water quality obtained through the use of Geographic Information Systems (GIS) software.

Following a restoration plan is mapped out, taking into account the existing data on the anthropogenic activity within the region, the most recent scientific data discussing within the literary review section and specific characteristics of the river and its failing sites.

The conclusions and future perspectives about the subject of restoration follow mentioning as well the results obtained which contextualized the template upon which the restorative actions were sustained. Finally the thesis ends with a record of the articles referenced throughout the paper.

2. Literature Review

2.1 – Introduction

Freshwater is the crucial resource upon which irrigation, livestock production, fisheries and aquaculture and, therefore Humankind, depends on. It regulates productivity on several economic and social activities and supports ecosystems and biodiversity (Gleick, 2000; Vitousek *et al.*, 1997; Vörösmarty *et al.*, 2004).

There is no surprise then, to find that water security has become increasingly important as populations grow, especially when you consider that more than half of all accessible surface fresh water is put to use by humanity (Vitousek *et al.*, 1997) and that nearly 80% of the world's population is exposed to high levels of threat to water security (Vörösmarty *et al.*, 2010).

Water security isn't, however, the only threat we will be facing well into the future. The rate of species extinctions and rapid transformations rivers are undergoing to respond to our needs only show signs of increasing, as do the economic costs associated to their exploration, leading to unsustainable levels both for aquatic ecosystems and Mankind (Gleick, 2000; Vitousek *et al.*, 1997; Vörösmarty *et al.*, 2010; Vörösmarty *et al.*, 2004; Wohl, 2005).

Both the sustainability and functionality of ecosystems depend on the maintenance of biodiversity (Blignaut & Aronson, 2008; Benayas *et al.*, 2009) but due to cultural differences and boundaries, the sharing of watersheds by more than one country usually invalidates global action, and many current efforts to preserve functionality and form of freshwaters have been unsuccessful due to the limitations of local scale interventions (e.g. Williams and Williams (1997); Kondolf (1998)).

Within this context, and considering the ever growing need to find sustainable ways of exploring freshwater, this literature review focuses on presenting and discussing the relevant scientific data and studies that verse on regional scale analysis and restoration efforts that involve the entirety of the watershed, discussing strong and weak points, as well as analysing the factors that delineate the physical and biological processes taking place within the watershed ecosystem. Lastly, restoration itself and its application to this thesis are debated, with all the previous subjects in view.

2.2 – Drainage Basin

A drainage basin is a delimited area, which encompasses the springs and all other types of surface water (e.g. rain-fall, snow, melting ice) that converges to a single point at a lower elevation. Anthropic activities and structures within the drainage basin impact in one-way or another its processes and functions. Thusly, it is the objective of this sub-chapter to analyse existing literature on the subject as well as examine the controlling factors in a drainage basin that determine the processes and functions of a river.

So far reality is that to achieve improvements in water quality major changes in current land use need to take place (Evans, 2012), as environmental vulnerability increases with development (Li *et al.*, 2006). In fact, the data available indicates that the economic benefits of land use change are commonly superior to engineering solutions for watershed restoration (Townsend *et al.*, 2012).

Current research indicates a number of anthropic factors that negatively impact rivers and their ecosystems. Examples of these anthropogenic stressors include land-use and resource management choices (Downs *et al.*, 2013), changes in land pattern and use (Zhou *et al.*, 2012) and transportation infrastructure (Blanton & Marcus, 2013) which ultimately affect everything from habitats and flow regime to sediment flux (Allan, 2004).

Furthermore Wohl (2012) states that from these previously discussed anthropogenic pressures it is anthropogenic induced uniformity that represents the main stressor. This uniformity is brought on by the placement of structures such as dams along the length of a river, which conditions flow regime, simplifying it and introducing homogeneity all year round, when flow variability in nature is essential. Naiman *et al.*, (2008) and Puckridge *et al.* (1998) both defend that the natural fluctuation in water flows is essential for long-term sustainability and function to continue the providence of services and benefits to the habitat.

Additionally, although it has been shown that physical heterogeneity can lead to an increase in macro invertebrate richness (Miller *et al.*, 2010), research indicates that habitat heterogeneity does not encourage diversity of species (Palmer *et al.*, 2010). What was found by those researchers was that the overall simplification of the rivers natural fluctuation turned out to be a determining factor in habitat selection and population constitution.

With an overall heterogeneous flow regime, an overall heterogeneous habitat exists throughout a drainage basin. This conclusion is further supported by Wohl (2005) that indicates that complexity and diversity of both form and function of a river are reduced by the net effect of most land use and, furthermore, by Taylor *et al.* (2013) which states that the biodiversity of rivers is directly an effect of channel complexity and hydrologic variability.

Poff *et al.* (1997) introduces five components (magnitude, frequency, duration, timing and rate) that, according to their findings, define river flow. Indicating that it is indeed a dynamic force, the authors conclude that any interactions with river processes and physical space that significantly affect any of the five components will alter and regulate the natural fluctuation of the flow, which in turn effectively reduces the river's ability to support natural processes and native species.

Additionally Jacobson and Jacobson (2013) state that hydrological changes have critical impacts on physical and biotical processes, a statement supported by Zanoni *et al.* (2008) who further established that these changes when conjoined with poor management of riparian vegetation may result in a shift of the river system, thusly upsetting the balance of the ecosystem and possibly creating unfavourable survivability conditions to native species.

So far, the literature broached seems to indicate that anthropogenic interventions that seek to benefit human living conditions, either by removing the fear of floods or assuring the availability of water for the numerous activities developed, have a detrimental impact on the life supported by that river. Another aspect of the anthropogenic intervention is that, even though its effects can be mitigated, its impacts cannot be fully removed and efforts to restore health to freshwater body always carry the risk of failure. This should be a concern of all stakeholders, as the structures will pressure flow for as long as they stand seriously affect ecosystems.

So the question that arises is exactly what mechanisms are behind a river's variability and ability to support life. Montgomery and Bolton (2003) offer a some clues in their paper which states that a river's variability is controlled not just by hydrologic regimes, but also geomorphology and vegetation, creating unique conditions for the formation of specific ecosystems. This idea of controlling factors was proposed by Sheldon (1968) who stated that geomorphology determines fish distribution and diversity.

Coincidently, Evans *et al.* (2007) states that changes in channel pattern and sinuosity impact the hydrologic system offering further proof that all dimensions of a river basin are interconnected. A conclusion that is further supported by research showing that both longitudinal connectivity and riffle proportion are important for native fish richness (Olaya-Marín *et al.*, 2012), which supports as well Sheldon's (1968) conclusions. This way we can connect processes to controls such as a drainage basin's geomorphology and controls to ecosystems.

Benda *et al.* (2004) further supports these conclusions as report findings that species diversity and riparian attributes throughout a river basin are regulated by physical attributes (geomorphology) such as basin size and shape, drainage density and network geometry. This is also reported by Hudson *et al.* (2012) who state that the ecological integrity of meandering river corridors has a basis in the hydrologic connectivity between rivers and floodplains and, consequently, in geomorphic controls.

As an added example, Beechie *et al.* (2006) states as well that channel patterns of forested mountain river systems effectively stratify the dynamics of rivers and floodplains.

Having established that a drainage basin's geomorphology is a key controlling factor over processes and ultimately over ecosystems and species diversity. The next clue to this puzzle is finding what is the role of vegetation and if there are any other controlling factors that are linked to processes and ultimately habitats and communities.

When considering that each stream type has a set of characteristics that relate to the local climate, geology and disturbance regime, literature indicates that these characteristics depend on either ultimate or proximate controls.

Naiman *et al.* (1992) defines ultimate controls as being stable over long periods of time, acting over large areas and shaping the range of conditions in a drainage network - like, for example, regional geology and climate do - and proximate controls as a function of the ultimate factors and can change stream characteristics over relatively short time periods - as do hill slope, temperatures and erosion. Furthermore it states that understanding how these different types of controls interact gives the manager the ability to predict adjustments in the physical and biotic characteristics and hereafter allow the development and application of management decisions. This notion is additionally supported by Wissmar and Beschta (1998) who state that restoration strategies need to encompass and understand the physical and biological processes that take place.

In this sense, Naiman *et al.* (1992) provides further support to the idea that there are controlling factors that determine the all the natural processes which occur within a drainage basin. Given all the ones mentioned above, the last controlling factor to be mentioned here is climate. Which, in tandem with the first two controlling factors mentioned above, vegetation and geomorphology, mould and shape the processes, ecosystems and water condition within the river basin. Stevaux *et al.* (2012) further states that a manager seeking to restore a watershed needs to assess restorative actions using a mesh of vegetation and geomorphic characteristics as these create a more realistic view of the overall natural processes that take place in the river.

Riparian vegetation can provide an indication of the hydrogeomorphologic conditions of a river (Hupp & Osterkamp, 1996; Osterkamp & Hupp, 2010) not to mention that a river's biomass distribution impacts margin morphology (Gurnell *et al.*, 2012). Although not species rich by nature, a river's biomass is supposed to be composed of areas where different species of vegetation overlap (Pollock *et al.*, 2012).

An example of how vegetation serves as a control for the river basin is riparian margin vegetation, which serves as an essential supplier of woody debris (Erskine & Webb, 2003; Hyatt *et al.*, 2004) that provides an habitat for several species of fish, when the river geomorphology and flow regime are suitably characterised to allow for proper wood deposition (Bertoldi *et al.*, 2013).

Furthermore, large trees surrounding a freshwater body provide ecosystems with protection from human impact (Collins *et al.*, 2012). Also referred in restoration research is the knowledge that restoration interventions aimed at maintaining ecological condition and macroinvertebrate condition are more effective when taking place in sites with substantial areas of catchment already in headwater forest (Death & Collier, 2009).

The real issue for any manager seeking to restore or protect through vegetation oriented techniques is to weight the benefits and services provided by a continuous riparian protective vegetation buffer area and the long-term investment that such restorative actions require (it may take some trees over 20 years to grow to maturity on the banks of a river). This depends, of course, of the aims and goals of the restoration project at hand and the investment that stakeholders are willing to make. This is true even though most authors agree that, in the long run, the benefits to sustainable development of restoration methods that involve interventions through actions that impact riparian vegetation largely surpass the time investment.

Despite the services provided by vegetation in restoration efforts and the information on the condition of the river basin managers can obtain from analysing the state of its vegetation, taking only this control into consideration would result in an incomplete picture of the drainage basin and limit the effects of ant restoration attempt, as the river channel is also strongly influenced by the interactions between topography, flow, and sediment transport (Legleiter, 2012).

Tague & Grant (2004) further argue that geology and geomorphology are often the dominant controls on flow regimes through their direct effect on hydrologic pathways, storage properties, and relief, and indirectly through their effect on meteorological forcing.

Comiti *et al.* (2011) further argues that often the key factor of channel adjustments is sediment supply (and not flow regime), which acts as an arbitrator, by keeping a balance between changes in water discharge, climatic variability and other anthropogenic influences (Rădoane *et al.*, 2013)

Poole *et al.* (2008) state inclusively that flow paths, short or long, have an influence on habitat characteristics, as well as community structure and function and that measuring this characteristic provides a clearer picture of the river's functioning and nutrient cycle, even though it requires a considerable financial investment and hard to assess its influence.

The study of the controls mentioned in this sub-chapter are helpful in classifying regional flow along the drainage basin, essential to assess which steps are necessary to avoid loss of fauna and flora from regime regularization (Liermann *et al.*, 2011).

Additionally, authors have found that geomorphic templates create a picture of the case study, and an indication of a rivers' fragility and vulnerability points (Beechie, Liermann *et al.*, 2006).

Finally less studied than the other factors affecting the watershed, is climate - the pattern of variation in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle count and other meteorological variables in a given region over long periods - even though authors like Chiriloaei *et al.* (2012) believe it to be an essential controlling factor over fluvial processes.

Others authors have found that climate change is an important factor to consider on conservation efforts as it may ultimately limit their effectiveness by impacting the flow regime some species of fish are dependant on (Beechie *et al.*, 2006).

Another concern regarding climate is future trends, as climate change is believed to have long term negative effects that, although hitting regulated rivers disporpotionally hard in its disruption of its functions, should impact all free flowing rivers in manners not yet fully foreseeable (Palmer *et al.*, 2008).

Fundamentally then, when broaching a restoration program, these controlling factors should be analysed and all restorative actions need to be contextualized within them. Furthermore, to establish a starting point or reference conditions for any management/restoration plan, knowledge of historical land use patterns and their associated effects are necessary, as well as the influence of persistent land use effects. Only after this evaluation is complete is it possible to identify changes in processes and ultimately river functionality and health, to build on this and, perhaps not return the river to a pristine pre-anthropocentric influence, but to an overall healthy state that can support humans and our impacts. The ultimate goal for managers being river sustainability in the face of current pressures as well as future pressures.

This approach requires a basin-wide study as argued by Wohl *et al.* (2005) which indicates that restoration projects that contemplate the entirety of the drainage basin are more successful than site-by-site restoration efforts. Although the authors agree that information isn't always readily available on a drainage basin scale, specific streams might be of difficult access, and the costs of evaluating a drainage basin for the first time are high, they consider this process-based approach to be fundamental, as its overall efficacy in restoring health to a river should be enough, when considering the services rivers provide for human benefit.

Some authors propose, as a way to protect aquatic ecosystems, to condition our interactions with the river and redesign structures already built within the drainage basin so as to mimic certain geomorphic processes which would provide biological benefits to the water body (Poff *et al.*, 1997). Further support to this statement is given by Hall *et al.* (2011) who suggest that adopting downscaled seasonal flow regimes and mimicking the natural seasonal pattern can restore the ecology of dammed rivers. On this subject, Stanford *et al.* (1996) states that dam operations can be used to restructure altered temperature and flow regime and therefore restore a large portion of the capacity of a river to sustain native diversity.

Thusly a drainage basin wide restoration project doesn't always have to rely on the destruction of existing infrastructures and, depending on a thorough evaluation of the current conditions of the river and the participation of the companies managing the infrastructures, alternatives can be found which, although not as good for the river's health, are still valid.

Dams substantially modify fish biotic-integrity, habitat and social preferences, both upstream and downstream (Wang *et al.*, 2011). As a means of freshwater restoration it is very site specific, costly and can only be applied for specific rivers. Hydraulic infrastructures can also greatly influence the flow and sediment transport at the river-structure interface hence affecting the rivers' morphology (Teraguchi *et al.*, 2011).

The literature concerning the entirety of the drainage basin indicates first and foremost that the undertaking of any restoration project cannot afford to only look at *in situ* issues, as this will provide a faulty picture of the status and lead to mistakes when determining restorative actions consequently leading to a failed restoration effort. The aforementioned authors generally state thusly that when evaluating a drainage basin, a top to bottom hierarchy assessment, which starts with the fundamental factors that control processes, should be adopted. This creates a context, a more reliable picture of the drainage basin itself and establishes the context, structure and metastructure essential to the understanding of system dynamics within the river's continuum (Benda *et al.*, 2004).

2.3 - Restoration

Restoration of the *Tua* river, the ultimate purpose of this thesis, is achieved through an analysis of all parameters mentioned in the subchapter above as well as the processes and functions therein discussed and the application of a set of available tested measures that seek to improve the water quality and establish conditions for the different fauna and flora species residing within the river to thrive, ultimately benefiting the human population that resides and conducts its activities in the drainage basin.

The current lifestyles and activities are unsustainable for any water body (Dudgeon *et al.*, 2006). This is especially true when evaluating areas with a high population density, industrial agricultural presence.

Additionally, whenever an economic interest is set, one can expect resources to be exploited with little concern for externalities. Anthropogenic effects such as soil pollution, sediment pollution and air pollution along the river have an effect on water quality and, as such, river health (Merlo *et al.*, 2011).

Even the ecological integrity of protected areas is in danger, as activities in surrounding areas increase their intensity and pressure on these increases along with air and water pollution (Thieme *et al.*, 2012). Not to mention that the maintenance of protected areas depends on the will of the stakeholders and the resources available to authorities to enforce legislation within the area.

Within this context there is a new urgency for managers to identify river processes and ecosystems that are failing, or close to failing, and develop restoration plans that will be effective and protect the freshwater body appears.

So when establishing both goals and actions for a restoration plan managers necessarily have to take into consideration a number of factors, such as watershed (Beechie *et al.*, 2008) climate change and current use of both water and surrounding land. Furthermore, an effective and sustainable restoration considers not only the current but future needs as well of both the ecosystem and the stakeholders that reside on its riverbanks or depend on the river for their livelihood. A view shared by Robson *et al.* (2011) as well, as they state that in order to ensure the success of a restoration process the manager must foresee and account for the interaction and disturbances generated by stakeholders in the long run and their effects on the recovery pathways of the water body under analysis.

A common mistake that is incurred by managers is to expect it to be possible to return a river to its pristine state: the condition it was in before any human influence. The objective of a manager should always be to achieve a functioning balance between the river, the life it supports and the populations and activities developed within the river reach (Décamps, 2011). Dufour (2009) further adds that the ultimate goal of a restoration plan should be set between what would be a wish state and what is achievable, taking into consideration the net social benefits of the process.

In addition, the restoration process itself should intervene where it allows the ecosystem to function naturally, avoiding unnecessary anthropogenic interventions brought on by attempting restoration to a perfect state (Camacho *et al.*, 2012). A view shared also in Tockner *et al.* (2011), which states that rivers are dynamic systems and, as such, adaptable to rapid change, meaning managers need to stop setting restoration goals for an ideal non-anthropogenic intervention state, and adapt to create a synergy between achievable goals and anthropogenic impact.

But even before any restoration attempt is to be put into practice, the priority should be set on identifying the underlying causes of river health stressors (Vörösmarty *et al.*, 2010), analysing watershed, vegetation, geomorphology and climate as previously discussed.

Once the most relevant stressors and their causes have been identified, the manager must turn his/her attention to policy (Poff *et al.*, 2003). As a process that needs to consider not only environmental components but economic, demographic, socio-cultural and institutional subsystems as well (Kundzewicz, 1997), as a successful river restoration process hinges on reconnecting people with their river, culturally and emotionally (Åberg & Tapsell, 2013).

Support for this notion comes from different studies, which , in general, argue that when the services provided by an ecosystem are properly communicated to the public, both stakeholders and decision makers will be more likely to show support and comply with restoration efforts (Karjalainen *et al.*, 2013; Trabucchi *et al.*, 2012; Zhao *et al.*, 2013; Amigues *et al.*, 2002; Gilvear *et al.*, 2013).

Simply put, a manager, when deciding what techniques to apply to a complex restoration plan should take all stakeholders into account by striving to design a restoration or monitoring plan in tandem with all interested parties (Convertin*o et al.*, 2013).

In fact, all restoration processes need to involve informing the stakeholders, since sometimes the perception of the public of what a healthy river should look like is different from a scientists' perception (Le Lay *et al.*, 2013).

Gumiero *et al.* (2013) states the same conclusions regarding communicating the importance of resources such as floodplains. In order for the population to understand, this importance must be translated in terms of the services rendered by the ecosystems targeted for protection or restoration.

Another study focusing on stakeholder and population support concluded that people inherently value aesthetical quality, recreational opportunities and the water quality of said body of water, particularly when a clear connection is established between the health of the ecosystem and population well-being (Frashure *et al.*, 2012).

In essence, should any restoration attempt fail to achieve a correct communication and should stakeholders not be aware of the benefits from having the river restored, the restoration process may not have the cooperation of people whose activities and property interact with the watershed on a daily basis, thus complicating and possibly leading to a failed restoration plan (Shields *et al.*, 2003). Pedersen *et al.* (2007) lists as one of the benefit to be obtained over the years through restoration, besides aquatic health and wealth, the provision of new habitats for other species, such as birds.

The simple message presented by Blignaut *et al.* (2013), that augmenting the natural capital through restoration increases the flow of services and benefits to society, should be clear to all parties affected by the restoration processes.

Should a restoration plan carefully account for community level effects and any important ecological shifts it might generate (Ilmonen *et al.*, 2013), a manager can expect that properly informed stakeholders will continue to support the restoration process two years into the start of the intervention (Bliem *et al.*, 2012).

Some of these services are easier to convey and be grasped than others. Flood mitigation achieved by the maintenance of vegetation ecosystems surrounding water bodies are an example of services where benefits are possible to be estimated (Fu *et al.*, 2013).

There is also evidence to indicate that, given the services provided by ecosystems, some restoration efforts might be cost containing in the long run (Sparks, 1995). This is information that stakeholders should take into account.

Additionally, there is an increasing pressure to include community integrity indicators in any analysis to meet legislative goals (Jaunatre *et al.*, 2013). Still, compliance with the Water Directive Framework should not be the final objective, as authors like Kail and Wolter (2011) argue that the legislative code is found wanting, specially for dealing with large-scale restoration.

As to what goals the manager can expect from the different stakeholders, he/she should take into consideration that while the public might be moved to work towards an improvement in the perceived services provided by the river, the decision makers will be mostly concerned with meeting policy objectives. This means management of water bodies should focus on ecosystem services that help meet policy target values (Honey-Rosés *et al.*, 2013), but he must never allow the diverse or competing interests concerning freshwater resources to divert from embracing restoration as a way of guarantying water security (Gleick, 2000).

Another important aspect to take into consideration in the restoration process is the scale. Since river restoration projects can require a considerable amount of resources, a popular alternative is to conduct small-scale restoration processes, targeting a specific area of a river basin where pollution or ecosystem degradation is most notorious.

Although it is true that restoration processes should be implemented where ecological services are failing (Palmer *et al.*, 2005), and despite local efforts being less demanding, more easily accepted and coordinated with the local population, these projects may also cause degradation to the riparian zone. Efforts at a larger scale eventually improve ecological form and functioning of the entire catchment, which complies with the European Union legislative demand (Jähnig *et al.*, 2010). Also, regional/basin scale restoration projects obtain higher economic outputs (Spörri *et al.*, 2007).

Large scale does not mean, however, that managers should plan for one and the same intervention along the whole of the river. Before establishing restorative intervention sites, the managers must identify its pollution sources, both point and non-point, in order to establish priority areas and the different processes to establish in different zones (Peacock *et al.*, 2012). This must be done with an eye on the big picture and the final results intended for the drainage basin (Ryder & Miller, 2005), but with site-by-site intervention, in accordance to local priorities.

Far from being consensual, the practice of river restoration still generates debate among managers, as some authors present evidence against large river restoration projects, arguing they lose their cost-effectiveness as regional stress builds upstream and downstream (Turner & Boyer, 1997).

Additionally, some authors have found that large scale site-by-site intervention presents a procedure that often ends with failed results (Rohde *et al.*, 2006).

Considering this, a manager should take care in how he applies large-scale river restoration to different sites along the river, applying different interventions in each site and attributing different priorities to each intervention, according to its specific characteristics and ecological stressors, always with large-scale restoration objectives for the drainage basin in consideration (Giri *et al.*, 2012).

Another approach to river restoration is organizing the river by landscape and community, which although providing an understand of the current aspects of the river does not provide a starting point for action, serving more as a reference state to be introduced into the restoration at a later stage (Poudevigne *et al.*, 2002).

Also important for all stakeholders to have present is that restoration interventions do not produce immediate effects. There are hydrological and biogeochemical time lags in responses of rivers and streams that need to be taken into consideration (Hamilton, 2012; Palinkas, 2013).

The reason why restoration processes take time to produce effects is that they act by seeking to add complexity to ecosystems when anthropologic activities and structures have removed it, in processes that attempt to mimic natural ecosystem growth or protection (Pedersen *et al.*, 2007).

Still, a manager should take into consideration that bioengineering techniques will, in general, produce better results in terms of biological continuity and diversity, as well as greater time efficiency than civil engineering solutions (Cavaillé *et al.*, 2013). Once local processes are restored, the river health should improve (Elosegi *et al.*, 2011).

For highly regulated rivers, flooding is a process commonly used to reintroduce sediments and enrich and recover damaged ecosystems (Lake, 2012). The paper also refers that wastewater can be used as a primary production booster in locations that are found lacking nutrients (Galindo-Bect *et al.*, 2013).
Focusing on restoration schemes that involve bio-ecological remediation (Wang *et al.*, 2012) or restructuring the use of land within the drainage basin (Lüderitz *et al.*, 2011) are both methods a manager should consider for obtaining fast changes in river health. Removing man-made structures that might be impairing the natural flow of water is another possibility (Vandenberghe *et al.*, 2012), but there are limits to what it can achieve in terms of restoration (O'Hanley, 2011).

The contribution of fish to services provided by the ecosystem need to be established in the design of the restoration plan in order for the full value of their conservation to be assessed (Cooke *et al.*, 2012).

However, restocking rivers does not provide managers with a sustainable restoration solution when river connectivity, navigability, habitat and water quality are not up to standards, as new arrivals to the ecosystem would meet the same conditions that led the previous fauna to a crisis situation (Griffiths *et al.*, 2011).

Another aspect to have into account is human intervention. It can be expected to influence channel evolution at reach scale in the long-term, representing a crucial aspect that, if ignored, can dictate the failure of the best laid restoration plans (Ziliani & Surian, 2012).

Taking that into consideration, managers should not view hydropower production as a impeachment to the conduction of restoration efforts, although it does considerably increase the costs of restoring the river's ecosystems to acceptable levels of performance (Fette *et al.*, 2007).

When it comes to choosing where to perform specific interventions, managers should look for river areas with low habitat connectivity and diversity as spots where restorative actions can take place (De Jager & Rohweder, 2012).

Additionally, understanding channel responses to how a stream relates to its watershed across space and time, and through the system as a whole, from the channel network to pools, riffles and microhabitats is essential (Frissell *et al.*, 1986).

Equally important is understanding the links between the chemical and biological dynamics within isolate portions of the catchment in order to define priority restoration locations (Hutchins *et al.*, 2009).

For all the variables and processes that must be taken into consideration, a range of scenarios and possible outcomes must be evaluated, mostly focused on channel dynamics and ecosystem interaction (Richards *et al.*, 2002), as there is always uncertainty associated to any restoration plan (Bark *et al.*, 2013).

This is especially true if you consider that any intervention can develop negative effects, which would imply management must be prepared to decide whether a particular negative response would endanger the final restoration goal for the drainage basin (Salant *et al.*, 2012). Local and manageable negative effects might have no impact in the restoration process as a whole, or attempting to reverse these local negative responses might trigger in turn a decrease in the restoration of the drainage basin as a whole. As such, managers need to prepare for these possibilities.

When considering a restoration plan a range of possible scenarios and their outcomes must be evaluated, focusing on channel dynamics and ecosystem interactions (Richards *et al.*, 2002).

Statistically, managers that make decisions based on a single restoration goal (such as saving a specific type of mussel in the basin) are more likely to be successful (Emery *et al.*, 2013). What this finding seems to indicate is that, independently of the problem or solution’s complexity, one should strive to keep restoration goals simple. Simplicity insures that all stakeholders and decision makers understand the actions undertaken as it simultaneously helps guide managers through the rivers’ responses as the restoration process unfolds.

Simplicity also guarantees the most valuable species are protected. In the course of a restoration plan design, a single preferred species must be selected for protection, in the recognition that any intervention will alter the competitive balance between native and invasive species. Setting this objective might appear as over-simplification, but in fact it prevents a most severe negative impact from restoration efforts, such as harming the habitat of the single most important species for the ecosystem under restoration (Tang *et al.*, 2013).

This analysis of available research into the field of river restoration ends with a recommendation introduced by Pander & Geist (2013). In their paper, the authors mention that if river restoration is to become more effective, national established guidelines or adopted frameworks, such as ecological indicators, must be provided.

The current literature review is proof of this statement: with so many variables for river basin managers to consider in the course of a restoration process, there would be much to gain if information necessary for this specific purpose was readily available and national guidelines were set and available to be applied anywhere in the country.

3. Methodology

This chapters' purpose is to present the methodology adopted in the elaboration of this dissertation, in such a way to be replicable to future researchers' needs.

With the aforementioned purpose, it has been subsequently divided into sub-chapters, each complementing the other and all created with the aims and goals of the dissertation in mind, as well as the issues already broached.

The program ArcGis10© (ESRI, 2013) and the supplemental XTools Pro© and ArcSWAT© were used to gauge these controls, used, as well as supplemental maps provided and formulas taken from articles, and books. The data used to estimate precipitation as well as the water chemical quality were obtained through *"Sistema nacional de informação de recursos hídricos"*, a national information system concerned with monitoring the water bodies throughout Portugal. Further information regarding data from wastewater treatment facilities was obtained from "*Águas de Trás-os-Montes e Alto Douro"* the entity currently managing water supply and wastewater treatment throughout the drainage basin.

3.1 - Case Study Framework

To introduce the case study area appropriately the program ArcGIS© (ESRI, 2013) in conjunction with Bing Maps© were used to present a visual location of the area under study by this dissertation in the entirety of continental Portugal and then as well the northern region of the country.

Furthermore to introduce the river and establish a basic understanding of its functions and complexity using once again ArcGIS© (ESRI,2013). Additionally the counties present in the case study area were also identified.

3.2 – Building Blocks

Throughout history the human race has thrived near bodies of water. Currently, investments made into securing our own wellbeing are often at the cost of natural resources and result in detrimental effects to these.

This methodology encompasses a hierarchical analysis of the various factors that are currently stated as the building blocks of a habitat (such as the physical habitat, water quality and primary productivity), as well as biological responses (Beechie *et al.*, 2010; Beechie *et al.*, 2009b).

There are several stages of planning involved in the restoration of a river. Firstly, when planning a restoration process it is necessary to assess and differentiate between elements that can be controlled and elements that cannot. It is important to bear in mind that there is no miracle fix (Beechie & Bolton, 1999; Beechie *et al.*, 2010, 2009b; Wohl, 2005).

Being aware of the constraints imposed by both types of restoration elements, will reveal what is lacking as well as provide boundaries to what can be achieved in both form and function, without having a project working against these constraints, which would eventually result in a failed restoration project (Beechie *et al.*, 2009b; Wohl, 2005).

With this in mind, the first step of the hierarchy is designated Landscape Controls, and is composed of three parameters: vegetation, geology and climate (Beechie & Bolton, 1999; Beechie *et al.*, 2009b; Naiman *et al.*, 2009). These parameters, which can be observed in figure 4 and provide a context for all the processes that occur in a given aquatic ecosystem, and therefore are the building blocks of any efficient restoration projects (Beechie *et al.*, 2010; Naiman *et al.*, 2009).

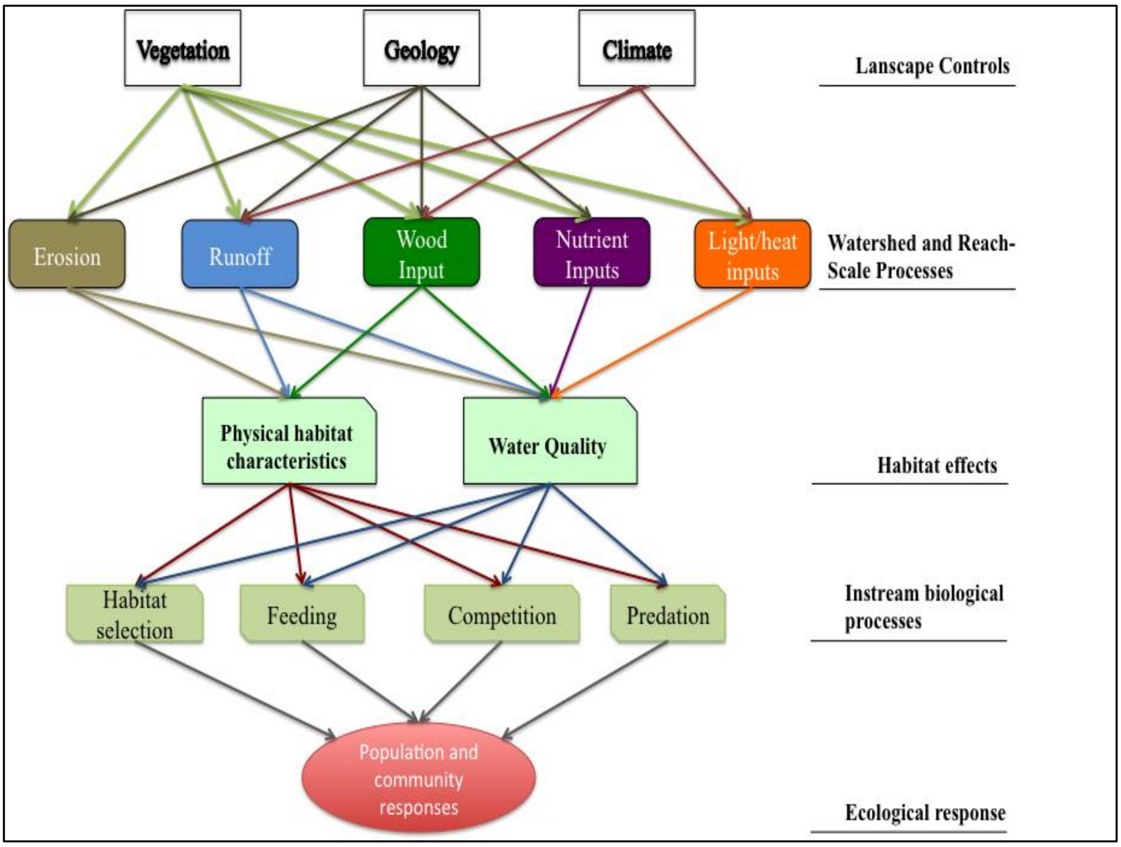

Figure 4. Process linkages between landscape controls, watershed processes, instream processes and biological responses adapted from Beechie & Bolton, 1999 and Beechie *et al.*, 2009b.

3.3 - Landscape Controls

These elements ultimately define the physical, chemical and biological attributes of a riverine ecosystem (Beechie *et al.*, 2010), consequently therefore controlling the arrangement of channel and habitat types across the riverine landscape (Beechie & Bolton, 1999; Beechie *et al.*, 2009b; Naiman *et al.*, 2009).

3.3.1 – Vegetation

Riparian zone and plant species are characterized next to assess this ultimate control vegetation cover.

To assess vegetation cover the most current land use map, *"Carta de Uso e Ocupação do Solo de Portugal Continental para 2007"*, also known as COS2007 was used. It maps the different types of land use in existence between July 11th and November 15th of 2007 in Continental Portugal.

Using the aforementioned program, ArcGis© (ESRI, 2013), this map was fitted to the case study location, in table 1 the different types of land use found to be in existence during the time period mentioned can be observed.

Table 1. Land-use type present in the study area and its respective code.

Code	Land-Use
1,1	Urban Fabric
1,2	Industry, Commerce and Transportation Infrastructures
1,3	Waste Landfill, Inert Extraction and Construction Infrastructures Sites
1,4	Sport, Cultural and Leisure Facilities, Historical and Green Areas
2,1	Non-Perennial Crops
2,2	Perennial Crops
2,3	Permanent Pasture
2,4	Heterogeneous Agricultural Areas
3,1	Forests
3,2	Open Forests and Herbaceous and Shrubby Vegetation
3,3	Open Areas with Minimal Vegetation
4,1	Inland Wetlands
5,1	Inland Waters

From the land-use types identified those deemed necessary to estimate riparian vegetation and upland forests were:

3,1 – Forests,

3,2 - Open forests and herbaceous and shrubby vegetation.

Therefore, they were isolated to create a map of the distribution of these types of vegetation and evaluate the riparian areas without vegetation cover, in order to identify possible restoration sites.

The plant species located in the watershed, taken from "Carta Dos Solos E Carta Da Aptidão Da Terra Do Nordeste De Portugal" are listed in table 2.

Table 2. Common vegetation found throughout the drainage basin.

Scientific Name	Layer	Common Name
Quercus rotundifolia	Tree	Evergreen Oak
Quercus faginea		Portuguese Oak
Quercus pyrenaica		Pyrenean Oak
Juniperus oxycedrus		Cade Juniper
Olea europaea		European Olive
Lygos sphaerocarpa	Undergrowth	Heywood
Pistacia terebinthus		Terebinth
Phillyrea angustifolia		Narrow-leaved Mock Privet
Cistus ladanifer		Labdanum
Lavandula pedunculata		Lavander
Thymus mastichina		Mastic Thyme
Daphne gnidium		Flax-leaved Daphne
Cistus albidus		Rock Rose
Cistus salvifolius		Sage-leaved Rock Rose
Alnus glutinosa	Riparian	Black Alder
Fraxinus angustifolia		Ash ‘Raywood’
Ulmus spp.		Elm
Populus spp.		Aspen
Salix spp.		Willow
Celtis australis		Nettle Tree
Frangula alnus		Glossy Buckthorn
Lythrum salicaria		Purple Loosestrife

3.3.2 – Geomorphology

The purpose of the geomorpholocial control is to characterize the physical characteristics related to geology, such as elevation and slope.

A digital elevation model provided by ESRI (2013), having a grid cell of approximate 27 m was used to characterize the elevation of the area under study.
With this information and in order to further characterize the basin the hypsometric curve was determined.
A longitudinal profile of the river was also determined making use of the upstream distance (determined through the total length of waterway contained in each elevation class).
Slope was derived from the digital elevation model. Table 3 indicates the maximum and minimum slope, in degrees.

Table 3. Slope extremes, maximum and minimum, in degrees.

Slope (degrees)	
Minimum	0
Maximum	54

3.3.3 – Soil Erosion

The determination of the erosion rate throughout the watershed was based on the Universal Soil Loss Equation (USLE) by determining each factor and them using ArcGis© (ESRI, 2013) to create a map of the rate of erosion taking place.

The USLE formula is expressed by the following equation,

$$A = R \ast K \ast LS \ast C \ast P,$$

in which A corresponds to the annual soil loss, R is rainfall erosivity factor, K represents soil erodibility, LS are topographic factors and both C and P correspond to cropping management factors (Beskow *et al.*, 2009; Hipólito & Vaz, 2011; Lencastre & Franco, 2010).

Rainfall-Runoff Erosivity Factor (R)

Factor R is the potential of rainfall to cause erosion, in a given soil, without protection (Beskow *et al.*, 2009; Lencastre & Franco, 2010). Total precipitation and kinetic energy of raindrops that fall onto the soil, as well as rainfall intensity and raindrop size are taken in account when estimating this factor. Table 4 compromises a list of all the meteorological stations selected to calculate this factor (3 stations where eliminated as they had fewer than 30 data entries deemed thusly statistically invalid).

Table 4. Metereological stations, their Global Positioning System (gps) coordinates and altitude located in the case study watershed.

Code	Name	Latitude	Longitude	Altitude (m)
02O/01UG	Gestosa	41,883	-7,151	706
02O/02UG	Vinhais	41,827975	-6,993837	636
02P/01C	Moimenta Da Raia	41,947424	-6,976995	837
03N/01G	Travancas	41,827972	-7,305606	884
03N/02UG	Tinhela	41,728	-7,307	592
03O/01UC	Rebordelo	41,736	-7,16	557
03P/01UG	Celas	41,714088	-6,922264	905
04N/01C	Rio Torto	41,537968	-7,280597	322
04O/01G	Torre De Dona Chama	41,65654	-7,115887	359
04P/06UG	Macedo De Cavaleiros	41,532973	-6,958648	551
05L/02C	Minas De Jales	41,463795	-7,589765	853
05M/01UG	Jou	41,481	-7,418	694
05O/01UG	Bornes	41,456	-7,004	760
06N/01C	Folgares	41,303242	-7,282811	739

The equation adopted for the calculation of R is the equation for average monthly erosivity. It was developed by Renard and Freimund (1994), also known as the Fournier Index, as the data necessary is more readily available and is based on monthly precipitation records,

$$EL_i = \frac{125{,}92 * \left(\frac{r_i^2}{P}\right)^{0{,}603} + 111{,}173 * \left(\frac{r_i^2}{p}\right)^{0{,}691} + 68{,}73 * \left(\frac{r_i^2}{p}\right)^{0{,}841}}{3}$$

where EL_i is the average monthly erosivity (MJ mm ha^{-1} h^{-1} month) for month i, r is the average monthly rainfall (mm) for month i, and P is the mean annual precipitation (mm).

Table 5 represents the values of R, for each station obtained through the sum of the values corresponding to the different months of the year.

Table 5. Rainfall-runoff erostivity factor (R) for each metereological station.

Code	Name	**R (MJ mm ha^{-1} h^{-1})**
02O/01UG	Gestosa	5009,85
02O/02UG	Vinhais	5288,64
02P/01C	Moimenta Da Raia	5597,76
03N/01G	Travancas	4938,92
03N/02UG	Tinhela	4792,67
03O/01UC	Rebordelo	4406,11
03P/01UG	Celas	5688,37
04N/01C	Rio Torto	3218,42
04O/01G	Torre De Dona Chama	3645,41
04P/06UG	Macedo De Cavaleiros	3877,69
05L/02C	Minas De Jales	5832,37
05M/01UG	Jou	4693,85
05O/01UG	Bornes	17795,97
06N/01C	Folgares	3547,37

Figure 5 represents the spatial mean of R throughout the basin being obtained through the employment of the Thiessen Polygon Methodology, a tool available in ArcGis© (Beskow *et al.*, 2009; ESRI, 2013).

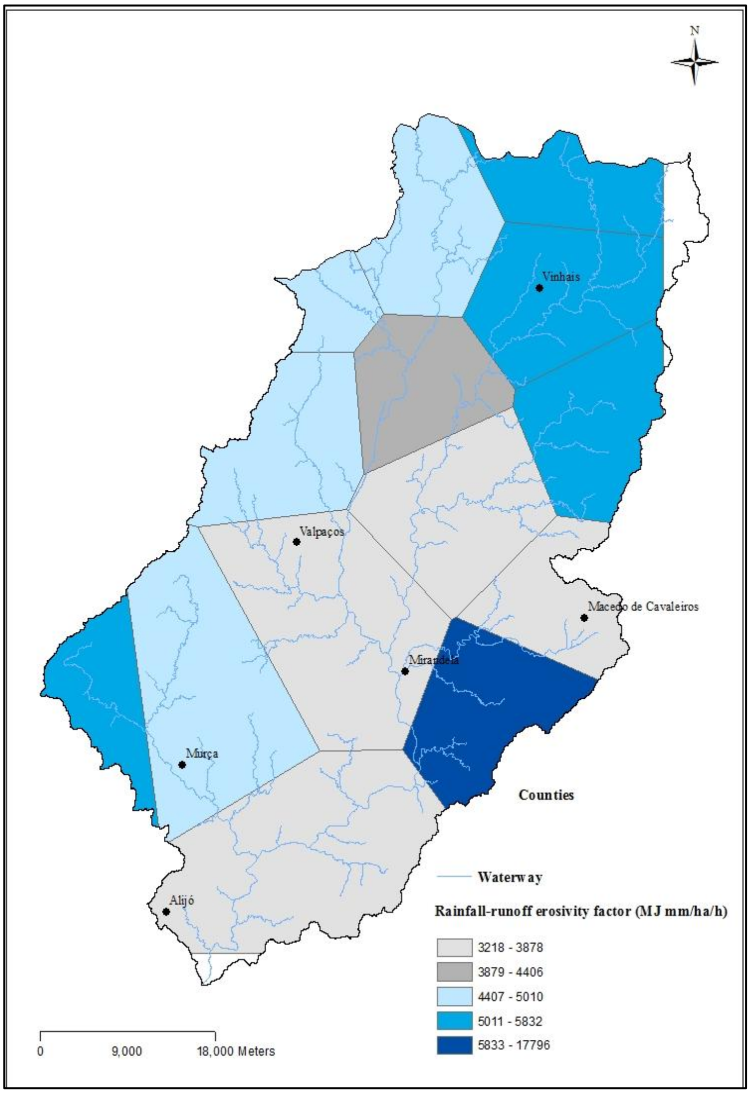

Figure 5. Rainfall-runoff erosivity factor.

Soil Erodibility Factor (K)

Erodibility is the intrinsic susceptibility of soil to water erosion. It depends on many soil attributes, that can be mineralogical, chemical and physical (Hipólito & Vaz, 2011; Lencastre & Franco, 2010; Pérez-Rodríguez *et al.*, 2007).

Thus Soil Erodibility Factor (Factor K) represents the rate of soil loss per unit of rainfall erosion index for a specific type of soil, for a clean tilled fallow condition at 9% slope (Lencastre & Franco, 2010; Renard *et al.*, 1997).

It can be determined through field experiments, but in this study the values for K were obtained from Pimenta (1998) and the appendices of *"Carta Dos Solos E Carta Da Aptidão Da Terra Do Nordeste De Portugal"* (1990) to complement missing soil types. Table 6shows factor K for the soil types registered in the drainage basin and figure 6 represents its graphic display.

Table 6. Erodibility factor per soil type found in the watershed of this case study.

Soil Code	Erodibility Factor (t h MJ^{-1} mm^{-1})	Soil Code	Erodibility Factor (t h MJ^{-1} mm^{-1})
Urb	0	**Ieob**	0,0039
Bdod	0,0031	**Ieou**	0,0039
Bdog	0,0031	**Ieox**	0,0039
Bdox	0,0031	**Isg**	0,0016
Bdxm	0,0031	**Iub**	0,0027
Bdxx	0,0031	**Iug**	0,0016
Buog	0,0023	**Iux**	0,002
Buox	0,0021	**Ixb**	0,0024
Buxx	0,003	**Jdoa**	0,0026
Bxs	0,0023	**Jea**	0,0026
Idog	0,0039	**Jua**	0,0027
Idom	0,0039	**Tasdx**	0,0038
Idox	0,0039	**Tatdg**	0,0023
Iebb	0,0039	**Uhs**	0,0025

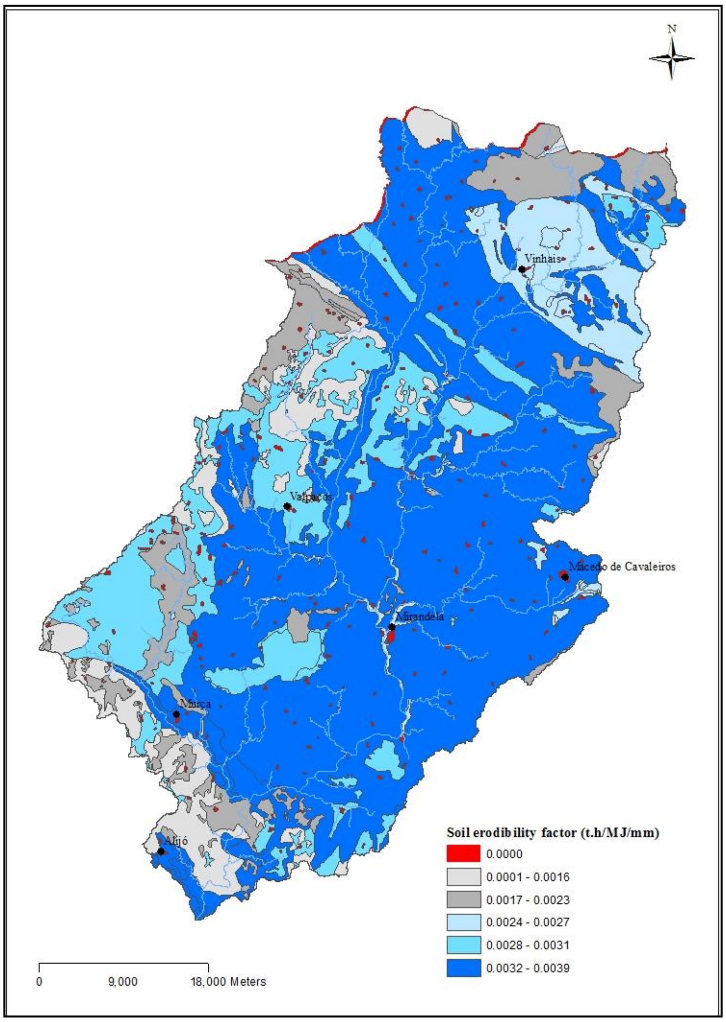

Figure 6. Soil erodibility factor in t.h.MJ^{-1}.mm^{-1}.

Topographic Factor (LS)

The topographic factor reflects the effect of topography on erosion (Lencastre & Franco, 2010; Renard et al., 1997). It depends on slope length factor (L) and slope steepness factor (S), it quantifies the erosion due to surface runoff speed (Beskow *et al.*, 2009; Lencastre & Franco, 2010).

There are several methods for determining this factor, the adopted method is from Moore & Wilson (1992) and has been adopted in several studies, e.g. Duskey, *et al.*, 2011. The following equation was applied,

$$LS = \left(\frac{A_s * C}{22{,}13}\right)^m * \left(\frac{\sin\beta}{0{,}0896}\right)^P$$

in which A_s is the specific catchment area ($m^2\ m^{-1}$), C is the size of a pixel, m and p are two empirical values, generally being 0,4 and 1,3, respectfully and finally, β is the slope of the grid cell. Figure 7 was obtained.

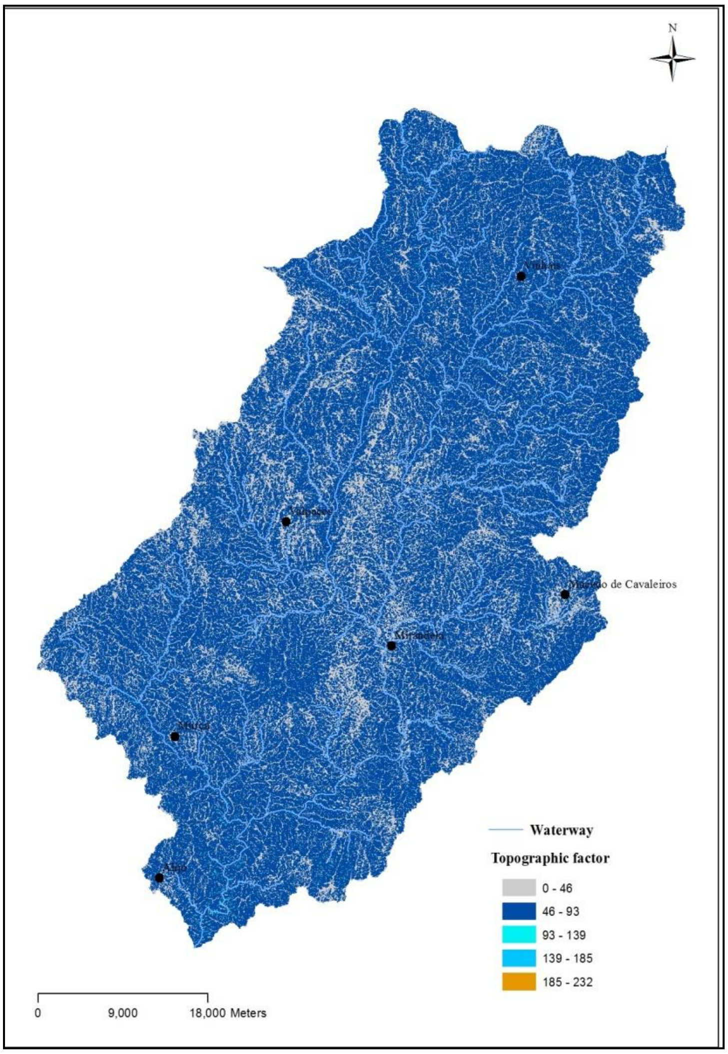

Figure 7. Topographic factor variation.

Cover Management Factor (C)

Cover management is related to soil erosion vulnerability and how land use is a increasing factor of this. Therefore, C, represents the rate of soil loss from an area with a given cover and in comparison to that from an identical area in tilled continuous fallow on the same soil and slope (Beskow et al., 2009; Hipólito & Vaz, 2011; Lencastre & Franco, 2010).

The values for C were adapted from Pimenta (1998) according to the land use types identified in *"Carta de Uso e Ocupação do Solo de Portugal Continental para 2007"*, and can be observed in Table 7.

Table 7. Cover Management Factor per land use type found in the drainage basin.

Code	Land-Use	C
1,1	Urban Fabric	0,01
1,2	Industry, Commerce and Transportation Infrastructures	0,01
1,3	Waste Landfill, Inert Extraction and Construction Infrastructures Sites	0,5
1,4	Sport, Cultural and Leisure Facilities, Historical and Green Areas	0,02
2,1	Non-Perennial Crops	0,3
2,2	Perennial Crops	0,1
2,3	Permanent Pasture	0,02
2,4	Heterogeneous Agricultural Areas	0,3
3,1	Forests	0,1
3,2	Open Forests and Herbaceous and Shrubby Vegetation	0,02
3,3	Open Areas with Minimal Vegetation	0,4
4,1	Inland Wetlands	0,005
5,1	Inland Waters	0,005

Figure 8 was obtained and is an indicative of the variation of this parameter throughout the drainage basin.

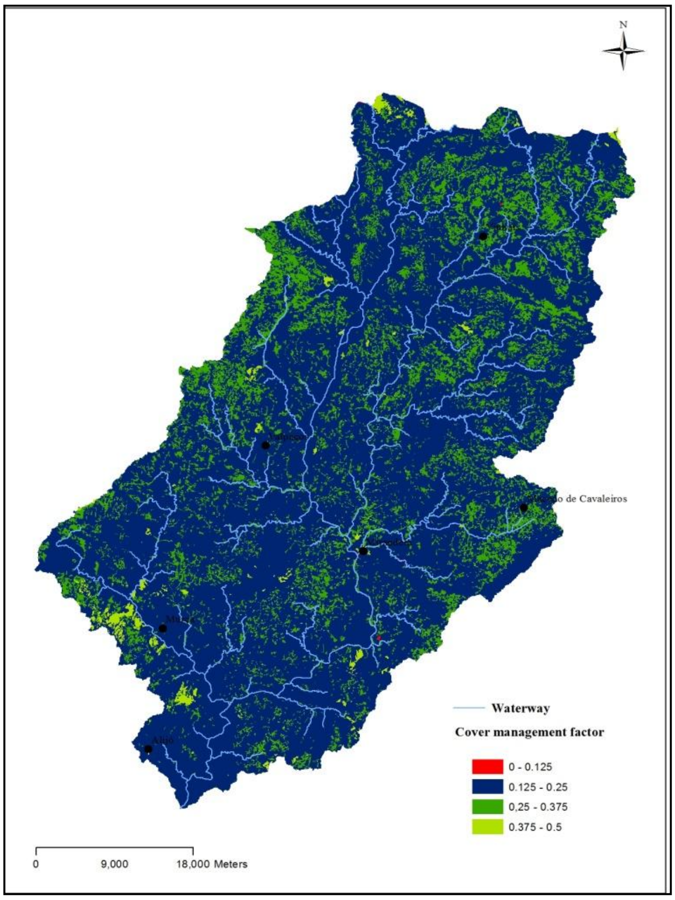

Figure 8. Cover management factor variation.

