Towards cost-effective watershed management in the Brazilian Atlantic Forest: valuing forest ecosystem services related to water quality in the Guapi-Macacu watershed

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Abstract

The Brazilian Atlantic forest is considered a global biodiversity hotspot, harbouring a large number of endemic species, and providing essential watershed services to millions of urban water users. However, agricultural expansion and urban development have reduced the forest area to less than 8% of its original size. Multiple pressures on the Atlantic forest ecosystem continue. Payments for ecosystem services (PES) schemes are increasingly proposed by local initiatives and supported by international cooperation to manage the trade-offs among agricultural uses and watershed services in a cost-effective manner. Studying the provision costs of as well as the demand for watershed services can help decision makers to evaluate the scope and economic feasibility of PES and alternative management options.

The Guapi-Macacu watershed in the state of Rio de Janeiro supplies water to 2.5 million inhabitants within five municipalities. Water resources are of utmost importance for agriculture and industries, such water bottle companies, breweries and the biggest Brazilian petrochemical complex COMPERJ. Our study concentrates on valuing watershed services in terms of controlling nutrient and sediment loads under different land use systems. Nutrient loads include Nitrogen and Phosphorus found in surface water, whereas sediment loads are measured in terms of turbidity and total solids. Replacement and avoided cost methods are applied focusing on the local water treatment facility to estimate demand for service maintenance and improvement. To provide empirical evidence of the link between land use/land cover and water quality indicators, we rely on water quality modelling and monitoring specifically adapted to this area. This takes place within the framework of the multi-disciplinary German-Brazilian cooperation project DINARIO/MP2. Spatial conservation opportunity cost analysis is used to study the costs of watershed services maintenance and improvement and derive implication for cost-effective management on the basis of scenario analyses.

Keywords: ecosystem services, water quality, cost-effective watershed management, PES, Atlantic Forest

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1. Introduction

Particularly, the Guapi-Macacu watershed (GPW) is experiencing significant pressures as a result of various processes, which include changes in land-use systems, unplanned growth of cities, mining and expansion of agricultural and exotic tree monocultures planted without planning, among others (Da Conceição *et al.*, 2009; Ministry of Environment and the Atlantic Forest Network, 2006; UFF/Petrobras, 2007).

Just this watershed supplies with water to 2.5 million inhabitants of the municipalities of Cachoeiras de Macacu, Guapimirim, Itaboraí, São Gonçalo and Niterói, that also use water for irrigation and fish farming (Da Costa, 2007; Da Conceição *et al.*, 2009). Besides this, there are several enterprises that benefit from good quality of water coming from this watershed as an important input, like breweries and farms that produce pasture (Strobel *et al.,* 2007; Da Costa, 2007). Furthermore, it is important to mention that within the study area the construction of Rio de Janeiro's Petrochemical Complex is taking place, being the largest industrial undertaking in the history of Brazil (Business New America, 2008).

Degradation of ecosystems has a significant negative impact on human well-being. Even with the shortage of information about the magnitude of such impacts, there is strong evidence showing the substantial damaging effects of the ecosystem service degradation on livelihoods, health and local and national economies (MA, 2005). Destruction and fragmentation of natural habitats and unsustainable land-use practices affect adversely physical and chemical aspects of landscapes (Gaese *et al*., 2009). The negative effects of anthropogenic habitat degradation are weakening the productivity of land and water systems (Gaese & Schlüter, 2011).

Despite these pressures, forest ecosystems in this particular region are essential in the provision of benefits or services to society. However, the importance of such benefits or services are not sufficiently recognised and accepted by society, partly also due to the lack of scientific evidence that makes clear the benefits provided by such ecosystems (MA, 2005; TEEB, 2009; TEEB, 2010b).

Within the conservation strategies for the Atlantic Forest Region, one of the most highlighted topics is related to the sustainable management of water resources. It is undeniable that within this biome already limitations and conflicting demands in water supply to domestic, industrial and agricultural consumption have already been taken place. This fact gives rise to discussions and actions for the protection, recuperation and rational use of water resources. In this line, given the essential role of forests in the conservation of such that in different degrees influence quantity, quality and constancy in the supply of sweet water (Landmills & Porras, 2002), the perspective of summing up forces to the ones of the biodiversity conservation becomes evident (Strobel *et al.*, 2007).

Payments for ecosystem services (PES) schemes are gradually more proposed by local projects and supported by international cooperation as means to manage the trade-offs among agricultural uses and watershed services in a cost-effective manner. Decision makers need a reliable data basis and suitable tools to take the right decisions about managing their environments while maintaining valuable ecosystem services. The recognizing of ecosystem service values contributes to a more transparent process of decision making (Chen *et al*., 2008; MA, 2005; TEEB, 2009). Identifying and measuring such values has started to feed policy processes and shows an increasing trend worldwide, especially regarding watershed services (Daily & Watson, 2008; MMA, 2011; Stanton *