Support Practice Factor (P)

The support practice factor is related to soil conservation practices, as these have an influence on increasing erosion processes (Lencastre & Franco, 2010; Ruhoff *et al.*, 2006). Since erosion control practices weren't found in the case study watershed, the value one was attributed over the entire case study area.

3.3.4 - Soil Description

Table 8 represents a description of each soil type located within the drainage basin.

Table 8. Soil type and its description according to soil code, the information for the description was adapted from Encyclopedia Brittanica, 2013

Soil Code	Soil Type	Description
Bdod	Orthi-Dystric Cambisol	These have no layer of accumulated clay, humus, soluble salts or iron and aluminium oxides .
Bdog	Orthi-Dystric Cambisol	
Bdox	Orthic-Dystric Cambisol	
Bdxm	Chromi-Dystric Cambisol	
Bdxx	Chromi-Dystric Cambisol	
Buog	Orthi-Umbric Cambisol	
Buox	Orthi-Umbric Cambisol	
Buxx	Chromi-Umbric Cambisol	
Bxs	Chromic Cambisols	
Idog	Orthi-Dystric Leptosol	These have a very shallow profile and they often contain large amounts of grave and are especially susceptible to erosion, desiccation, or waterlogging, depending on climate and topography
Idom	Orthi-Dystric Leptosol	
Idox	Orthi-Dystric Leptosol	
Iebb	Cambi-Eutric Leptosol	
Ieob	Orthi-Eutric Leptosol	
Ieou	Orthi-Eutric Leptosol	
Ieox	Orthi-Eutric Leptosol	
Isg	Leptosol	
Iub	Umbric Leptosol	
Iug	Umbric Leptosol	
Iux	Umbric Leptosol	
Lxb	Chromic Luvisol	These form on flat or gently sloping landscapes under climatic regimes that range from cool temperate to warm Mediterranean - they are suitable for a wide range of agriculture due to their high nutrient content and good drainage
Jdoa	Orthi-Dystric Fluvisol	These are found typically on level topography that is flooded periodically by surface waters or rising groundwater.
Jea	Eutric Fluvisol	
Jua	Umbric Fluvisol	
Tasdx	Dystri-Surribi Aric Anthrosol	These are defined as any soils that have been modified profoundly by human activities, including burial, partial removal, cutting and filling, waste disposal and irrigated agriculture.
Tatdg	Dystric-Terraci Aric Anthrosol	
Uhs	Haplic Alisol	These soils are highly acidic and poorly drained soils which are prone to aluminium toxicity and water erosion.

3.3.5 – Climate

In order to properly classify this last ultimate control the following parameters were estimated.

Climate classification was adapted from *"Mapas Climáticos de Portugal"* by Daveau (1985), contextualizing the climatic processes in control of the case study area.

Assessing climate change within the context of the ultimate control serves to determine the impact of climate change thus far, and possibly adding an important component when considering various future scenarios to structure a proper restoration plan (Palmer *et al.*, 2008; Payne *et al.*, 2004; VanRheenen *et al.*, 2004).

To assess variations in average temperature a map of annual temperature was produced using data from the meteorological stations listed in Table **4** in an attempt to assess any pattern (Jones *et al.*, 1986; Klein Tank *et al.*, 2002; Wiens *et al.*, 2009).

Precipitation was assessed by the meteorological stations listed in Table **4**. An assessment of the total annual precipitation data was evaluated to assess any discerning patterns of interest (Klein Tank *et al.*, 2002; Wiens *et al.*, 2009).

Solar radiation influences biological processes and vegetation distribution as well as influencing directly annual temperature (Rich *et al.*, 1993; Swift *et al.*, 1973).

Using ArcGis© (ESRI, 2013), solar radiation maps, based on the altimetry map aforementioned in the geology section of the methodology, were created for each month of the year (Rich *et al.*, 1993).

This allows an assessment therefore of the energy received in the watershed and an understanding as to what can be achieved (Aguilar *et al.*, 2010; Hardy *et al.*, 2004; He *et al.*, 2000; Swift *et al.*, 1973).

The next step of the methodology refers to the assessment of the watershed water quality.

3.4 – Water Quality

A water quality assessment was deemed necessary to establish possible restoration locations, which in conjunction with the previous parameters evaluated would allow the creating of a viable picture of the current state of both physical and chemical processes within the watershed.

To evaluate the rivers chemical quality throughout the entirety of the drainage basin the data of the automated sampling stations located throughout the basin was used. Figure 9 indicates the location of the various stations.

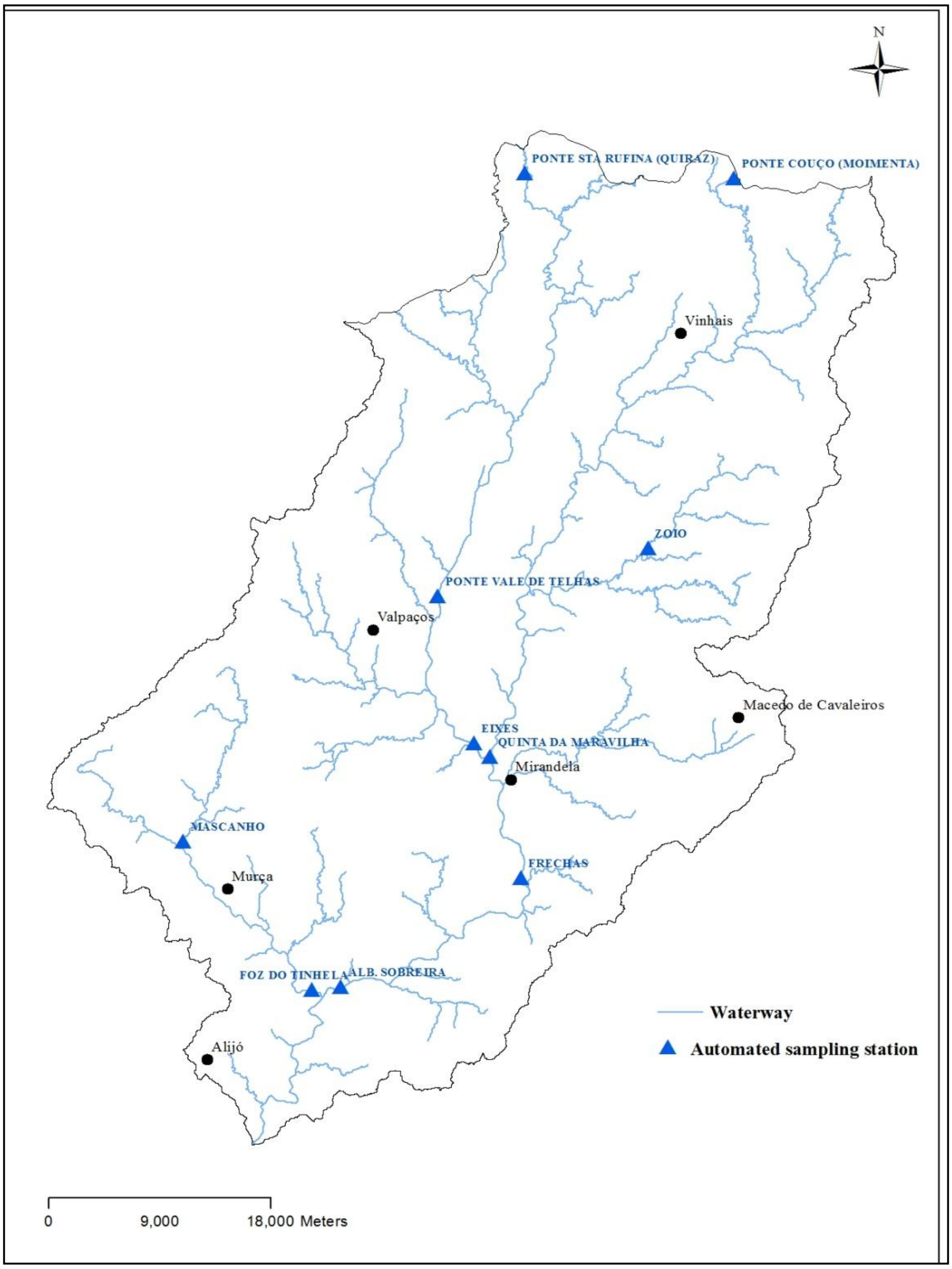

Figure 9. Distribution of automated sampling stations throughout the drainage basin (adapted from SNIRH (2013)).

The stations together evaluate over 130 parameters, some having a monthly sampling period, and others with no discerning sampling pattern. A process of selection of the most viable data per parameter analyzed, and as a further step the choosing of an index from these parameters to establish water chemical quality between stations.

From the assortment of parameters evaluated by the automated sampling stations the Water Quality Index (WQI) was deemed to be the most comprehensive. In table 9 are the parameters chosen for the WQI and their weight factors.

Table 9. Parameters required to assess WQI and their weight factors.

Parameters	Weight Factors
Dissolved Oxygen (mg O_2/l)	0.17
Faecal Coliform (MPN/100 ml)	0.16
Biochemical Oxygen Demand(mg O_2/l)	0.11
pH	0.11
Nitrate (mg NO_3/l)	0.10
Phosphate (mg PO_4/l)	0.10
Temperature (°C)	0.10
Turbidity (JTU)	0.08
Total Dissolved Solids (mg/l)	0.07

The WQI equation to determine the classification is as follows,

$$WQI = \sum W_x Q_x$$

in which W_x is weight factors of the water quality parameters, Q_x is the value of the water quality parameters and x is the parameter.

Table 10 represents the water quality assessment given the WQI value obtained.

Table 10. Final Classification based on the value obtained of the global WQI.

Index Ranges	Water Quality
0-25	Very bad
25-50	Bad
50-70	Medium
70-90	Good
90-100	Excellent

This WQI assessment was applied to each automated sampling station to provide a global estimate of the chemical quality of the basin.

Firstly wastewater discharge points were located within the drainage basin. Figure 10 represents thusly the distribution of wastewater treatment facilities in the basin.

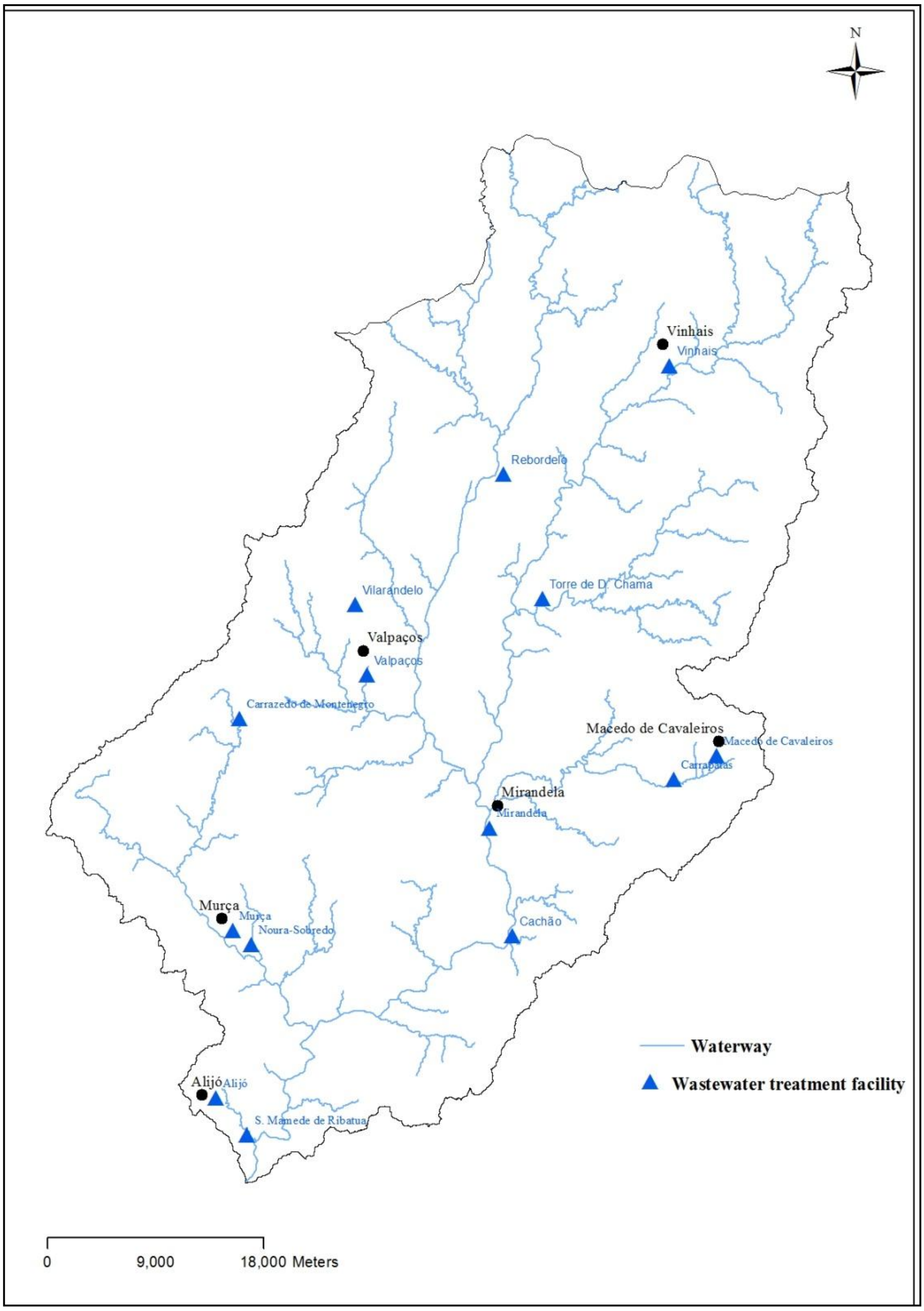

Figure 10. Location of the all the wastewater treament facilities (adapted from SNIRH (2013)).

To further assess the rivers chemical quality the Streeter-Phelps model was applied (Streeter & Phelps, 1925). This model evaluates the variation in dissolved oxygen in a river or a stream during a certain period of time by the degradation of organic matter. To apply the model, the location of the automated sampling stations and wastewater facility was determined.

Figure 11 indicates the location of the automated sampling stations and wastewater treatment facilities currently operating in the drainage basin. Furthermore it is discernible that the distances between some of the automated sampling stations and the wastewater treatment facilities is too great to allow a proper estimate of this factor.

So, considering the location of the worst anthropic pressure points in the drainage basin - Mirandela (biggest urban conglomerate) and Cachão (industrial site) - the wastewater facilities therein located were used to estimate the kind of pollution that these might cause.

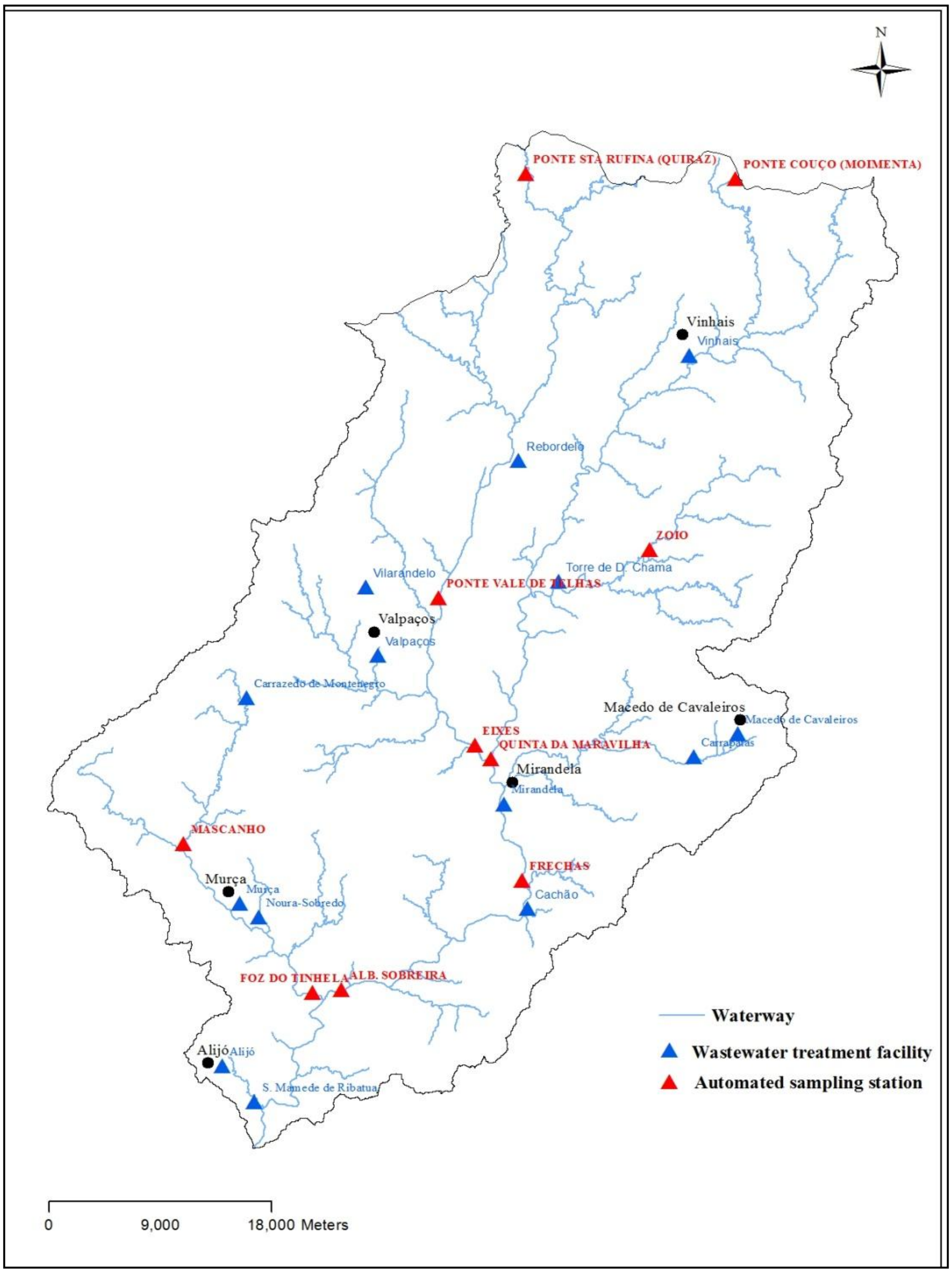

Figure 11. Location of the automated sampling stations and the wastewater treatment facilities throughout the drainage basin (adapted from SNIRH (2013)).

The data from the automated sampling stations *Quinta da Maravilha* and *Frechas* was cross-referenced with the data available from the wastewater treatment facilities (made available by *Águas do Alto-Douro e Trás-os-Montes*, the entity responsible for managing the facilities). However when cross-referencing *Frechas* and *Cachão* there was no overlapping data available and thusly this estimation point was eliminated.

Heretofore the model was applied as follows the schematic represented in Figure 12.

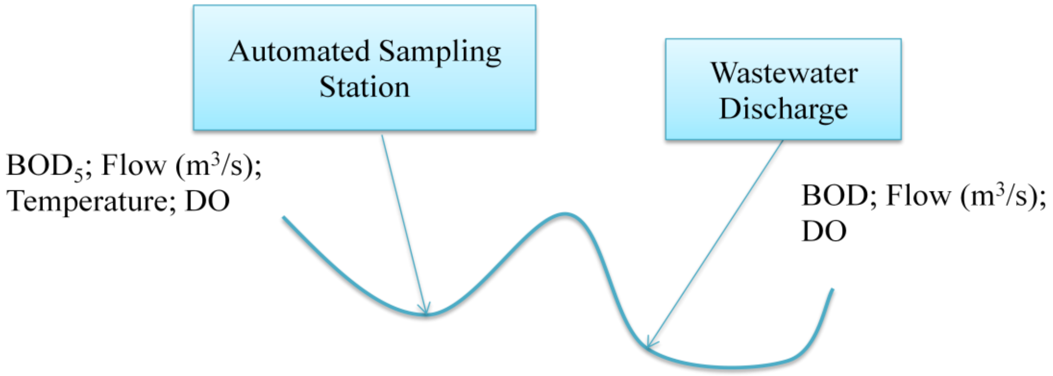

Figure 12. Schematical representation of the application of the Streeter-Phelps model.

So the Streeter-Phelps equation was then applied to determine the dissolved oxygen evolution after the wastewater discharge point. It goes as follows,

$$D = \frac{k_d L_0}{k_r - k_d}\left(e^{-k_d t} - e^{-k_r t}\right) + D_0 e^{-k_r t}$$

in which D is the saturation deficit given in mg/l, k_d is the deoxygenation rate usually in d^{-1}, k_r is the rearation rate also in d^{-1}, L_0 is the initial oxygen demand of organic matter in the water, D_0 is the initial oxygen deficit and t is elapsed time, in d. k_d and k_r are constants whose value is attributed through river and conjoining effluent characteristics.

For the case study application the equation was applied to data from both Winter (December, January, February and March) and Summer (June, July, August, September) periods as these are considered the lowest pollution and highest pollution seasons of the year. Following are the equations used to determine L_0 and D_{00}.

$$L_0 = \frac{BOD_{ASS} Flow_{ASS} + BOD_{WWD} Flow_{WWD}}{Flow_{ASS} + Flow_{WWD}}$$

where L_0 is the initial oxygen demand of organic matter in the water, BOD_{ASS} is the biochemical oxygen demand content of the river given in mg/l, $Flow_{ASS}$ is the flow of the river upstream of the discharge point given in m^3/s, BOD_{WWD} is the biochemical oxygen demand content of the treated wastewater effluent given in mg/l and $Flow_{WWD}$ is the flow of the discharge in m^3/s.

$$D_{00} = \frac{DO_{ASS} Flow_{ASS} + DO_{WWD} Flow_{WWD}}{Flow_{ASS} + Flow_{WWD}}$$

where D_{00} is the initial concentration of dissolved oxygen in the river downstream from the conjoining point, DO_{ASS} is the initial dissolved oxygen content of the river given in mg/l, $Flow_{ASS}$ is the flow of the river upstream of the discharge point given in m^3/s, DO_{WWD} is the initial dissolved oxygen content of the treated wastewater effluent given in mg/l and $Flow_{WWD}$ is the flow of the discharge in m^3/s.

Finally to determine D_0 firstly an assessment was made of the effluent temperature for both Winter and Summer (given that it usually is about 2 degrees higher than river temperature) to determine by application of the following equation the value of saturated dissolved oxygen.

$$DO_{SAT} = 14{,}642 - 0{,}41022T + 0{,}007990T^2 - 0{,}00007774T^3$$

in which T is water temperature given in degrees Celsius. D_0 is given then by the difference of DO_{SAT} and D_{00}.

3.5 - Anthropogenic Pressure

This sub-chapter was deemed as essential to determine not only current but future patterns of anthropic pressure throughout the drainage basin.

Population

To estimate the population parameter, the data from the National Statistical Institute of Continental Portugal were located and evaluated concerning total number of permanent residents in the counties that intercept the drainage basin.

With this data a study was pursued to determine the existence or not of a pattern, to thusly incorporate into expected estimates of population growth pressure on the drainage basin.

Agriculture

To estimate the agricultural activity parameter, the data from the National Statistical Institute of continental Portugal were located only concerning wine production and olive production in the counties that intercept the drainage basin.

With this data an study was pursued to determine the existence or not of a pattern concerning each type of agriculture but looking at each county it was found that the variability was too high to determine a clear overall pattern. Thusly an added study with determined the a total sum of all the counties over each year under study.

And with this final study a pattern for both wine production and olive production was found.

Livestock

To estimate the livestock parameter, the data from the National Statistical Institute of continental Portugal were located concerning the number of heads of cattle per species (Bovine, Ovine, Caprine, Equine and Swine) in the counties that intercept the drainage basin.

On this topic, there isn't any recent readily available information for counties. The last study to number the heads of cattle in each county of northern Portugal was done in 1990. Every year following this one would get a total number of heads of cattle for the whole of northern Portugal published. To assess the number of cattle heads the specific counties containing the water basin had, a proportion of cattle heads for each county was calculated for 1990 and the same annual evolution was assumed equally for the counties from this year on all the way to 2012.

This data has evidently an error associated, but as this study is only to discern a pattern of growth or decrease it is an acceptable error.

Future Infrastructures

To assess the construction of any future infrastructures that may increment the anthropic pressure on the river the master development plan for each county was studied.

4. Results and Discussion

Providing the context to construct a restoration process, especially at watershed-scale, is an important step, thusly, this chapter is constructed first to broach and discuss the individual findings of each parameter discussed in the previous chapter, such as landscape controls, water quality and anthropogenic pressures, finally ending with how these parameter are interconnected to create a template of the drainage basin, leading up to the identification of restoration spots.

4.1 – Landscape Controls

As aforementioned, this sub-chapter means to discuss the findings of each parameter individually, within context of itself.

4.1.1 – Vegetation

A visual comparison of the human impact can be observed between Figure 13, taken in 1917, and Figure 14, taken in July 2013 on the bridge displayed in the first picture, is how land use has either eliminated or separated riparian vegetation.

Figure 13. Present day view of the river and its corridors in an intercepting county - Mirandela.

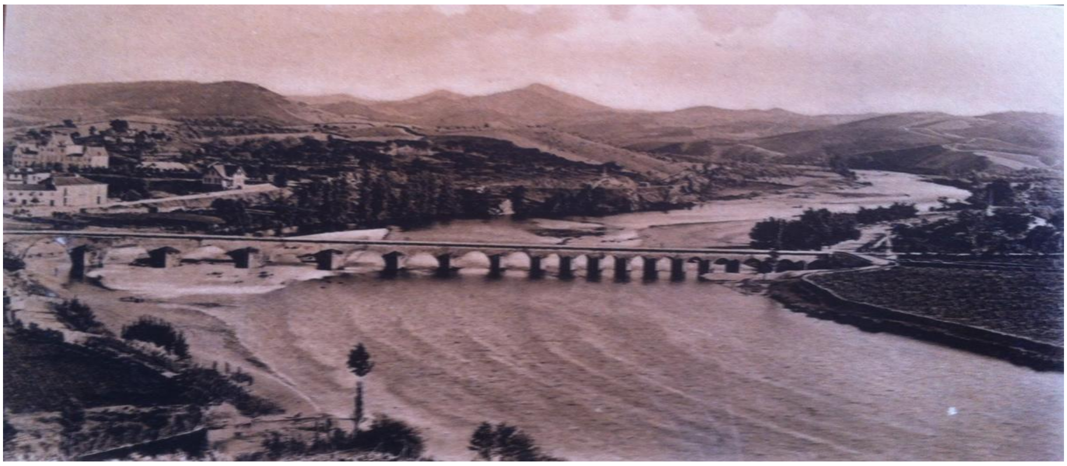

Figure 14. Picture taken of the river Tua in 1917 in an intercepting county - Mirandela

Observation of both figure 13 and figure 14, indicate that alterations to land use throughout the years have impacted riparian vegetation in the urban conglomerate, as well as putting in focus man-made alterations of the river's corridors has been a strain on the river from early human settlement..

Vegetation continuity throughout a drainage basin has been shown to provide habitats and promote diversity (Dallimer et al., 2012; Hale *et al.*, 2012; Moggridge *et al.*, 2009) but is also vulnerable to land use (Fernandes *et al.*, 2011; Ferreira *et al.*, 2005), depending on the context within which a watershed is located, such as mountain ranges, as is the one being studied, indicated by figure 15, it can be particularly vulnerable to livestock grazing (Samuelson & Rood, 2011).

Figure 15, indicates not only vegetation cover but in the context of urban land use as well as permanent livestock grazing. It can be observed thusly that some gaps in the longitudinal continuity of the rivers riparian vegetation are located in major urban landscapes, the biggest conglomerate being Mirandela.

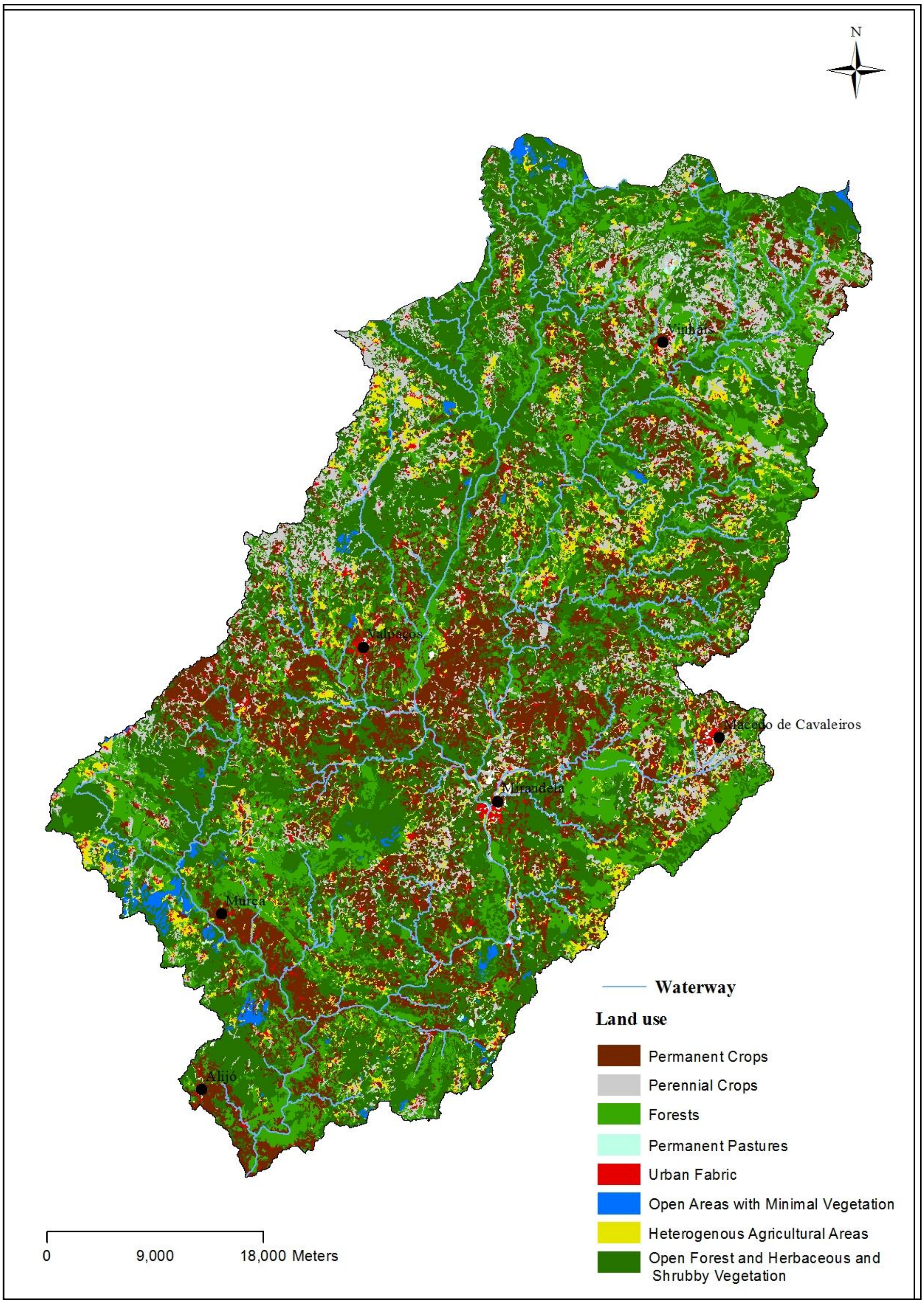

Figure 15. Vegetation cover as well as an assessment of grazing and existing urban fabric (adapted from COS 2007).

Furthermore to comprehensively evaluate the land use throughout the studied area a pie chart, represented in figure 16 was elaborated in accordance with the occupied area of each type of land use identified in table 1.

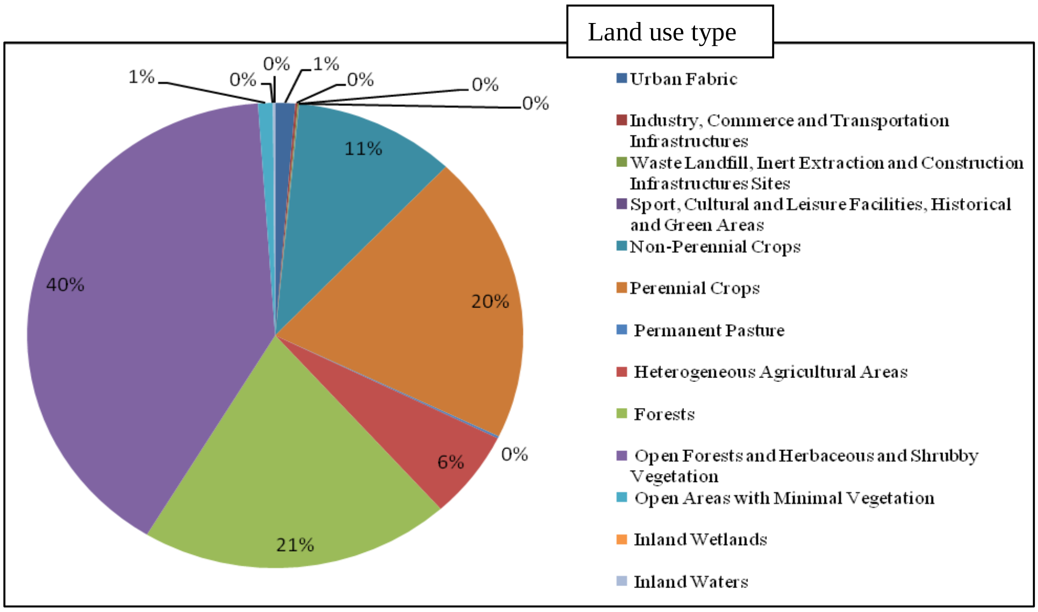

Figure 16. Area occupied by each type of land use type, in percentage.

According to figure 16 most of the drainage basin is occupied by vegetation and agriculture which is an accordance as well with the findings of Ferrão (2004), who states that this region of continental Portugal is inserted into a context of abandonment (migration of residents to coastal cities) and an increment of plant growth as well as agricultural presence.

4.1.2 – Geomorphology

Figure 17 represents the elevation of the study area within which the drainage basin is located. Through the characterization of the watershed elevation it is clear that it is located within a mountain range indicating as well the existence of a plateau type area in the centre of the case study area.

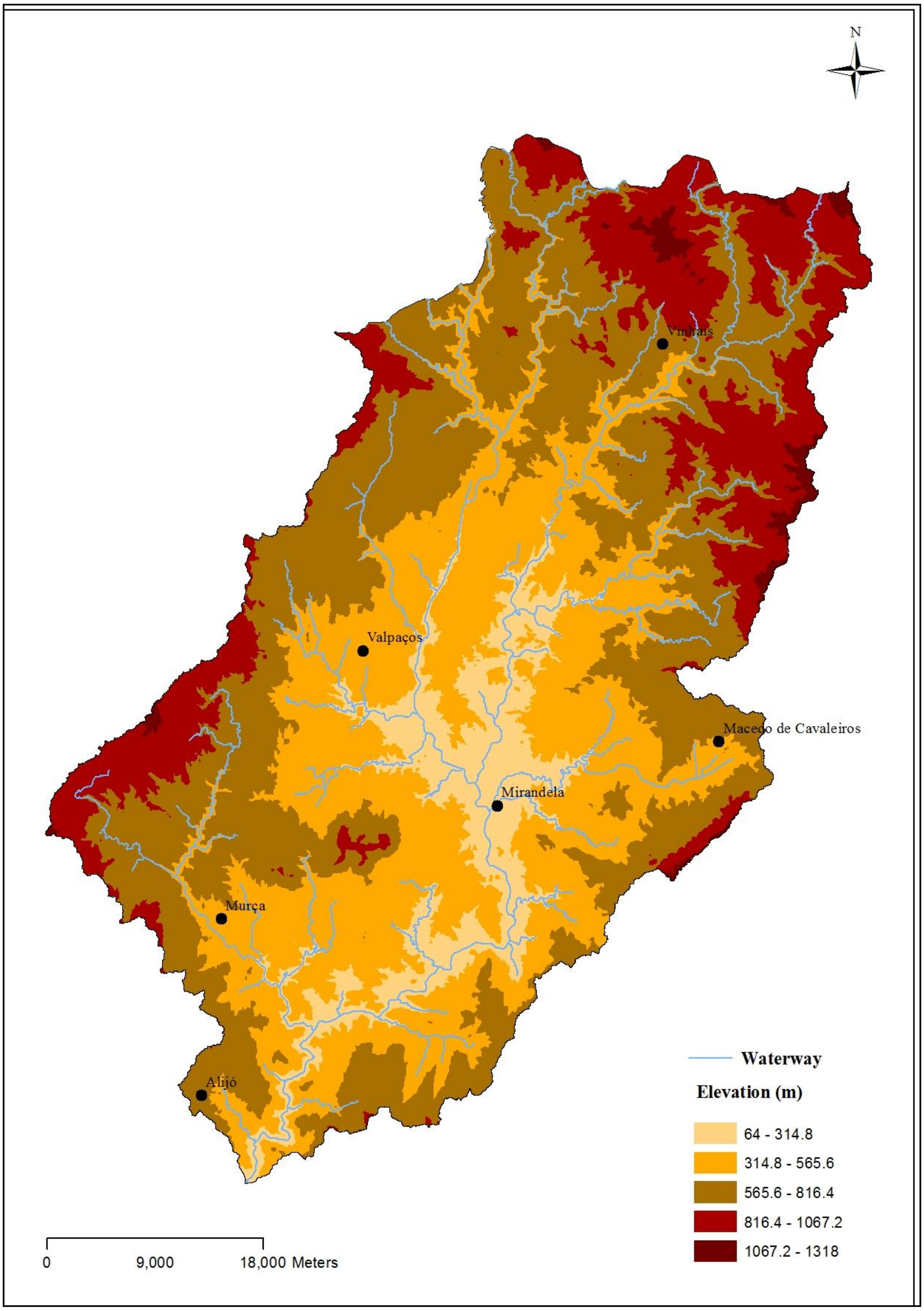

Figure 17. Drainage basin elevation (m) adapted from the Digital Terrain Model with a 30m resolution (ESRI. 2013).

To further evaluate the distribution of elevation throughout the drainage basin figure 18was determined. It indicates that most of the drainage basin is located within the first two classes therefore are below 816.5 meters.

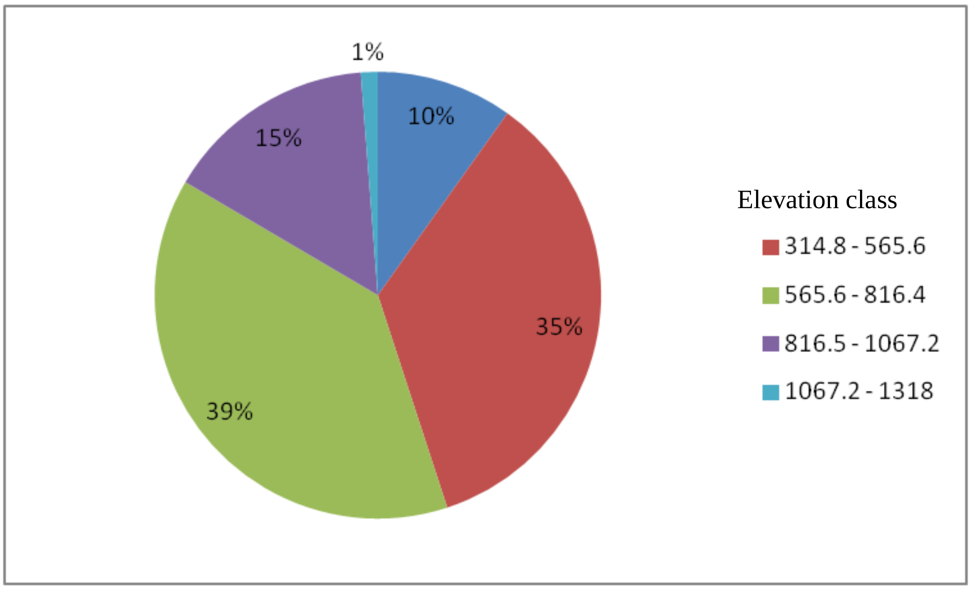

Figure 18. Total area for each class of elevation in percentage.

Although it can be observed both in figure 17 and in figure 18 that there is a big jump of height between classes, such as the minimum elevation registered is 64 meters which is paired with 314.8 meters to define class one. This fact is also supported by figure 19 which represents slope distribution throughout the watershed. It can be observed that indeed the topographic context is very important, as it indicates that there are valleys within the watershed where the river flows but also areas of such steepness that they can’t be targeted for restoration efforts.

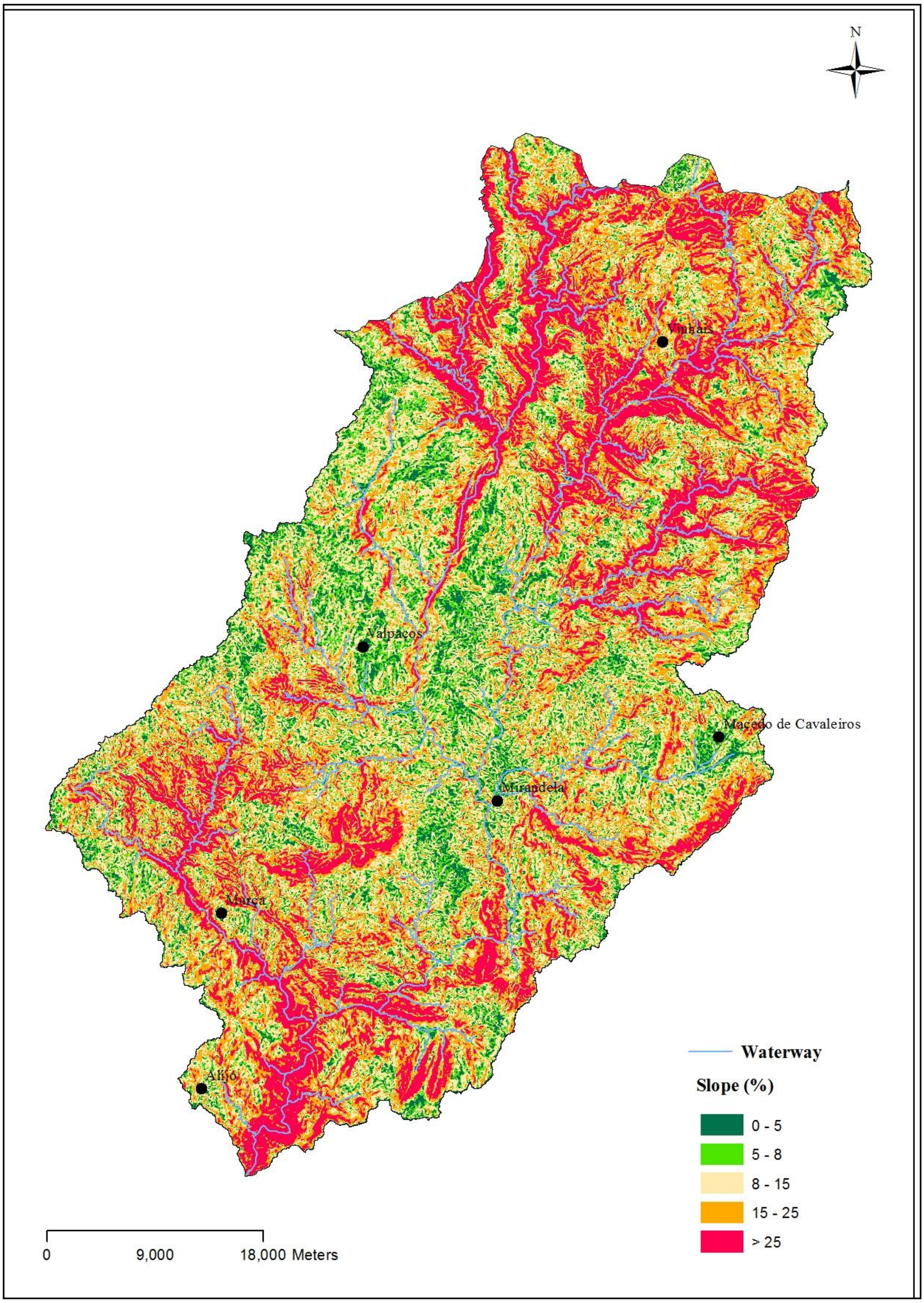

Figure 19. Slope variation throughout the drainage basin in percentage.

Figure 20 represents the total area for each class of slope in percentage.

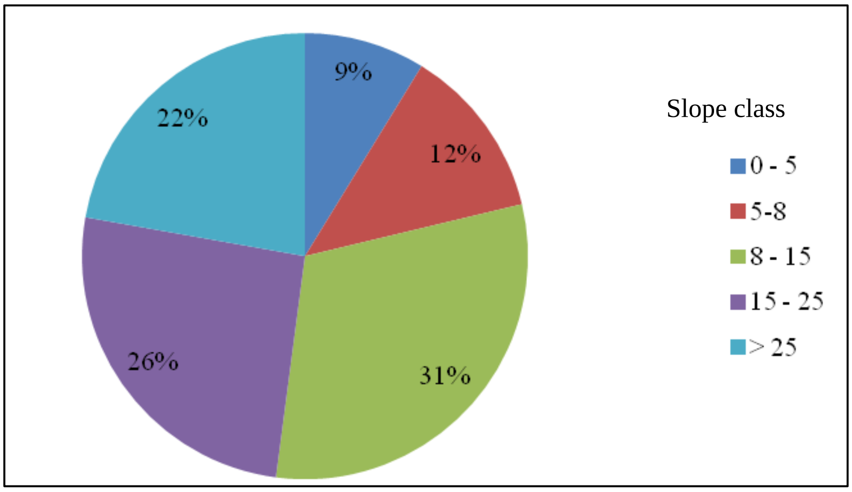

Figure 20. Total area for each class of slope in percentage.

As can be observed by figure 20 most of the drainage basin (approximately 79% of the total area) has a steepness above 8%. This is invaluable when considering which restorative actions can take place, not to mention the difficulty of moving work crews and machinery, if and when necessary, throughout these locations.

Further analysis as to the elevation characteristics, is represented byfigure 21, the hypsometric curve of the basin.

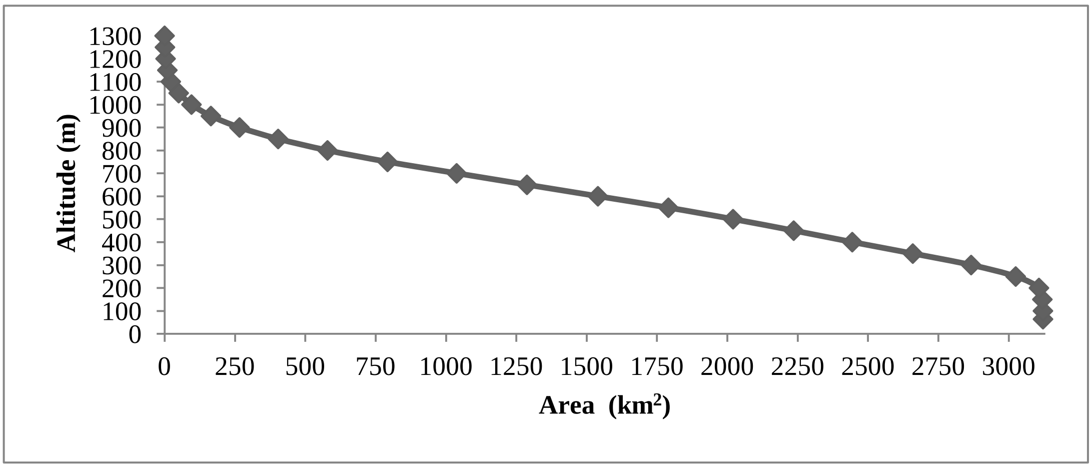

Figure 21. Hypsometric Curve of the drainage basin.

Figure 21, by Strahler (1954), is considered a “young” landform, which is congruent with previous findings, only establishing once more that this is located within a mountainous region. Willgoose and Hancock (1998) further studied the hypsometric curve, in an area-slope-elevation perspective, and concluded that the concavity of the toe end of the curve is due to the elevation of short and steep lateral inflows as the elevation increases. This argument is also congruent with figure 19 as can be observed with the steepness of the channels represented.

Furthermore, figure 22 which represents the longitudinal profile of the river, also confirms the previous claims, as by Perron and Royden (2013) the concavity of the profile is due to effect of the uplift rate of steepness.

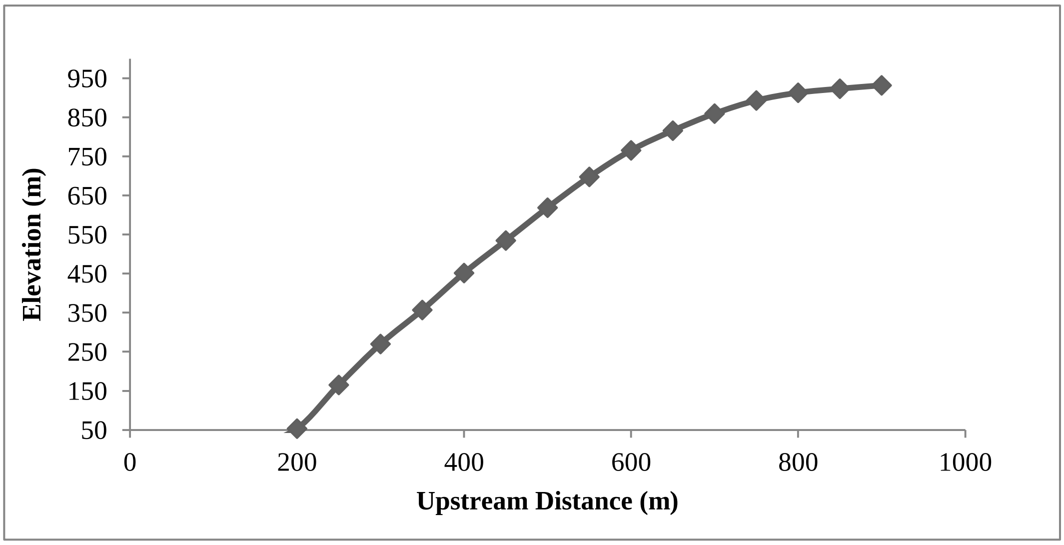

Figure 22. Longitudinal profile of the waterway throughout the drainage basin.

The geomorphic context, high elevation with some areas of the river contained within steep channels, thus far, identifies a template of potentially inaccessible restoration sites as well as a basis for the establishment of achievable restoration goals within this context.

Following from this, it is essential to know where restoration interventions might take place. The evaluation of figure 23 displays soil erosion rate over the basin.

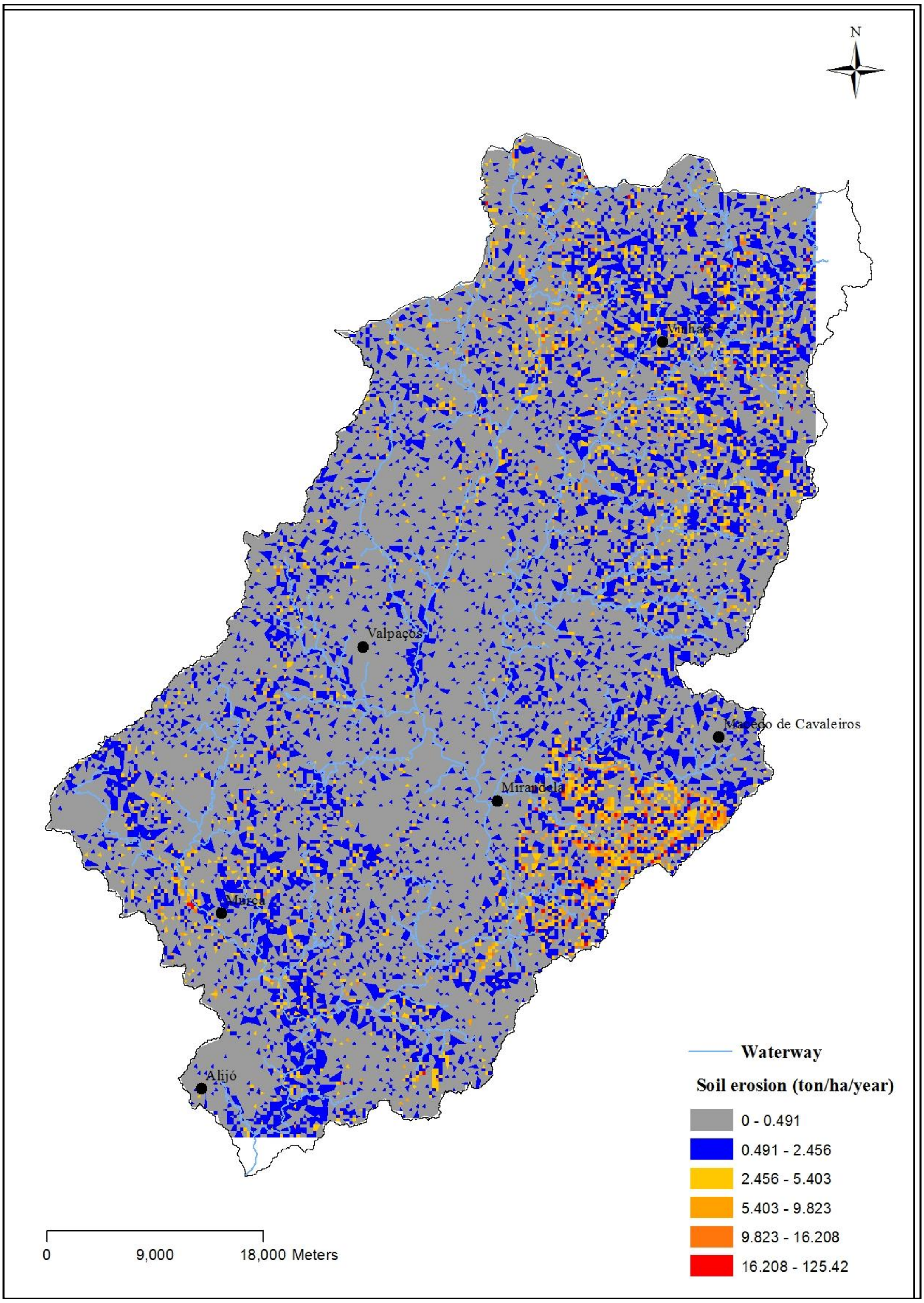

Figure 23. Soil loss rate throughout the drainage basin, in ton/ha/year.

Observation of figure 23, suggests that the erosion taking place throughout the drainage basin isn’t high, with the exception of pinpoint locations, which is further supported by figure 24 which indicates that the vast majority of soil erosion is at the most no higher than 0.491 tonnes per acre per year.

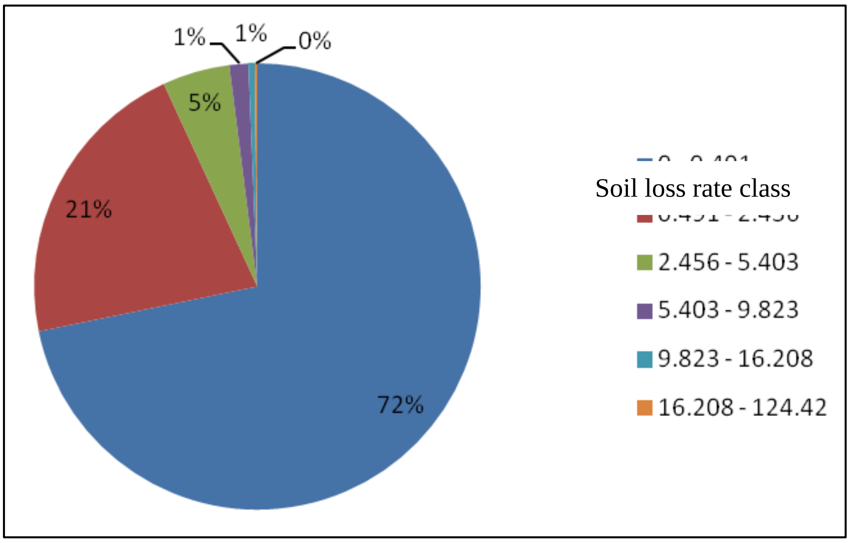

Figure 24. Total area per class of erosion in percentage.

Within the geomorphologic context and the findings so far, an overlapping of figure 19 with figure 23suggests that these erosion rates are due to the elevated steepness of the hillslopes in either zone (Bellin *et al.*, 2011; Feng *et al.*, 2010) .

From this point onwards in order to determine the reason behind the elevated concentration of erosion observed in figure 23, over the south-western end of the drainage basin, firstly, as can be observed in figure 25, a study of the lithology of the type of area indicates that it is constituted of basically the same type of rocks found throughout the basin. Henceforth it could be related either to the soil composition itself or to land-use practices over that area.

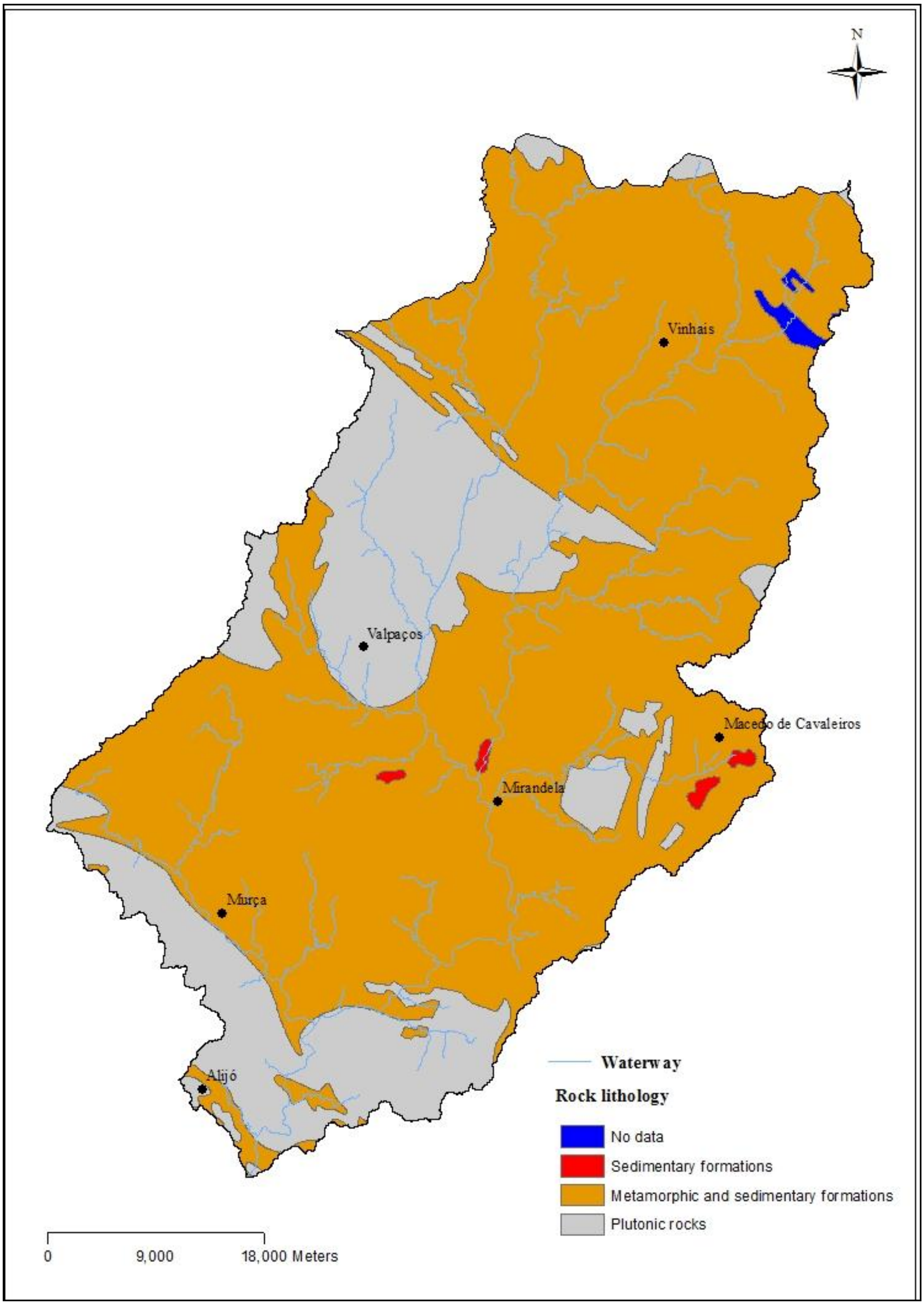

Figure 25. Rock lithology throughout the drainage basin (adapted from the *Carta Dos Solos E Carta Da Aptidão Da Terra Do Nordeste De Portugal*).

Figure 26 represents the total area occupied by each type of rock lithology identified, and it indicates that the most widespread lithology is metamorphic and sedimentary formations.

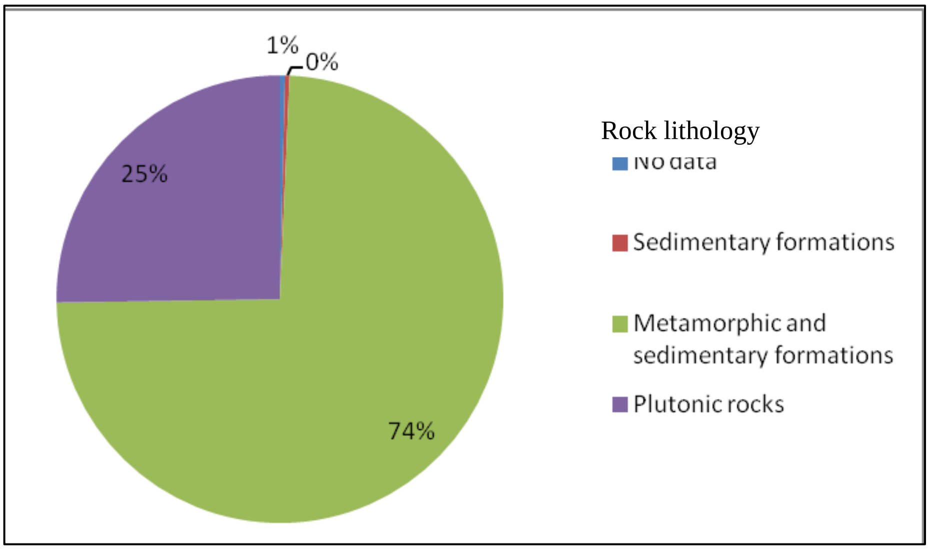

Figure 26. Total area per rock lithology in percentage.

Figure 27, represents soil type distribution throughout the watershed and as to allow a better interpretation of the map, a detailed listing of the soil types can be found in appendice 1. Furthermore, figure 15 in conjunction with a definition of soil type as well as use analysed during the charting process of *"Carta Dos Solos E Carta Da Aptidão Da Terra Do Nordeste De Portugal"* indicate that due in part to not only isolated slope steepness, but soil type as well as land use are conjoined in creating the erosion rate pattern observed in the south-western area of figure 23.

It can indicate areas of the watershed that could be pinpointed for restorative action, as the concentrated erosion rate observed overlaps river streams, and can cause a high input of sediment load.

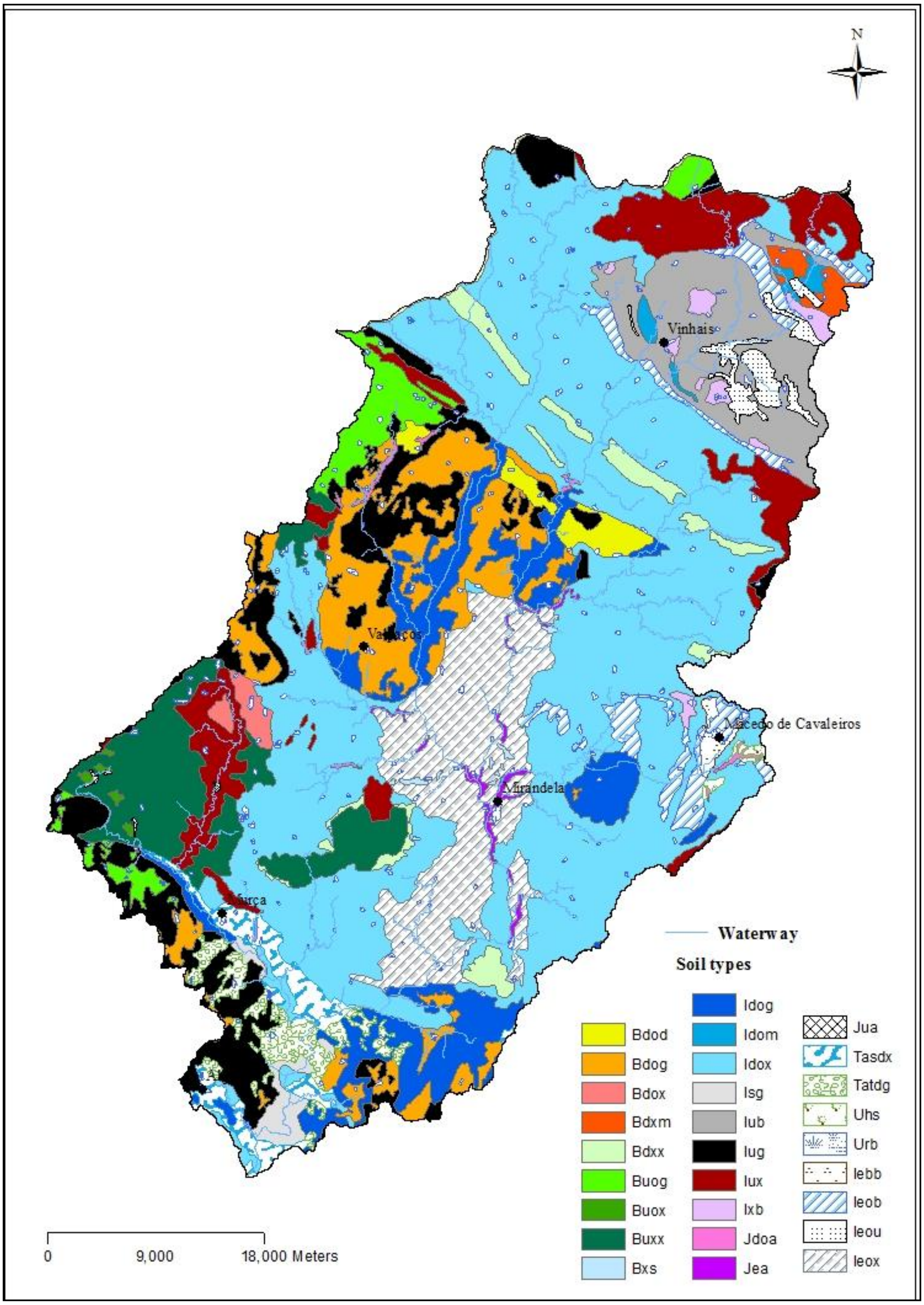

Figure 27. Distribution of the various soil types found throughout the watershed (adapted from *Carta Dos Solos E Carta Da Aptidão Da Terra Do Nordeste De Portugal*).

Finally, figure 28, indicates the type of soil with a larger presence throughout the watershed.

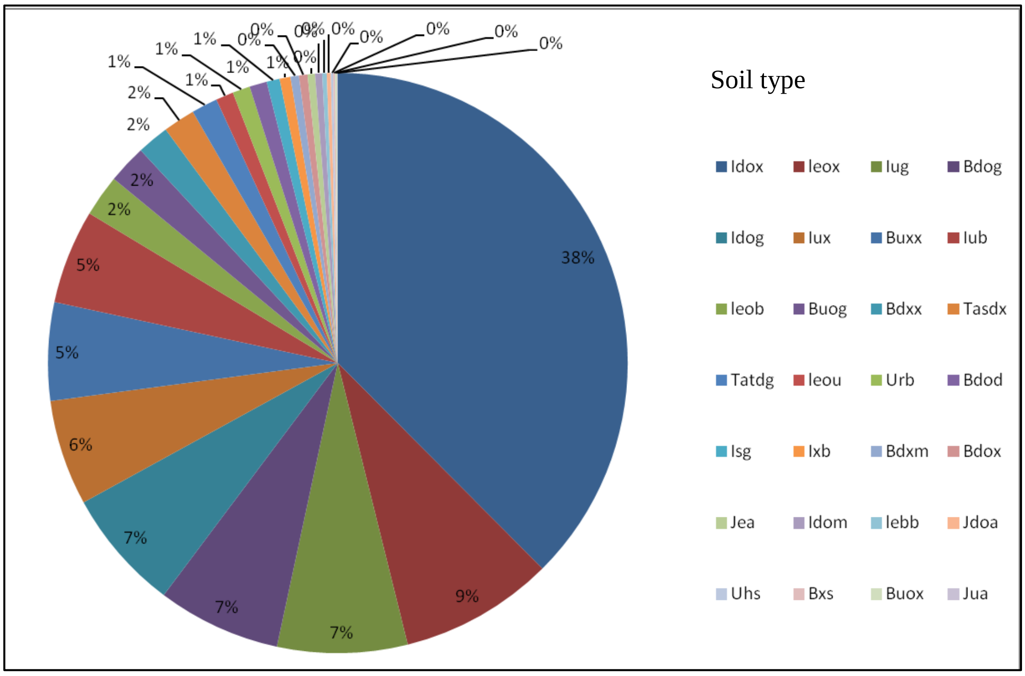

Figure 28. Total area occupied by each soil type present in the drainage basin in percentage.

Observation of figure 28 indicates that Idox is the most widely represented soil throughout the watershed with a presence of almost 40%. Its lithology is mostly slate and other such rocks, therefore metamorphic and sedimentary formations, with a high amount of steepness and elevation variations it is preferred soil for agricultural of cereals and olive trees as well as vineyards.

The geomorphologic context created thus far indicates that this is a highly sought after soil and that restoration interventions that require cessation of anthropogenic activities on this type of soil might have negative economic, social and cultural impacts that might turn stakeholders against the restoration process.

4.1.3 – Climate

The drainage basin is subject to a variety of climate classifications each diferent climate area is classified and divided into 4 zones as can be observed in Table 11.

Table 11. Climate characterization of each climatic zone located within the drainage basin.

Zone	Characteristics
1	- Very Hot Summers - Mild Winters - Ocasional Frost - Precipitation < 600 mm - Located within the *“Terra Quente Transmontana”*
2	- Typical Continental Climate - Cold Winters - Hot Summers - High Daily and Yearly Thermal Variations - Lengthy Frost Season - Located within the *“Terra Quente Transmontana”*
3	- Mountainous Region known as: *Serra da Nogueira* - Long Winters - Short Summers - Located within the *“Terra Fria Transmontana”*
4	- Mountainous Region known as: *Serra da Coroa* and *Serra de Montesinho* - Long Winters - Short Summers - Located within the *“Terra Fria Transmontana”*

This climate classification indicates that any restoration interventions should take into account the variability of the diferent climate zones present throughout the watershed, the identification of very specific locations where the climate conditions are very different provides restoration efforts a dynamic character and allows the adjustment of aims and goals as well as other factors when deleniating a restoration plan.

With this climate setting in context, the following step is global solar radiation, represented in figure 29. Temperature variation can be directly related with direct solar radiation (Budyko & Spasskaja, 1968; Makowski et al., 2009), and therefore it has an effect on the distribution of habitats throughout a drainage basin and is integrated into a restoration effort by providing information concerning vegetation distribution.

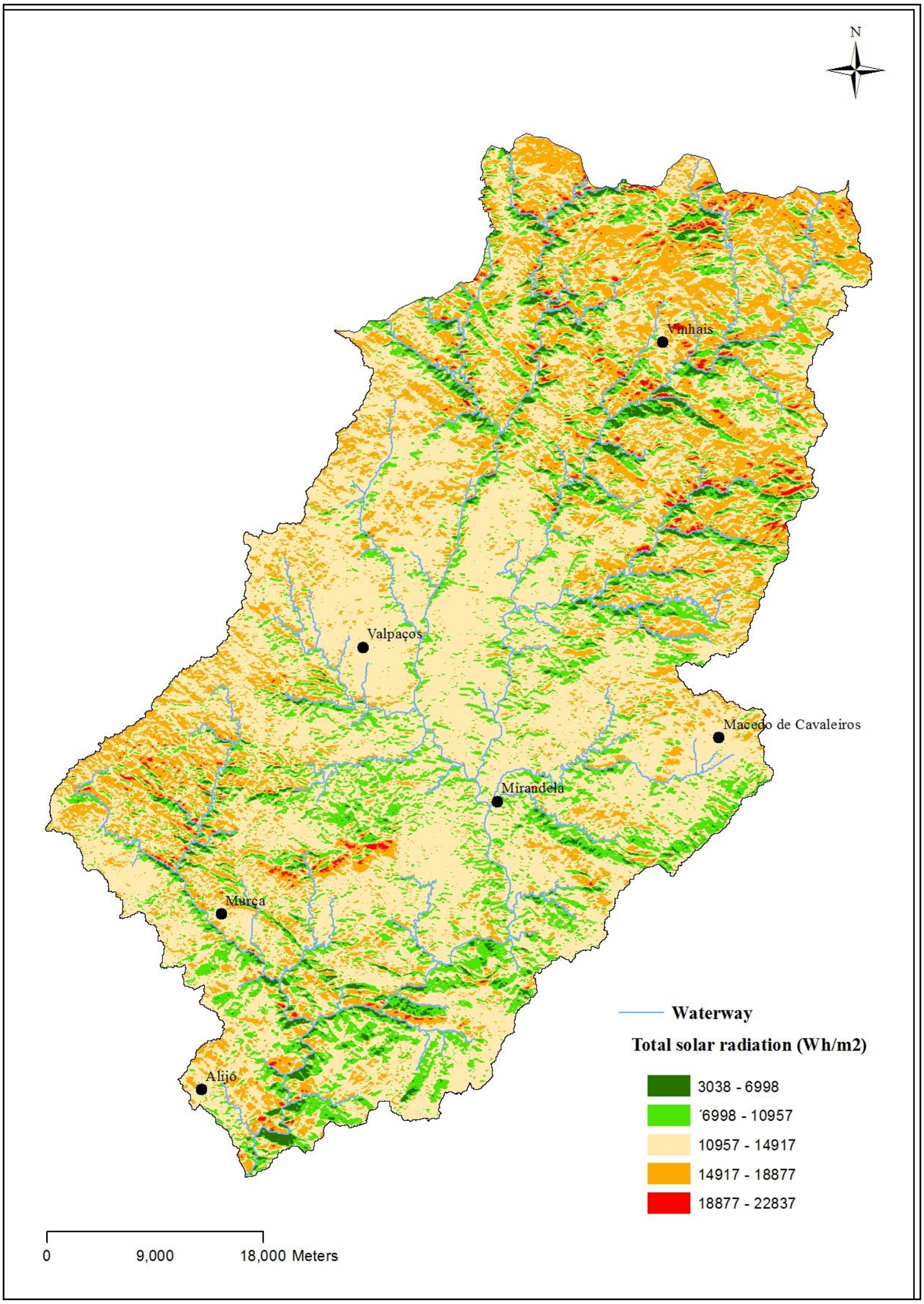

Figure 29. Solar radiation variation throughout the drainage basin in Wh/m^2 obtained from the digital terrain model (30 m resolution) ESRI (2013).

The range of variation of this parameter represented in figure 29, is in correspondence with the “European Solar Radiation Atlas” findings of Scharmer and Greif (2000).When observing figure 29, in conjuction with figure 15, which represents vegetation cover throughout the watershed, a link between the highest solar radiation values and vegetation distribution can be made, as where solar radiation is highest, there are no forests, or open forests, in fact it is the location of open areas with minimal vegetation, the type which has adapted to the harsh conditions of the climate of solar radiation.

Figure 30 represents the total area covered by each class of solar radiation defined in percentage. It indicates that the majority of the drainage basin (60%) receives between 10957 and 14917 watt-hours per square meter which is congruent with the findings of Rich *et al.* (1993) in the climate context.

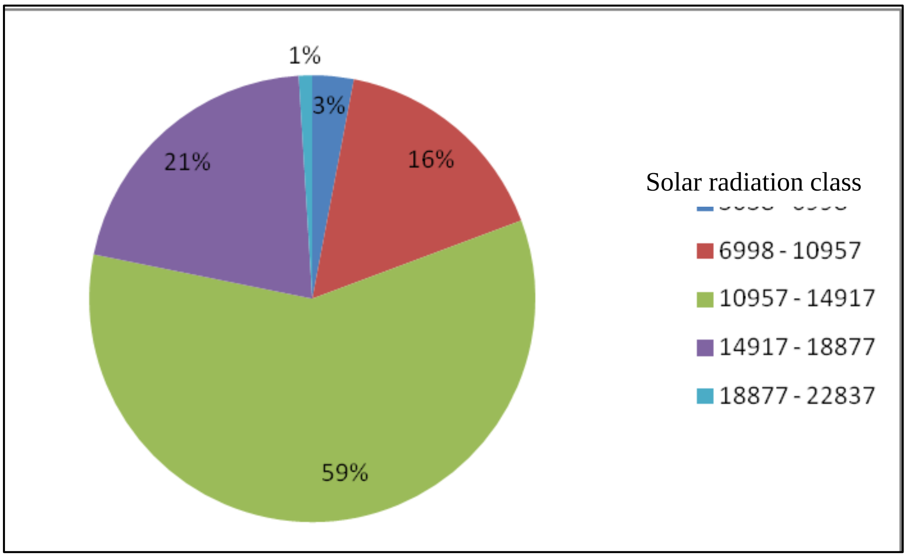

Figure 30. Total area covered by each solar radiation class in percentage.

Therefore, sites with a solar radiation higher than 18877 wh/m^2 a year should not be targeted for restorative actions which require the restoration of riparian vegetation, as it would work against the project objectives, and be deemed a failure.

Following are the findings of the analysis of precipitation and its variability throughout the years, to assess whether a pattern can be established concerning future precipitation in a world of climate change. Figure 31 represents the mean annual precipitation per station.

Observation of figure 31 indicates that the study of smaller time lines, such as 1957- 2007, show a much more rapid decrease than longer time lines, such as 1932-2007, therefore a progressive reduction in mean annual precipitation is taking place, but not at an accelerated rate, but enough to be accounted for in any restoration efforts connected to this parameter.

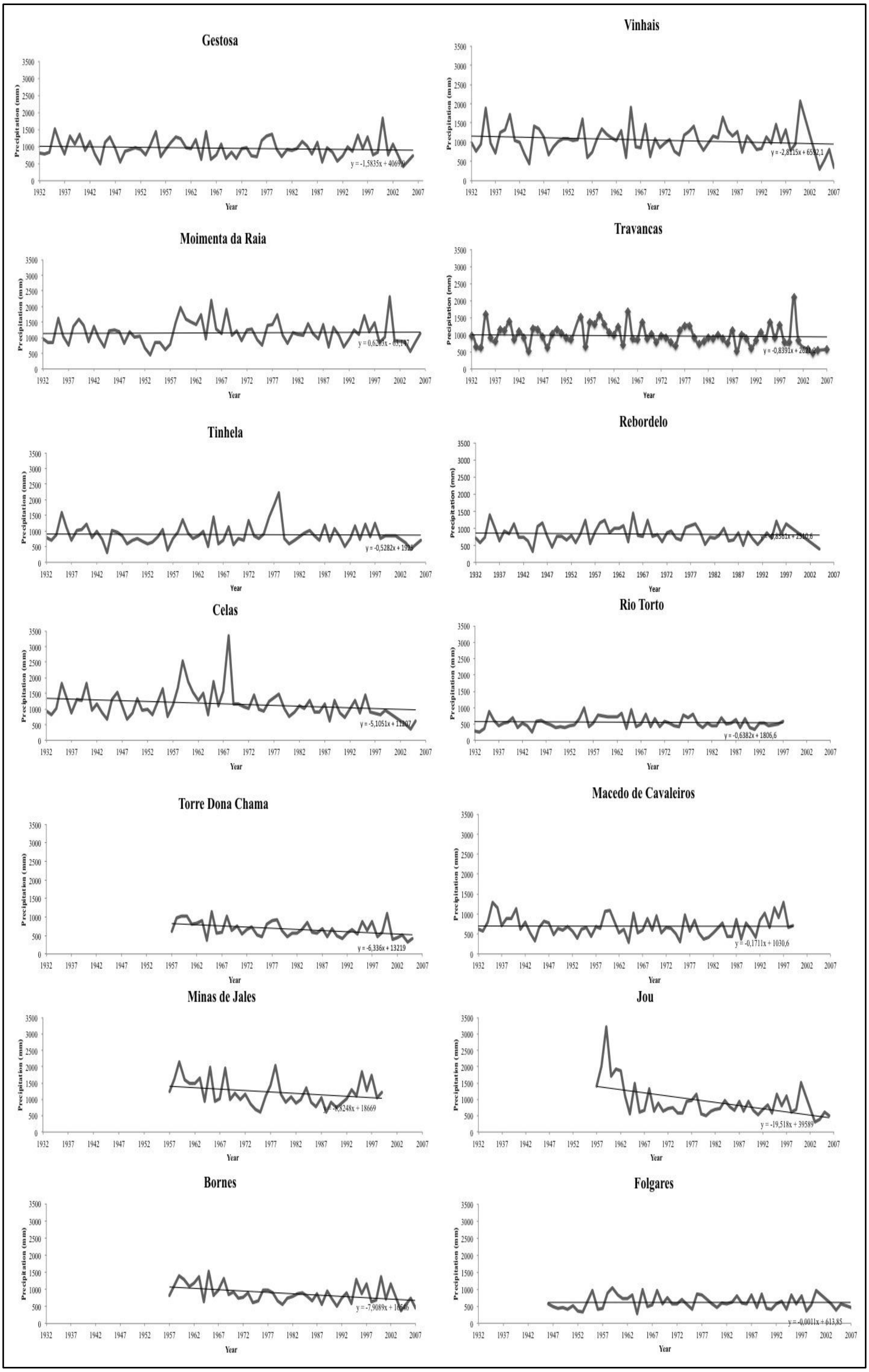

Figure 31. Mean annual precipitation, per meteorological station.

Furthermore Figure 32, which was created through the ArcGIS© IDW tool, indicates that the distribution of precipitation is in accordance with the values established in table 11. Precipitation is highest around the the mountainous reaches, indicated as zone 3 and zone 4 of table 11, declining towards the valley formed with the lowest steeps.

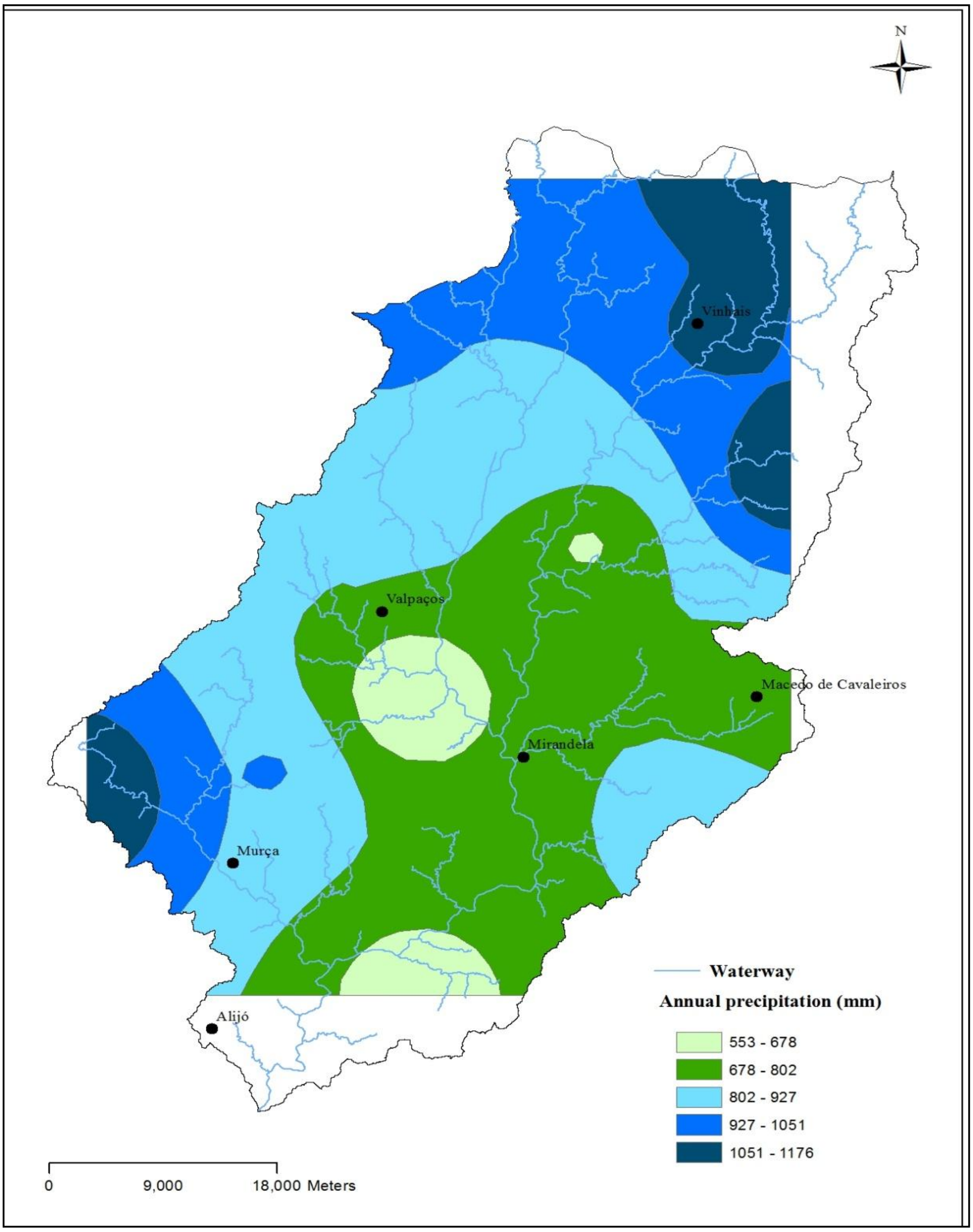

Figure 32. Distribution of mean annual precipitation throughout the watershed through IDW.

This estimated distribution of precipitation is an indication to what restorative actions can be, as to assess habitat forming conditions but as well, adding an adaptive perspective to other restorative actions, such as reducing erosion rates, or riparian vegetation restoration, as these need to adjusted to the climate they are going to be inserted in.

Figure 33 represents mean annual temperature distribution throughout the drainage basin. These temperature variations are congruent as well with Daveaus' (1985) classification, of "Terra Fria Transmontana" and "Terra Quente Transmontana".

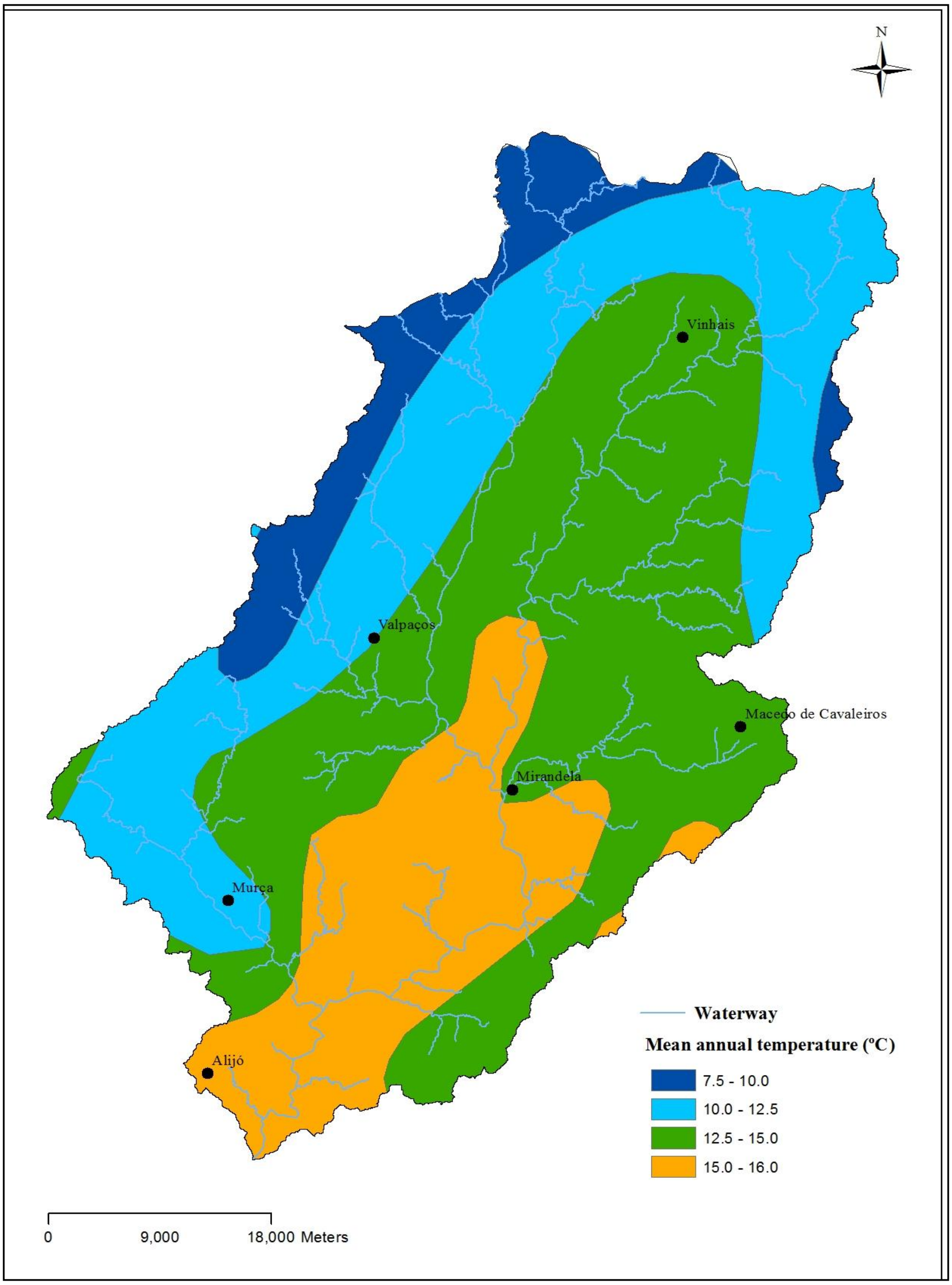

Figure 33. Distribution of the mean annual temperature.

The mean annual temperature is an indicative of habitat distribution, and in conjunction with the distribution of mean annual precipitation and solar radiation build a picture of fauna and flora distribution and are a valuable resource to the adaptativity and isolation of restoration sites and establishment of restoration goals.

4.2 – Water Quality

Table 12 represents the WQI results per automated sampling station.

Table 12. WQI results, per automated sampling station.

Station	WQI
“PonteCouço”	75
“PonteSantaRufina”	73
“PonteValeTelhas”	75
“QuintaMaravilha”	73
“Frechas”	70
“AlbSobreira”	71
“Zoio”	89
“Eixes”	74
“Mascanho”	78
“FozTinhela”	75

Dojlido *et al.* (1994) argues that although all the basic parameters need to be estimated, the advantages of the method surpass its disadvantages. Kumar and Dua (2009) argue further that the WQI does not indicate the real quality of the surface water in study as its determining parameters are not enough to appropriately assess water quality fully, and yet it indicates an idea of the water quality that managers can expect to find, as it is a simple and understandable index for all stakeholders involved.

The Water Framework Directive (WFD) demands good ecological and chemical status for all surface water at a European level by 2015 which considering the vastness of the riverine networks throughout the different countries belonging to the European Union allows the WQI determination from these automated sampling stations to become a valid monitoring and assessment tool, a subject which has been broached by Terrado *et al.* (2010) as well as Kumar and Dua (2009) and has been found to be an adequate preview as to the water quality that can be expected.

Within the context of legislative demands by the WFD, a closer observation of table 12 indicates that the water quality throughtout the reach is good (70-90), but some sampling stations are right on the edge of going down into medium (50-70) quality and therefore could be indicative of restoration needs in order not to fall below its current standard.

A closer observation at the upstream conditions of the sampling stations with the lowest scores can indicate parameters that require restoration efforts and allows the setting of goals for a drainage basin scale restoration plan to be put in place.

More recent studies indicate that although WQI can identify principles problems, such as wastewater-discharges and eutrophication it should be grouped up with a separate ecological assessment (Sánchez *et al.*, 2007; Terrado *et al.*, 2010).

The Streeter-Phelps model was first introduced in 1925 with an article by Streeter & Phelps concerning the study and pollution of the Ohio River, and the connection made between the rate of biochemical oxidation and the remaining concentration of unoxidized substance. It is a one-dimension steady-state model on the whole taking the river as a closed system, allowing thusly an assessment of the general pollution of a river.

Nas *et al.* (2008) as well as other studies (*e.g.* Sánchez *et al.*, 2007; Wang *et al.*, 2013) consider the model to be appropriate as it responds adequately to pressures such as population growth, industrial discharge as well as wastewater facility discharges and assesses that the model provides an indication of what managers can expect the ecological quality to be. Although it has been argued as well by Jha *et al.* (2007) and Peng *et al.* (2010) that the Streeter-Phelps model needs to be modified and take into account more parameters to accurately assess all externalities as well as adding an adaptability to estimate pollution far away from a sewage outlet.

Figure 34 represents the dissolved oxygen SAG curve for both Winter and Summer of the wastewater treatment facility *Mirandela*.

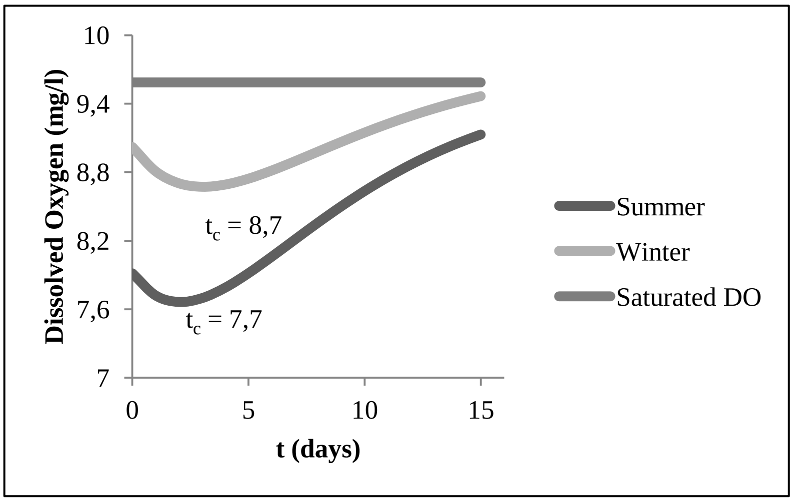

Figure 34. Dissolved oxygen deficit in mg/l.

The quality of the station observed through the SAG Curve indicates mild pollution, which is congruent with the findings of the the application of WQI, which indicate good status throughout the basin and could therefore be related to the impacts of point source pollution discharges such as the discharges of wastewater treatment facilities.

The assesment of the water quality of the river so far indicates that it is only mildly polluted and therefore with an overall good chemical quality.

4.3 – Anthropogenic Pressure

The total resident population in the municipalities where the drainage basin under study is located indicates, as shown in figure 35, a decreasing pattern throughout the period comprised between 1991 and 2012. With a decreasing number residents, residential water comsumption in the drainage basin can be expected either decrease or maintain current levels of consumption, acting as a release valve in anthropogenic pressure.

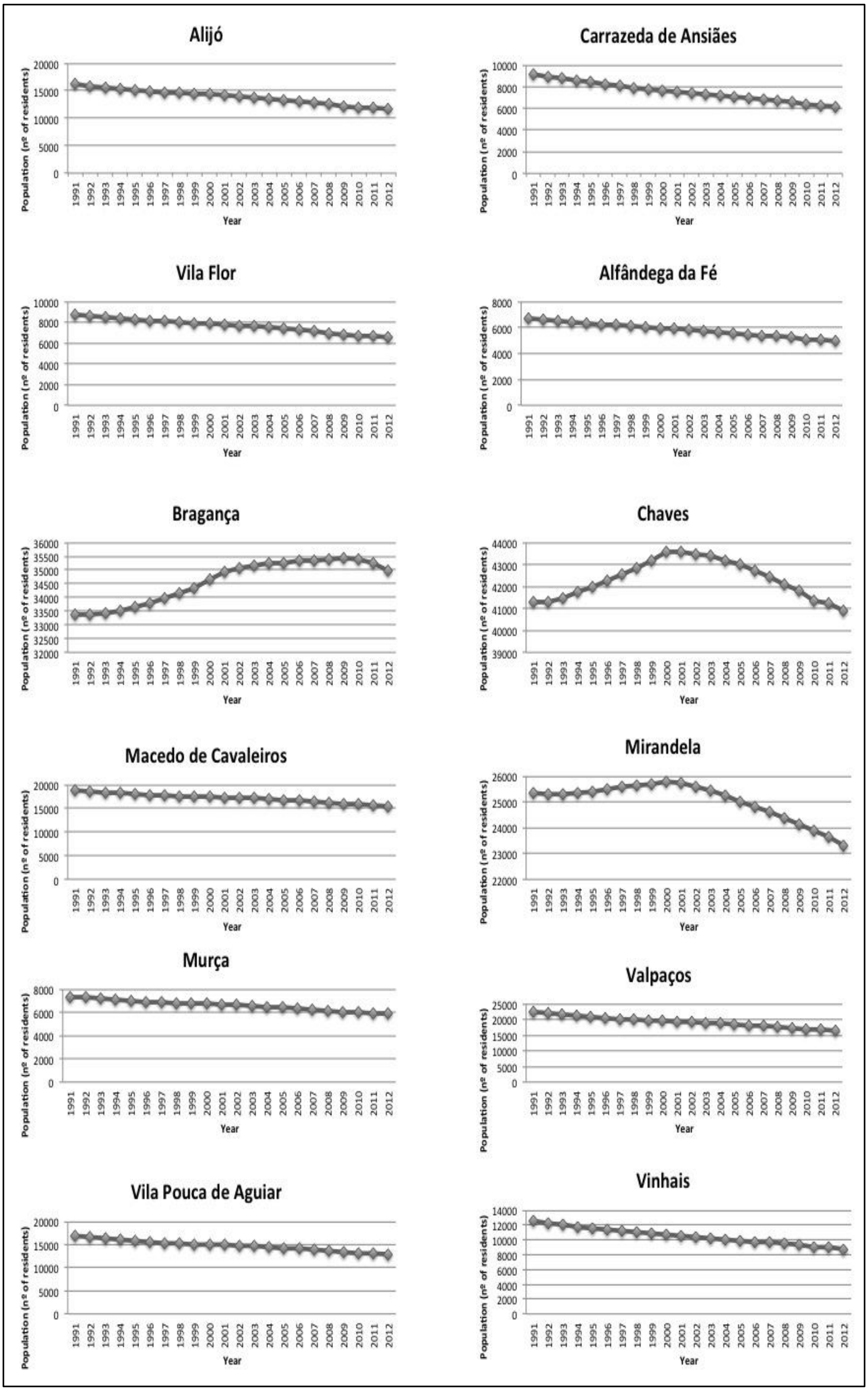

Figure 35 . Population growth variation throughout the counties that intercept the drainage basin

No overall discerning pattern could be determined from a closer observation of the each county's data corncerning wine production and olive production. As such a total sum of the data from all the counties was determined, represented by figure 36 and figure 37.

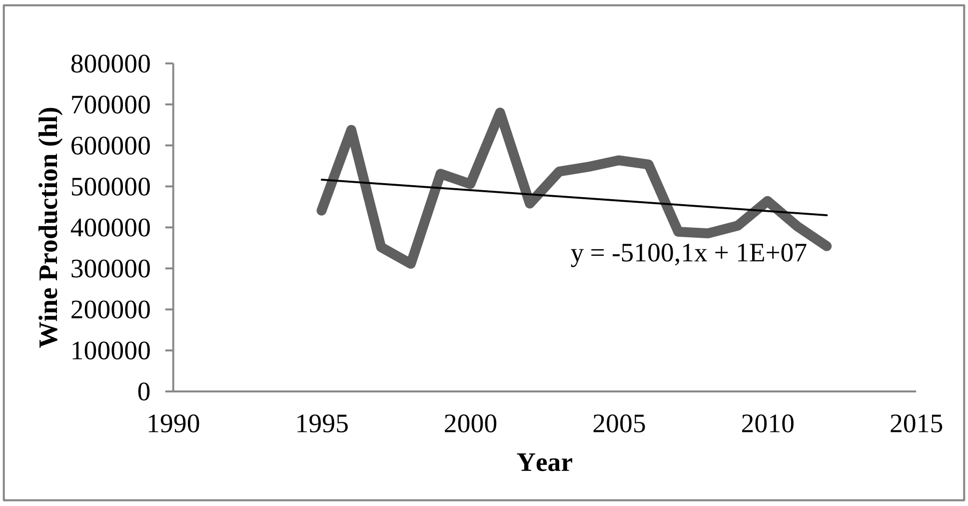

Figure 36. Total wine production (hl) and tendency line within the drainage basin.

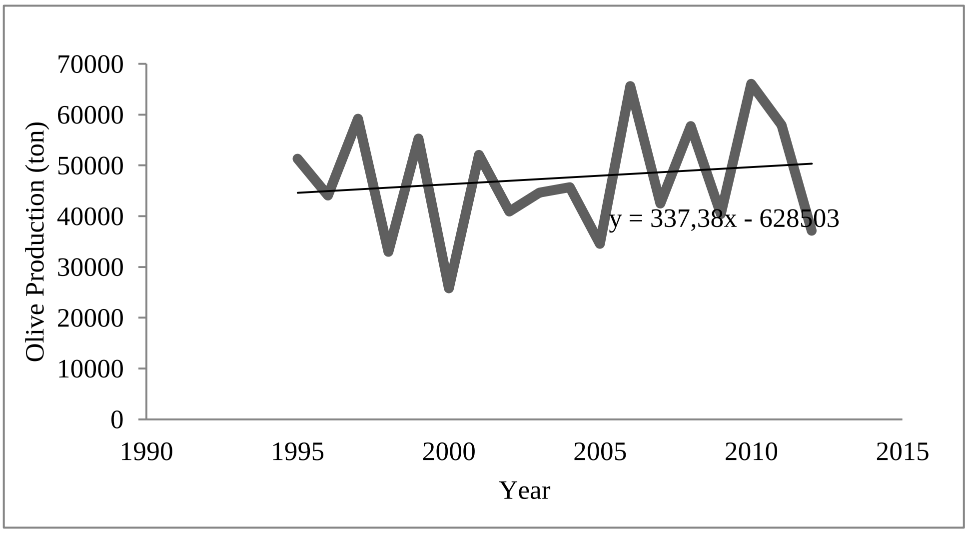

Figure 37. Total olive production (ton) and tendency line throughout the drainage basin.

Both figure 36 and figure 37 are an indication of anthropic pressure caused by agriculture in the drainage basin area, but while Figure 36 indicates that overall wine production is decreasing, figure 37 indicates that overall olive production has been increasing.

The viticulture throughout the basin can be found in terraced hillsides represented in figure 38. Findings by Castro *et al.* (2007) and Townsend (2011) suggest though that the current practices which the steepness and height of the hillslopes on current viticulture is taking place (the current trend is to explore against hillsides without building these terraced layers) cause instability and erosion, and the use of chemicals in weed control a necessity. The conjunction of these factors makes this type of agriculture unsustainable adding pressure to its surrounding environment.

Figure 38. Grapevines on the hillslopes of the river "*Tua*", by Delfim (2010).

No findings could be made on the practices of olive tree farming throughout the reach-scale, concerning farming methods and determination of their sustainability, therefore the current rate of growth of the olive production industry and the rate of decline of wine production indicate that in the future the pressure caused by agriculture cannot be predicted, as it may stagnate or increase depending on farming practices becoming more or less sustainable.

The evolution of animal husbandry in recent years indicates a reduction of cattle heads. So a closer at the total sum per type of animal from all the counties which intercept the drainage basin, is represented in figure 39. Its purpose is to confirm the decreasing pattern of cattle heads.

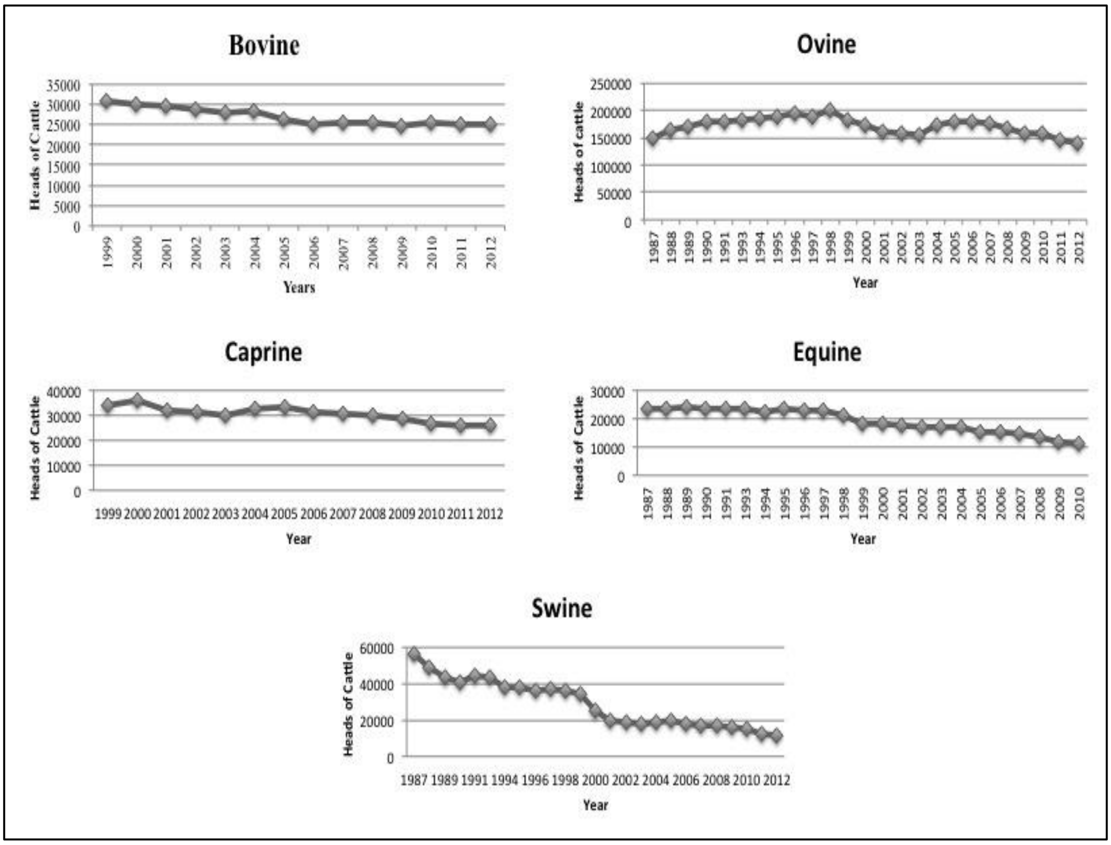

Figure 39. Animal husbandry evolution throughout the municipalities.

A closer look at figure 39, suggests that the bovine population appears to have stagnated in recent years, but all the other cattle types seem to follow the pattern determined, with an ever-reducing rate of growth. Therefore a general assessment as to the environmental pressure caused by animal husbandry is will be reduced.

To determine restorative actions an analysis of future plans concerning river infrastructures by the counties that may impact the river, as well as determine the success of these restoratives actions, it has been determined that at the moment the construction of a new dam is ensuing.

Table 13 indicates the characteristics of the new damn.

Table 13. Characteristics of the new dam.

Location	**1100 meters upstream from the mouth of river *Tua***
Length	2700 m
Inundated Area	4,2 km^2
Affected Waterways	*Rio Tinhela,* *Ribeira do Vale de Manhascal* *Ribeira de Milhais*

The new dam is going to have a profound impact, reaching far into the drainage basin as can be observed by figure 40 as was described from its environmental impact assessment (EIA) study. These impacts cannot simply be mitigated and even though there has been some controversy surrounding the construction of this dam, related to UNESCO findings it is still currently under construction.

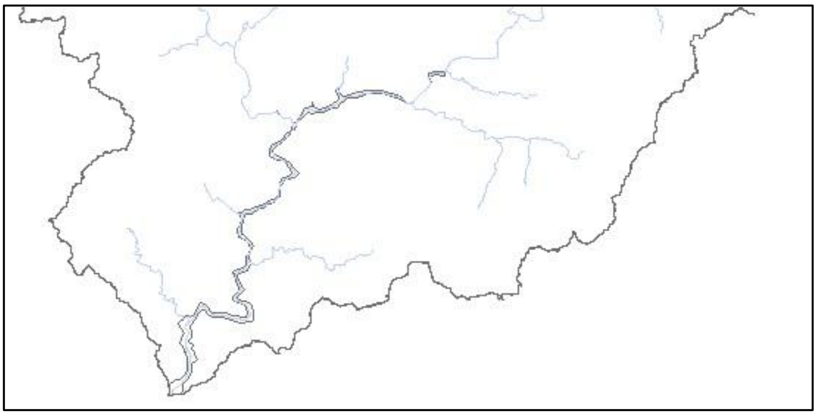

Figure 40. Close up of the length of river corridor that will be affected.

Therefore restoration actions need to include a scenario that takes into assessment these impacts when defining restoration sites.

4.4 – Template

The purpose of this final subchapter is to relate the drainage basin findings to a watershed-scale, observing where pinpoint restorative actions can take place in order to allow the aquatic ecosystem to naturally return to a higher chemical and ecological quality status.

The watershed-scale or sub-basin approach is defended by Beechie and Bolton (1999) although Beechie and Roni (2013) is more up to date. This type of approach follows basic forming processes of the drainage basin but takes a closer look at each sub-basin contained within the drainage basin, as to identify what alterations have occurred that led to the current chemical and ecological state.

Throughout the drainage basin, and through the application of the ArcSwat© extension to ArcGis© (ESRI, 2013) it has been determined that the basin has 29 sub-basins indicated by figure 41.

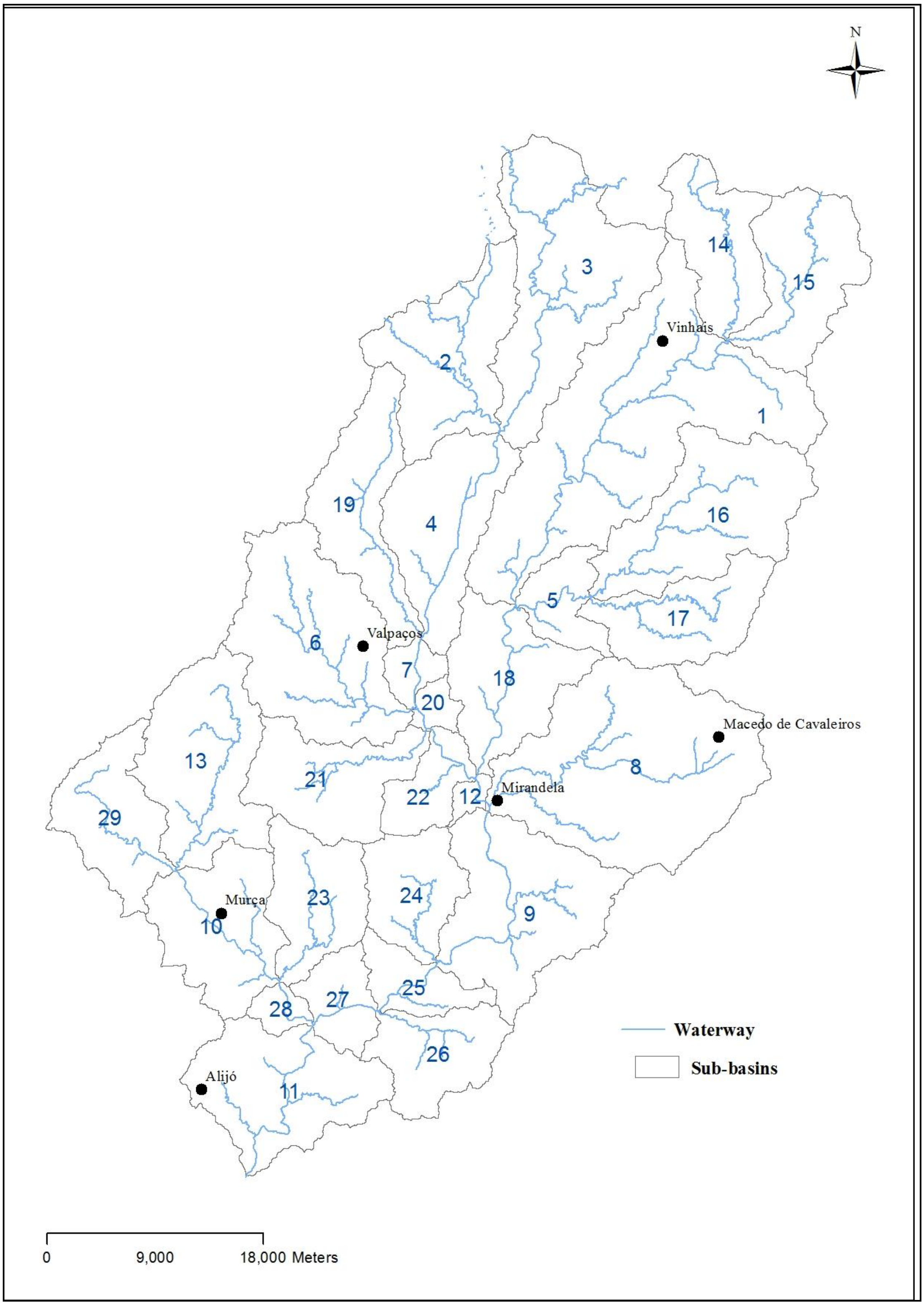

Figure 41. Sub-basin distribution throughout the drainage basin (numbered by application of ArcSWAT (2013)).

Ideally, restoration projects would be ranked either by cost-effectiveness or cost-benefit analysis. Ranking projects based on either would require information on both cost and the measure of cost effectiveness (Beechie & Roni, 2013).

For this restoration project, however, cost information on applicable restoration efforts was not available. Therefore a metric score was developed, which rates each sub-basin as to the perceived approximate cost to the services and benefits provided by the river, taking into consideration local characteristics such as slope, erosion, riparian structures, solar radiation or intensity of human presence, and human infrastructures (appendix B). Table 14 indicates an assessment of the cost, in which high indicates that the costs of this problem are high, and low that this causes very little issues (sometimes being nonexistent even).

Table 14. Cost assessment from each sub-basin.

Process/ Function	Cause of Problem	Sub-Basin									
		1	2	3	4	5	6	7	8	9	10
Hydrology	Reservoirs and Dams reduce channel-forming flows	L	H	H	H	L	L	H	M	M	L
Riparian	Reduced wood and nutrient delivery. Reduced shade	L	M	M	M	H	H	M	H	H	H
Connectivity	Passage of fish is restricted	L	M	L	M	L	L	H	L	M	L
Water Quality	Input of excess nutrients and pesticides	M	H	H	M	H	H	H	H	H	H
Sediment	Soil erosion	M	M	M	M	L	L	L	H	H	M
Channel	Bank armouring constraints channel	L	L	L	L	L	M	L	M	L	L

Process/ Function	Cause of Problem	Sub-Basin									
		11	12	13	14	15	16	17	18	19	20
Hydrology	Reservoirs and Dams reduce channel-forming flows	H	H	L	L	L	L	L	L	L	L
Riparian	Reduced wood and nutrient delivery. Reduced shade	L	H	H	H	L	H	H	H	H	H
Connectivity	Passage of fish is restricted	H	M	L	L	L	L	L	L	L	M
Water Quality	Input of excess nutrients and pesticides	H	H	H	H	H	H	H	H	M	H
Sediment	Soil erosion	M	L	M	M	M	H	M	L	L	L
Channel	Bank armouring constraints channel	L	H	L	L	L	L	L	L	L	H

Process/ Function	Cause of Problem	Sub-Basin								
		21	22	23	24	25	26	27	28	29
Hydrology	Reservoirs and Dams reduce channel-forming flows	L	L	L	L	L	L	L	L	L
Riparian	Reduced wood and nutrient delivery. Reduced shade	H	H	M	H	H	M	M	H	H
Connectivity	Passage of fish is restricted	L	L	L	L	L	L	L	L	L
Water Quality	Input of excess nutrients and pesticides	H	M	H	H	M	M	H	M	M
Sediment	Soil erosion	H	M	H	H	H	M	H	H	M
Channel	Bank armouring constraints channel	M	M	L	L	L	L	L	L	L

To determine the order of restoration sites each type of impairment (High, Medium, Low) was attributed a weight which is listed in table 15.

Table 15. Weight factor for each type of priority.

	Weight Factor
High	50
Medium	30
Low	20

Finally table 16 lists the total final score for each sub-basin ordered from highest to lowest score thusly establishing a restoration priority between the watersheds throughout the drainage basin.

Table 16. Cost assessment scores and priority restoration watersheds**.**

Sub-Basin	Scores	Sub-Basin	Scores	Sub-Basin	Scores
12	250	**3**	200	**28**	190
8	230	**4**	190	**5**	180
9	230	**6**	190	**18**	180
7	220	**10**	190	**22**	180
11	220	**13**	190	**14**	170
20	220	**17**	190	**29**	170
21	220	**23**	190	**15**	160
2	210	**25**	190	**19**	160
16	210	**27**	190	**26**	150
24	210			**1**	140

Furthermore measures of effectiveness concerning not only the effectiveness of restoration action but the do-ability of the action as well within the context of the findings previously determined. In which high indicates that the given action isn't feasible and low indicates that the action is easily achieved.

Following table 17 lists the findings of such an evaluation.

Table 17. Effectiveness assessment from sub-basin.

Process/ Function	Restoration Action	Sub-Basin									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Hydrology	Remove flow restriction infrastructures	-	H	-	H	-	-	H	H	H	-
Riparian	Riparian planting to increase shade and restore riparian continuity Increase wood recruitment	M	H	H	M	L	L	L	M	M	M
Connectivity	Installation of culverts that allow fish migration	-	H	-	H	-	-	H	H	-	-
Water Quality	Provide riparian buffers to filter pesticides and provide shade which reduces primary production	H	M	M	L	L	L	L	L	M	M
Sediment	Erosion diminishing actions	H	H	H	M	M	M	M	H	M	H
Channel	Remove bank armouring	-	.	-	-	-	-	H	H	H	-

Process/ Function	Restoration Action	Sub-Basin									
		11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Hydrology	Remove flow restriction infrastructures	H	H	-	-	-	-	-	-	-	-
Riparian	Riparian planting to increase shade and restore riparian continuity Increase wood recruitment	H	H	M	M	M	H	M	L	M	L
Connectivity	Installation of culverts that allow fish migration	H	-	-	-	-	-	-	-	-	-
Water Quality	Provide riparian buffers to filter pesticides and provide shade which reduces primary production	H	M	M	M	M	M	M	L	L	H
Sediment	Erosion diminishing actions	-	-	M	H	H	H	M	M	M	M
Channel	Remove bank armouring	-	H	-	-	-	-	-	-	-	-

Process/ Function	Restoration Action	Sub-Basin								
		21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
Hydrology	Remove flow restriction infrastructures	-	-	-	-	-	-	-	-	-
Riparian	Riparian planting to increase shade and restore riparian continuity Increase wood recruitment	L	L	H	L	H	M	H	H	M
Connectivity	Installation of culverts that allow fish migration	-	-	-	-	-	-	-	-	-
Water Quality	Provide riparian buffers to filter pesticides and provide shade which reduces primary production	L	L	M	L	H	M	H	H	H
Sediment	Erosion diminishing actions	M	L	H	-	H	H	M	H	M
Channel	Remove bank armouring	-	-	-	-	-	-	-	-	-

Following with an attribution of weight to each type of impairment as listed in table 18.

Table 18. Weight factor for each type of priority assessment.

	Weight Factor
High	10
Medium	30
Low	60

Finally table 19 lists the total final score for each sub-basin ordered from highest to lowest thusly establishing a restoration priority between the watersheds throughout the drainage basin.

Table 19. Effectiveness assessment and priority restoration sub-basins.

Sub-Basin	Score	Sub-Basin	Score	Sub-Basin	Score
5	150	**13**	90	**12**	60
6	150	**17**	90	**1**	50
7	150	**20**	90	**3**	50
22	150	**2**	70	**16**	50
4	140	**10**	70	**21**	50
18	130	**14**	70	**23**	50
8	120	**15**	70	**27**	50
9	110	**26**	70	**11**	40
19	110	**29**	70	**25**	30
24	100			**28**	30

A weighted assessment of both cost and effectiveness metrics was calculated by multiplying both these metric scores, thusly prioritizing the restoration needs of the various sub-basins. Table 20 lists the findings of the weighted assessment also ordered according to highest to lowest final scores.

Table 20. Final score of the weighted assessment as well as priority restoration watersheds

Sub-Basin	Effectiveness	Cost	Final Score	Sub-Basin	Effectiveness	Cost	Final Score

7	150	220	33000
6	150	190	28500
8	120	230	27600
5	150	180	27000
22	150	180	27000
4	140	190	26600
9	110	230	25300
18	130	180	23400
24	100	210	21000
20	90	220	19800
19	110	160	17600
13	90	190	17100
17	90	190	17100
12	60	250	15000
2	70	210	14700
10	70	190	13300
14	70	170	11900
29	70	170	11900
15	70	160	11200
21	50	220	11000
26	70	150	10500
16	50	210	10500
3	50	200	10000
23	50	190	9500
27	50	190	9500
11	40	220	8800
1	50	140	7000
25	30	190	5700
28	30	190	5700

From this last assessment the top 10 watersheds with the highest final scores within the 29 total sub-basins were chosen to be restored, as the restoration of these 10 locations will improve the overall quality of the drainage basin.

The following chapter takes into consideration the findings and from them a restoration program was defined for the drainage basin.

5 – Restoration Plan

The efforts of this paper so far have been in establishing the foundations to set up restorative actions throughout the drainage basin which will provide an overall chemical and ecological quality improvement.

Firstly the vegetation, geomorphic and climate parameters throughout the case study drainage basin were determined, providing a context of what can be achieved. A further study was elaborated to determine the overall present day chemical and ecological quality of the river water, further establishing the current pressures on this ecosystem, and a follow up study on these pressures has determined future pressures that might arise.

Finally, considering the anthropic pressure patterns, and analysing the drainage basin on a watershed scale a prioritization of restoration needs per watershed was determined. Honing in therefore from a large template of process forming parameters (vegetation, geomorphology and climate) into a picture of what needs to be achieved.

It is the purpose of this chapter to determine what can be achieved, and whether the socioeconomic costs and benefits are worth the investment consequently narrowing down restoration actions which will provide a better service to stakeholders and to the body of water. From this point on it will also define which restoration actions will take place, where and how, finally determining what else would be required to implement the restoration plan and what monitoring needs to be entailed (Skidmore *et al.*, 2011).

5.1 – Planning

This subchapter has been divided into three further sub-chapters, Project Context, Goals and Objectives and Alternatives Evaluation.

The first of the three (project context) is to set the context within which the drainage basin is inserted. The second step (goals and objectives) establishes the overall goals and objectives of the restoration plan, indicating how these restoration steps can be achieved and what is the overall end result expected. The final third step (alternative evaluation) is an overall evaluation of the different restoration techniques that can take place and the context into which they can be inserted.

5.1.1 – Project Context

The physical characteristics of the drainage basin, with steep hillslopes and floodplains in conjunction with the dominant type of rocks as shale, greywacke and quartz create almost natural terraces over the landscape which have been more thoroughly explored over the past decades for agricultural purposes, such as viticulture and olive production.

Additionally, these physical characteristics and the ever-decreasing number of permanent residents, which is indicative of a migratory pattern from inland to seaside cities, are the reason for the existing isolated spots of urban fabric and the big condensed spots of urban fabric of the bigger cities contained within the drainage basin.

The region where the drainage basin in study is located within is thusly characterized by being fundamentally agricultural, with a couple of condensed and larger spots of urban fabric but having an overall isolated spots of urban fabric throughout the drainage basin.

The southern part of the drainage basin is located within the denominated *"Terra Quente Transmontana"* which means it has gentler winters with extremely high summer extremes while the northern part of the basin is located with the *"Terra Fria Transmontana"* which is characterized by extremely cold and long winters as well as moderate summer. The land in between both is known and transitional land as it takes on aspects of both to a varying degree.

Presently River *Tua* is one of the last natural flowing rivers in Portugal but the currently under construction dam at the river's mouth will alter significantly flow regime and landscape as we know it and even though there has been some controversy concerning this infrastructure public attention hasn't been sufficient to warrant discontinuing the construction process.

5.1.2 – Goals and Objectives

The drainage basin is located within a context where agriculture pressure is on a rise, human presence is diminishing but human pressures (*e.g.* infrastructures) are increasing. A need to maintain the good chemical quality of the river and assure that it is able to continue to provide is services and benefits whilst assuring that when 2015 comes around legislative demands for a good ecological status are met as well are the driving forces of this restoration program.

The goal of this restoration program is thusly assuring that the current WQI status is maintained, requiring thusly some minor *in-situ* restorative actions that will boost the system as a whole and help cope with current and future pressures put upon it.

The objective is thusly to look at the top 10 selected watersheds and assure their form and function can be maintained and that overall the ecological and chemical quality of the drainage basin will be improved as well.

Table 21 lists the overall objectives that will allow the accomplishment of the goals established.

Table 21. Restoration objectives according to process/function of the river.

Process/ Function	Objectives
Hydrology and Sediment	Reduce sediment and runoff from farms; improve water quality; provide adequate flows for biota and habitat; restore runoff and hydrology
Riparian	Restore riparian zone, vegetation and processes, increase shade
Connectivity	Reconnect channels; allow natural transport of nutrients and sediments
Habitat	Increase available habitats; increase cover and habitat complexity

5.1.3 – Actions

This sub-chapter will evaluate the different techniques against the different time lag responses and landscape template to determine what can be achieved to fulfil the objectives and goals of the restoration program.

A careful study of applied techniques through a range of studies enabled the identification of the techniques applicable to the objectives aforementioned. Table 22 lists these techniques.

Table 22. Techniques and their objectives defined by process/function of the river.

Process/ Function	**Objectives**	**Techniques**
Hydrology and Sediment	Reduce sediment and runoff from farms; improve water quality; provide adequate flows for biota and habitat; Restore runoff and hydrology.	Breaching a flood bank to reconnect active floodplain processes (RRC, 2013) New meandering channel through open fields (RRC, 2013) Change agricultural practices (Beechie & Roni, 2013)
Riparian	Restore riparian zone, vegetation and processes; increase shade.	Felling and Placing Trees for Habitat Flow and Diversity (RRC, 2013) Fencing and grazing reduction (Beechie & Roni, 2013) Complete removal of grazing (Beechie & Roni, 2013) Riparian buffers and protection (Beechie & Roni, 2013) Planting of trees and vegetation (Ward *et al.*, 2001)
Connectivity	Reconnect channels; allow natural transport of nutrients and sediments.	Dam removal or breaching (Beechie & Roni, 2013) Reconnections of channels (Beechie & Roni, 2013) Fish Passage (RRC, 2013)
Habitat	Increase available habitats; increase cover and habitat complexity.	Bank protection using root wads (RRC, 2013) Replacing an armoured bed with boulder step-pools (RRC, 2013) Placement of logs (Beechie & Roni, 2013)

Furthermore the habitat has a response time, thusly long-term and short-term strategies can be implemented at the same time, benefiting the system immediately as well as putting it onto a path of recovery.

Hence table 23 encompasses each technique its usual process response time and maintenance required accordingly. Some processes might take more time to respond due to various factors such as the landscape template into which it is inserted so when this response time is not properly considered within this landscape template some restoration projects might be deemed unsuccessful, or even inappropriate.

Table 23. Global assessment of each technique, their response time and the maintenance required.

Techniques	Response Time (years)	Maintenance
Breaching a flood bank to reconnect active floodplain processes (RRC, 2013)	1-5	M
New meandering channel through open fields (RRC, 2013)	1-5, 5-20	M
Change agricultural practices (Roni & Beechie, 2013)	1-5, 5-20	H
Felling and Placing Trees for Habitat Flow and Diversity (RRC, 2013)	1-5	L
Fencing and grazing reduction (Roni & Beechie, 2013)	1-5	H
Complete removal of grazing (Roni & Beechie, 2013)	1-5	H
Riparian buffers and protection (Roni & Beechie, 2013)	1-5	M
Planting of trees and vegetation (Ward et al., 2001)	>20	M
Dam removal or breaching (Roni & Beechie, 2013)	1-5, 5-20	L
Reconnections of channels (Roni & Beechie, 2013)	1-5	M
Fish Passage (RRC, 2013)	1-5	M
Bank protection using root wads (RRC, 2013)	5-20	M
Replacing an armoured bed with boulder step-pools (RRC, 2013)	1-10	M
Placement of logs (Roni & Beechie, 2013)	1-5	L

From this context of techniques, and response times as well as maintenances required an evaluation, of each sub-basin selected and its issues was cross-referenced to find which techniques would be most suitable from watershed to watershed.

Table 24 lists the techniques chosen for each watershed.

Table 24. Techniques selected for each watershed sorted according to process/function.

Sub-Basin	Process/ Function	Technique	Response Time (year)	Maintenance
7	**Riparian**	Riparian buffers and protection (Roni & Beechie, 2013)	1-5	M
	Habitat	Placement of logs (Roni & Beechie, 2013)	1-5	L
6	**Hydrology and Sediment**	Change agricultural practices (Roni & Beechie, 2013)	5-20	H
	Riparian	Felling and Placing Trees for Habitat Flow and Diversity (RRC, 2013)	1-5	L
		Planting of trees and vegetation (Ward *et al.*, 2001)	>20	M
		Riparian buffers and protection (Roni & Beechie, 2013)	1-5	M
5	**Hydrology and Sediment**	Change agricultural practices (Roni & Beechie, 2013)	5-20	H
	Riparian	Riparian buffers and protection (Roni & Beechie, 2013)	1-5	M
		Planting of trees and vegetation (Ward *et al.*, 2001)	>20	M
	Habitat	Placement of logs (Roni & Beechie, 2013)	1-5	L
8	**Riparian**	Riparian buffers and protection (Roni & Beechie, 2013)	1-5	M
		Planting of trees and vegetation (Ward *et al.*, 2001)	>20	M
22	**Riparian**	Fencing and grazing reduction (Roni & Beechie, 2013)	1-5	H
		Planting of trees and vegetation (Ward *et al.*, 2001)	>20	M
		Riparian buffers and protection (Roni & Beechie, 2013)	1-5	M
4	**Hydrology and Sediment**	Dam removal or breaching (Roni & Beechie, 2013)	1-5	L
9	**Riparian**	Planting of trees and vegetation (Ward *et al.*, 2001)	>20	M
		Riparian buffers and protection (Roni & Beechie, 2013)	1-5	M
	Habitat	Placement of logs (Roni & Beechie, 2013)	1-5	L
18	**Riparian**	Riparian buffers and protection (Roni & Beechie, 2013)	1-5	M
	Habitat	Placement of logs (Roni & Beechie, 2013)	1-5	L
24	**Hydrology and Sediment**	Change agricultural practices (Roni & Beechie, 2013)	5-20	H
	Riparian	Riparian buffers and protection (Roni & Beechie, 2013)	1-5	M
		Planting of trees and vegetation (Ward *et al.*, 2001)	>20	M
20	**Hydrology and Sediment**	Change agricultural practices (Roni & Beechie, 2013)	5-20	H
	Riparian	Riparian buffers and protection (Roni & Beechie, 2013)	1-5	M
		Planting of trees and vegetation (Ward *et al.*, 2001)	>20	M
	Habitat	Placement of logs (Roni & Beechie, 2013)	1-5	L

From this template of techniques that can be applied to each watershed the restoration program design follows.

5.2 – Design

This phase of the restoration program is to indicate the specifics of each technique selected and the location of each in each separate sub-basin selected. A brief description of each type of restoration technique and what it aims to achieve is listed in table 25.

Table 25. Description of the restoration technique and what it entails.

Technique	Description
Change agricultura practices (Roni & Beechie, 2013)	Considering the context into which the drainage basin is settled this is perhaps the most difficult technique, and requires
Felling and Placing Trees for Habitat Flow and Diversity (RRC, 2013)	This technique is used to promote a more rapid growth of desirable species. It involves removing a portion of the trees within the riparian forest.
Fencing and grazing reduction (Roni & Beechie, 2013)	Fencing off a section of the river allows the system to recover and allows restoration actions to take place successfully.
Riparian buffers and protection (Roni & Beechie, 2013)	These provide inhibit minimized stream damage and enhanced water quality. A mix of trees and shrubs can be used to repair the riparian buffer (Beechie & Roni, 2013).
Planting of trees and vegetation (Ward *et al.*, 2001)	This is the most widely used method of all the listed techniques. It involves the planting of live trees, shrubs, live stakes or cuttings, forbes and grasses.
Dam removal or breaching (Roni & Beechie, 2013)	This practice is highly contentious; thusly the costs and benefits of this step need to be carefully studied to determine whether the application of this technique is invaluable. It restores flow, and reconnects river channels, becoming invaluable when returning a river to its natural state (Beechie & Roni, 2013).
Reconnections of channels (Roni & Beechie, 2013)	Allows the natural flow, migration and sediment deposition to return to the river as well as reconnects the lateral habitats, it is a costly alternative to Dam Removal and Breaching (Beechie & Roni, 2013).
Placement of logs (Roni & Beechie, 2013)	The placement of a single log can provide benefits in certain situations the placement of a couple of logs and added items are more beneficial. If is composed of different logs, branches and leaves of different plant species in different stages of decomposition it will provide the base for different aquatic life to find food, shelter, and space to thrive (Beechie & Roni, 2013)

Following in table 26 is a listing of the design criteria for the techniques due to be implemented.

Table 26. Design criterion per restoration technique.

Goal	Project Element	Design Criterion
Restore Riparian Forest	Felling and Placing Trees for Habitat Flow and Diversity (RRC, 2013)	At most a 10 meter width of riparian forest; Reconnect riparian corridors.
	Fencing and grazing reduction (Roni & Beechie, 2013)	
	Riparian buffers and protection (Roni & Beechie, 2013)	
	Planting of trees and vegetation (Ward *et al.*, 2001)	
Habitat Creation	Placement of logs (Roni & Beechie, 2013)	Increase the habitat availability for fish spawning and others.
River dynamics	Dam removal or breaching (Roni & Beechie, 2013)	Return natural flow variation to the river
Anthropogenic Pressure	Change agricultural practices (Roni & Beechie, 2013)	Add sustainability to agricultural practices; Seminars; Involve stakeholders and municipalities.

The locations chosen for each technique and a indication of where they will be applied according to each sub-basin previously selected are represented over the next few pages. The sites were selected using ArcGis© (ESRI, 2013) in conjunction with Bing Maps; each waterway in each sub-basin was thoroughly analyzed and each problem area was identified with the context of the findings of the previous chapter as well as the objectives and goals of this restoration program in mind.

Sub-basin 7

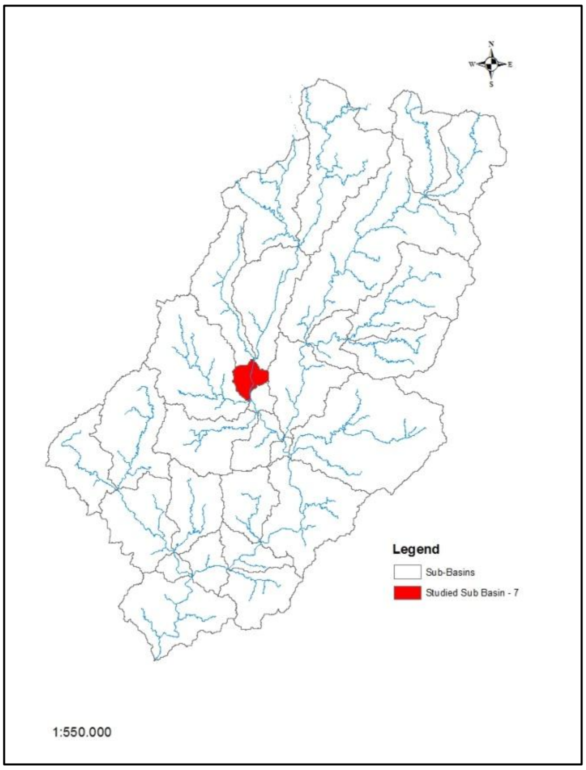

Figure 42. Location of sub-basin 7.

Represented in figure 42 is the location of the watershed within the drainage basin. Figure 43 indicates the sites chosen for restorative actions.

Figure 43. Sites that require restorative interventions for sub-basin 7.

As can be observed from sites 1and 2 the river in these particular spots is composed of riffles and could benefit from the deposition of logs as these are essential for especific habitat boostings and some species of fish flourish in this type of habitat (Beechie & Bolton, 1999; Beechie *et al.*, 2005; Miller *et al.*, 2010).

Sites 3 and 4 (although site 3 does appear to have some riffle type habitat) would not benefit as much as sites 1 and 2 from log placement placement technique as these are located in deeper water . Both sites 3 and 4 have a marked absense of riparian vegetation and riparian connectivy as well as the shade it provides shade is essential (Anbumozhi *et al.*, 2005; Beechie *et al.*, 2006; Collins *et al.*, 2012; Newham *et al.*, 2010).

Additionally closer observation of sites 1 and 2 indicate this same lack of riparian vegetation but within the geomorphologic context in which this watershed is inserted in it was not deemed an effective restoration action**.**

Sub-basin 6

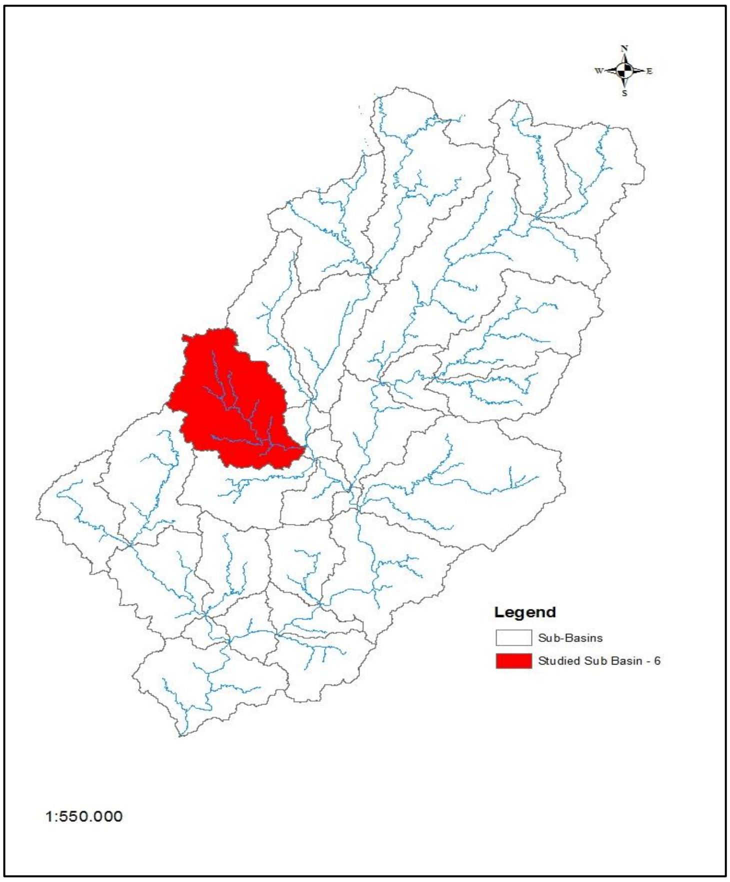

Figure 44. Location of sub-basin 6.

Represented in figure 44 is the location of the watershed within the drainage basin. Figure 45 indicates the sites chosen for restorative actions.

Figure 45. Sites that require restorative interventions for sub-basin 6.

Sites 1 through 8 indicate a clear loss of riparian vegetation, in some cases agricultural practices extended almost to the edge of the water, which according to Portuguese legislation (*Lei n.º 54/2005 de 15 de Novembro*, 2005) is an illegal practice, as any given surface body of water, whose depth does not allow boating, a 10 meter buffer to either side of the river corridor is in place to protect the water body.

The loss of vegetation indicates that not only is there a discernible lack of undergrowth but of trees as well and thusly the 3 techniques employed over the sites should work conjointly to reconnect riparian vegetation throughout this watershed.

Sub-basin 5

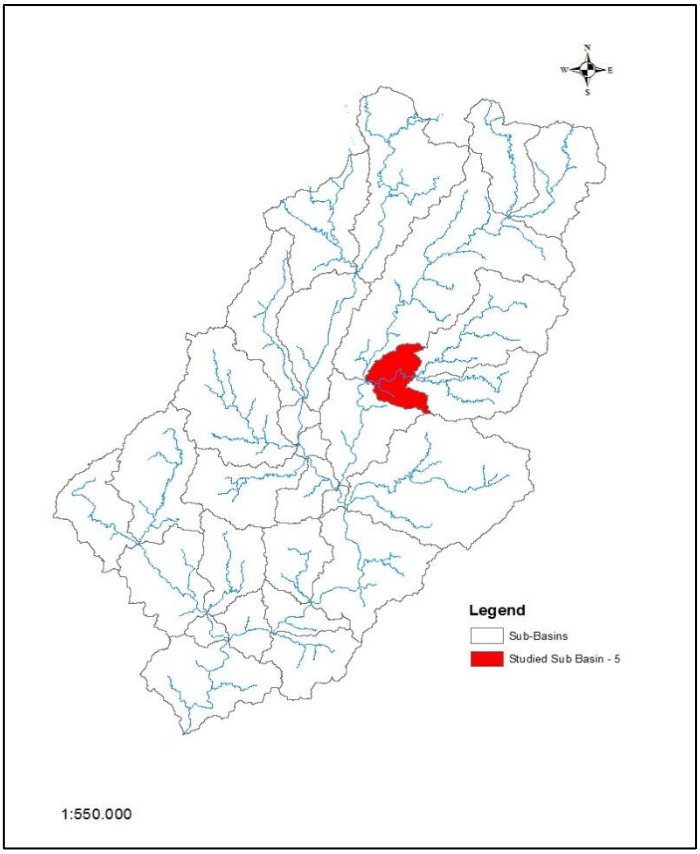

Figure 46. Location of sub-basin 5.

Represented in figure 46 is the location of the watershed within the drainage basin. Figure 47 indicates the sites chosen for restorative actions.

Figure 47. Sites that require restorative intervention for sub-basin 5.

In general this sub-basin is in a better condition (from restorative intervention standpoint) than the previously analyzed sub-basins but there still are an amalgamate of sites in which riparian connectivity is found to be lacking,. In some cases the lack of riparian vegetation is due to impromptu river crossing (site 5).

The remainder of sites do have some riparian growth but trees are found lacking and a more robust riparian undergrowth should deter further human pressure on the vegetation.

Furthermore sites 5 and 4 have also been chosen for the placement of logs, site 5 particularly to restore habitat loss due the crossing and site 3 to improve general habitat availability.

Sub-basin 8

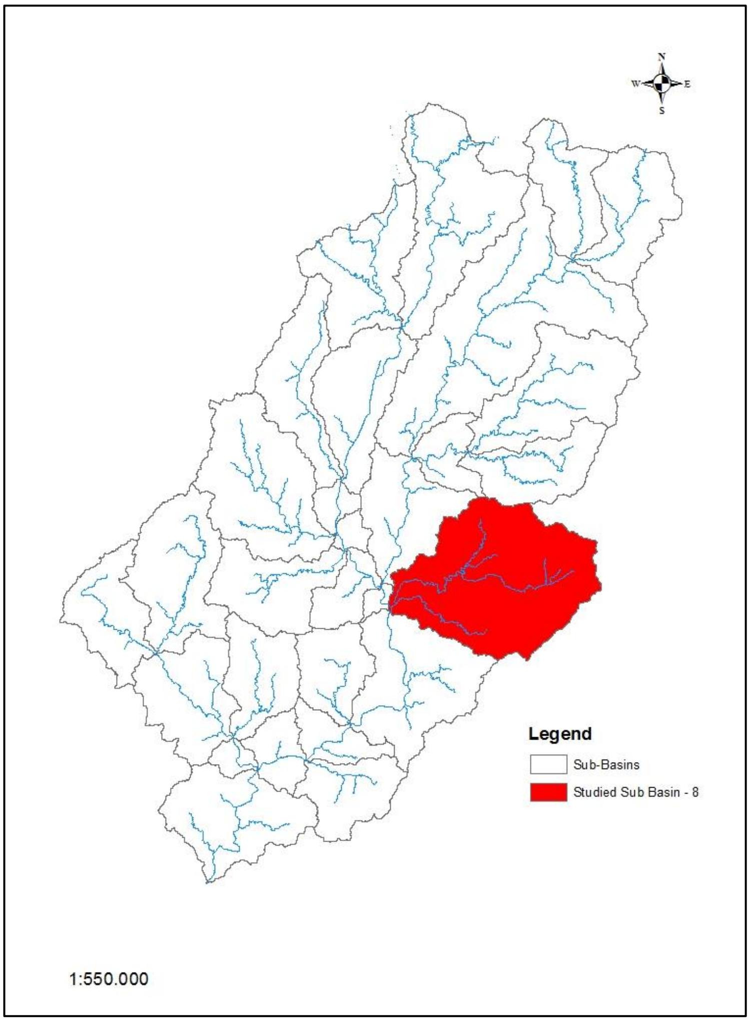

Figure 48. Location of sub-basin 8.

Represented in figure 48 is the location of the watershed within the drainage basin. Figure 49 indicates the sites chosen for restorative actions.

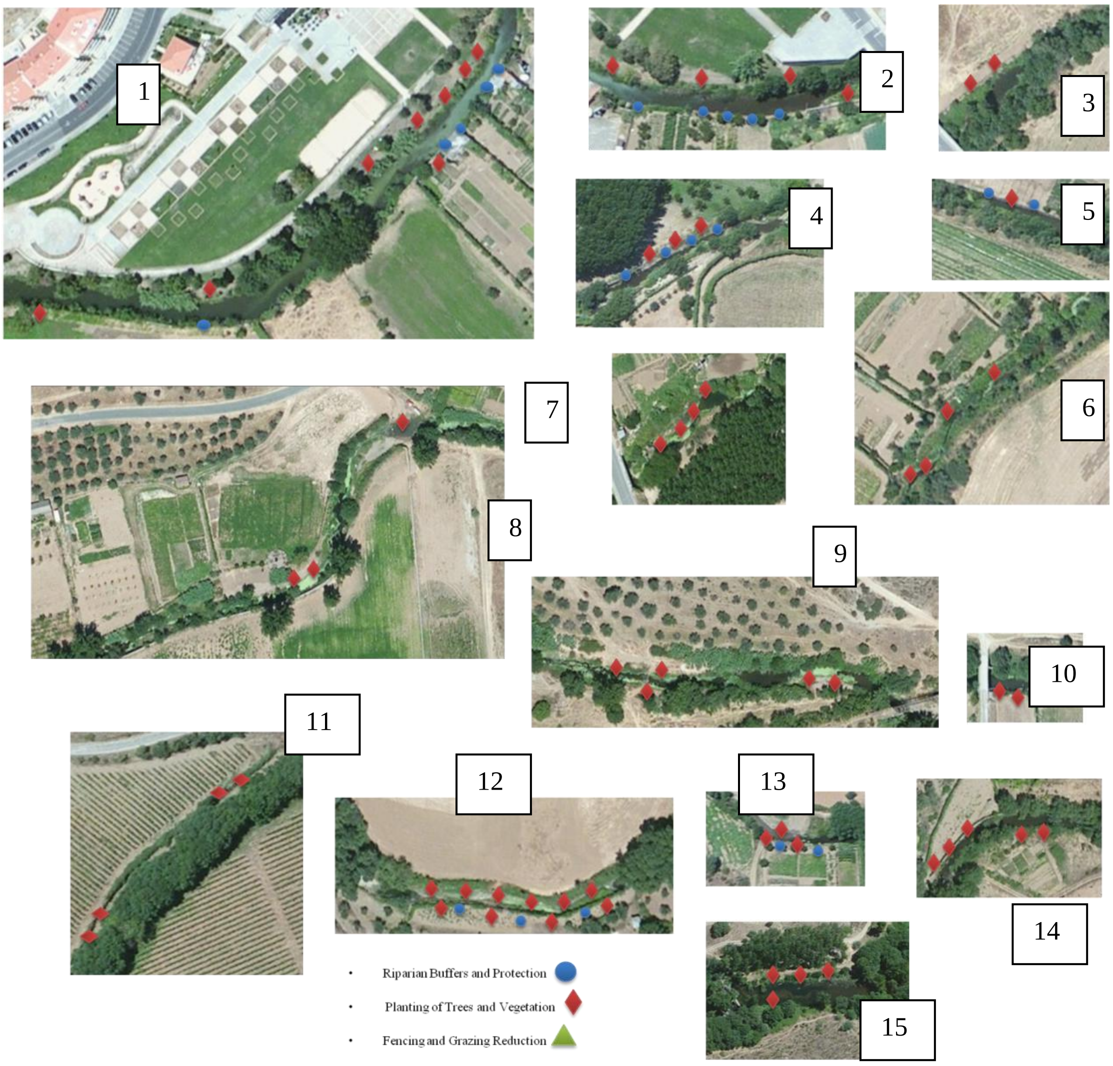

Figure 49. Sites that require restorative intervention for sub-basin 8.

This sub-basin is closely located to one of the biggest urban conglomerates located within the drainage basin (Mirandela). This is also the location of the highest soil loss rate found, as can be seen in Figure 23, and as such an effort to ensure riparian connectivity throughout the waterway in this watershed is essential (Bellin *et al.*, 2011; Feng *et al.*, 2010). Sites 1 through to 3 are nearest to the city centre and as such a lack of trees and riparian undergrowth is distinctive.

A closer analyses further upstream indicated the same issues, be it a consequence of agricultural activities (sites 4, 5, 6, 8, 11, 12, 13,14) and or just a break in the riparian connectivity (sites 7, 9, 10 and 15). Therefore these pinpoint sites require a restoration of not only undergrowth, as well as trees as the need to create a riparian forest that is more robust will deter as well further anthropic impact and assure a healthy continued riparian forest.

Sub-Basin 22

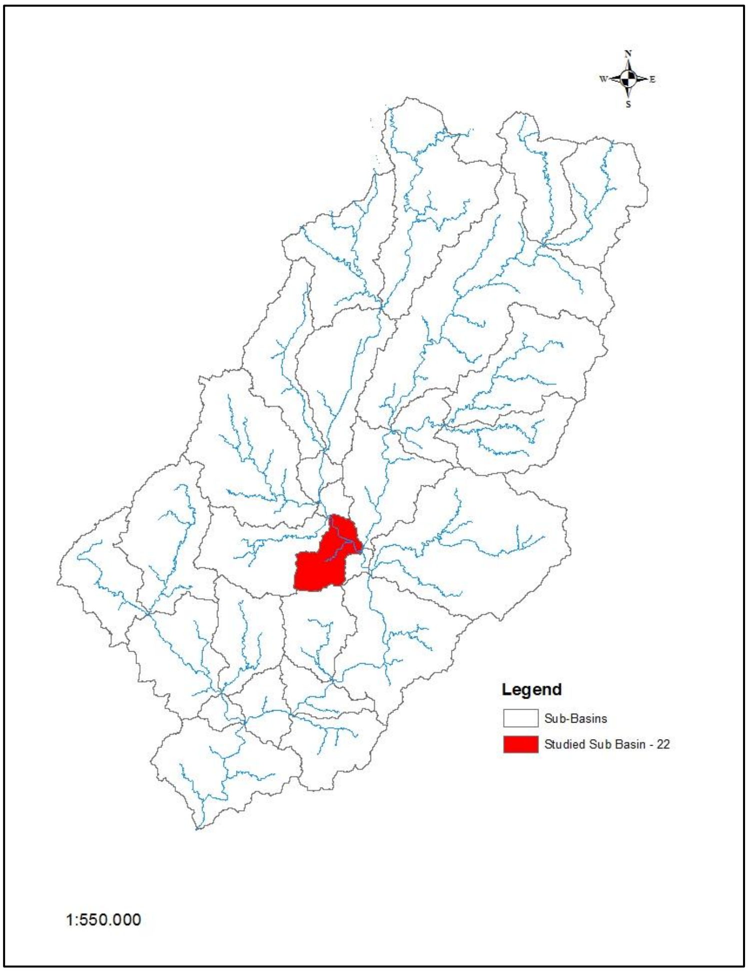

Figure 50. Location of sub-basin 22.

Represented in figure 50 is the location of the watershed within the drainage basin. Figure 51 indicates the sites chosen for restorative actions.

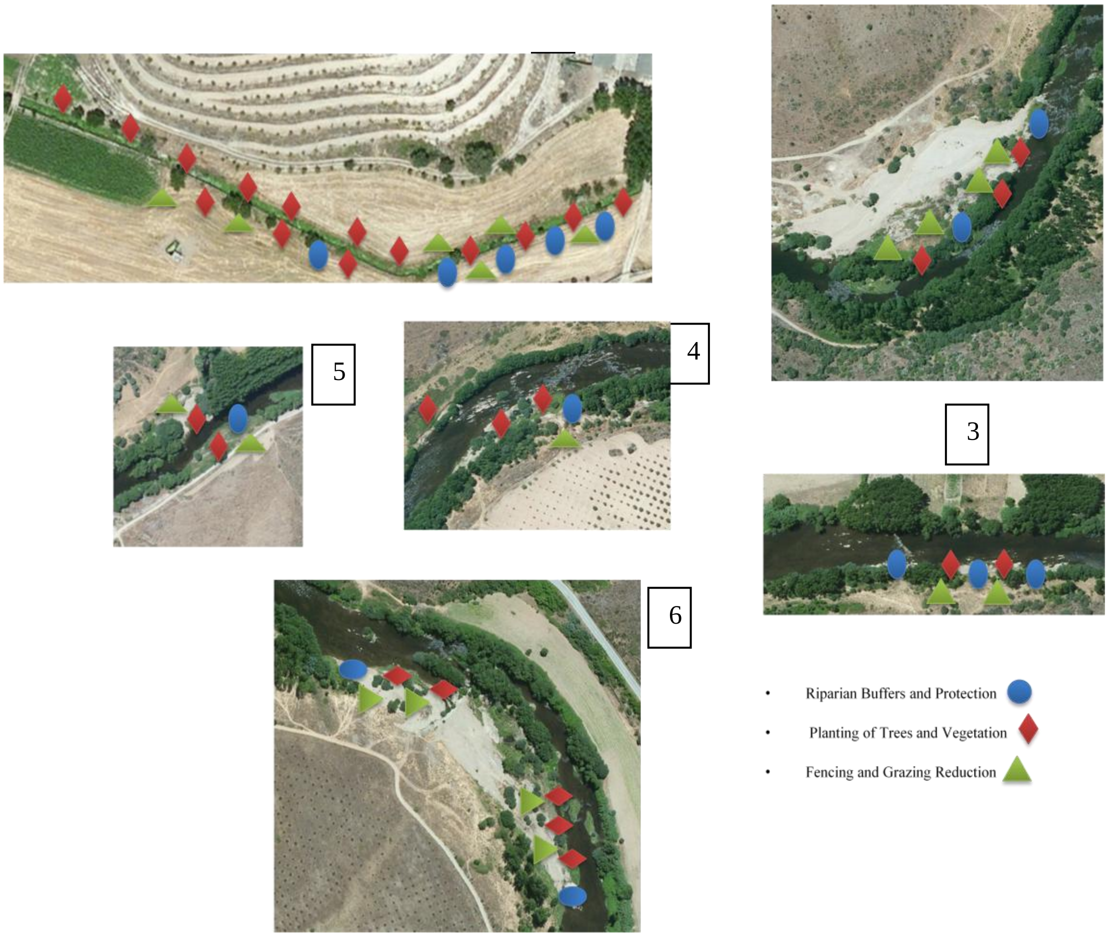

Figure 51. Sites that require restorative intervention for sub-basin 22.

This sub-basin has had its riparian corridors also highly altered by agricultural and other derived human behaviour impacts as this watershed is located on a metamorphic and sedimentary soil type which is preferred by farmers and it is located on the plateau which in comparison to other sub-basins in the drainage basin is of much easier access. Additionally the climate setting into which this sub-basin is inserted as well as the solar radiation it receives does indeed make it an ideal location for agriculture (Swift *et al.*, 1973; Townsend, 2011).

Site 1 and 5 indicate that once again agricultural practices are not respecting the legislative buffer and although 5 indicates some loss of an arboreal stratus it seems as well to serve as some sort of crossing therefore fencing off the site on both sides of the stream and applying the techniques listed will allow the riparian vegetation time to recover on its own. Additionally site 1 indicates a large stretch of river bank where there is a complete lack of riparian forest therefore its restoration will require a considerate amount of time to fully recoup from this.

The remainder of the sites chosen for restoration, sites 2, 3, 4 and 6, seem to be location where leisure activities could take place (such as sunbathing or swimming) and although it is not the imperative of this restoration program to deny access to the river a common ground must be found to ensure a healthy river and happy swimmers so pinpoint locations should be fenced off to serve both purposes (restoration efforts and while still allowing these activities to take place).

Sub-basin 4

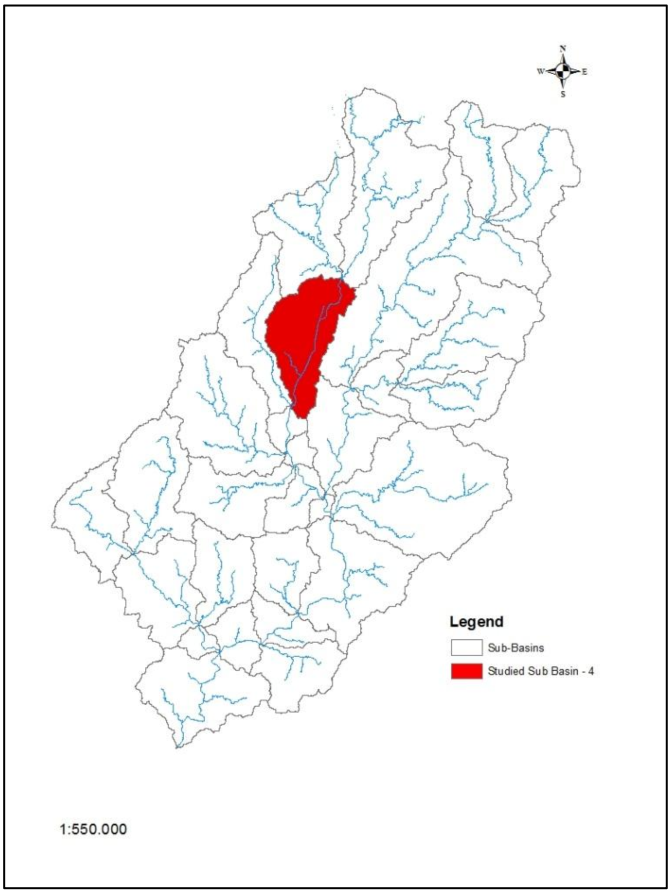

Figure 52. Location of sub-basin 4.

Represented in figure 52 is the location of the watershed within the drainage basin. Figure 53 indicates the sites chosen for restorative actions.

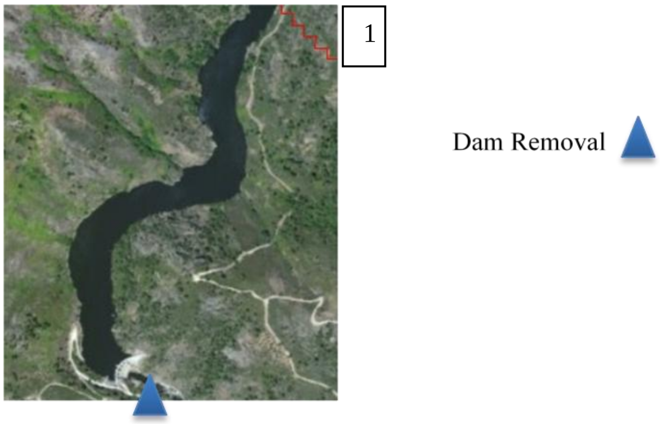

Figure 53. Site that requires restorative intervention for sub-basin 4.

The assessment made within a vegetation, geomorphologic and climate context indicate that the only applicable measure that would improve overall health of this sub-basin would be the removal of this dam. The lithology and soil type in conjunction with the overall aspects of slope as well as solar radiation into which the sub-basin is inserted in, indicate that although some vegetation exists it could never be upgraded to a full riparian forest.

Therefore although it is a costly technique this action will greatly benefit the overall processes and functions of the entire drainage-basin.

Sub-Basin 9

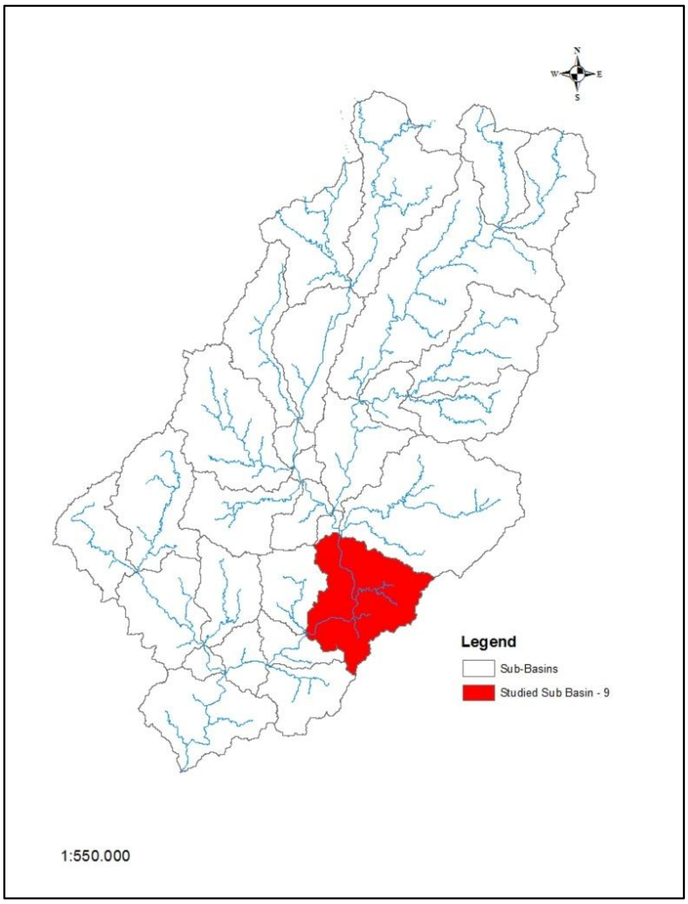

Figure 54. Location of sub-basin 9.

Represented in figure 54 is the location of the watershed within the drainage basin. Figure 55 indicates the sites chosen for restorative actions.

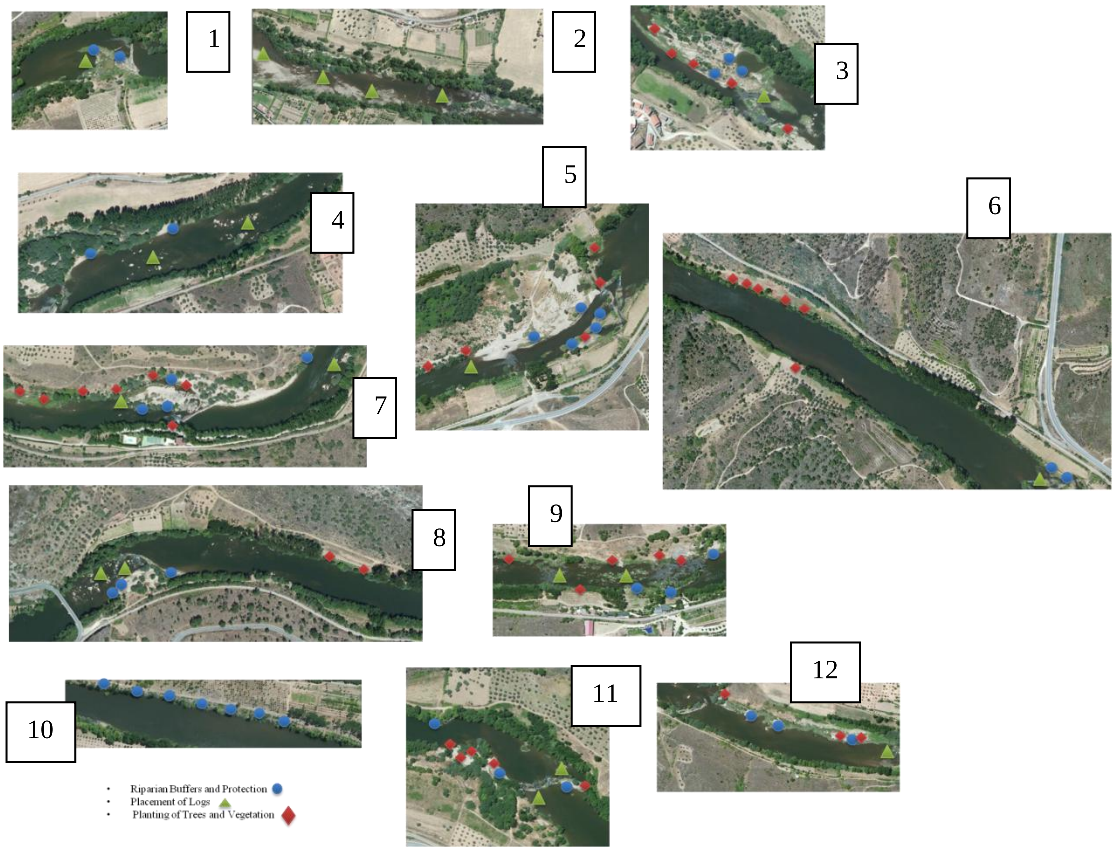

Figure 55. Sites that require restorative action for sub-basin 9.

Overall this sub-basin has the same issues as the previously studied sub-basins. Anthropic pressure caused by agriculture and river crossings (be it by using appropriate crossing infrastructures or not) have damaged the riparian forest continuity. Furthermore the river flow and depth make it an optimal implementation site for a habitat creating implementation technique (as there is a large amount of riffles), such as sites 1, 2, 3, 4, 5, 6, 7, 8, 9, 11 and 12.

The river flow also creates meandering isles throughout the watershed; these can be seen in sites 1,3,5,7 and 8, and thusly they should be taken advantage off and used to establish riparian forest as their benefits will increase overall river health (Naiman *et al.*, 2008; Poff *et al.*, 1997; Tague & Grant, 2004).

Finally sites 6, 7, 9, 10, 11 and 12 also indicate breaks in riparian continuity and so restorative techniques selected intend to contribute to a healthy riparian forest.

Sub-Basin 18

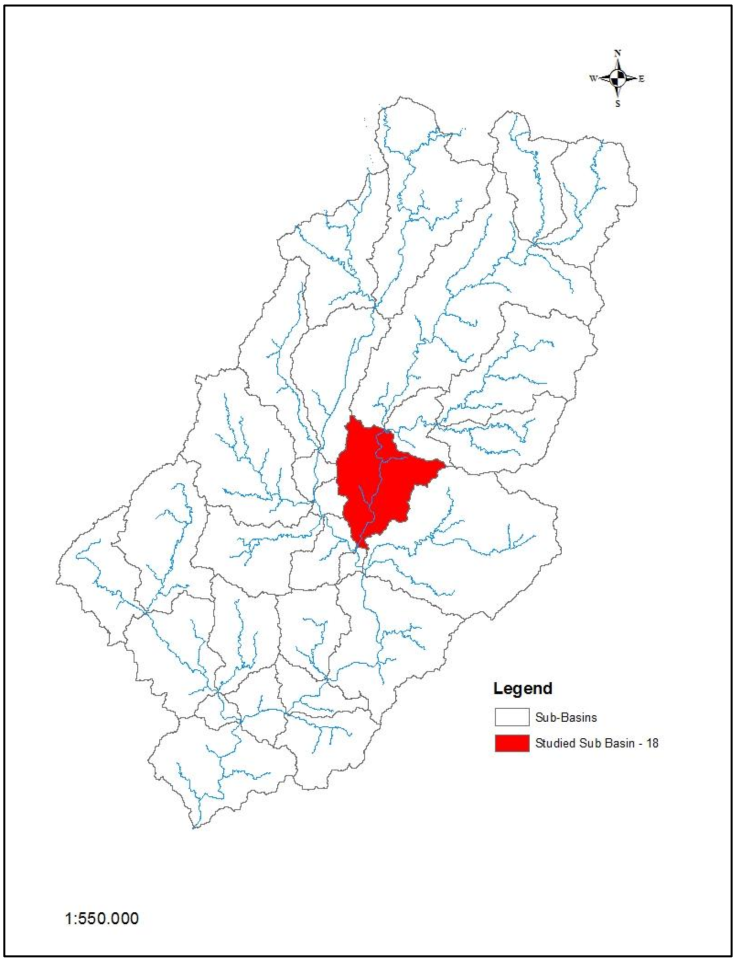

Figure 56. Location of sub-basin 18.

Represented in figure 56 is the location of the watershed within the drainage basin. Figure 57 indicates the sites chosen for restorative actions.

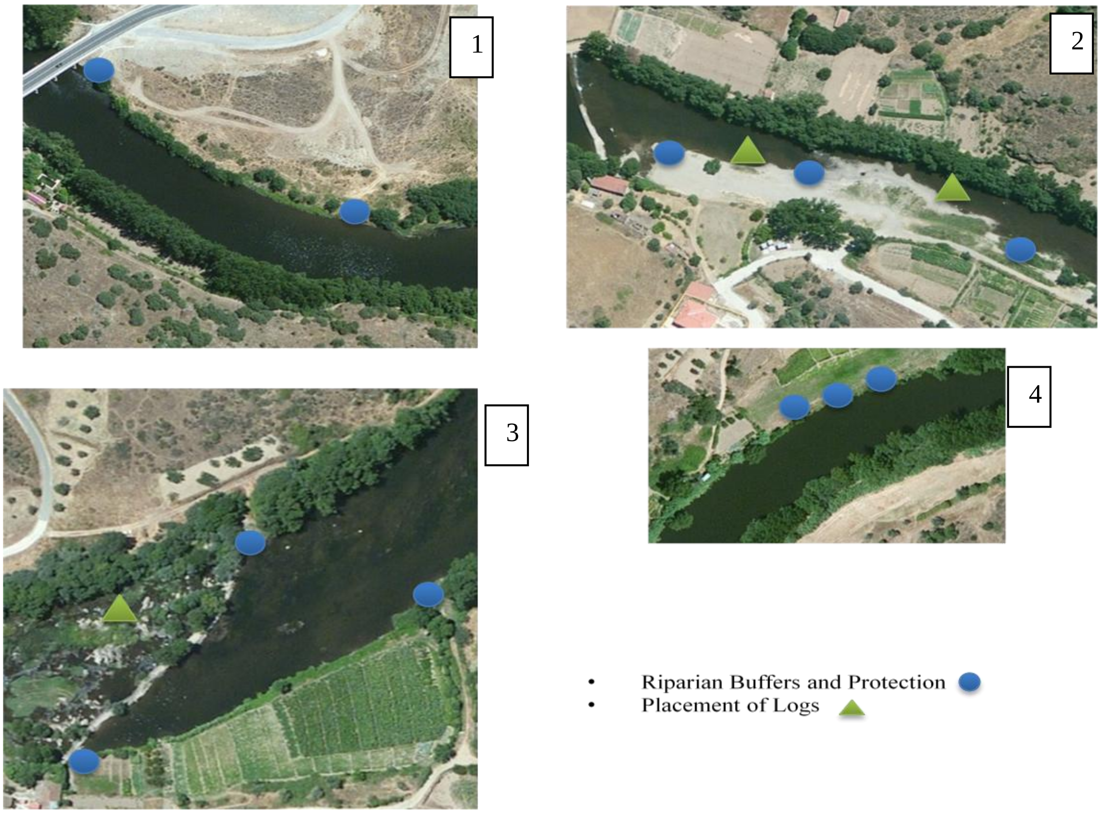

Figure 57. Sites that require restorative action for sub-basin 18.

This sub-basin has had its riparian corridors also altered by agricultural as this watershed is also located on a metamorphic and sedimentary soil type and most of it is located on the plateau. Additionally the climate setting into which this sub-basin is inserted is still in the optimal range for agriculture and the solar radiation it receives does indeed make it an ideal location for agriculture (Swift *et al.*, 1973; Townsend, 2011).

Sites 3, 4 and 5 indicate that once again agricultural practices are not respecting the legislative buffer and applying the techniques listed will allow the riparian vegetation time to recover on its own. . Once again the 10 meter legislative buffer is not being respected, such as sites 3 and 4 show. Thusly an overall restoration of riparian forest continuity takes places in sites 1, 3 and 4.

Furthermore the sites 2 and 4 are optimal locations the implementation of habitat creating techniques as they are of riffle type and of low water depth. Site 2 is also a sandbank of the river bank and riparian forest should be fenced off but a closer look to the site indicates that access to it is somewhat impaired therefore fencing off access to the site was not deemed necessary.

Sub-Basin 24

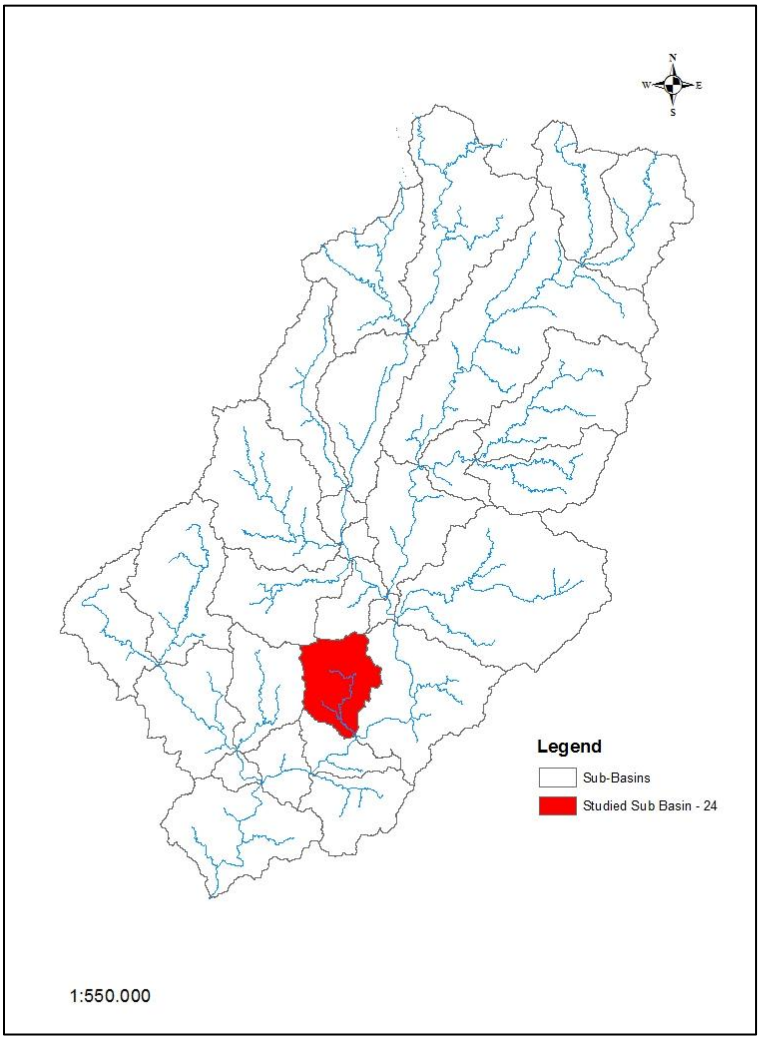

Figure 58. Location of sub-basin 24.

Represented in figure 58 is the location of the watershed within the drainage basin. Figure 59 indicates the sites chosen for restorative actions.

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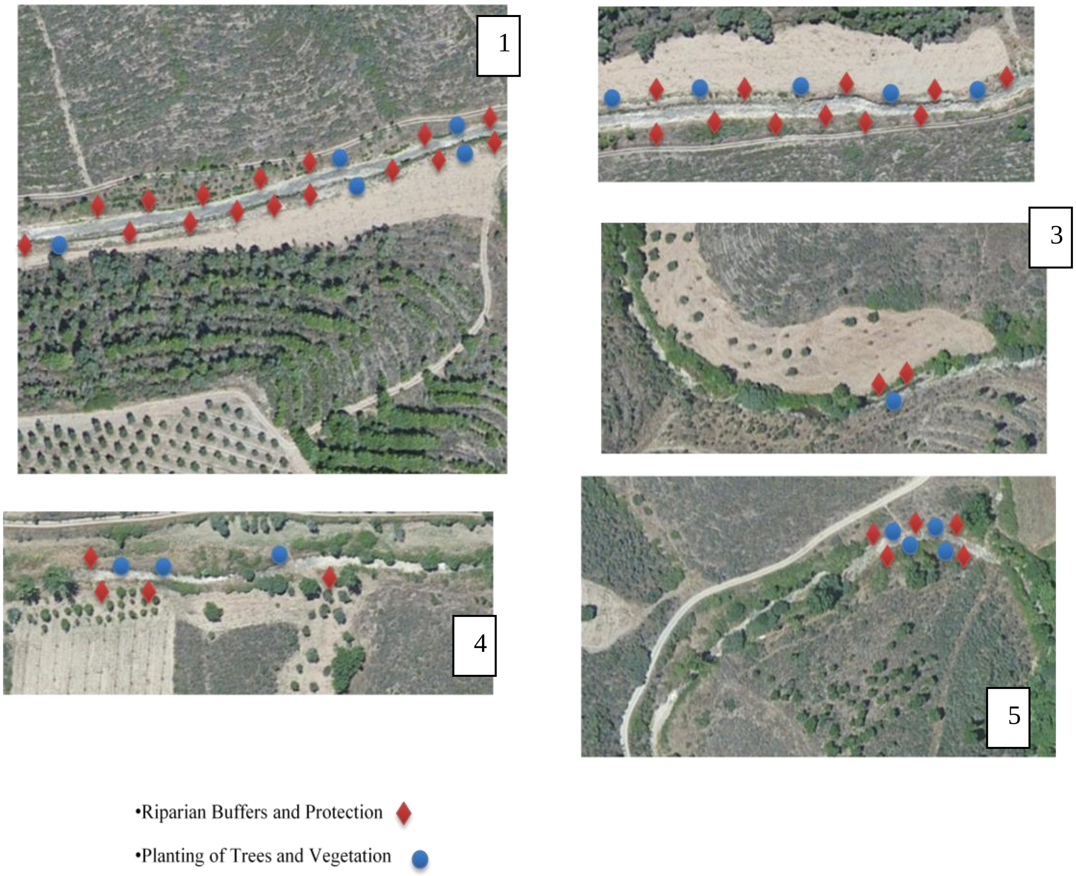

Figure 59. Sites that require restorative action for sub-basin 24.

This sub-basin has had its riparian corridors also highly altered by agricultural and other derived human behaviour impacts as this watershed is located on a metamorphic and sedimentary soil type which is preferred, is located on the plateau which in comparison to other sub-basins in the drainage basin is of much easier access. Additionally the climate setting into which this sub-basin is inserted as well as the solar radiation it receives does indeed make it an ideal location for agriculture (Swift *et al.*, 1973; Townsend, 2011).

Sites 1 and 2 are the most grossly indicative of this lack of riparian vegetation over a stretch which in context with previous findings concerning soil, lithology, slope and solar radiation indicate that this sub-basin would benefit greatly and can support a thriving riparian forest even though these restorative efforts will take a large period of time to come to completion.

Sites 3, 4 and 5 are also found to be lacking riparian vegetation just not to the extent of sites 1 and 2 and should be restored to provide continuity and consequently all the benefits of a riparian forest.

Sub-Basin 20

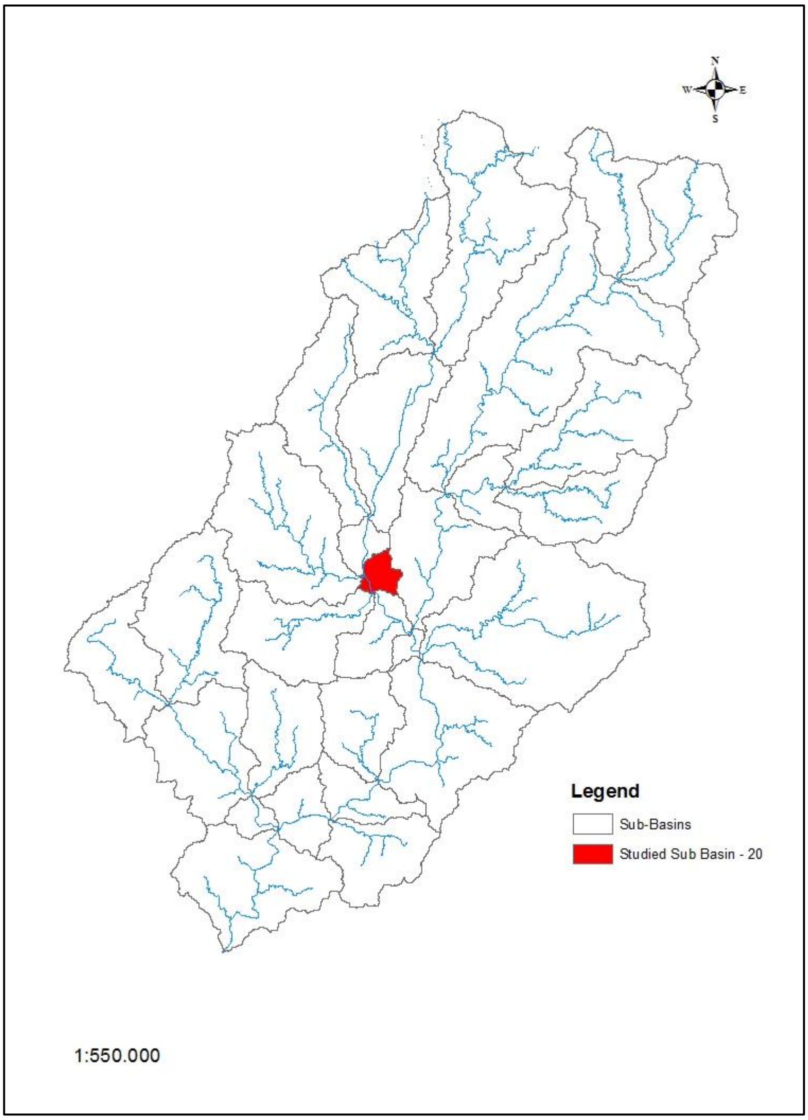

Figure 60. Location of sub-basin 20.

Represented in figure 60 is the location of the watershed within the drainage basin. Figure 61 indicates the sites chosen for restorative actions.

This final sub-basin only has pinpoint problem sites, overall related to riparian forest discontinuity. All 3 sites show gaps with the riparian forest and thusly these need to addressed. Furthermore in order to boost the benefits of this type of restoration techniques site 3 and its island were chosen and to enhance the habitat availability this location, due to its other characteristics also was chosen for log placement.

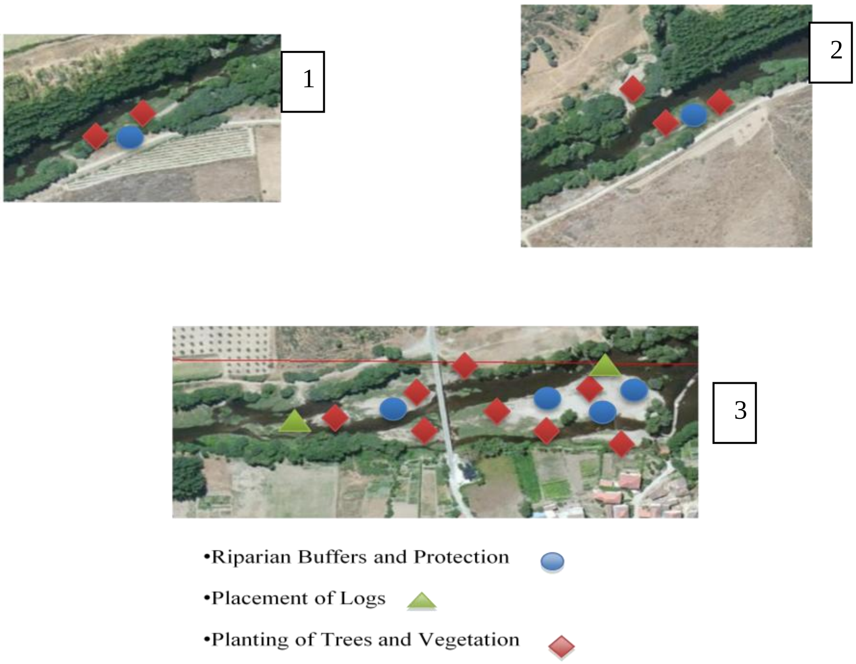

Figure 61. Sites that require restorative action for sub-basin 20.

5.3 –Monitoring

Monitoring is critical to a restoration project as it can evaluate whether the techniques are meeting their objectives and providing the projected ecological and social benefits. Figure 62 indicates the location of the sub-basins targeted for restorative actions.

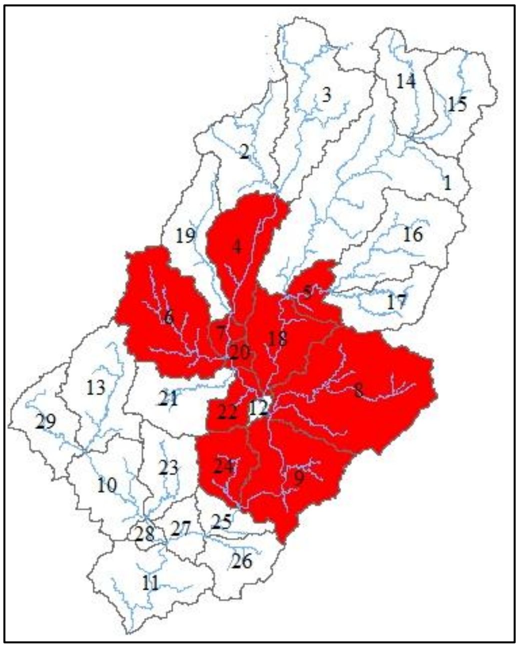

Figure 62. Sub-basins under restorative actions.

As this project is targeting towards a drainage basin scale overall functions and processes improvement the monitoring initially would entail a selection of control (or reference) watersheds, thusly a regional analysis that examines the degree to which the response variables covariate between sites. But as the distances between watersheds that could be used, as controls, and the watersheds pin pointed for restorative actions are greater than 50 km this is not an option (Downes, 2002).

Therefore the monitoring plan should assume values of the control pairs. These need to be closely related to the watershed under monitoring but nevertheless statistically independent.

Furthermore rather than opting for a long-term monitoring program the multiple watersheds understudy and the delineation of control pairs for each watershed allow for a better correlation of the responses with key physical or other independent variables (Beechie & Roni, 2013). This will allow the monitoring to not drag out over the years but to be something that can be assessed with less cost and more quickly.

From this the parameters to be monitored according to watershed and restoration technique can be specified. Table 27 lists the restoration techniques applied and the monitoring parameters for these.

Table 27. Monitoring parameter in accordance to restoration technique applied.

Restoration Technique	Monitoring Parameter
Change agricultural practices (Roni & Beechie, 2013)	Physical: measure distance from the riverbank to farmlands (>10 m), no disturbance from crossing the river over sand banks, measure sediment input Biological: nutrient and pesticide input in the stream
Felling and Placing Trees for Habitat Flow and Diversity (RRC, 2013)	Riparian area: tree or plant survival, species composition, density and biomass; tree growth, height and diameter In-Channel: shade, temperature, organic inputs, bankfull width, bank stability
Fencing and grazing reduction (Roni & Beechie, 2013)	
Riparian buffers and protection (Roni & Beechie, 2013)	
Plan ting of trees and vegetation (Ward *et al.*, 2001)	
Dam removal or breaching (Roni & Beechie, 2013)	Physical: change in channel morphology and elevation, sediment storage and composition Biological: presence and absence of migratory fish species, seasonal species abundance and diversity, composition and age structure of riparian vegetation
Reconnections of channels (Roni & Beechie, 2013)	Physical: flow connection with main channel, channel morphology, habitat, wood and organic retention Biological: fish abundance and diversity, macroinvertebrate and periphyton communities.
Placement of logs (Roni & Beechie, 2013)	Physical: channel morphology, habitat area and composition Biological: fish abundance, diversity, growth and survival

Monitoring is an essential element of a well built restoration program as it follows closely the effects of the interventions and allows changes to be made to the overall restoration process, when necessary, to ensure its ultimate success.

6. Conclusions and Future Perspectives

River health is a pertinent subject that should concern both present-day and future generations, since not only is fresh water a scarce resource but also, with the current rate of population growth, river health will be essential for the continuance health standards and survival of our race.

In this context, evermore the subject of restoration will become a priority as we face anthropic impacts of the past and need to take in account impacts of the future. So far river restoration is seen as something costly that requires a long-term investment and in the end is likely to not be successful.

Thusly it has been the objective of this thesis to illustrate that restoration can be done without an inexhaustible amount of resources being needed. All the necessary tools to determine where to act and what restoration methods to use are available and can produce a proper restoration program that will answer the needs of the drainage basin, the ecosystems it supports and the adjoining populations as a whole.

The tools used during the elaboration of the thesis, such as vegetation, geomorphic and climate maps served the purpose of creating a biophysical picture into which the drainage basin is inserted which extends as well into the social economical characteristics of the populace residing in the counties that intercept the case study.

Current trends of human population growth and activities indicate as well that although there seems to be a pattern of populace migration the anthropic pressure will either stabilize or is likely to increase. Heretofore the conjugation of these anthropic pressures, estimation of future pressures and knowledge of the current state of processes and functions of the river is essential to create a present day picture of the state of the river and to move from this towards a path that benefits all the stakeholders involved as well as the river.

The image created from this template of vegetation, geomorphology, climate and anthropogenic assessment is that, presently, the river's processes and functions are coping and getting by. It has an overall good chemical quality status and a mild pollution ecological status. Considering that future planned infrastructures and other anthropic activities will have a big impact, this water and ecological quality assessment might change in the near future. This is where the need for restoration appears. Its role can be to completely restore a highly polluted river or just assure that a river can cope and maintain all of its processes and function.

Insofar as was possible, this thesis has shown that an estimate of overall river processes and functions can be determined with limited resources and any actions that take place need to focus on restoring natural processes and functions to the river. Firstly when assessing the river *Tua* it was necessary to find data that could recreate these processes and define the overall state of functionality of the river but for the most part this data was not readily available. And as these restorative actions will need to take place more and more frequently, institutions with data pertaining to any restoration might need to adapt and not only make this sort of data available online but make it easy to access and process by the public in general.

The division of the river into sub-basins and their evaluation indicate what was expected - the sub-basins surrounding the biggest conglomerate of urban fabric within the drainage basin are the ones with more pressing need for restoration. Although the restoration sub-basins selection was based on a cost-effectiveness assessment, future restoration programs should focus on a cost-benefit assessment as it offers a more likely picture of restoratives actions within a socioeconomic context; the assessment of the sub-basins in this thesis couldn't find enough data to make a reliable cost-benefit assessment, so future work in this area might look into gathering this data and reviewing this analysis.

The restoration program itself needs to be carefully thought out, keeping in mind the overall context within which the drainage basin is located. The role of freshwater managers will need to grow to encompass an assessment of what can be done to improve the chemical and ecological status of a river in order to fulfil water security but also allow the aquatic ecosystem to provide the benefits and services it always has. This is where river restoration becomes a valuable tool to managers, and a relatively fast way to assess key locations and what can be done to return them to a healthy state is fundamental. It is hoped that this thesis will stimulate further investment in this field.

True sustainable development for any country will require preservation and restoration of their aquatic ecosystems, as engineers it is our job to pave the road to future. Restoration will definitely be the next stop.

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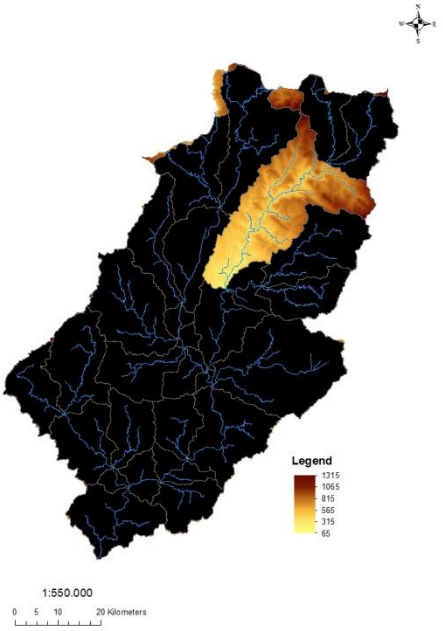
8. Appendixes

Appendix A

Table A.1. Soil type description

Soil Code	Soil Type	Description
Bdod	Orthi-Dystric Cambisol	These have no layer of accumulated clay, humus, soluble salts or iron and aluminium oxides .
Bdog	Orthi-Dystric Cambisol	
Bdox	Orthic-Dystric Cambisol	
Bdxm	Chromi-Dystric Cambisol	
Bdxx	Chromi-Dystric Cambisol	
Buog	Orthi-Umbric Cambisol	
Buox	Orthi-Umbric Cambisol	
Buxx	Chromi-Umbric Cambisol	
Bxs	Chromic Cambisols	
Idog	Orthi-Dystric Leptosol	These have a very shallow profile and they often contain large amounts of grave and are especially susceptible to erosion, desiccation, or waterlogging, depending on climate and topography
Idom	Orthi-Dystric Leptosol	
Idox	Orthi-Dystric Leptosol	
Iebb	Cambi-Eutric Leptosol	
Ieob	Orthi-Eutric Leptosol	
Ieou	Orthi-Eutric Leptosol	
Ieox	Orthi-Eutric Leptosol	
Isg	Leptosol	
Iub	Umbric Leptosol	
Iug	Umbric Leptosol	
Iux	Umbric Leptosol	
Lxb	Chromic Luvisol	These form on flat or gently sloping landscapes under climatic regimes that range from cool temperate to warm Mediterranean - they are suitable for a wide range of agriculture due to their high nutrient content and good drainage
Jdoa	Orthi-Dystric Fluvisol	These are found typically on level topography that is flooded periodically by surface waters or rising groundwater.
Jea	Eutric Fluvisol	
Jua	Umbric Fluvisol	
Tasdx	Dystri-Surribi Aric Anthrosol	These are defined as any soils that have been modified profoundly by human activities, including burial, partial removal, cutting and filling, waste disposal and irrigated agriculture.
Tatdg	Dystric-Terraci Aric Anthrosol	
Uhs	Haplic Alisol	These soils are highly acidic and poorly drained soils which are prone to aluminium toxicity and water erosion.

Appendix B



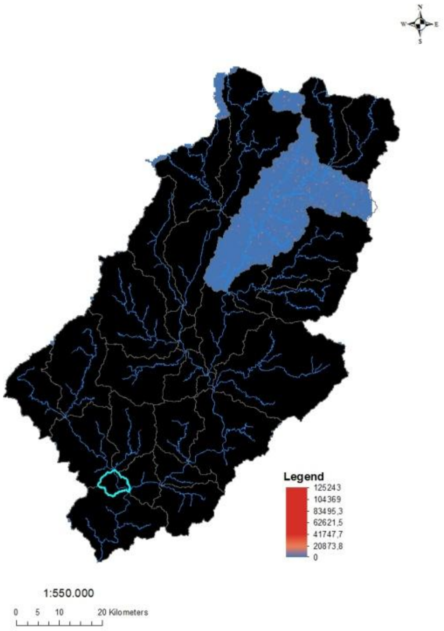


Figure B.1. Elevation - SubBasin 1

Figure 63. Erosion - SubBasin 1

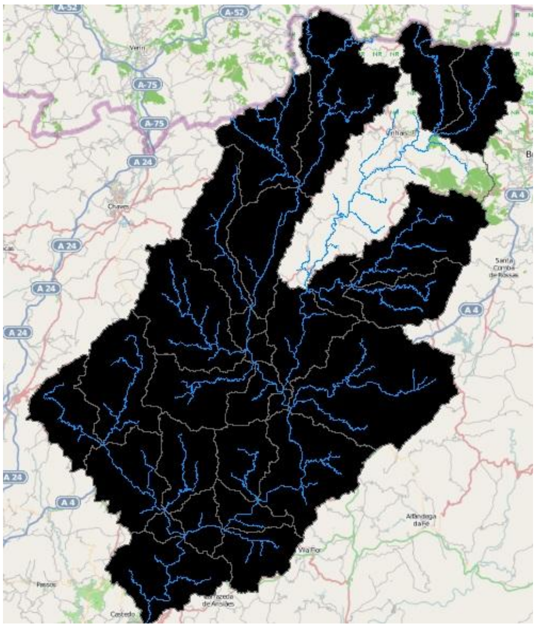


Figure B.3. Roads - SubBasin 1

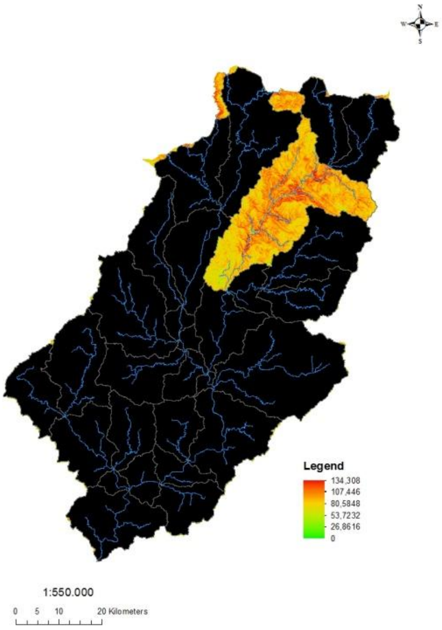


Figure B.4. Slopes - SubBasin 1

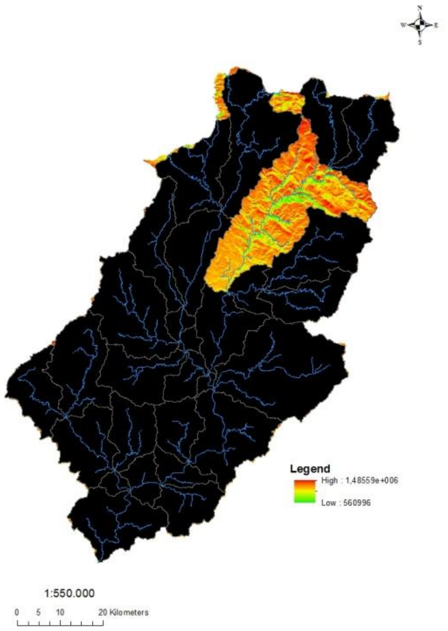


Figure B.5. Solar Radiation - SubBasin 1

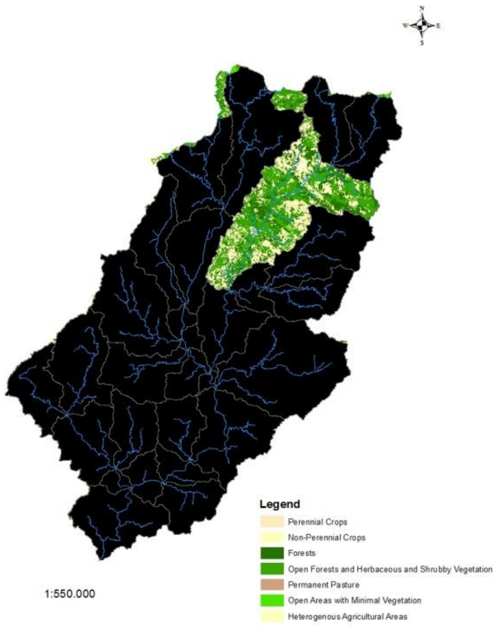


Figure B.6. Vegetation Cover - SubBasin 1

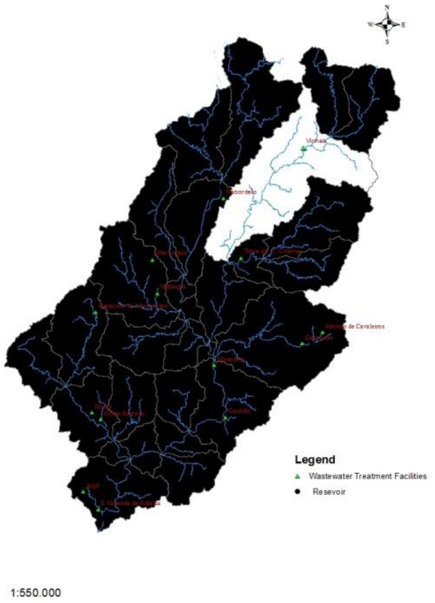


Figure B.7. Resevoirs and wastewater treatment facilities - SubBasin 1

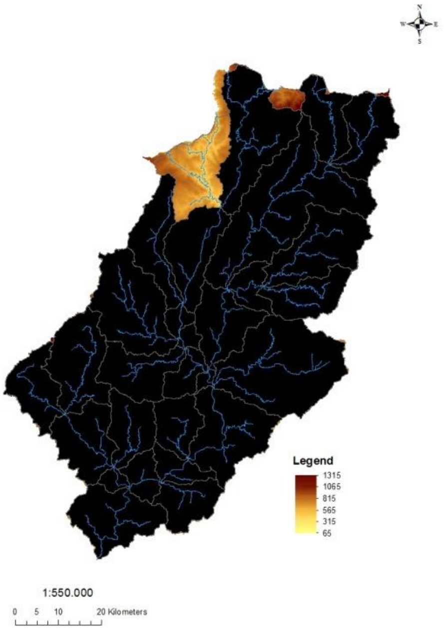


Figure B.8. Elevation - SubBasin 2

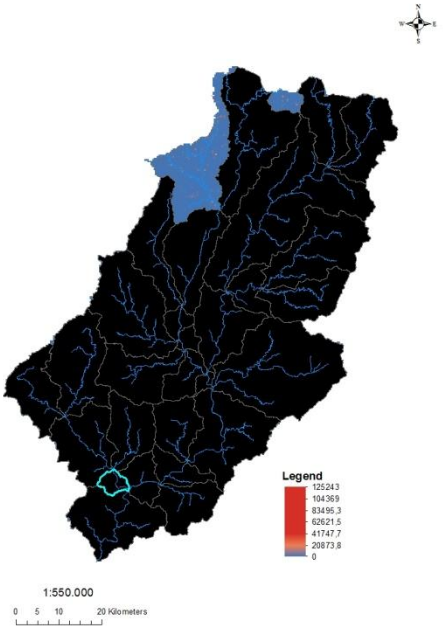


Figure B.9. Erosion - SubBasin 2

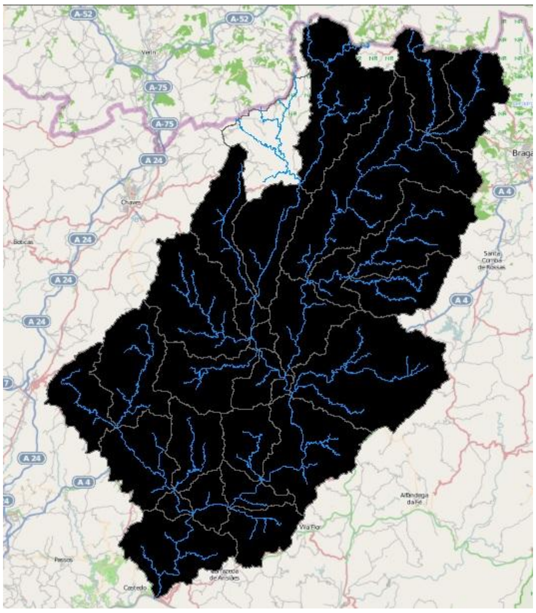


Figure B.10. Roads - SubBasin 2

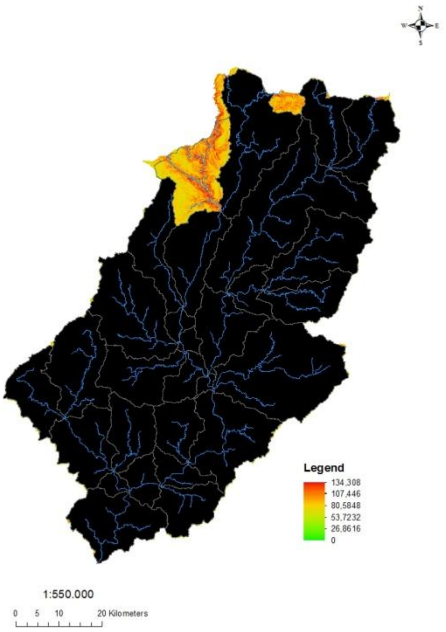


Figure B.11. Slopes - SubBasin 2

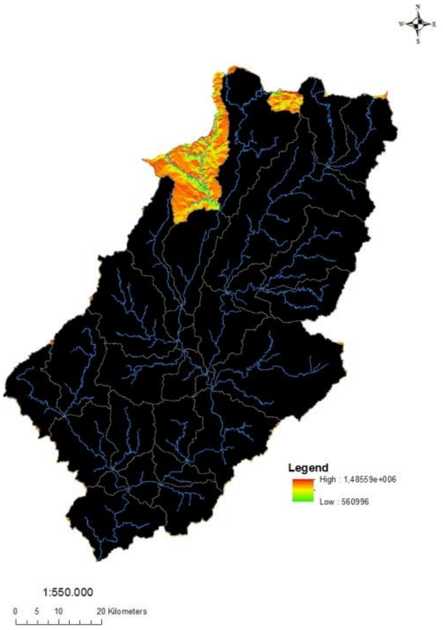


Figure B.12. Solar Radiation - SubBasin 2

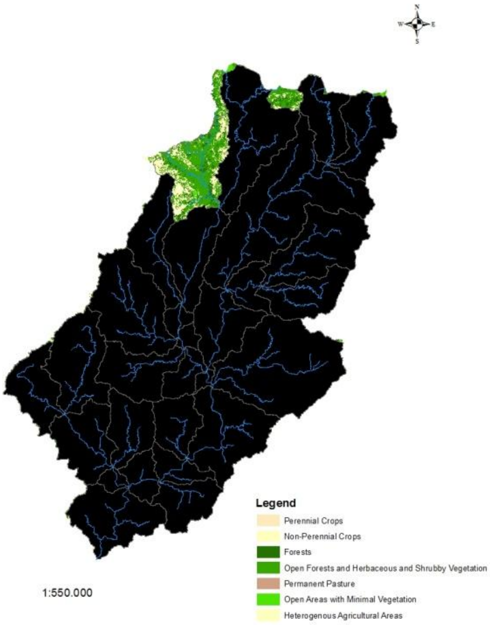


Figure B.13. Vegetation Cover - SubBasin 2

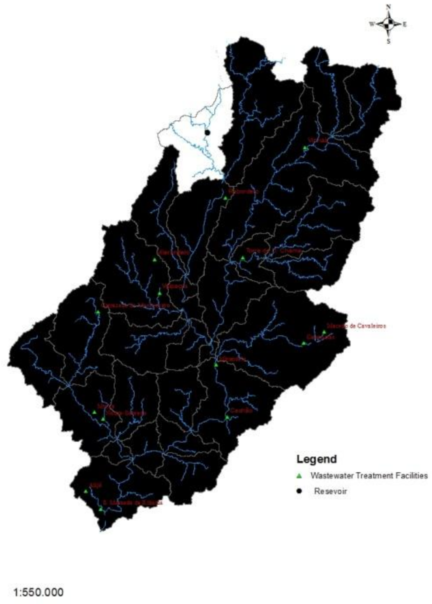


Figure B.14. Resevoirs and wastewater treatment facilities - SubBasin 2

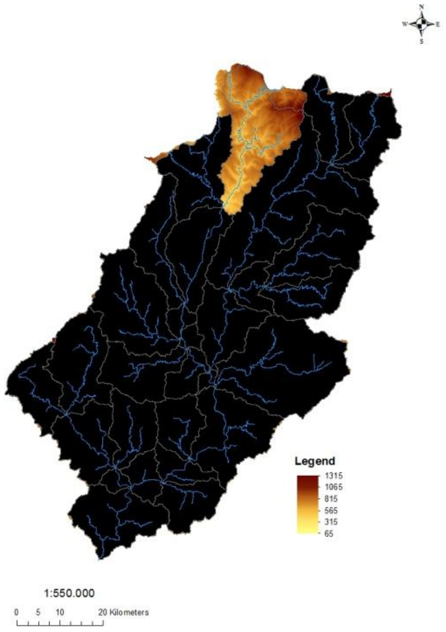


Figure B.15. Elevation - SubBasin 3

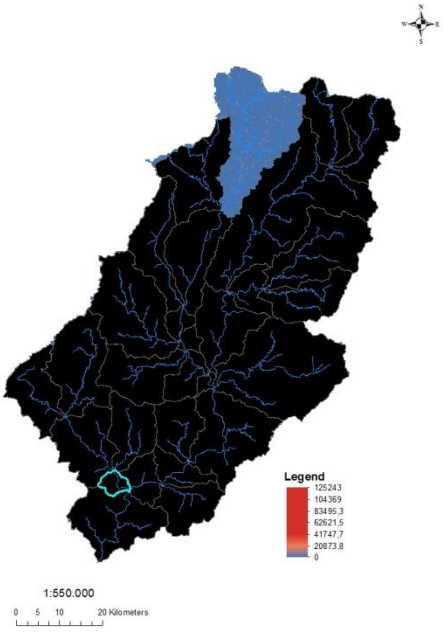


Figure B.16. Erosion - SubBasin 3

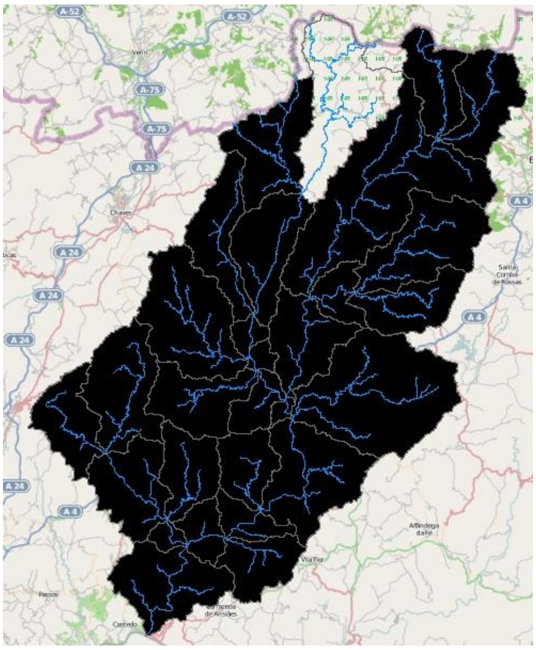


Figure B.17. Roads - SubBasin 3

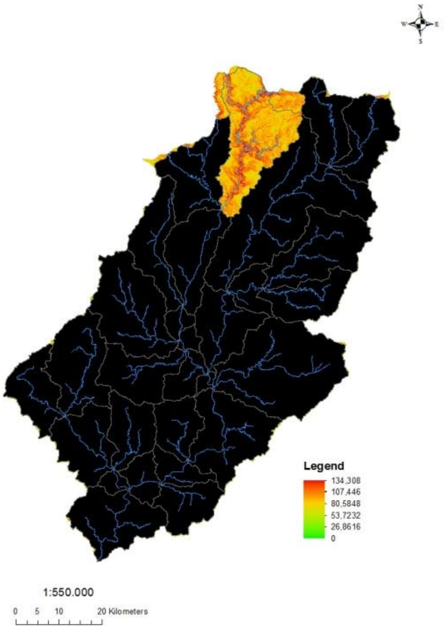


Figure B.18. Slopes - SubBasin 3

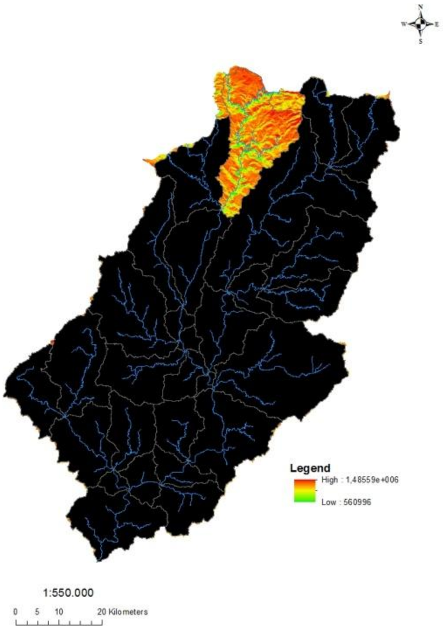


Figure B.19. Solar Radiation - SubBasin 3

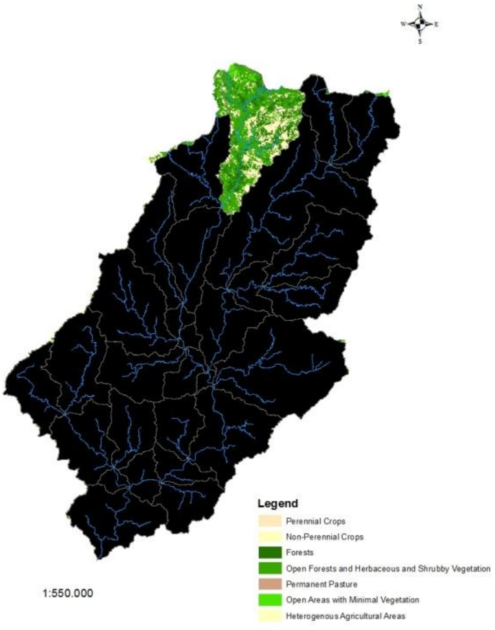


Figure B.20. Vegetation Cover - SubBasin 3

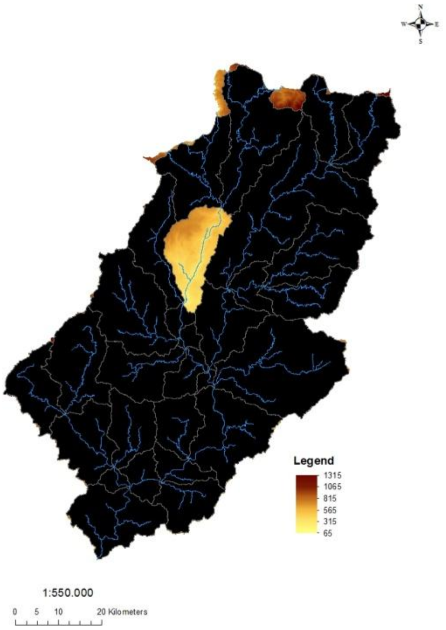


Figure B.21. Elevation - SubBasin 4

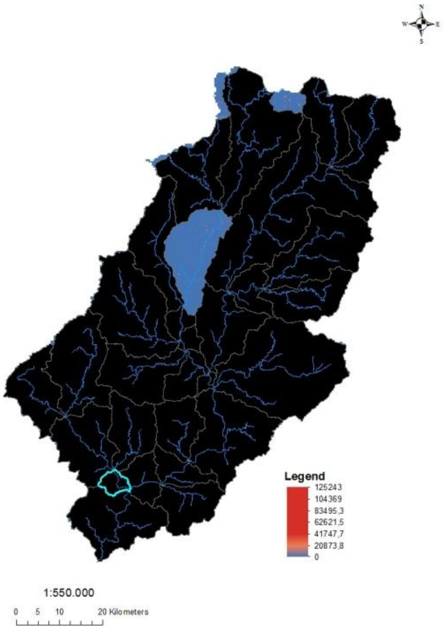


Figure B.22. Erosion - SubBasin 4

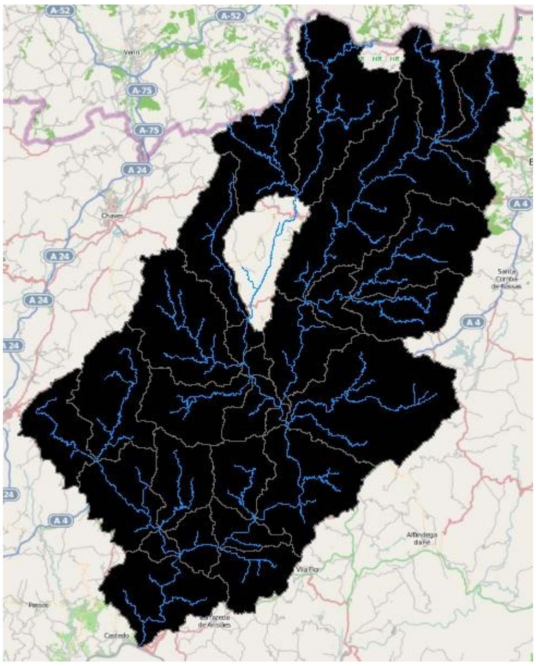


Figure B.23. Roads - SubBasin 4

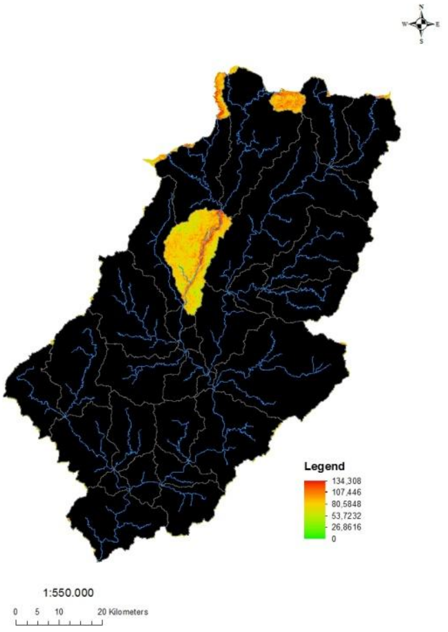


Figure B.24. Slopes - SubBasin 4

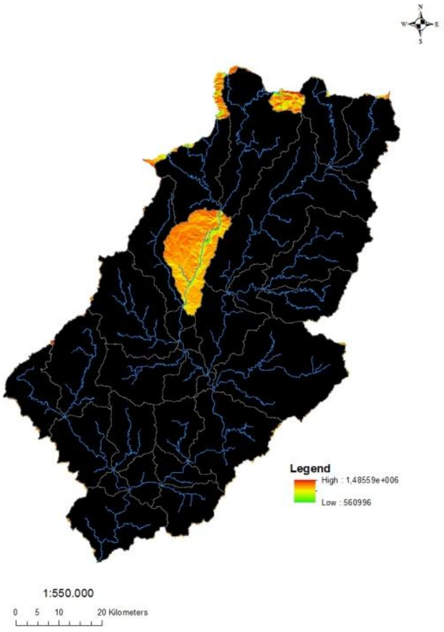


Figure B.25. Solar Radiation - SubBasin 4

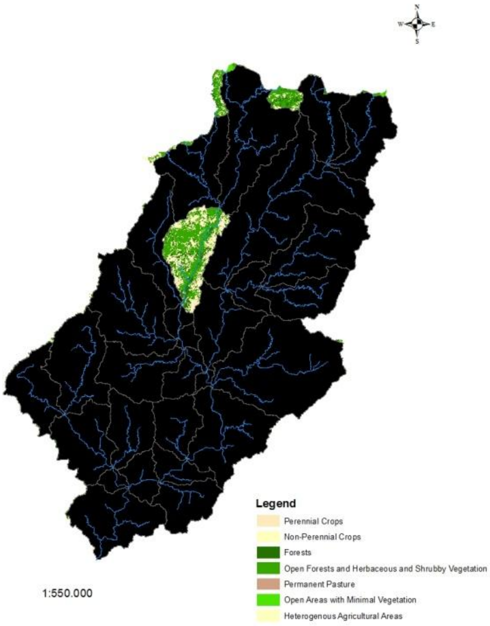


Figure B.26. Vegetation Cover - SubBasin 4

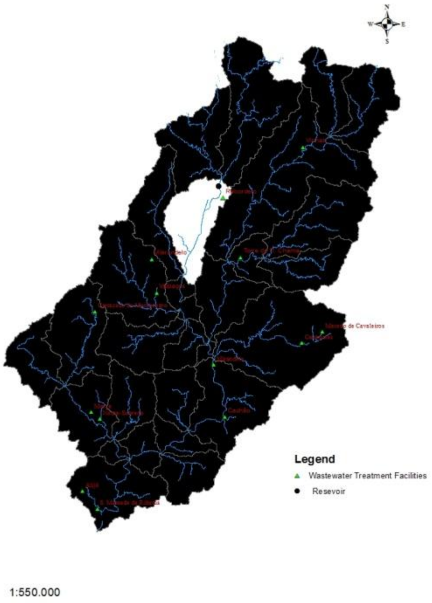


Figure B.27. Resevoirs and wastewater treatment facilities - SubBasin 4

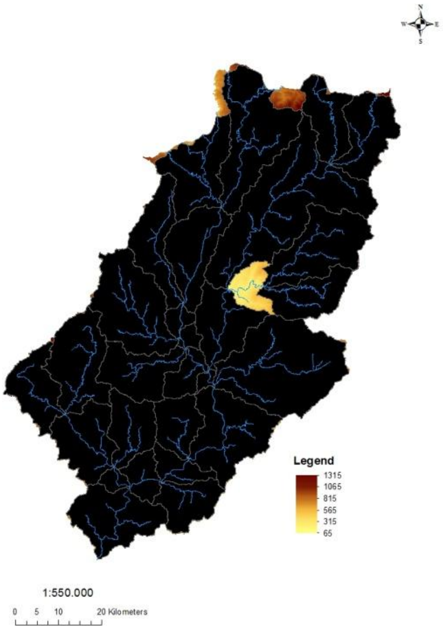


Figure B.28. Elevation - SubBasin 5

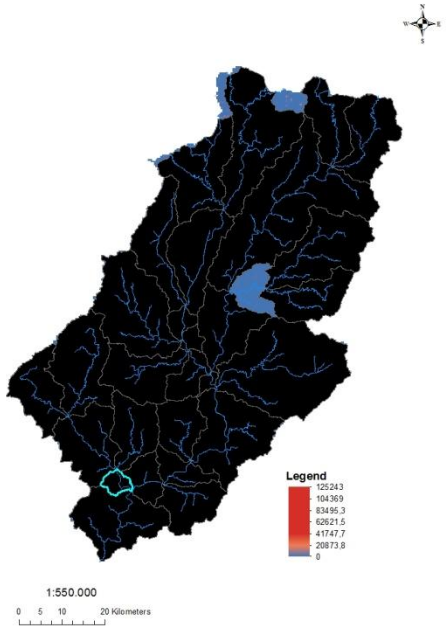


Figure B. 29. Erosion - SubBasin 5

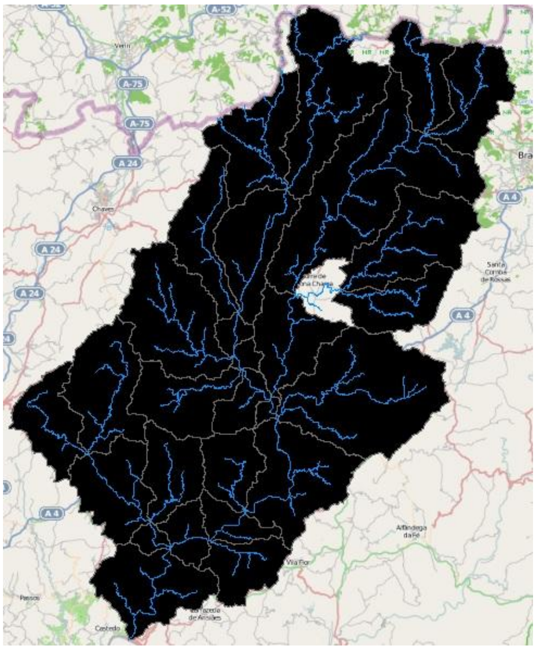


Figure B.30. Roads - SubBasin 5

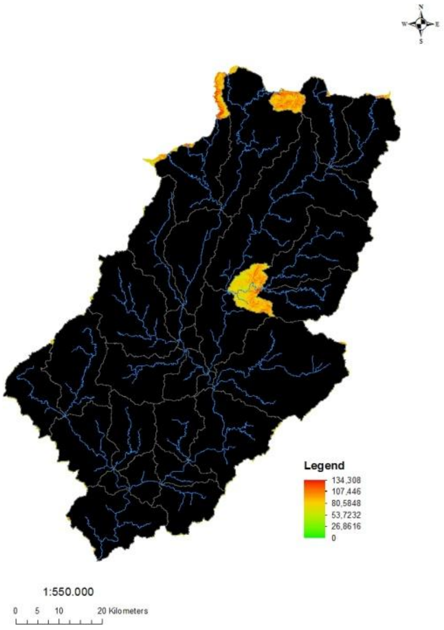


Figure B.31. Slopes - SubBasin 5

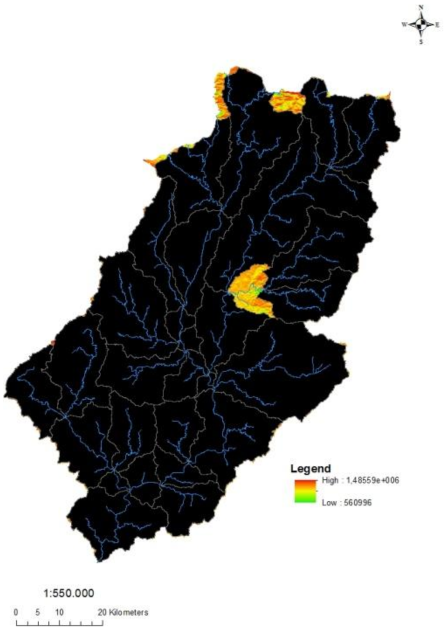


Figure B.32. Solar Radiation - SubBasin 5

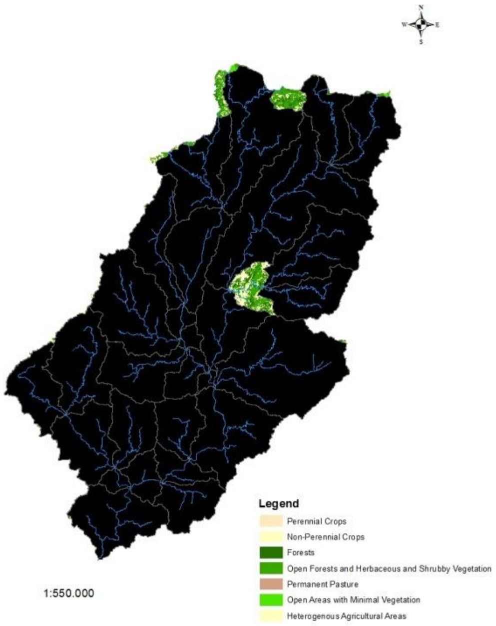


Figure B.33. Vegetation Cover - SubBasin 5

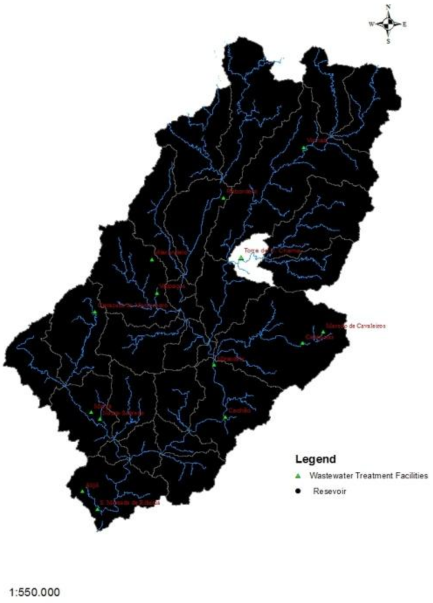


Figure B.34. Resevoirs and wastewater treatment facilities - SubBasin 5

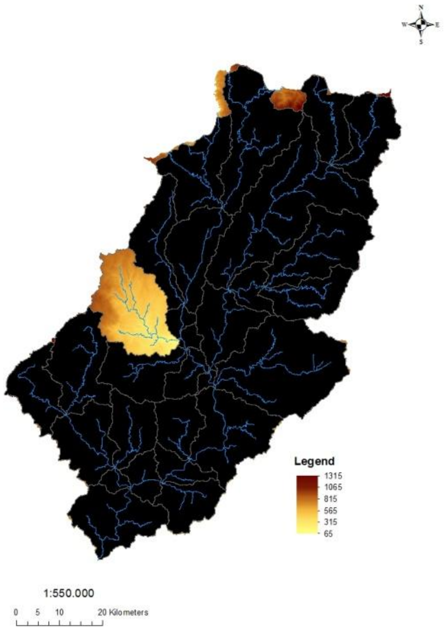


Figure B.35. Elevation - SubBasin 6

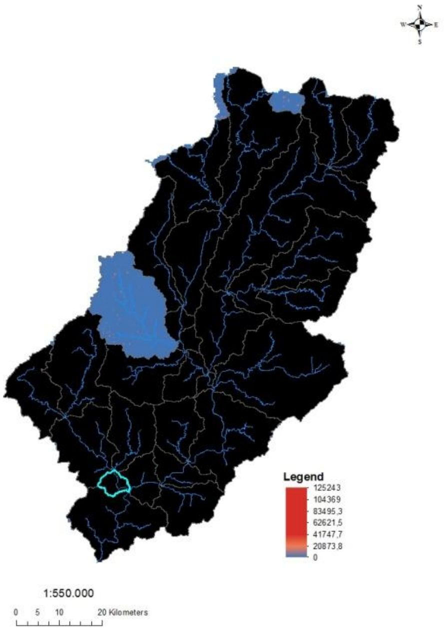


Figure B.36. Erosion - SubBasin 6

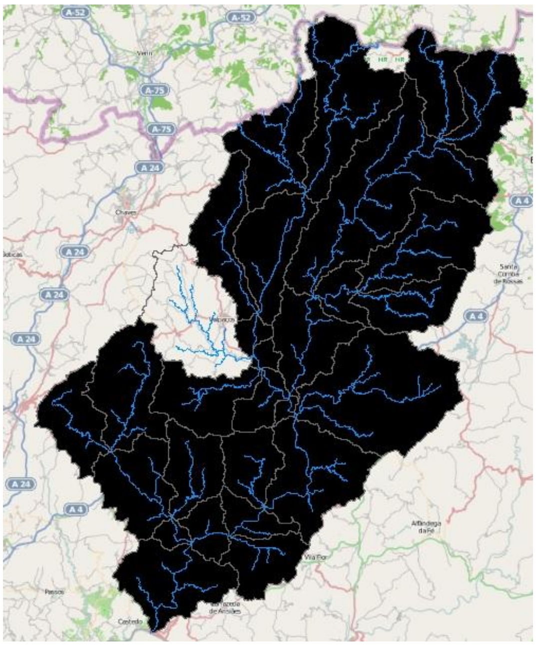


Figure B.37. Roads - SubBasin 6

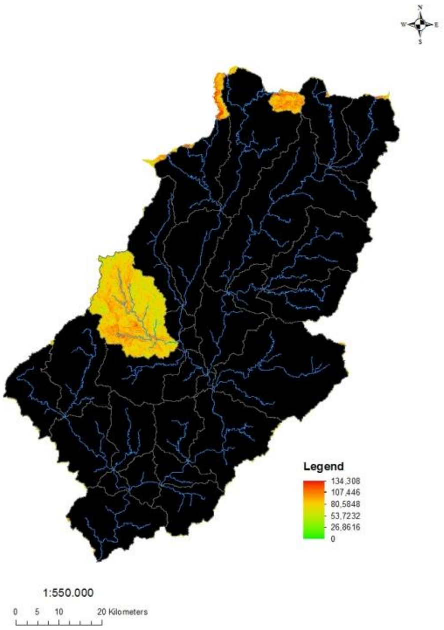


Figure B.38. Slopes - SubBasin 6

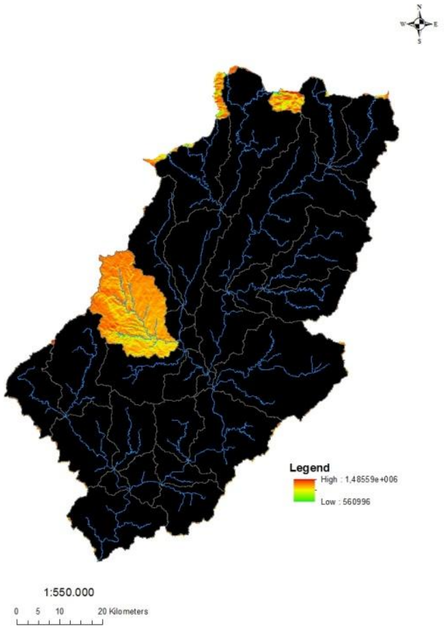


Figure B.39. Solar Radiation - SubBasin 6

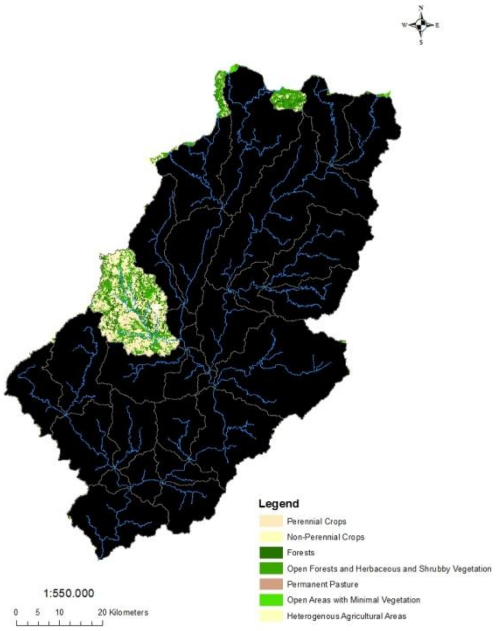


Figure B.40. Vegetation Cover - SubBasin 6

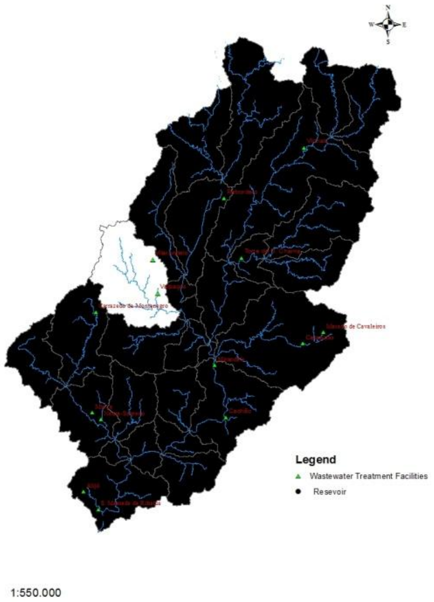


Figure B.41. Resevoirs and wastewater treatment facilities - SubBasin 6

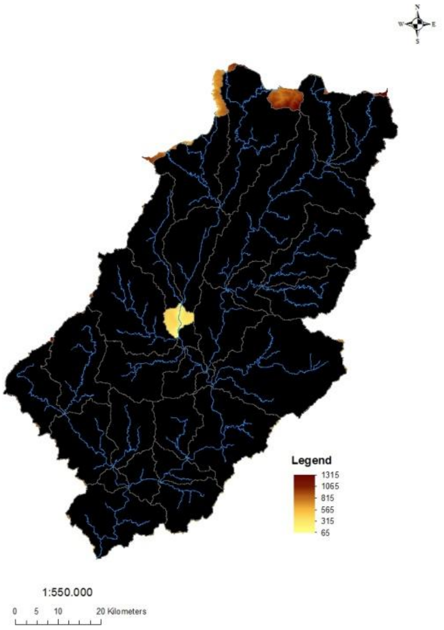


Figure B.42. Elevation - SubBasin 7

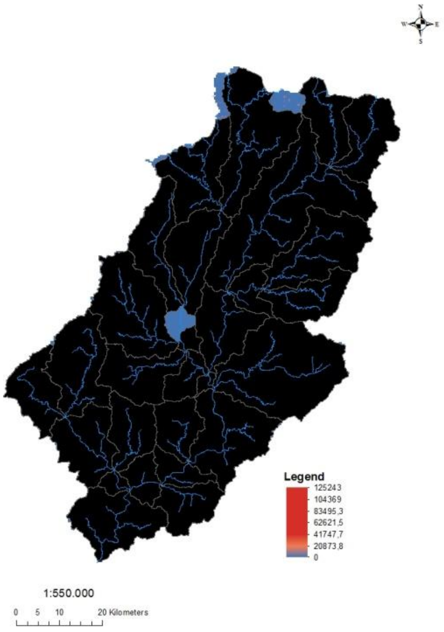


Figure B.43. Erosion - SubBasin 7

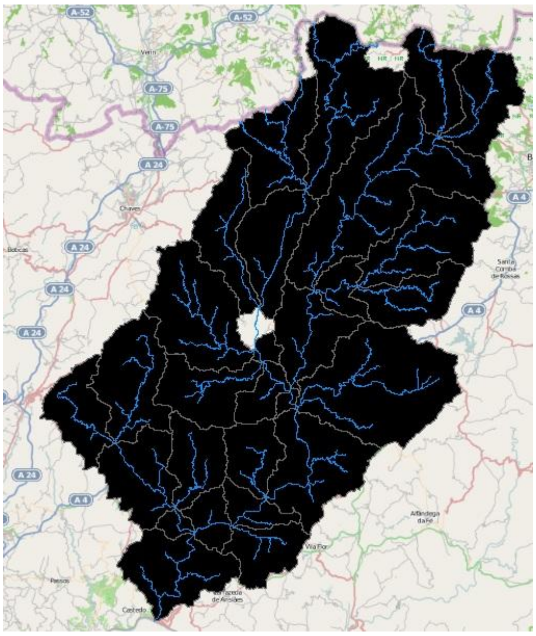


Figure B.44. Roads - SubBasin 7

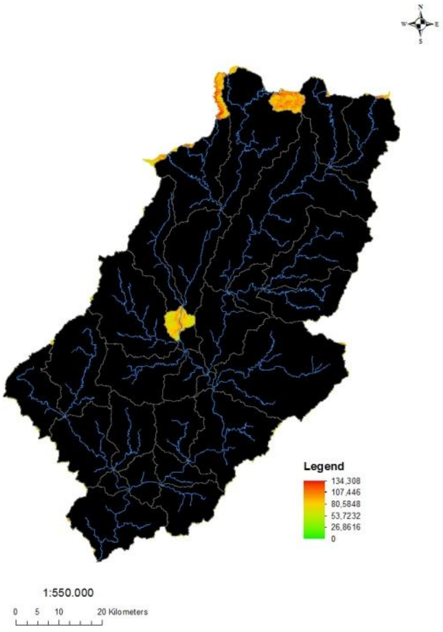


Figure B.45. Slopes - SubBasin 7

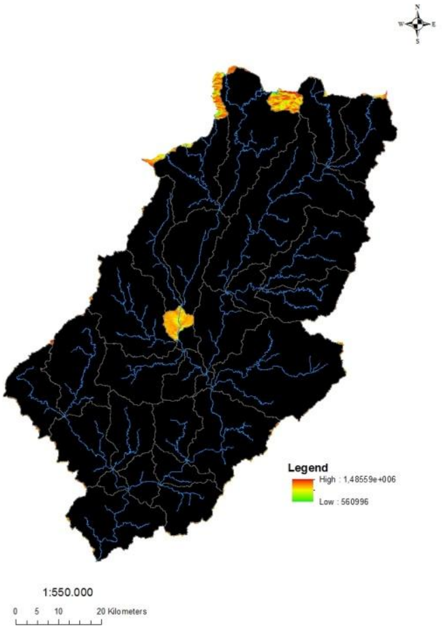


Figure B.46. Solar Radiation - SubBasin 7

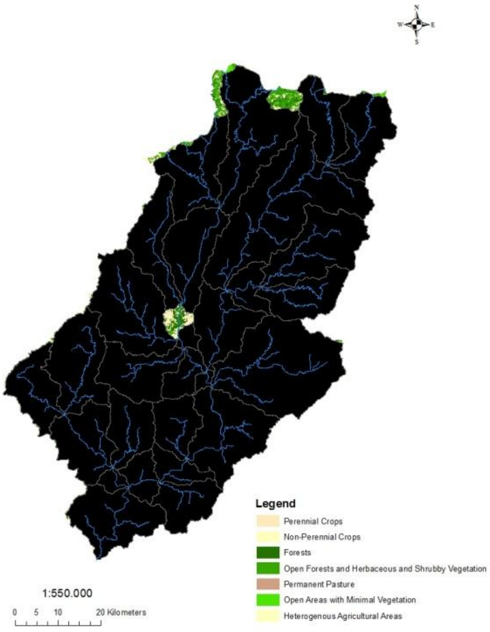


Figure B.47. Vegetation Cover - SubBasin 7

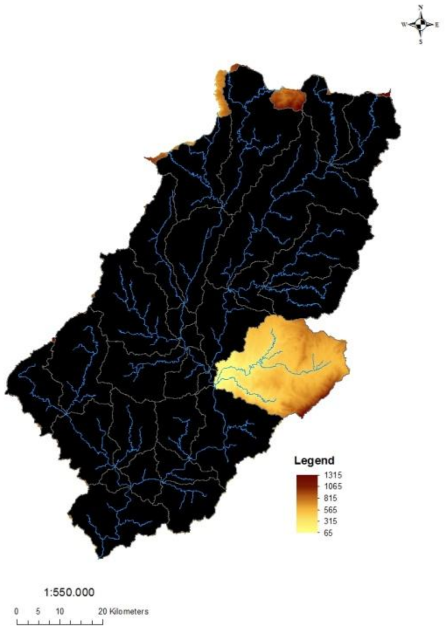


Figure B.48. Elevation - SubBasin 8

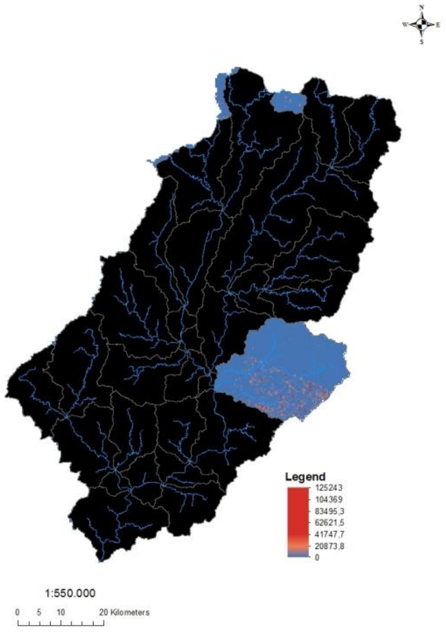


Figure B.49. Erosion - SubBasin 8

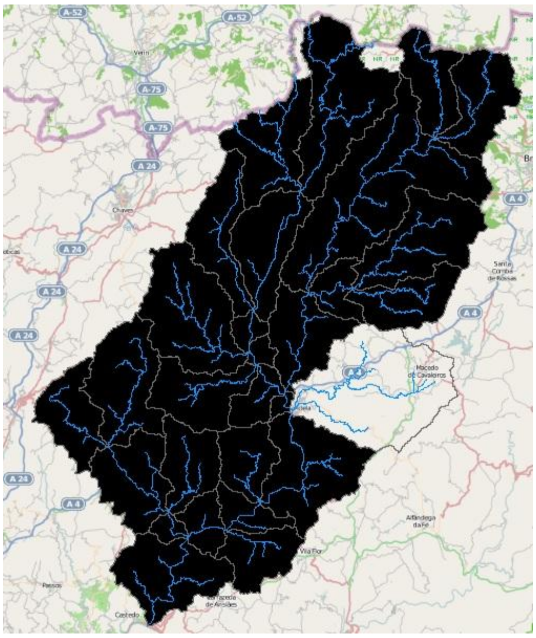


Figure B.50. Roads - SubBasin 8

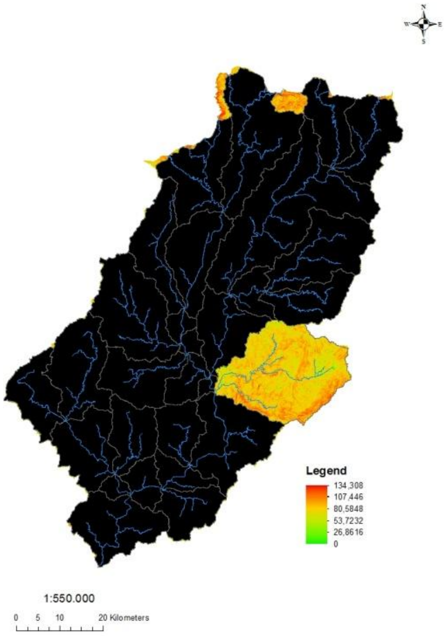


Figure B.51. Slopes - SubBasin 8

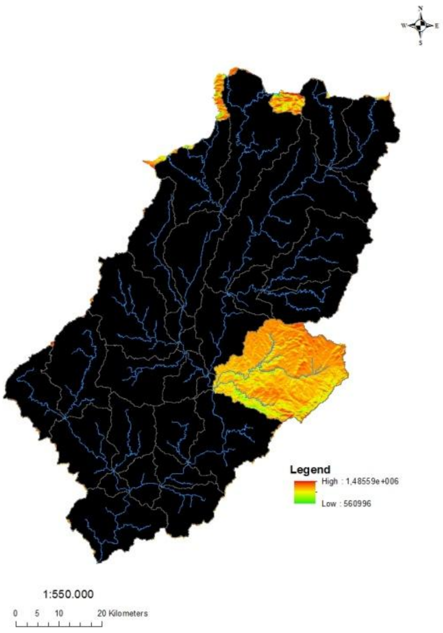


Figure B.52. Solar Radiation - SubBasin 8

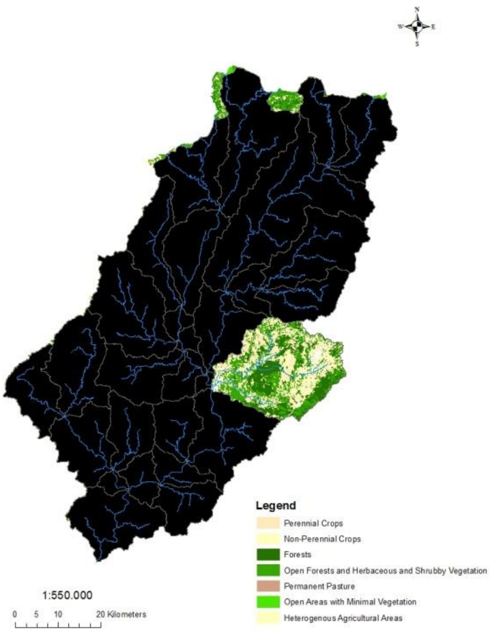


Figure B.53. Vegetation Cover - SubBasin 8

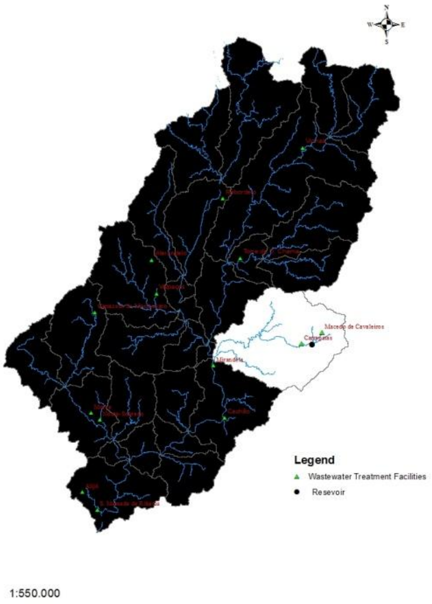


Figure B.54. Resevoirs and wastewater treatment facilities - SubBasin 8

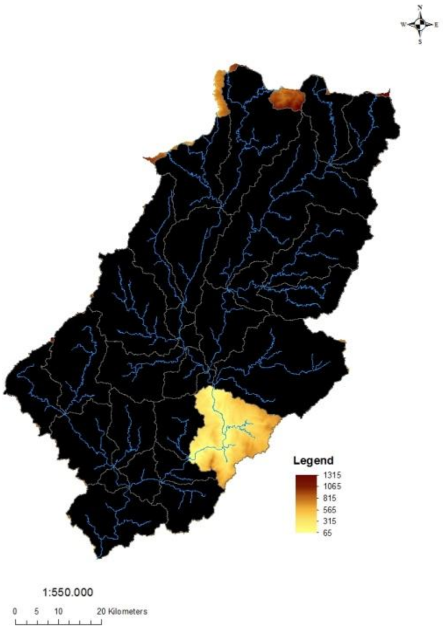


Figure B.55. Elevation - SubBasin 9

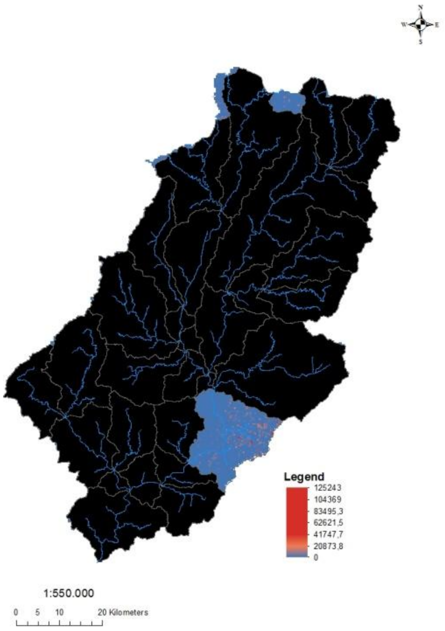


Figure B.56. Erosion - SubBasin 9

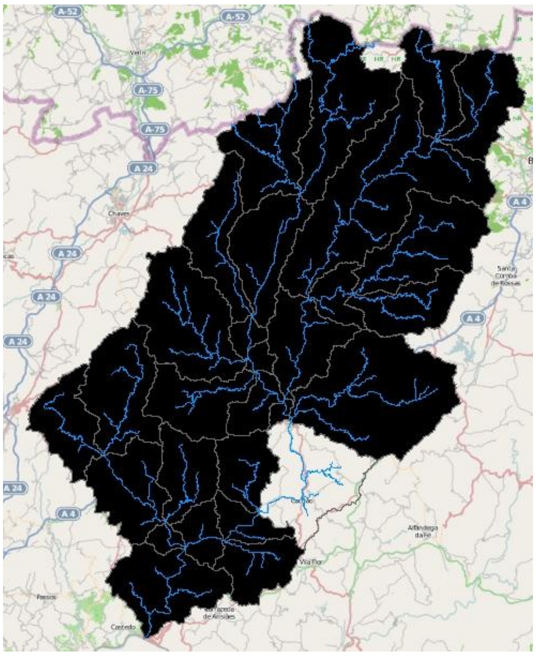


Figure B.57. Roads - SubBasin 9

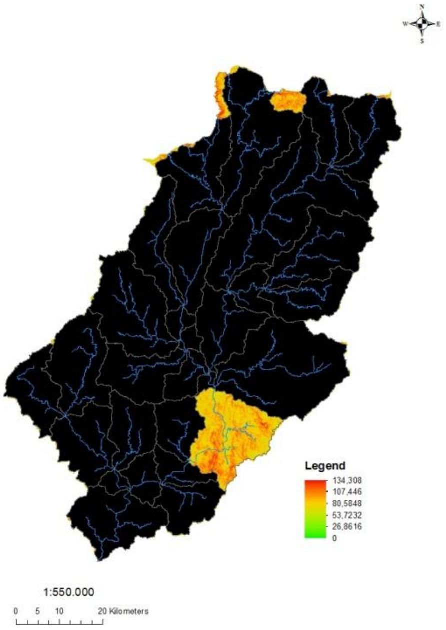


Figure B.58. Slopes - SubBasin 9

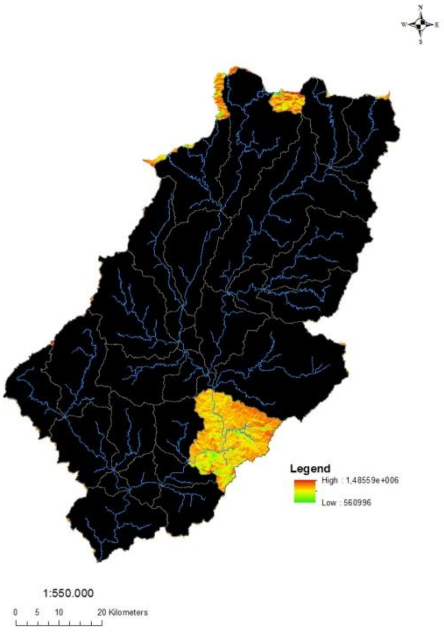


Figure B.59. Solar Radiation - SubBasin 9

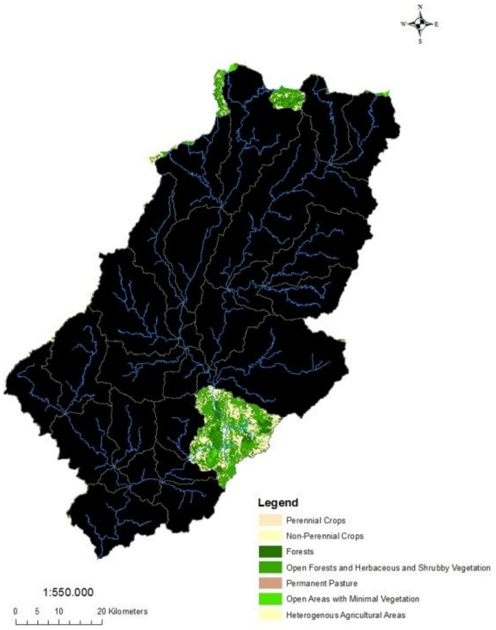


Figure B.60. Vegetation Cover - SubBasin 9

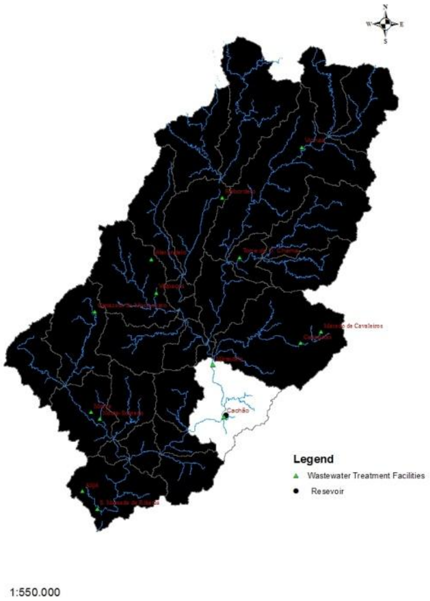


Figure B.61. Resevoirs and wastewater treatment facilities - SubBasin 9

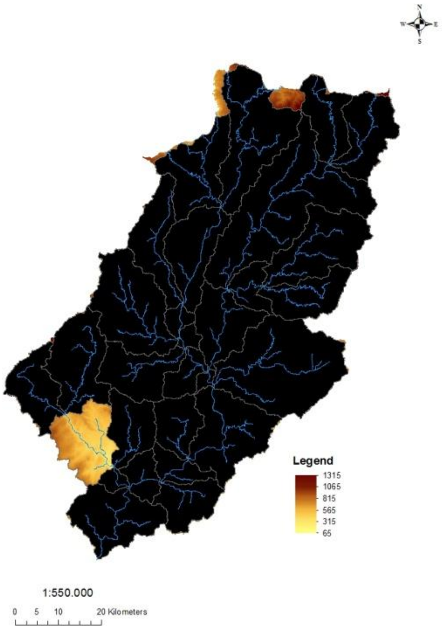


Figure B.62. Elevation - SubBasin 10

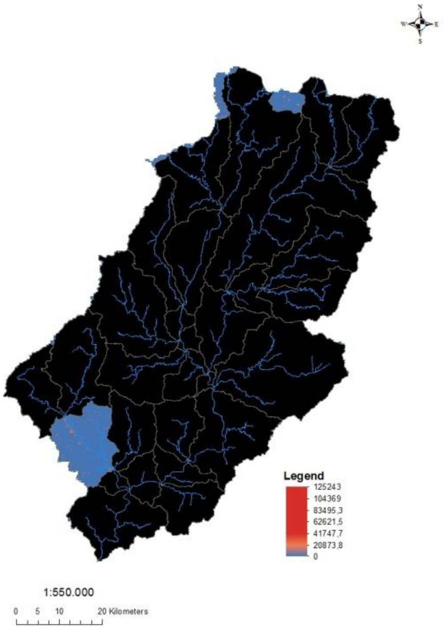


Figure B.63. Erosion - SubBasin 10

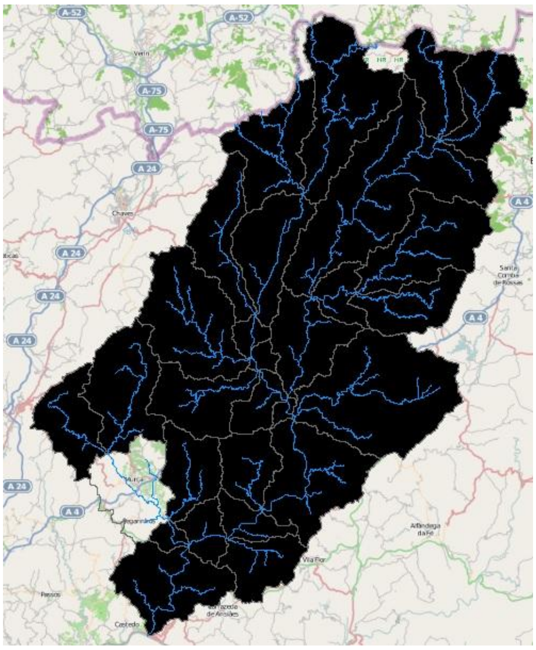


Figure B.64. Roads - SubBasin 10

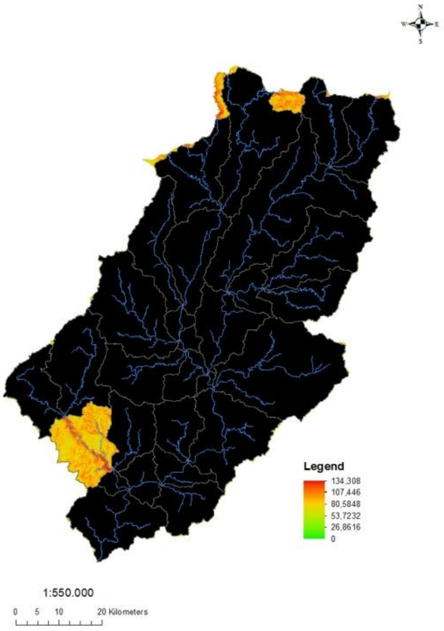


Figure B.65. Slopes - SubBasin 10

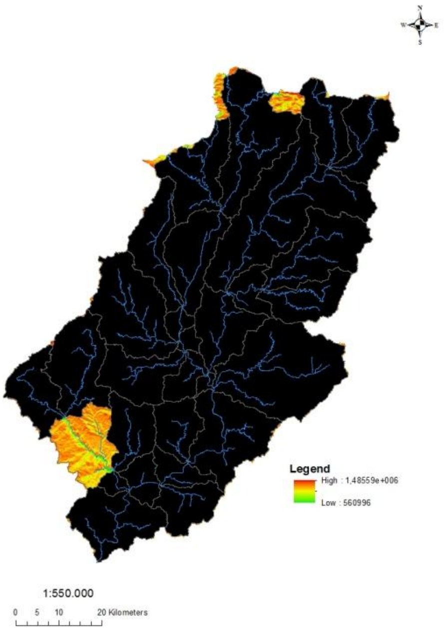


Figure B.66. Solar Radiation - SubBasin 10

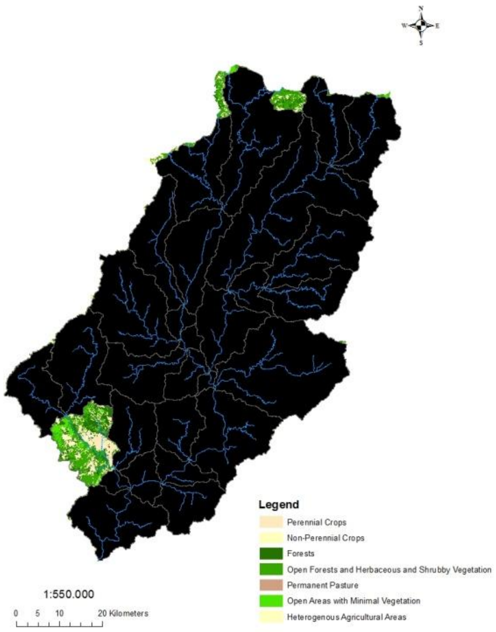


Figure B.67. Vegetation Cover - SubBasin 10

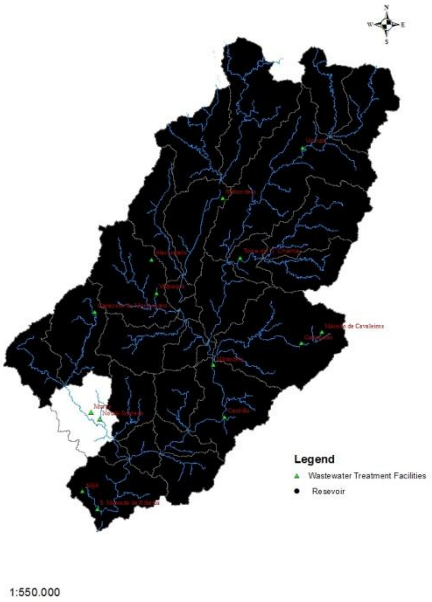


Figure B.68. Resevoirs and wastewater treatment facilities - SubBasin 10

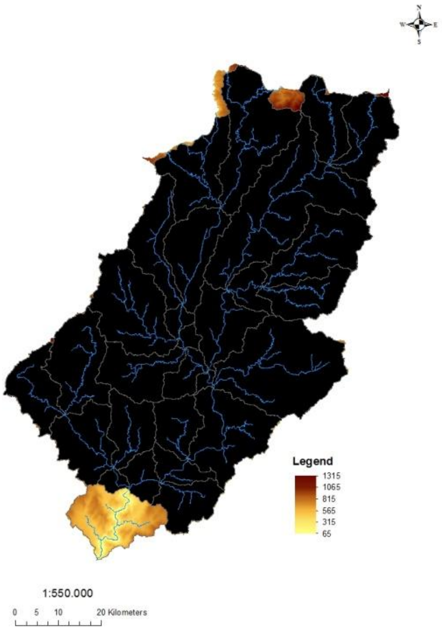


Figure B.69. Elevation - SubBasin 11

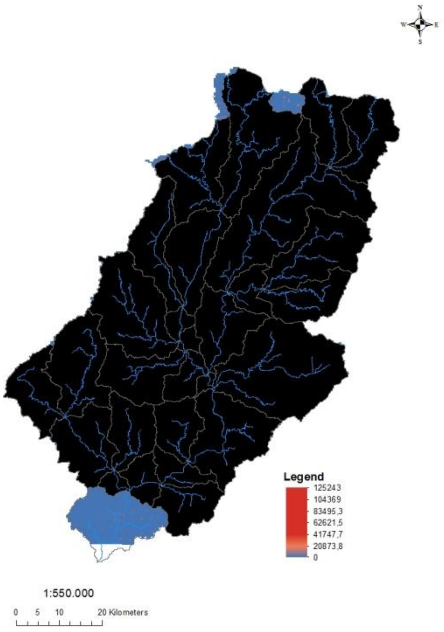


Figure B.70. Erosion - SubBasin 11

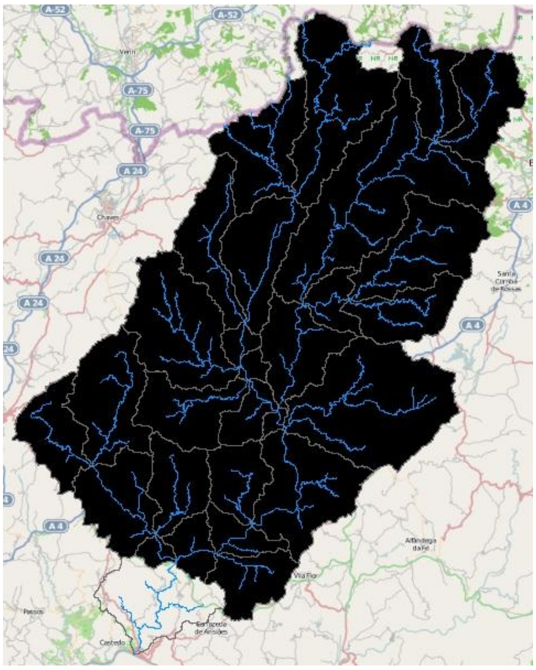


Figure B.71. Roads - SubBasin 11

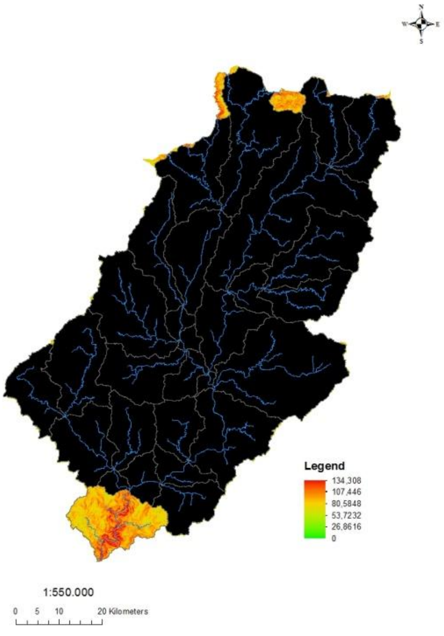


Figure B.72. Slopes - SubBasin 11

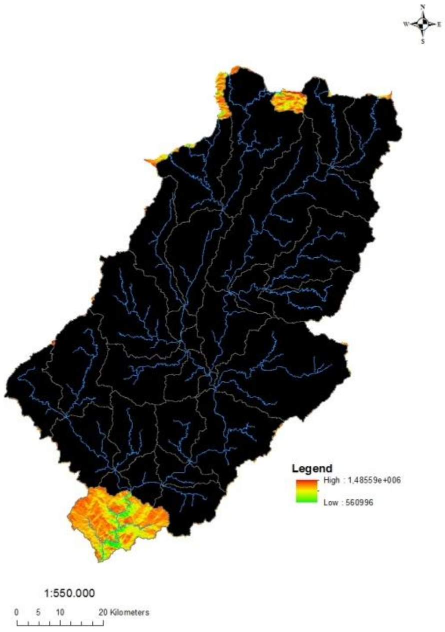


Figure B.73. Solar Radiation - SubBasin 11

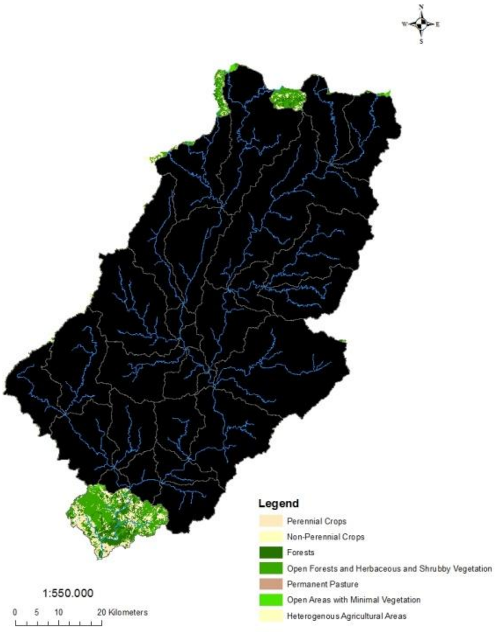


Figure B.74. Vegetation Cover - SubBasin 11

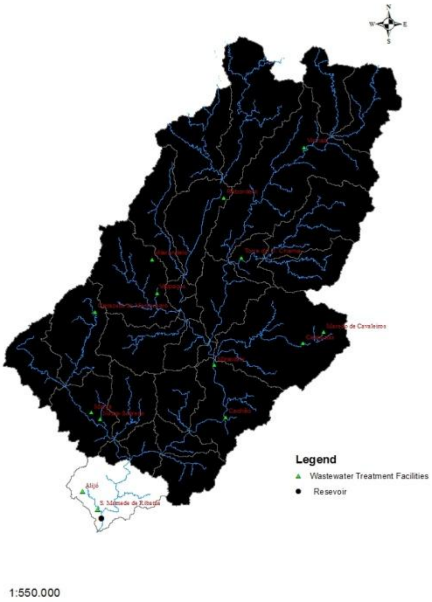


Figure B.75. Resevoirs and wastewater treatment facilities - SubBasin 11

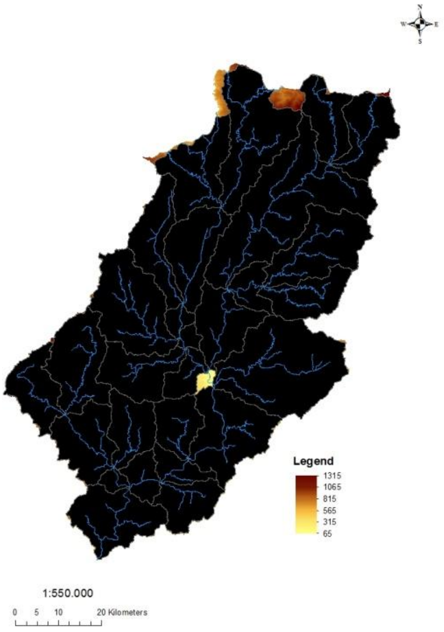


Figure B.76. Elevation - SubBasin 12

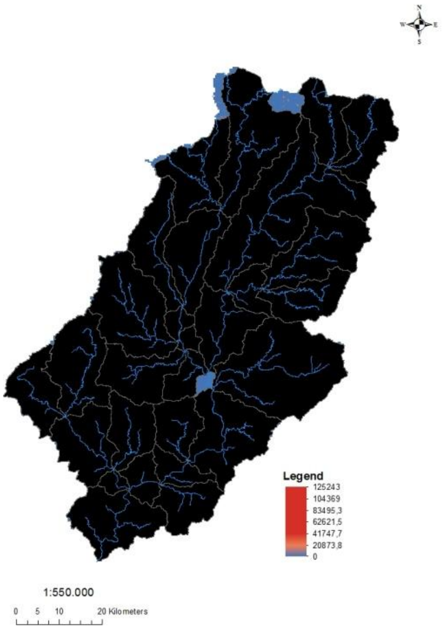


Figure B.77. Erosion - SubBasin 12

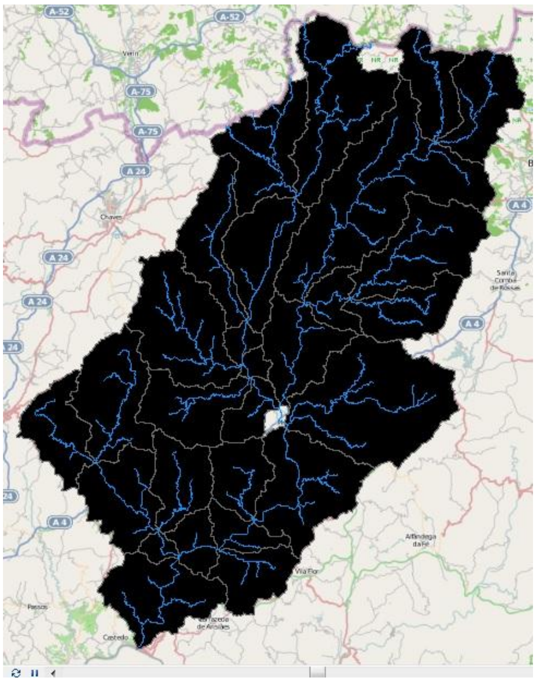


Figure B.78. Roads - SubBasin 12

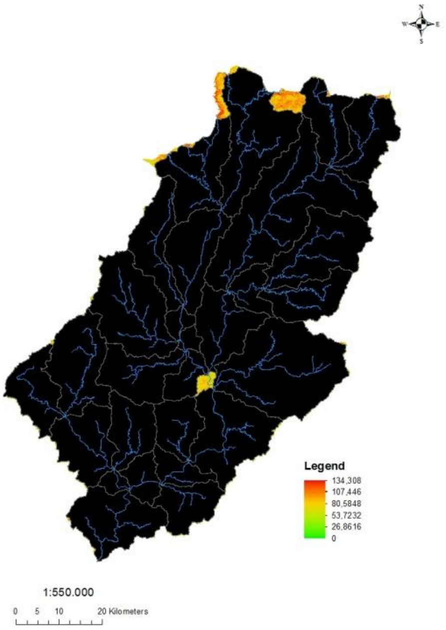


Figure B.79. Slopes - SubBasin 12

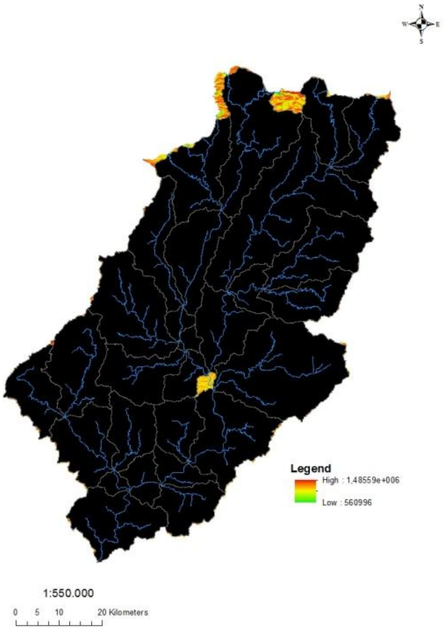


Figure B.80. Solar Radiation -
SubBasin 12

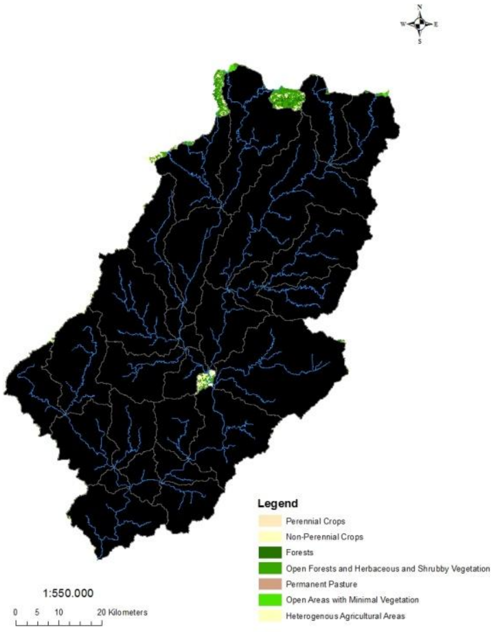


Figure B.81. Vegetation Cover -
SubBasin 12

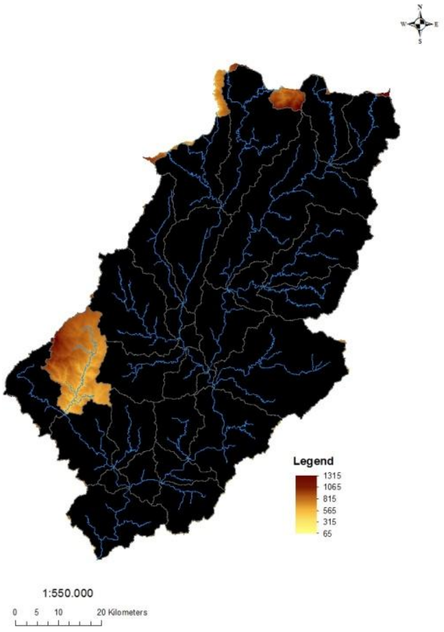


Figure B.82. Elevation - SubBasin 13

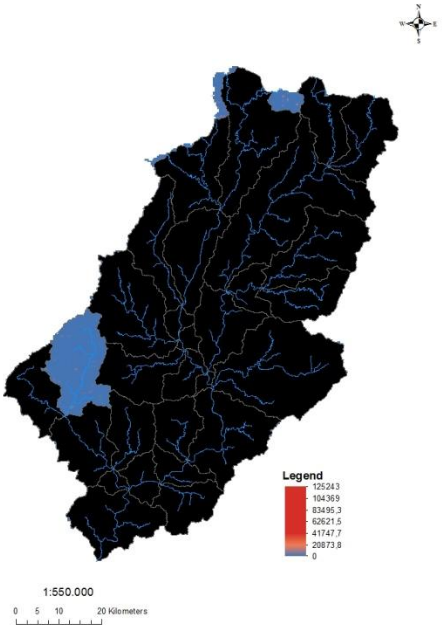


Figure B.83. Erosion - SubBasin 13

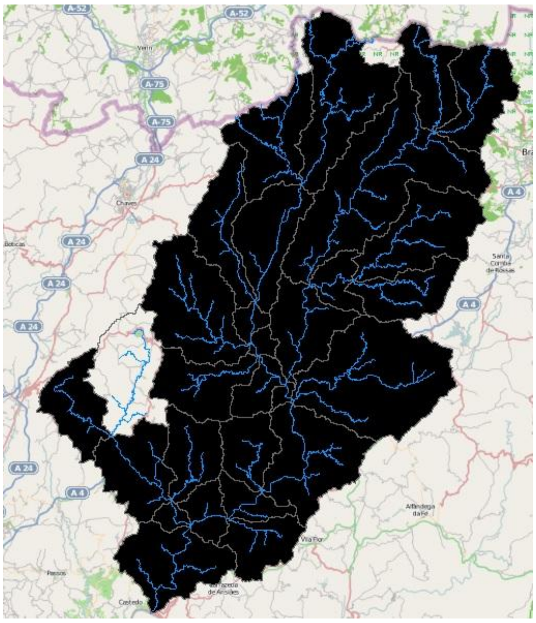


Figure B.84. Roads - SubBasin 13

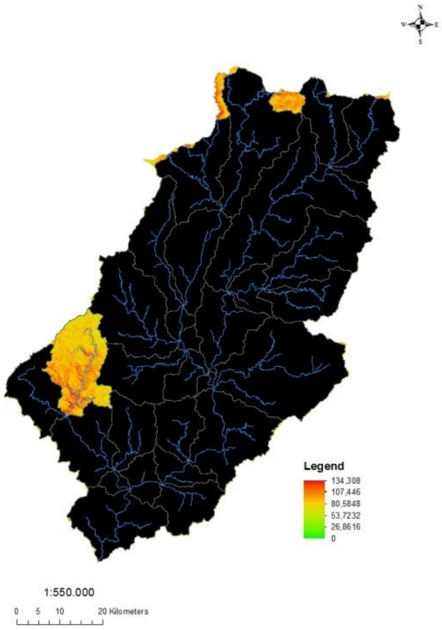


Figure B.85. Slopes - SubBasin 13

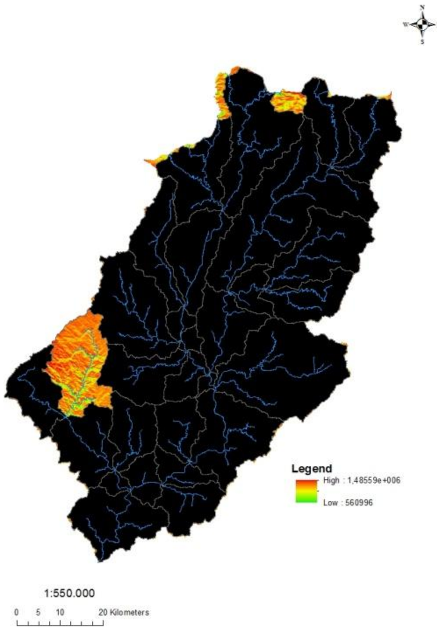


Figure B.86. Solar Radiation - SubBasin 13

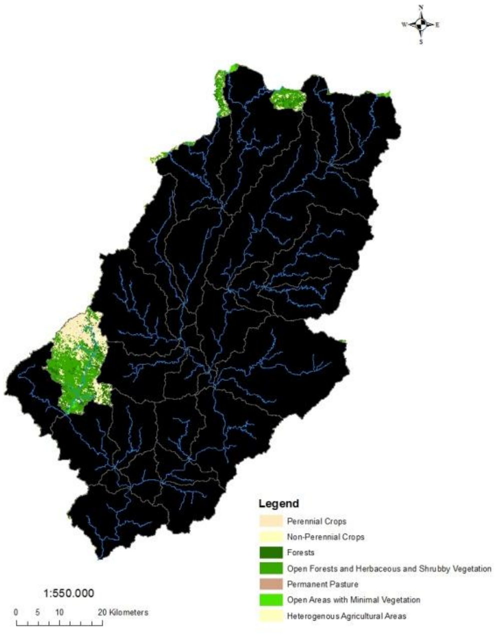


Figure B.87. Vegetation Cover - SubBasin 13

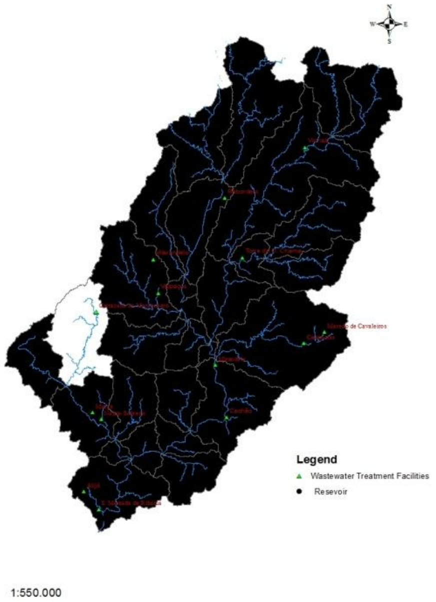


Figure B.88. Resevoirs and wastewater treatment facilities - SubBasin 13

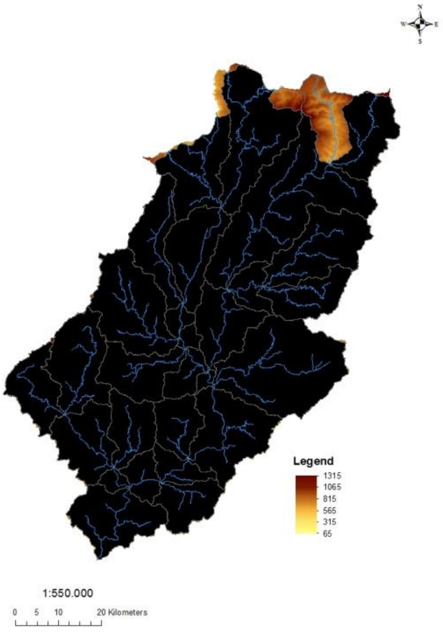


Figure B.89. Elevation - SubBasin 14

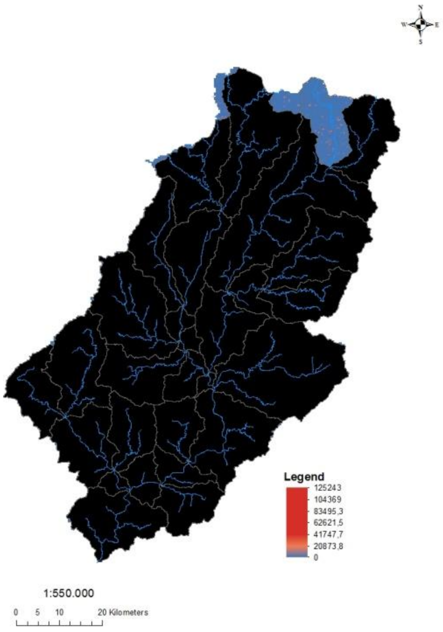


Figure B.90. Erosion - SubBasin 14

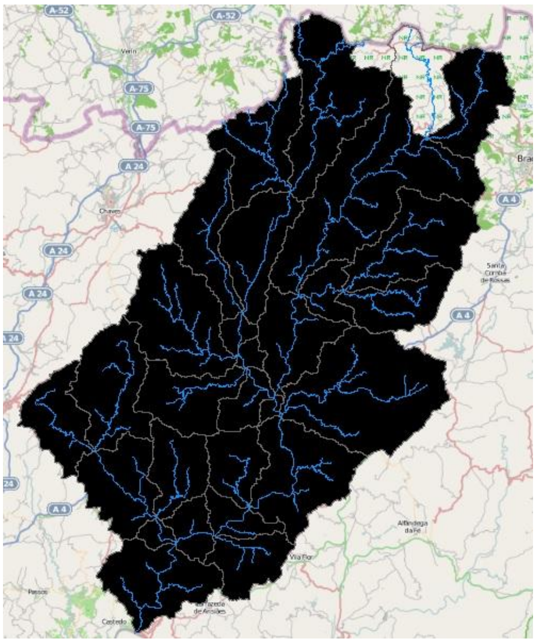


Figure B.91. Roads - SubBasin 14

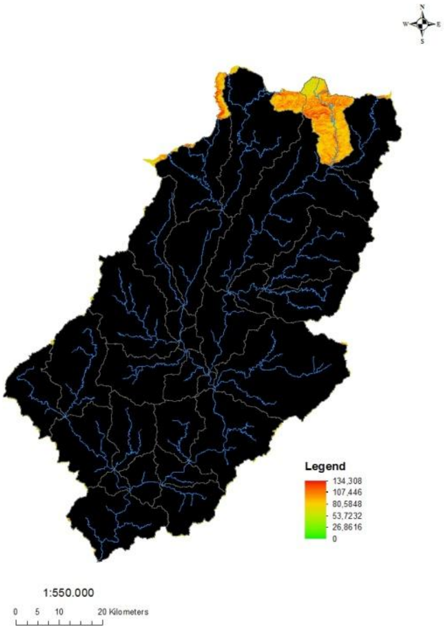


Figure B.92. Slopes - SubBasin 14

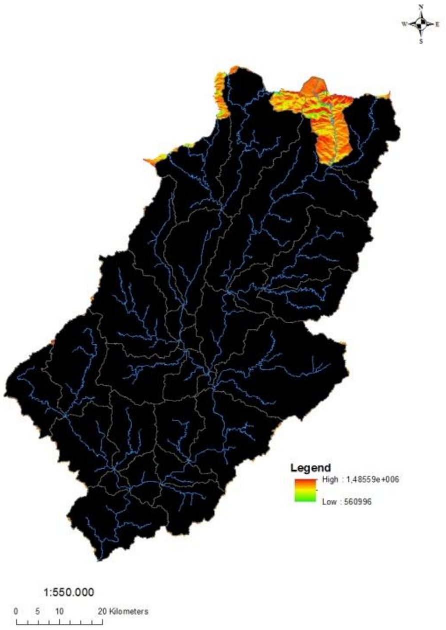


Figure B.93. Solar Radiation - SubBasin 14

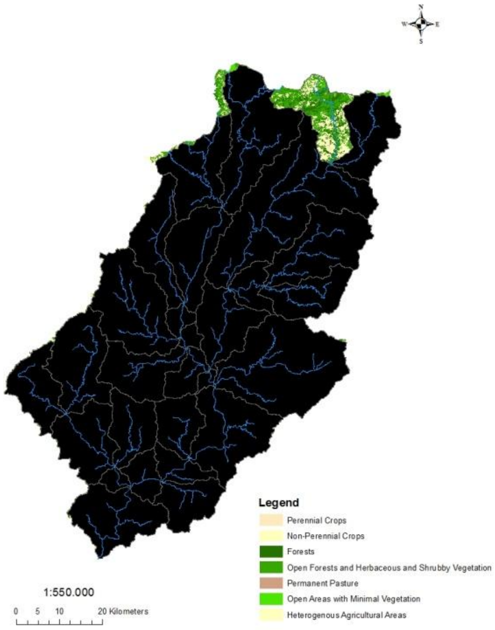


Figure B.94. Vegetation Cover - SubBasin 14

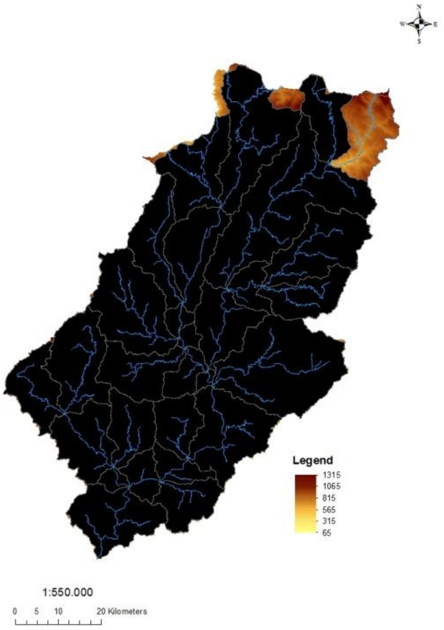


Figure B.95. Elevation - SubBasin 15

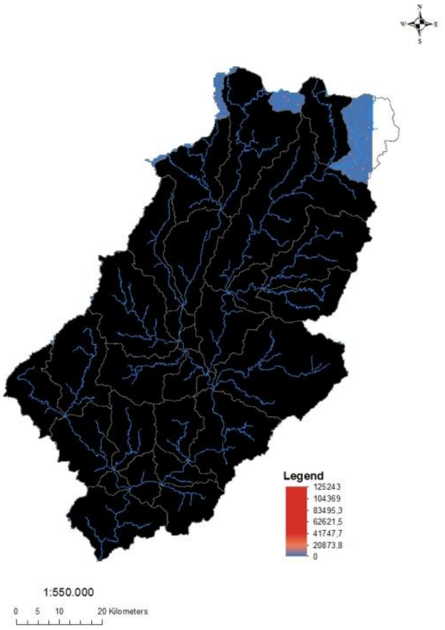


Figure B.96. Erosion - SubBasin 15

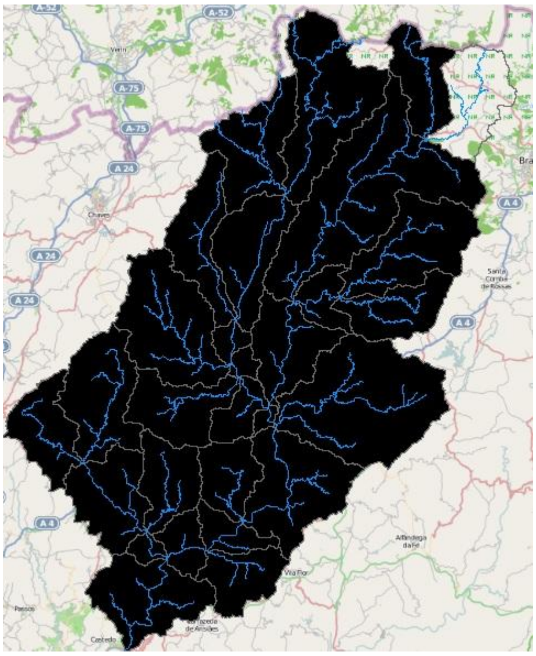


Figure B.97. Roads - SubBasin 15

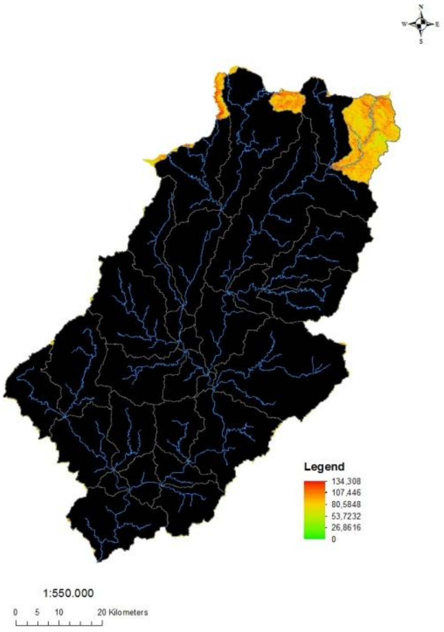


Figure B.98. Slopes - SubBasin 15

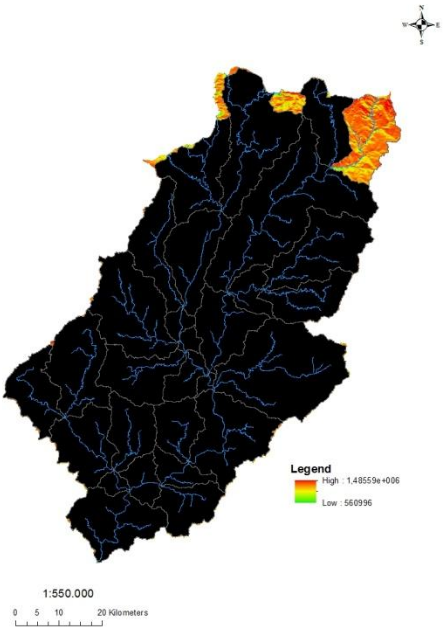


Figure B.99. Solar Radiation - SubBasin 15

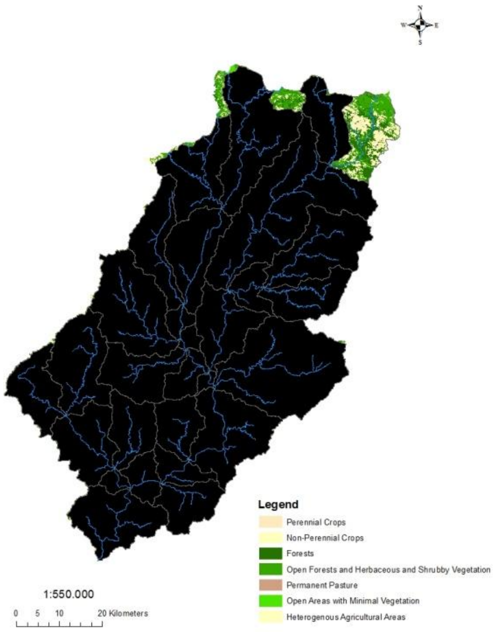


Figure B.100. Vegetation Cover - SubBasin 15

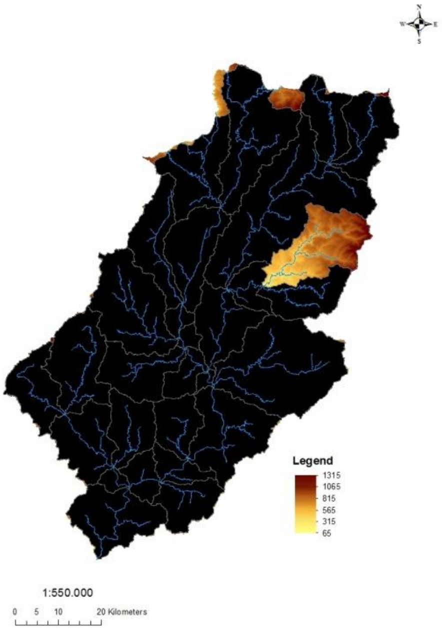


Figure B.64101. Elevation - SubBasin 16

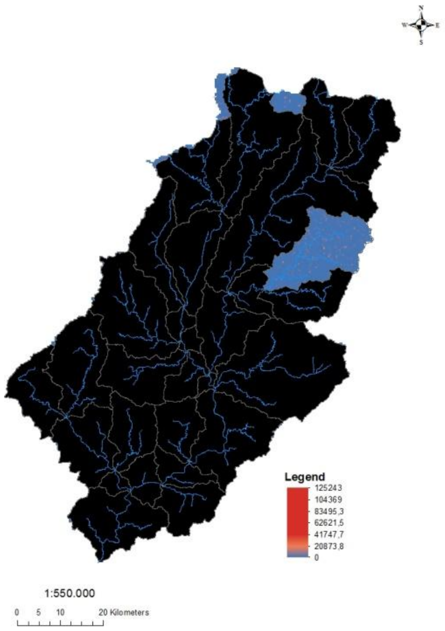


Figure B.102. Erosion - SubBasin 16

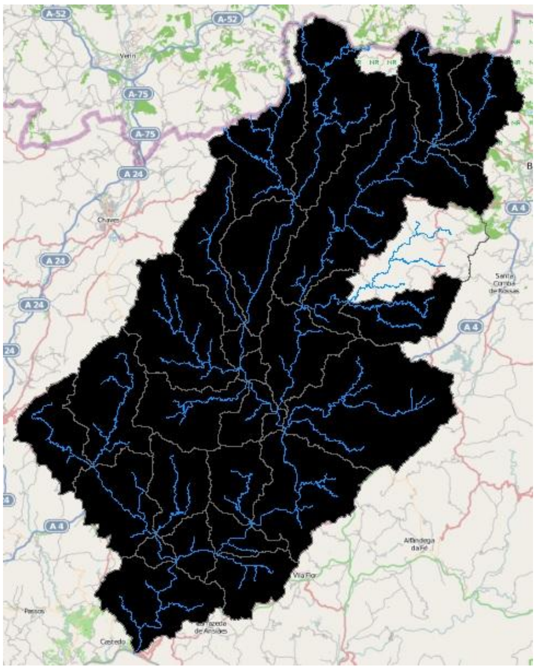


Figure B.103. Roads - SubBasin 16

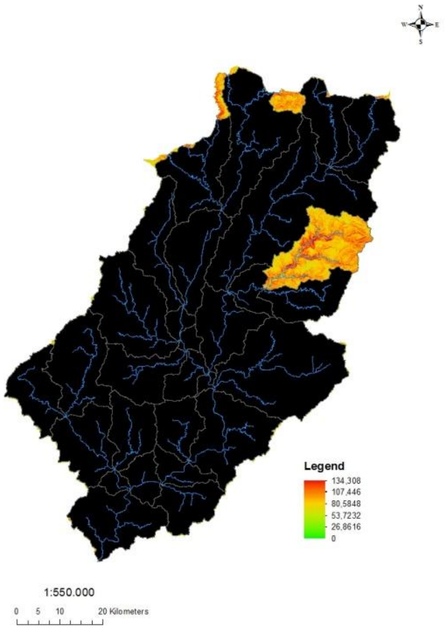


Figure B.104. Slopes - SubBasin 16

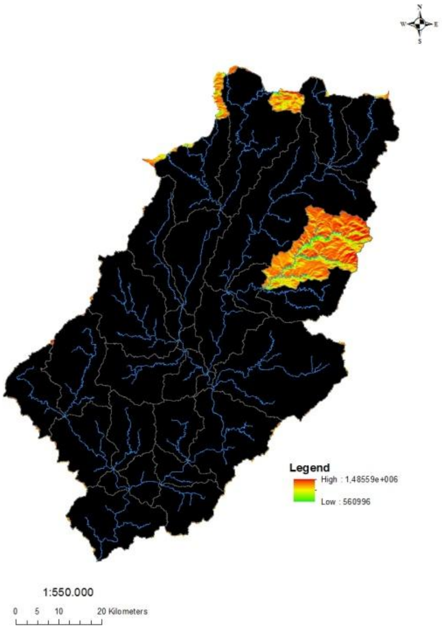


Figure B.105. Solar Radiation - SubBasin 16

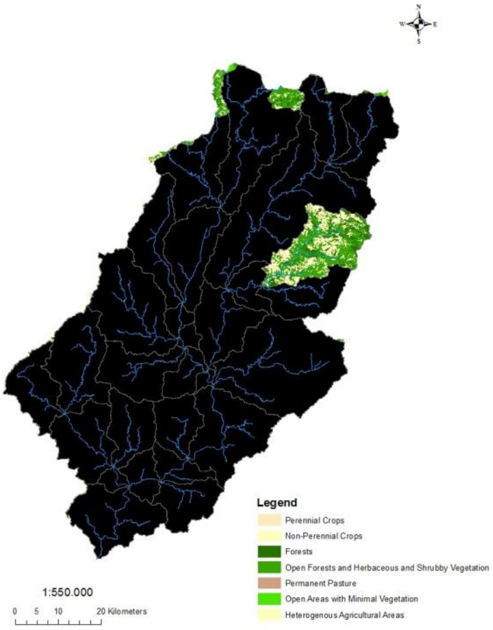


Figure B.106. Vegetation Cover - SubBasin 16

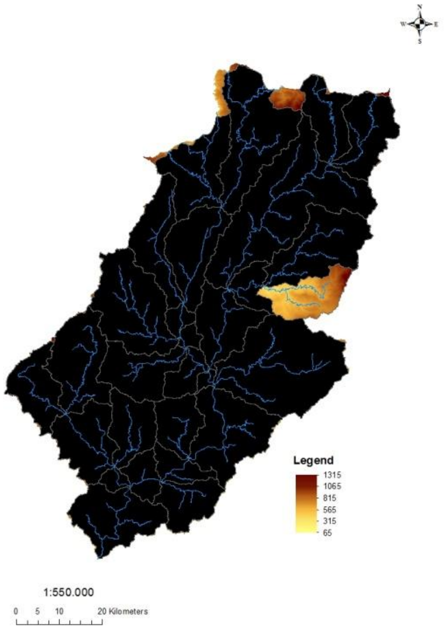


Figure B.107. Elevation - SubBasin 17

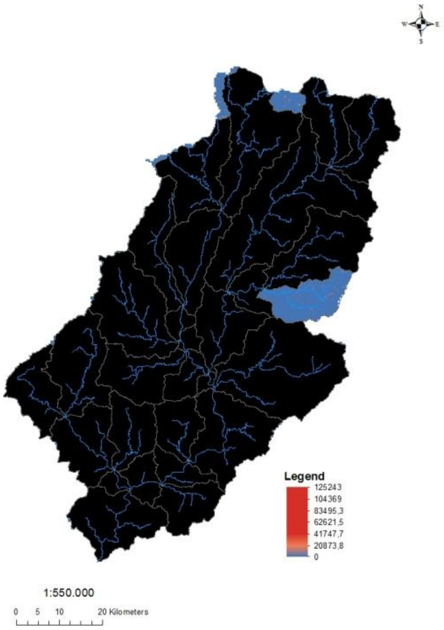


Figure B.108. Erosion - SubBasin 17

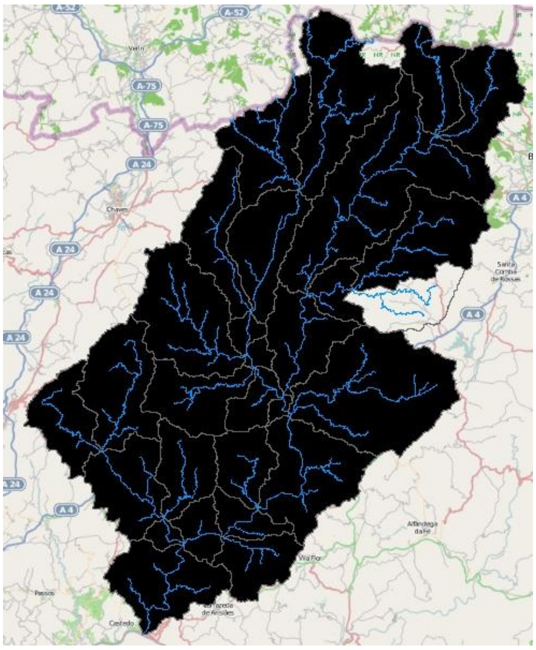


Figure B.109. Roads - SubBasin 17

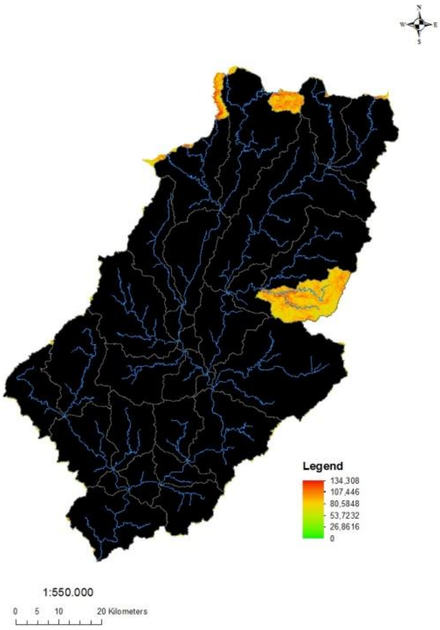
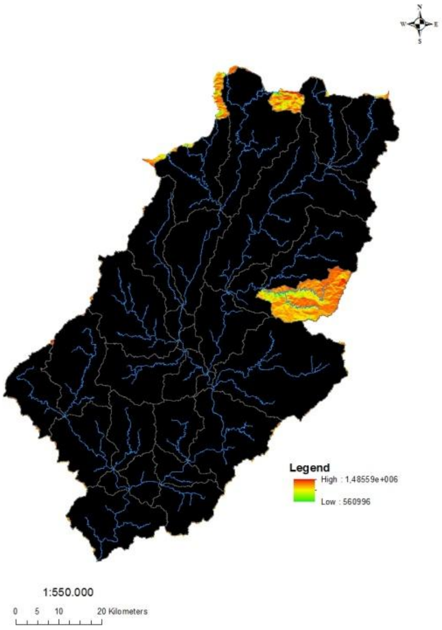


Figure B.110. Slopes - SubBasin 17



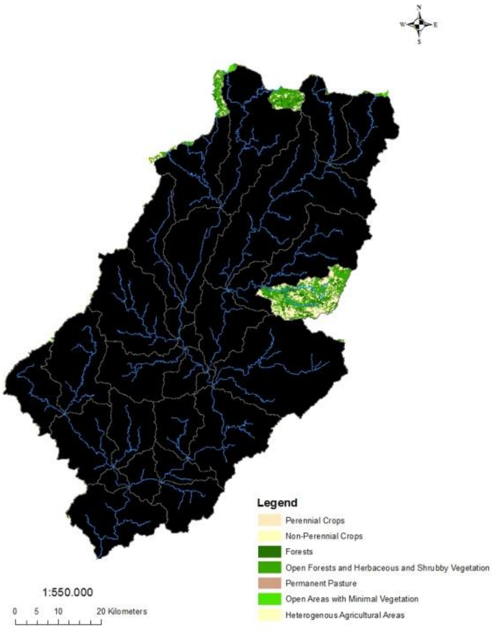


Figure B.111. Solar Radiation - SubBasin 17

Figure B.112. Vegetation Cover - SubBasin 17

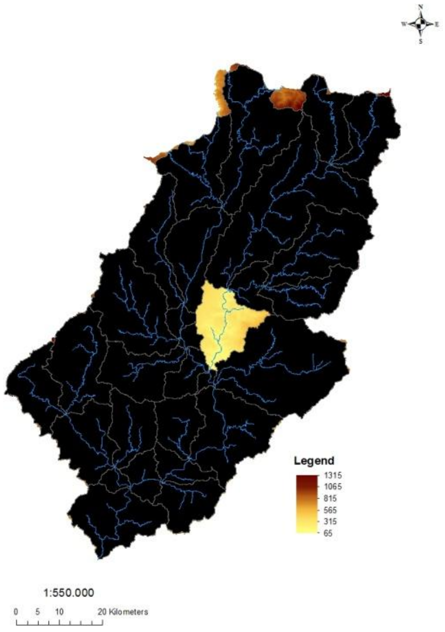


Figure B.113. Elevation - SubBasin 18

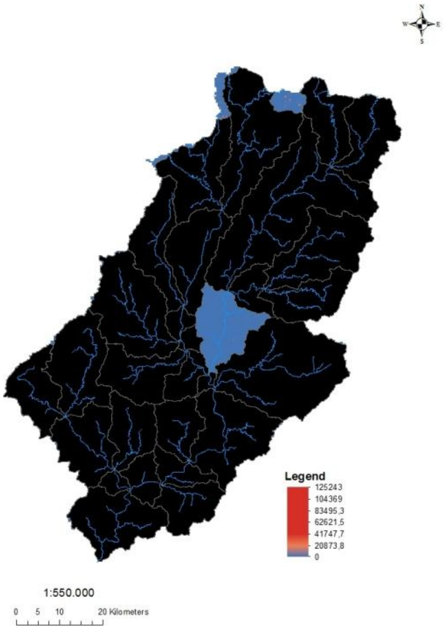


Figure B.114. Erosion - SubBasin 18

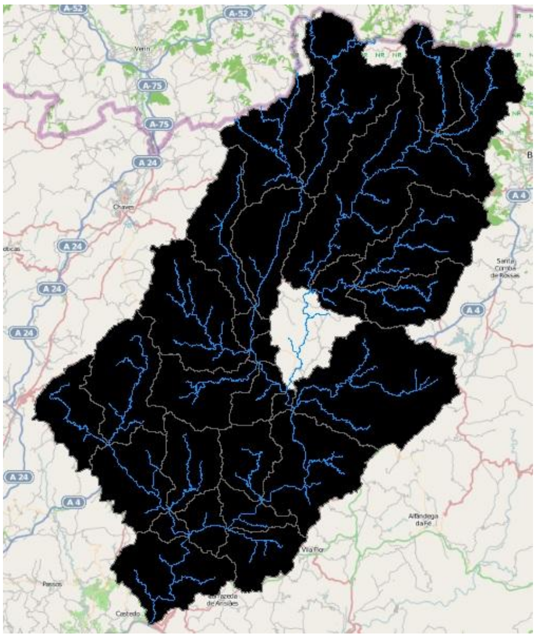


Figure B.115. Roads - SubBasin 18

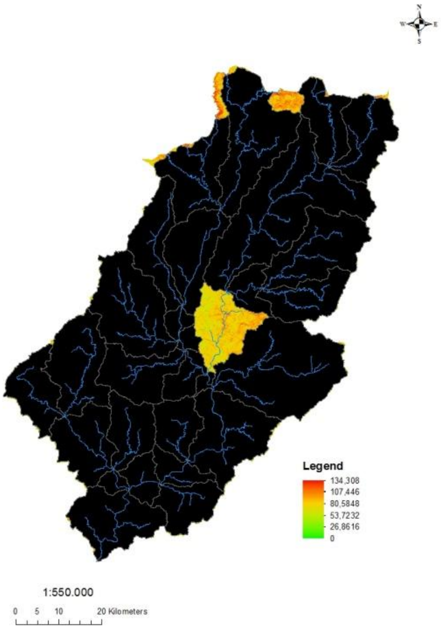


Figure B.116. Slopes - SubBasin 18

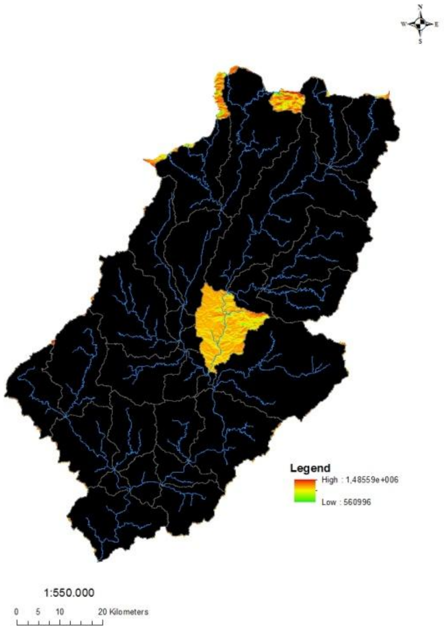


Figure B.117. Solar Radiation - SubBasin 18

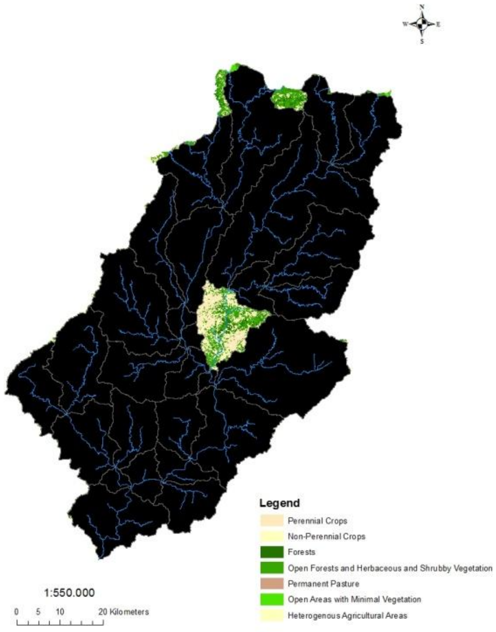


Figure B.118. Vegetation Cover - SubBasin 18

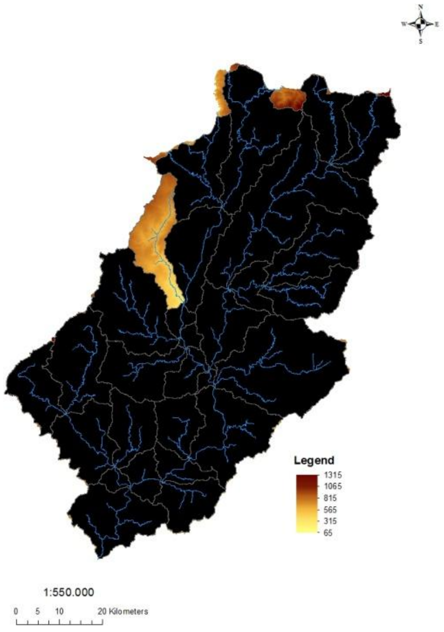


Figure B.119. Elevation - SubBasin 19

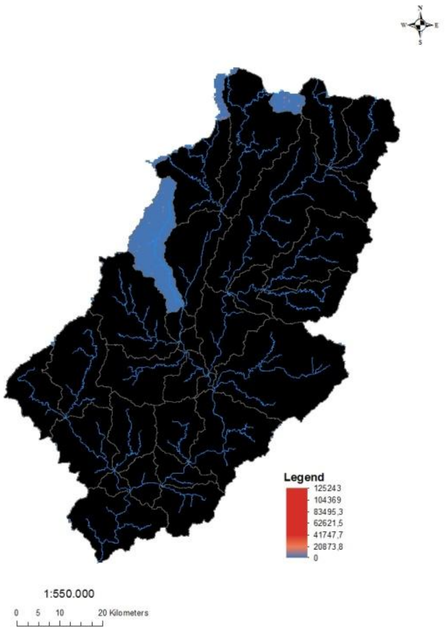


Figure B.120. Erosion - SubBasin 19

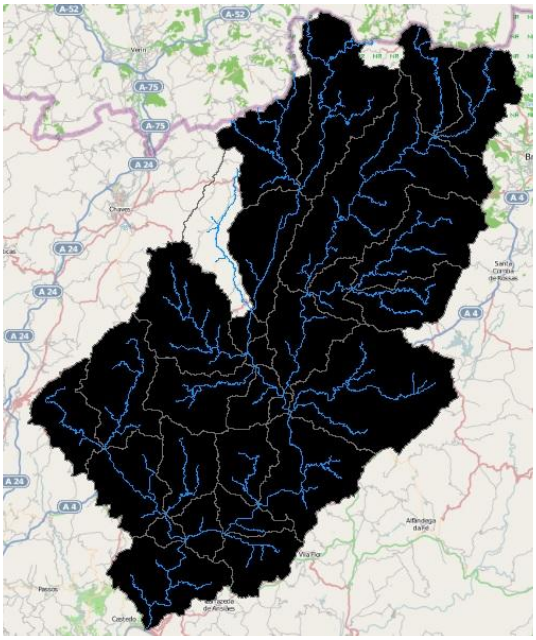


Figure B.121. Roads - SubBasin 19

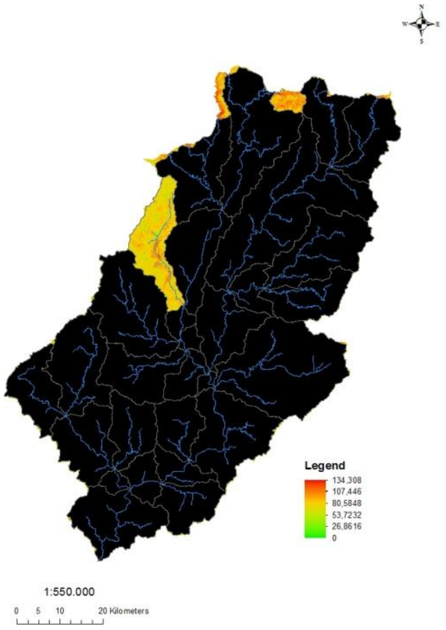


Figure B.122. Slopes - SubBasin 19

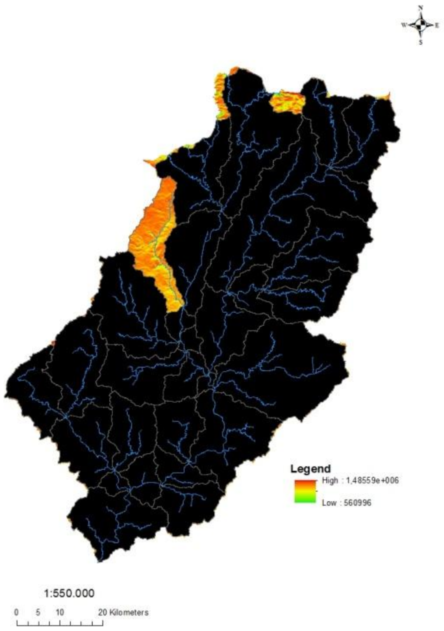


Figure B.123. Solar Radiation - SubBasin 19

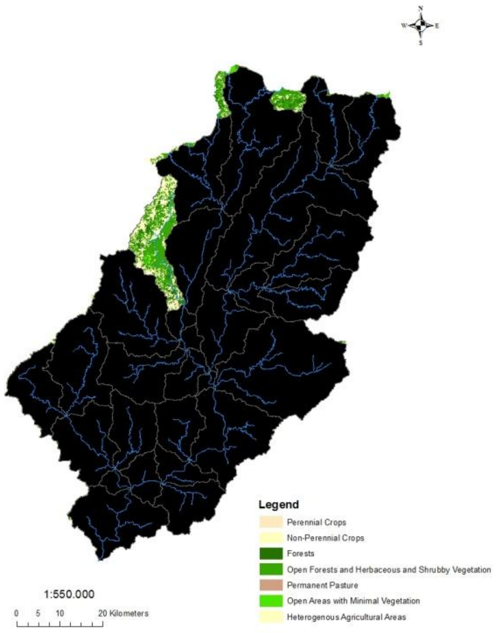


Figure B.124. Vegetation Cover - SubBasin 19

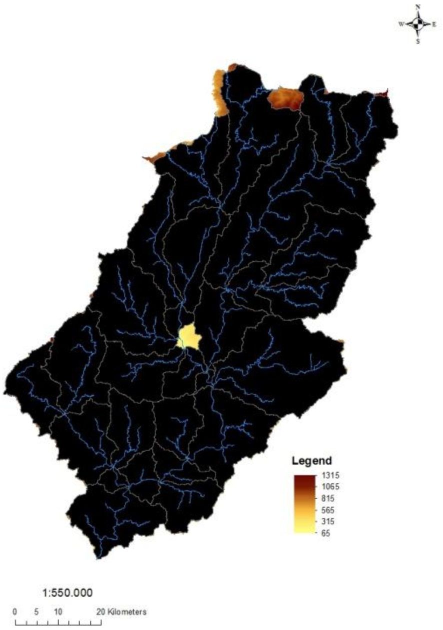


Figure B.125. Elevation - SubBasin 20

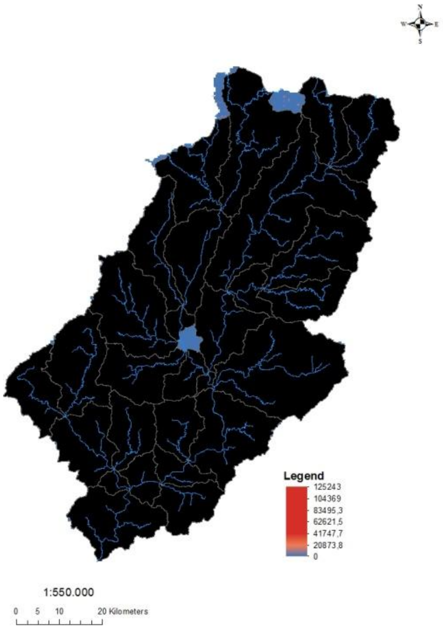


Figure B.126. Erosion - SubBasin 20

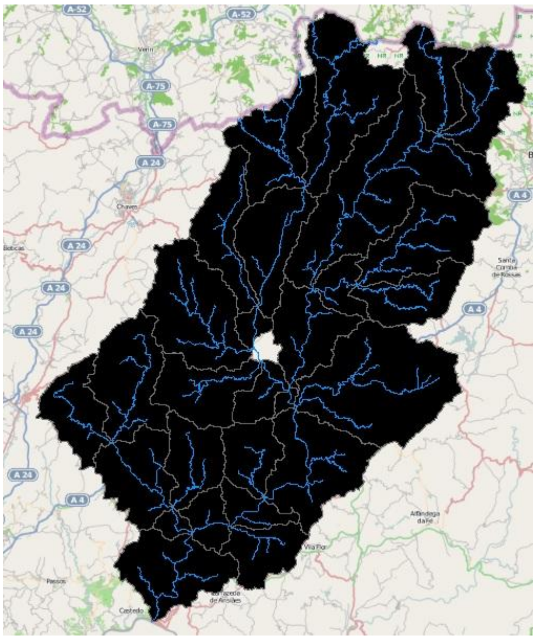


Figure B.127. Roads - SubBasin 20

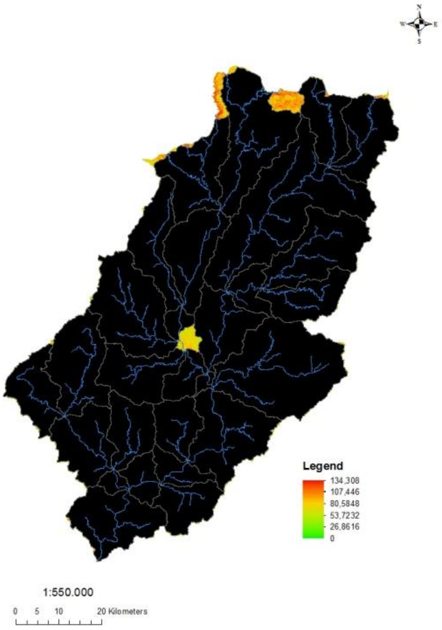


Figure B.128. Slopes - SubBasin 20

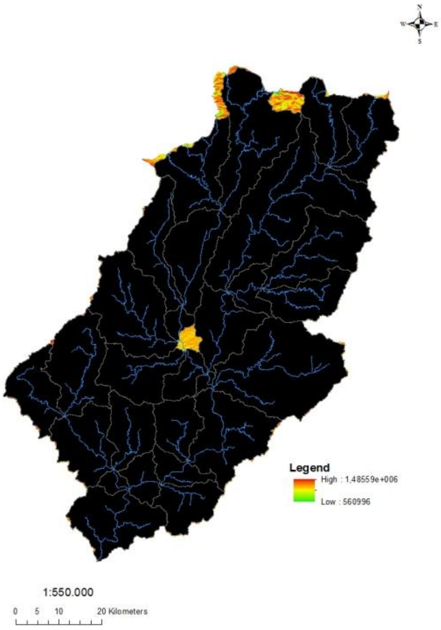


Figure B.129. Solar Radiation - SubBasin 20

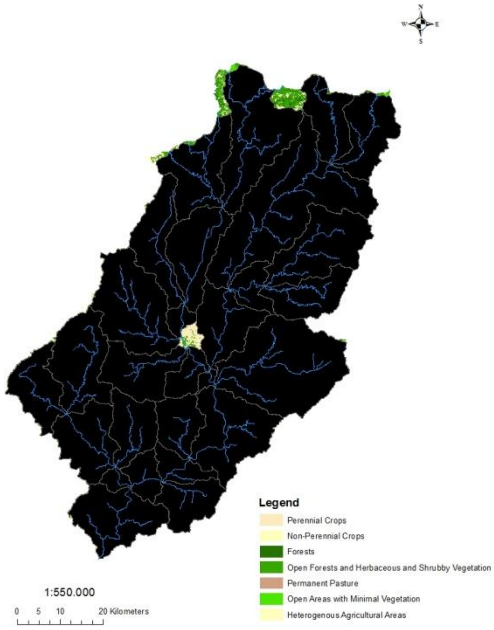
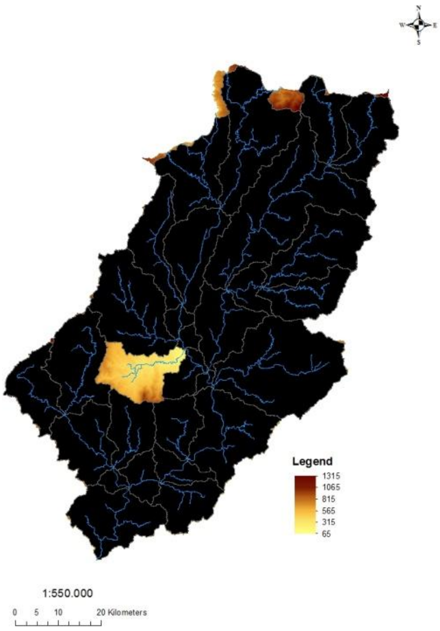


Figure B.130. Vegetation Cover - SubBasin 20



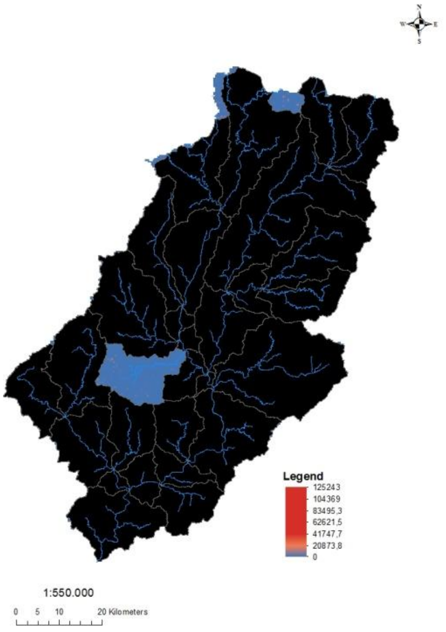


Figure 131. Elevation - SubBasin 21

Figure 132. Erosion - SubBasin 21

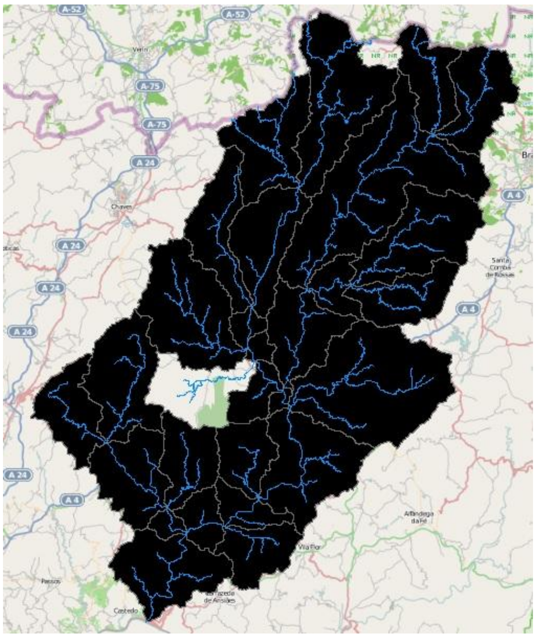


Figure B.133. Roads - SubBasin 21

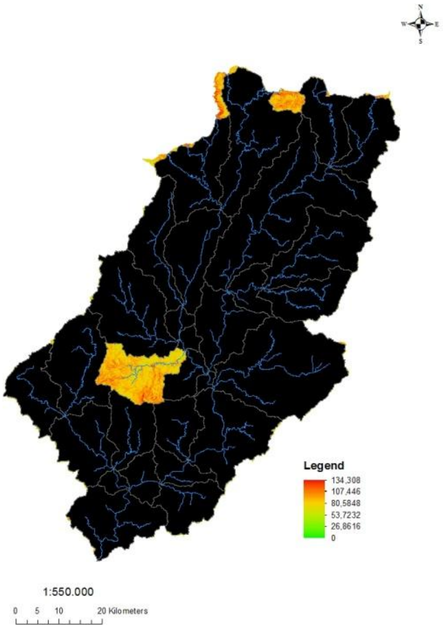
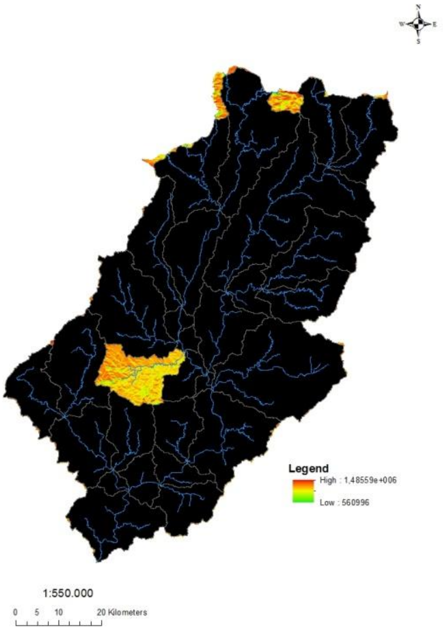


Figure B.134. Slopes - SubBasin 21



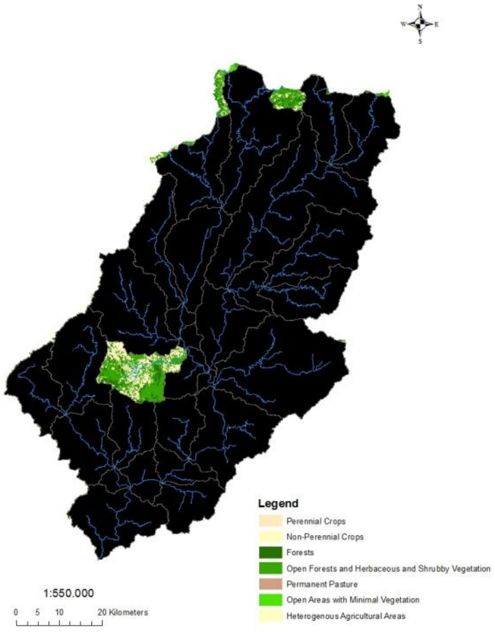


Figure B.135. Solar Radiation - SubBasin 21

Figure B.136. Vegetation Cover - SubBasin 21

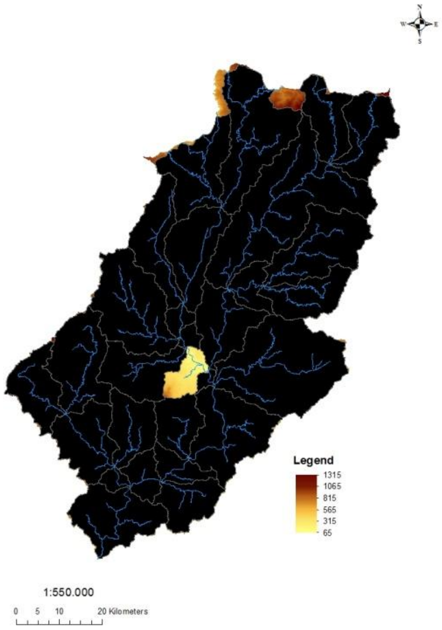


Figure B.137. Elevation - SubBasin 22

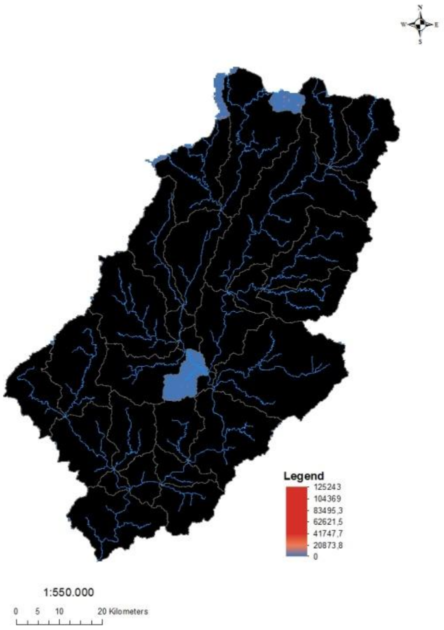


Figure B.138. Erosion - SubBasin 22

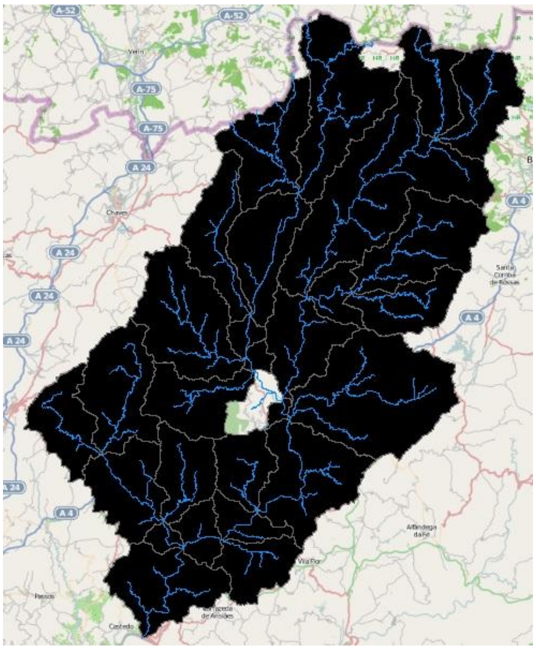


Figure B.139. Roads - SubBasin 22

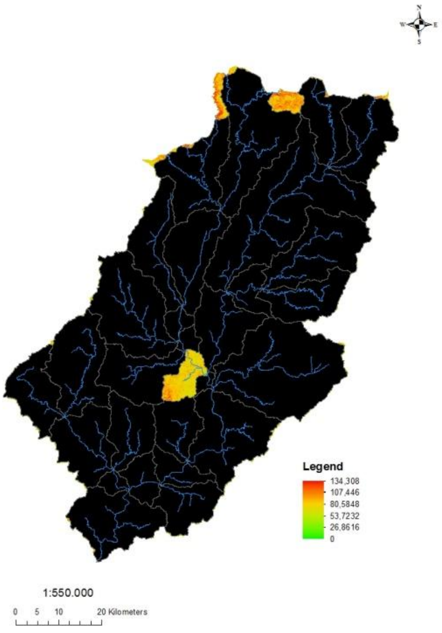
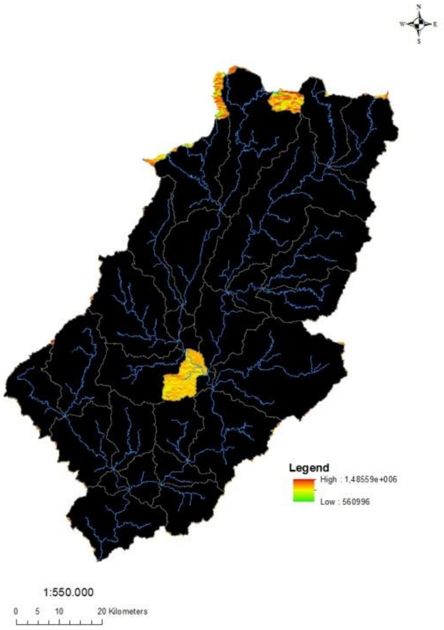


Figure B.140. Slopes - SubBasin 22



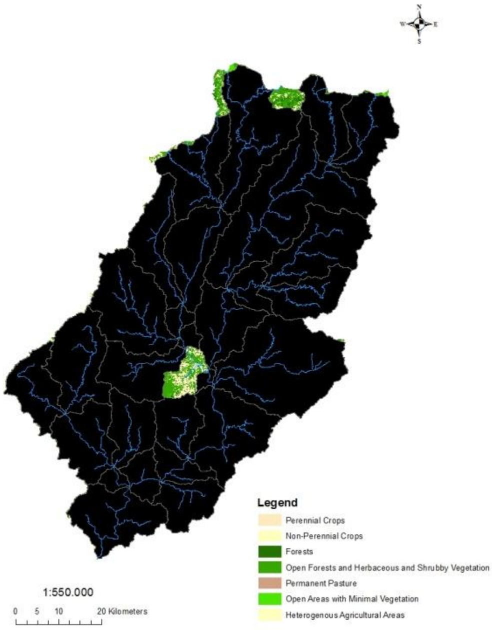


Figure B.141. Solar Radiation - SubBasin 22

Figure B.142. Vegetation Cover - SubBasin 22

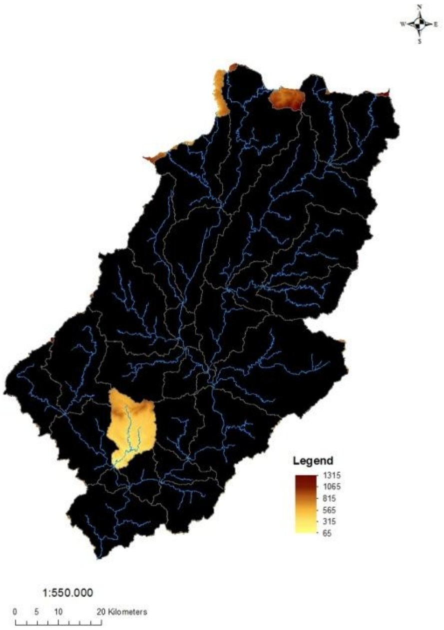


Figure B.143. Elevation - SubBasin 23

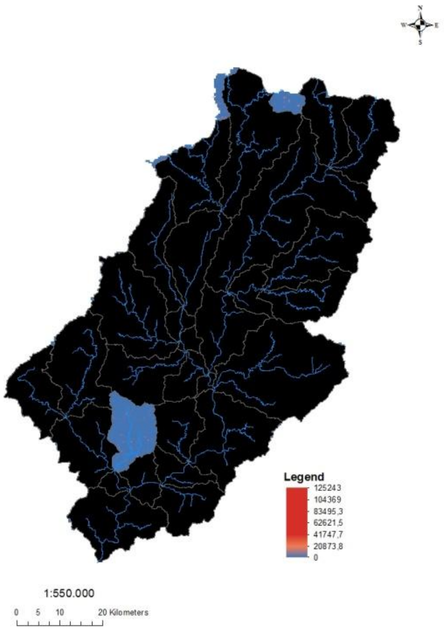


Figure B.144. Erosion - SubBasin 23

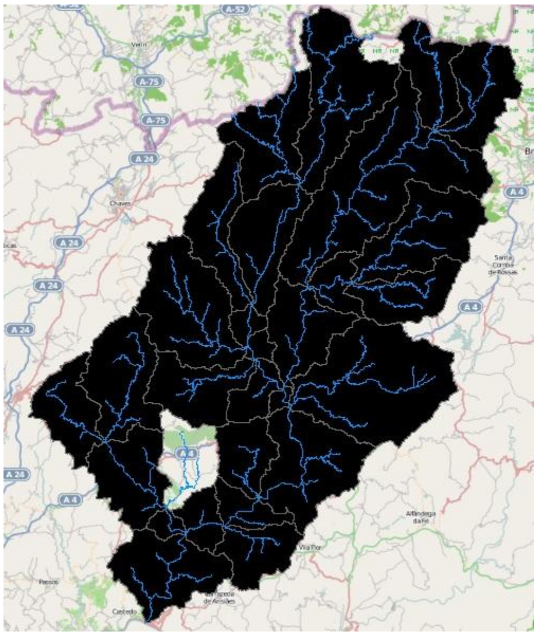


Figure B.145. Roads - SubBasin 23

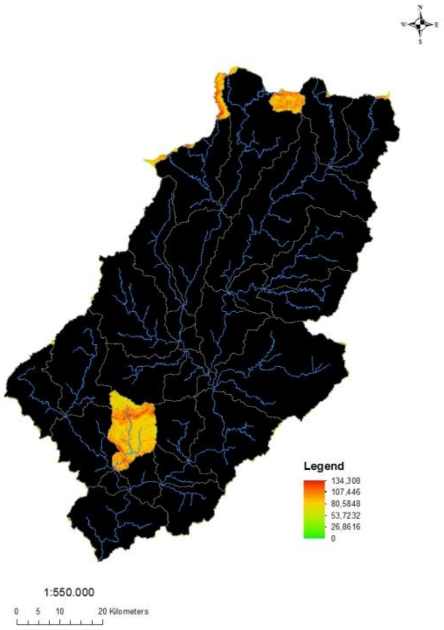


Figure B.146. Slopes - SubBasin 23

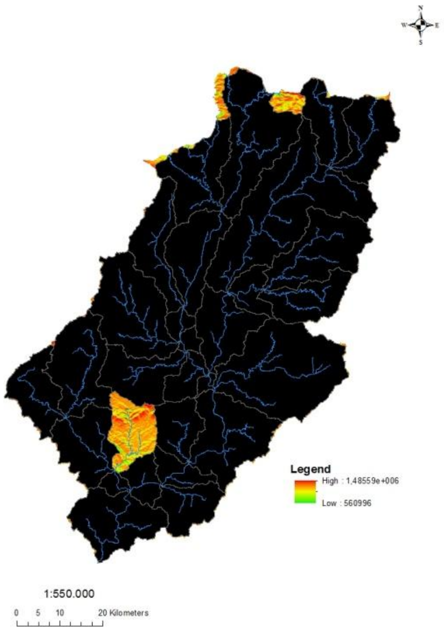


Figure B.147. Solar Radiation - SubBasin 23

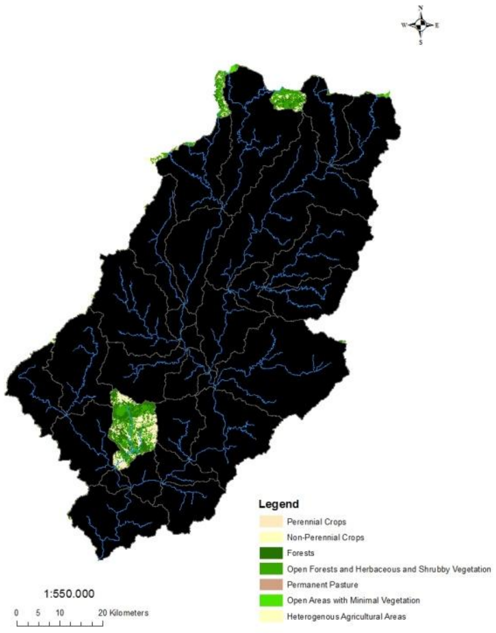


Figure B.148. Vegetation Cover - SubBasin 23

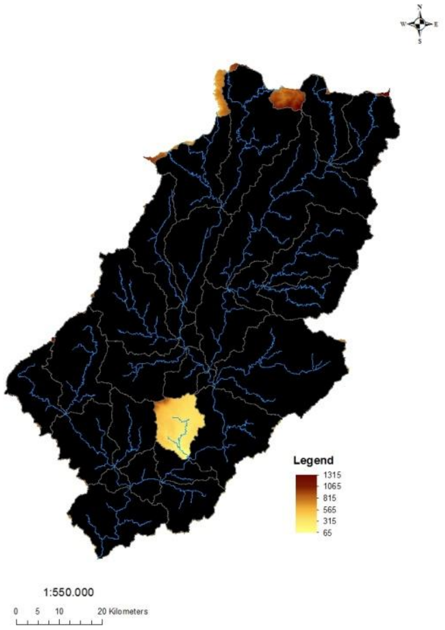


Figure B.149. Elevation - SubBasin 24

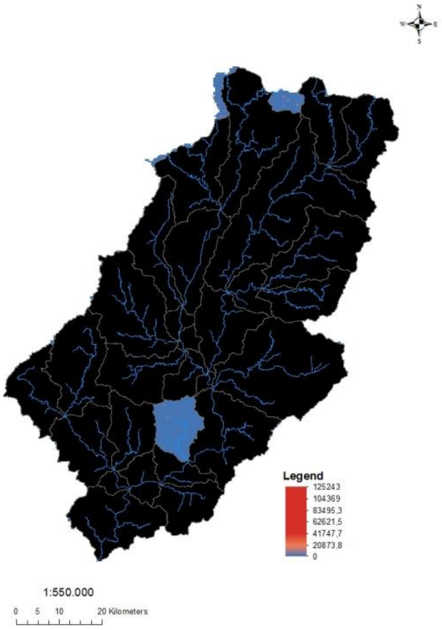


Figure B.150. Erosion - SubBasin 24

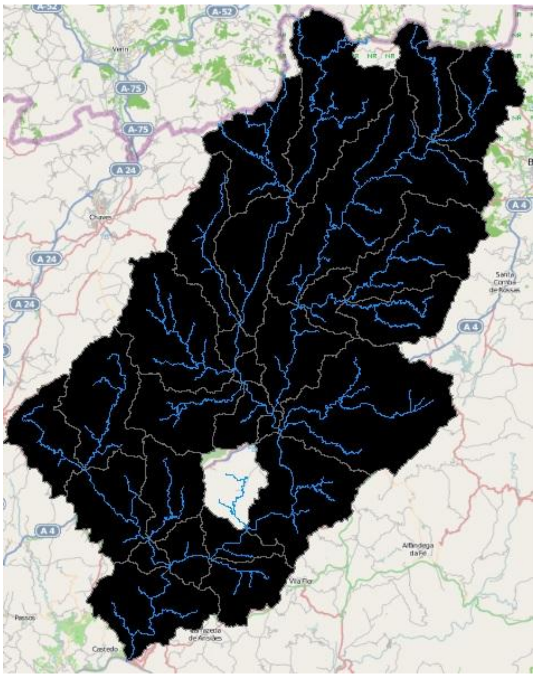


Figure B.151. Roads - SubBasin 24

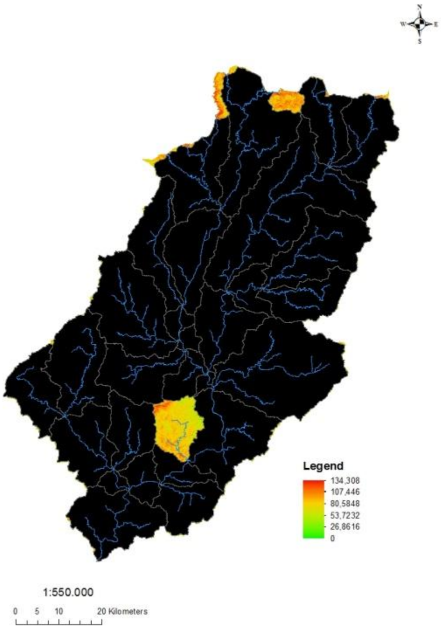


Figure B.152. Slopes - SubBasin 24

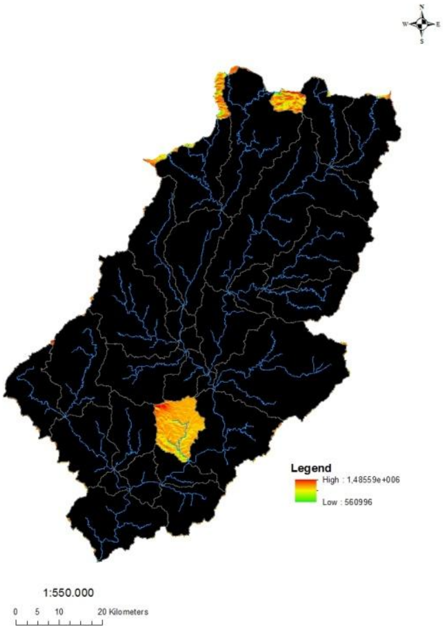


Figure B.153. Solar Radiation - SubBasin 24

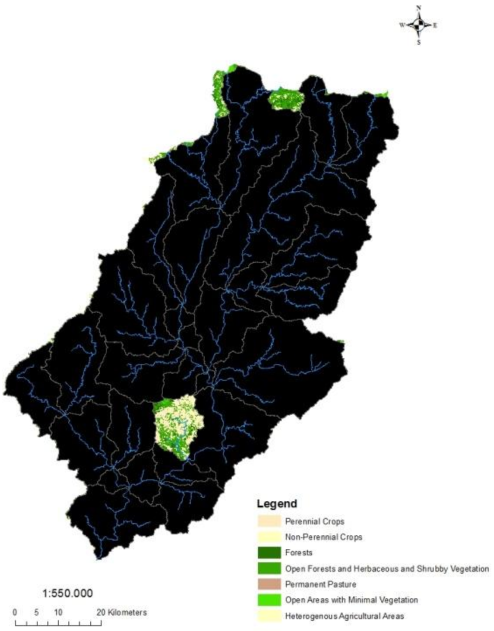


Figure B.154. Vegetation Cover - SubBasin 24

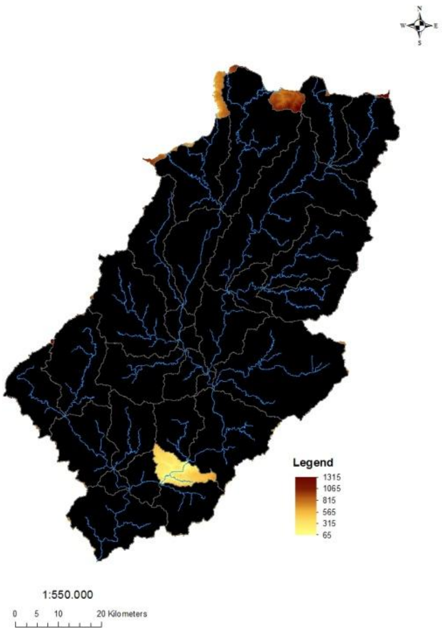


Figure B.155. Elevation - SubBasin 25

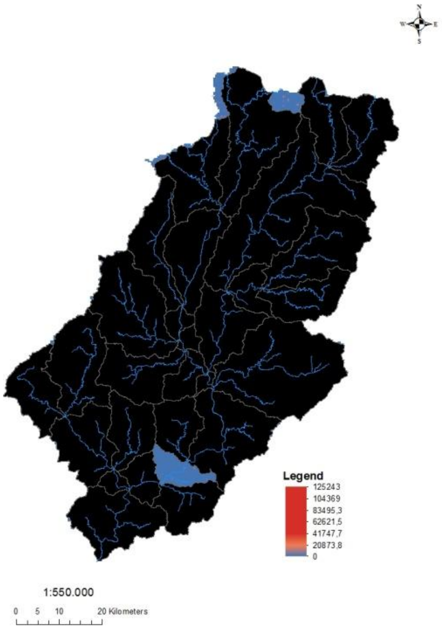


Figure B.156. Erosion - SubBasin 25

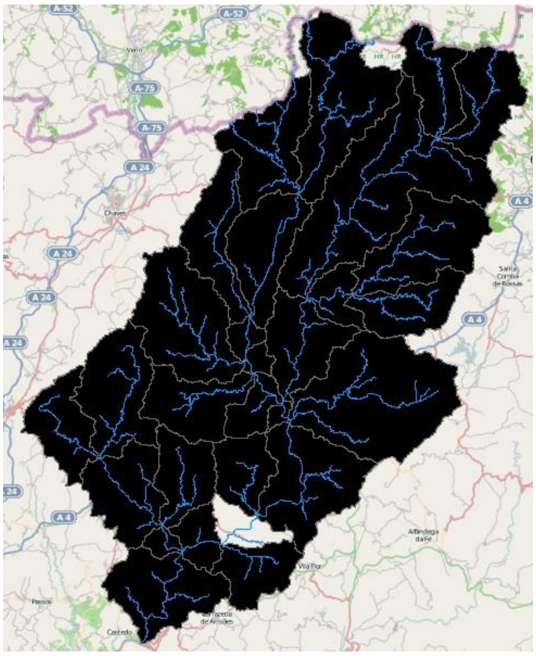


Figure B.157. Roads - SubBasin 25

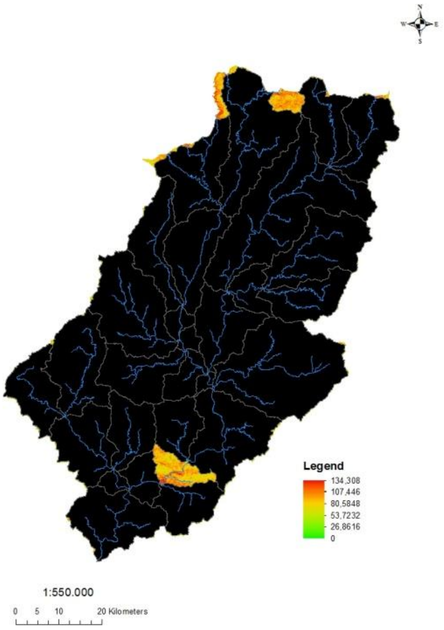


Figure B.158. Slopes - SubBasin 25

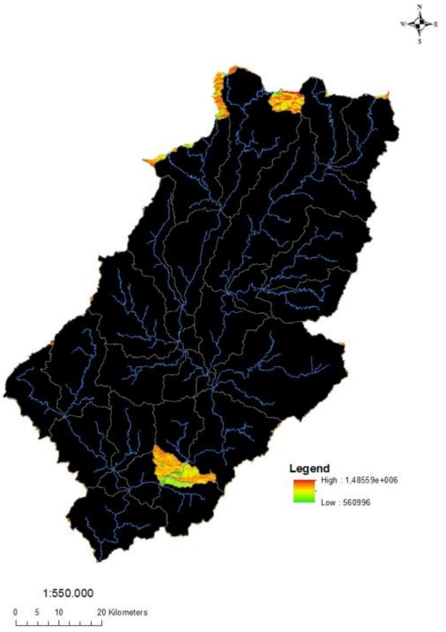


Figure B.159. Solar Radiation - SubBasin 25

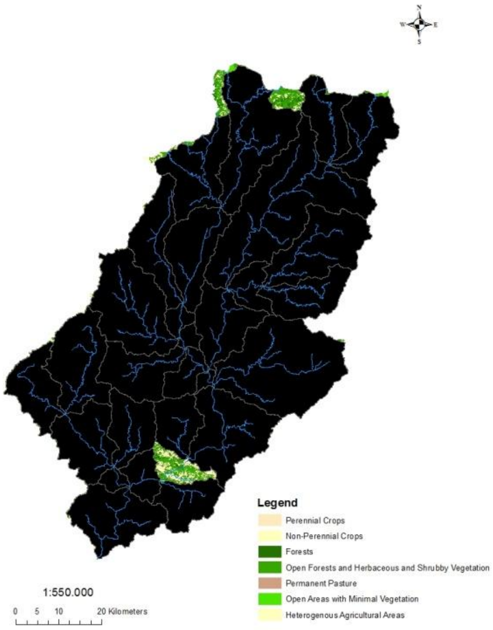


Figure B.160. Vegetation Cover - SubBasin 25

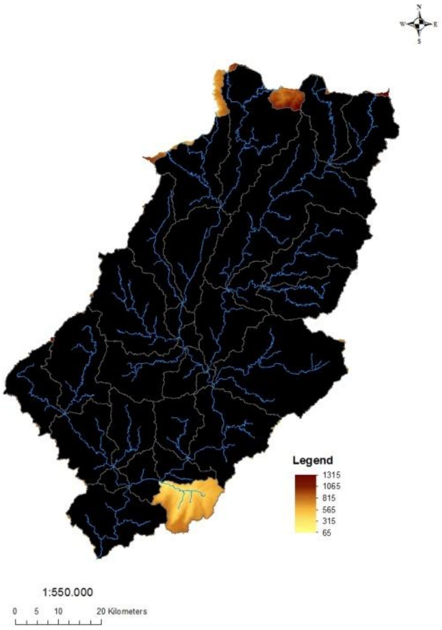


Figure B.161. Elevation - SubBasin 26

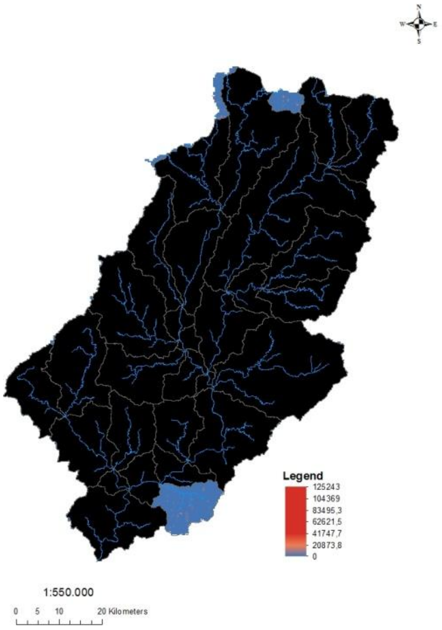


Figure B.162. Erosion - SubBasin 26

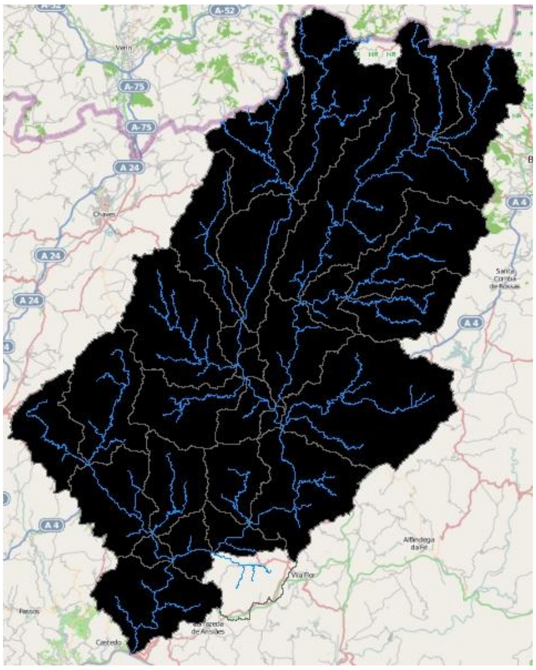


Figure B.163. Roads - SubBasin 26

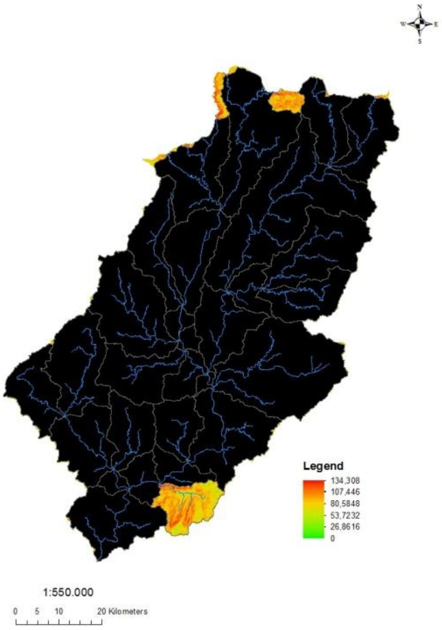


Figure B.164. Slopes - SubBasin 26

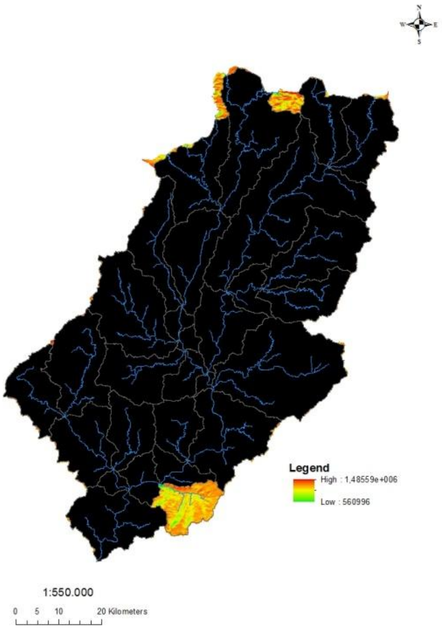


Figure B.165. Solar Radiation - SubBasin 26

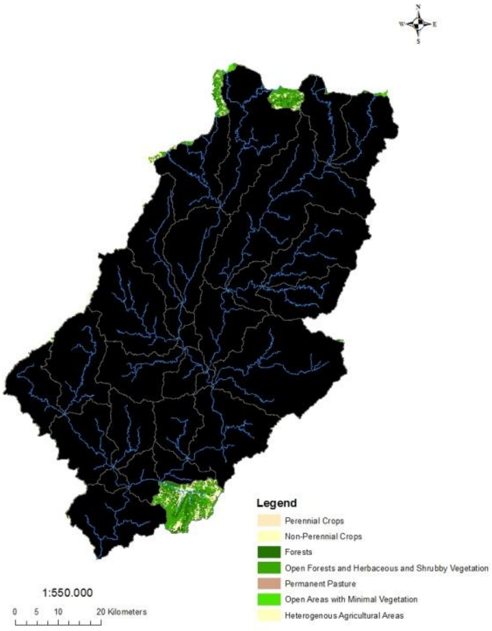


Figure B.166. Vegetation Cover - SubBasin 26

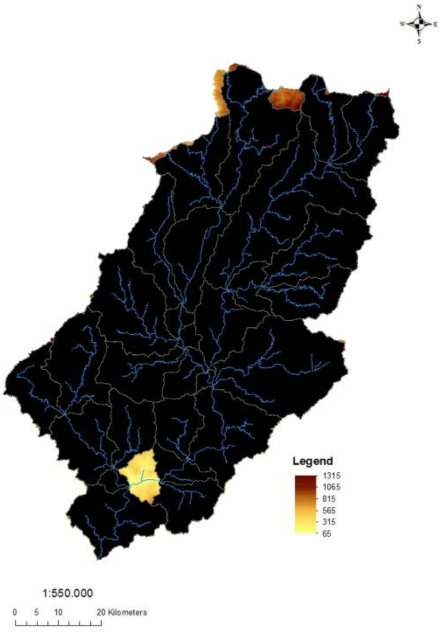


Figure B.167. Elevation - SubBasin 27

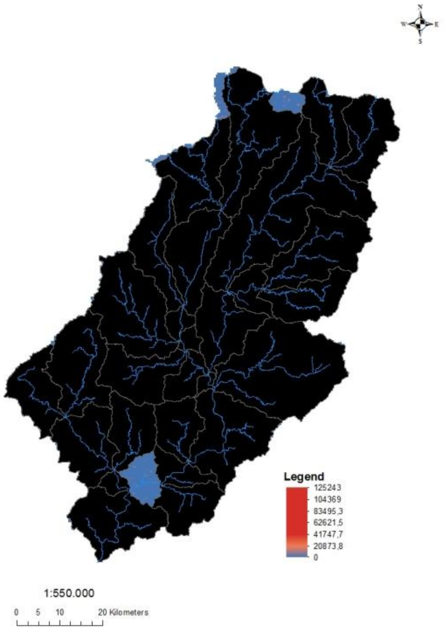


Figure B.168. Erosion - SubBasin 27

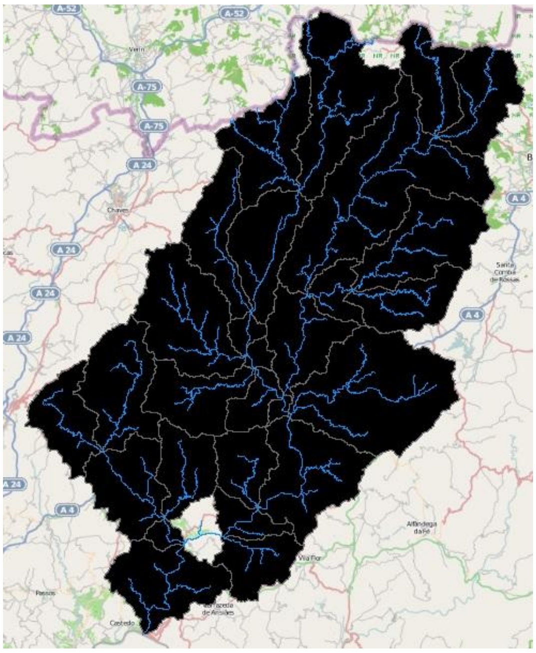


Figure B. 169. Roads - SubBasin 27

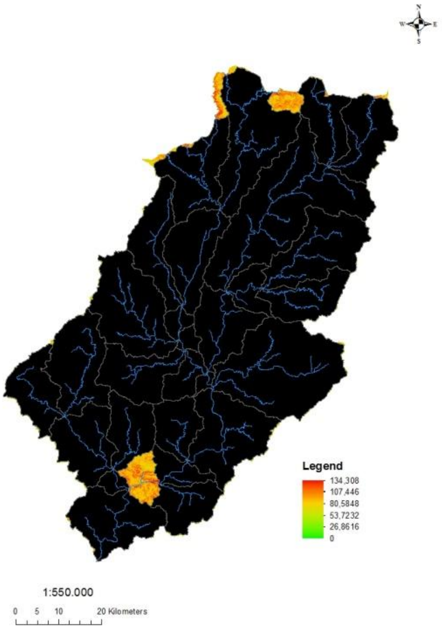


Figure B. 170. Slopes - SubBasin 27

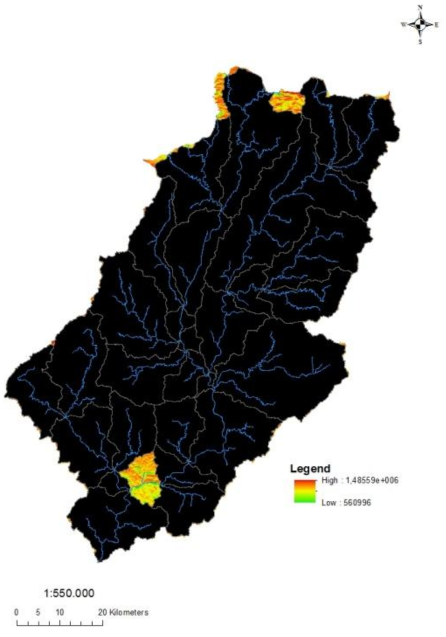


Figure B.171. Solar Radiation - SubBasin 27

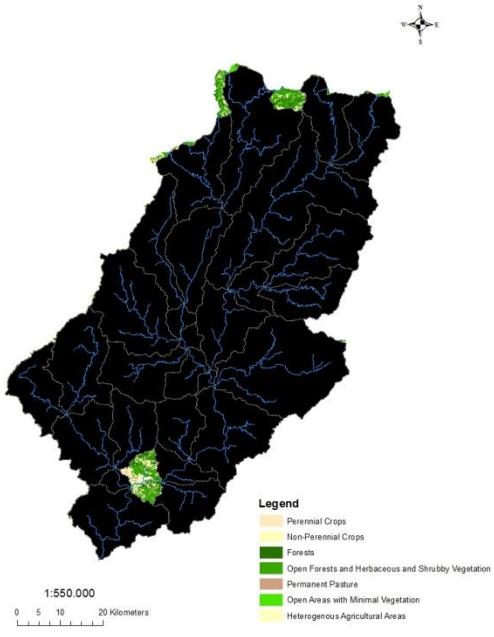


Figure B.172. Vegetation Cover - SubBasin 27

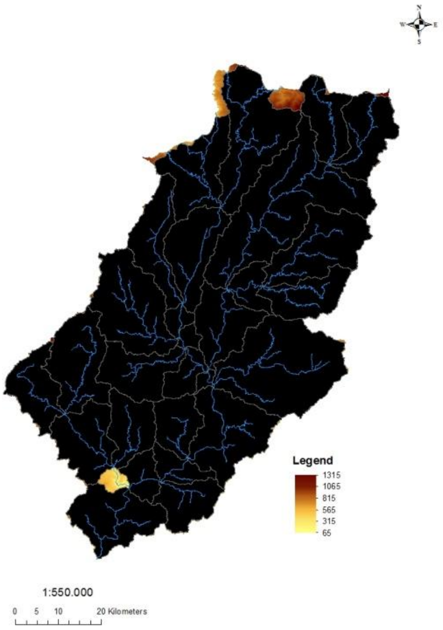


Figure B.173. Elevation - SubBasin 28

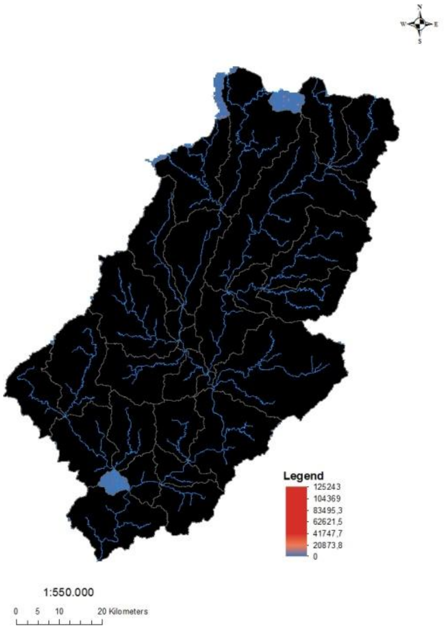


Figure B.174. Erosion - SubBasin 28

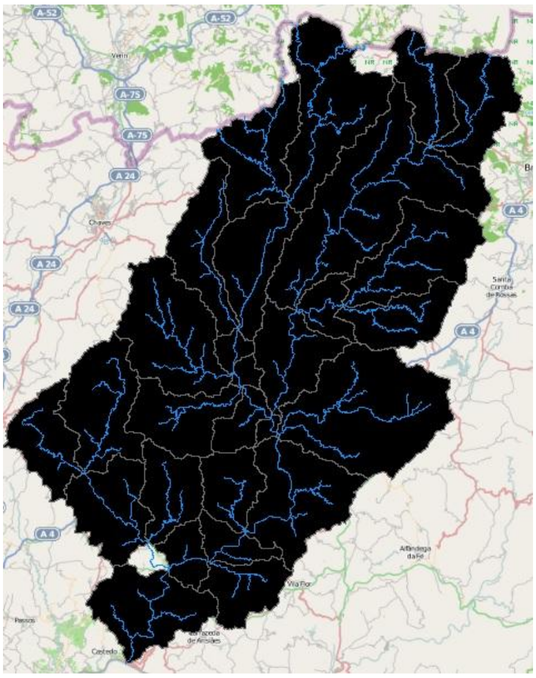


Figure B.175. Roads - SubBasin 28

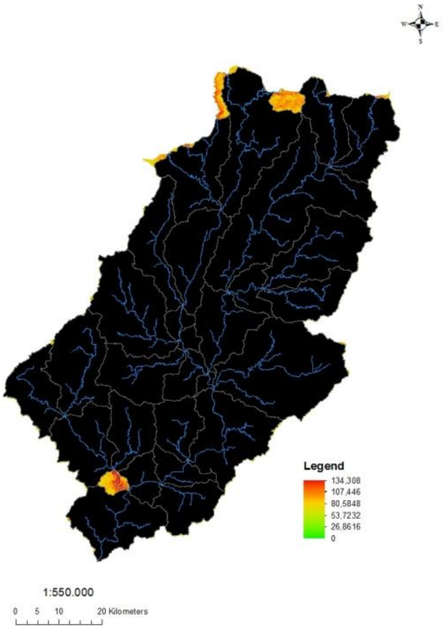


Figure B.176. Slopes - SubBasin 28

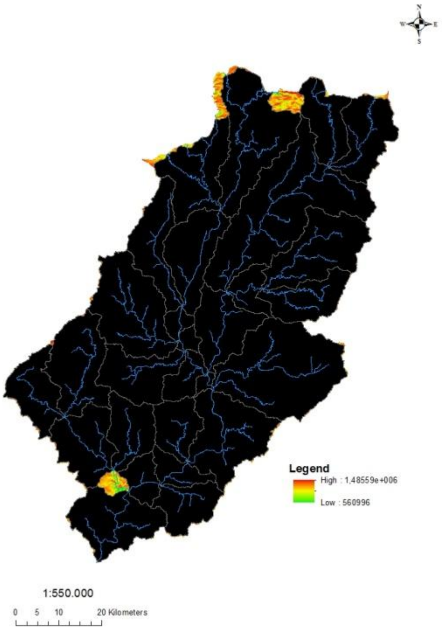


Figure B.177. Solar Radiation - SubBasin 28

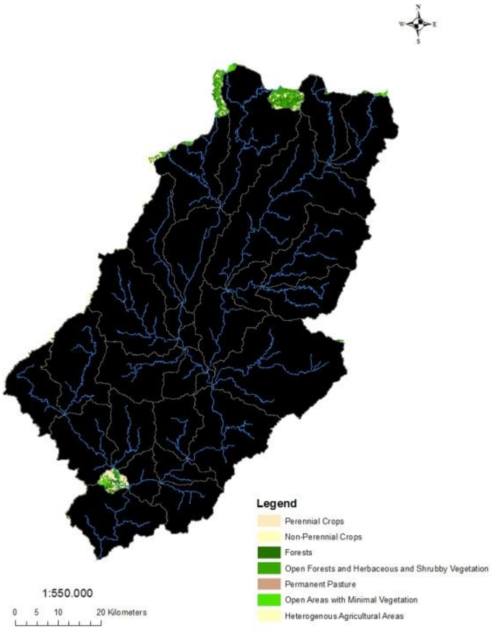


Figure B.178. Vegetation Cover - SubBasin 28

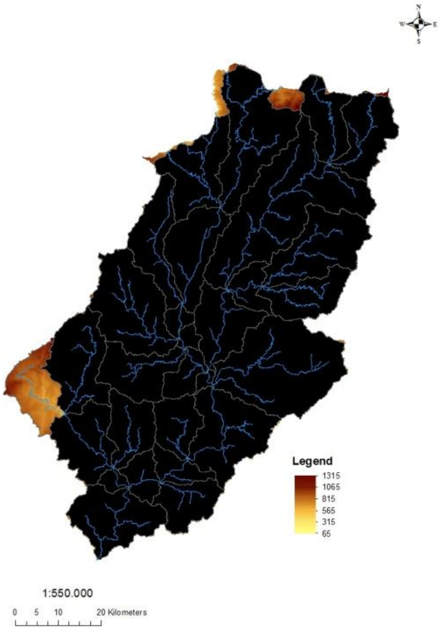


Figure B.179. Elevation - SubBasin 29

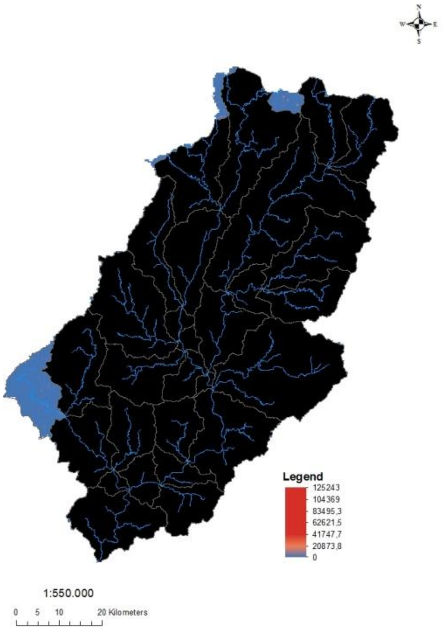


Figure B.180. Erosion - SubBasin 29

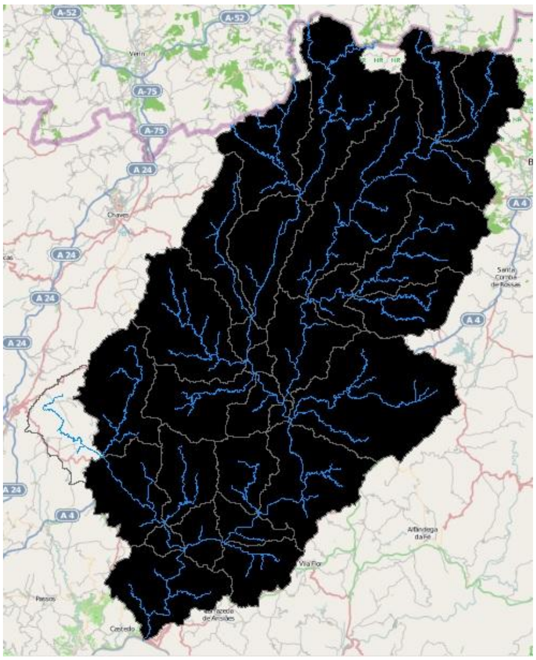


Figure B.181. Roads - SubBasin 29

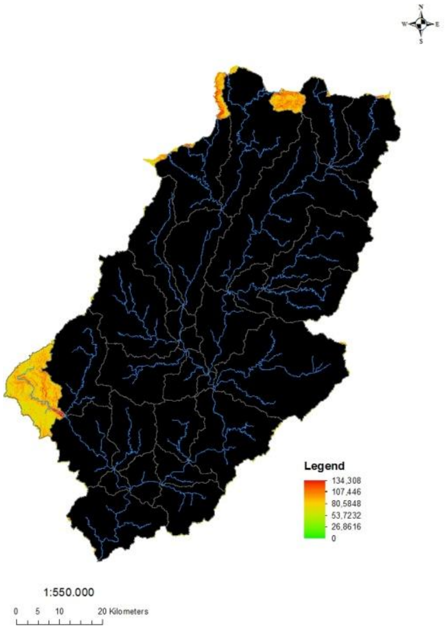


Figure B.182. Slopes - SubBasin 29

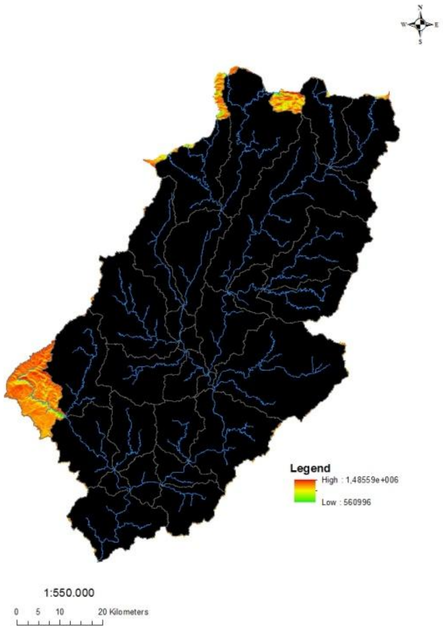


Figure B.183. Solar Radiation - SubBasin 29

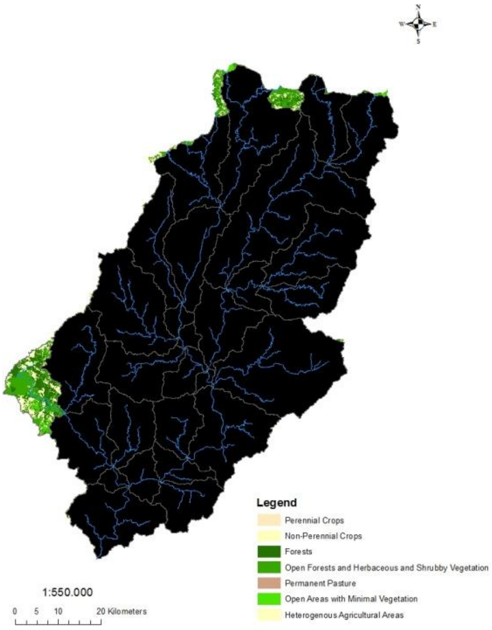


Figure B.184. Vegetation Cover - SubBasin 29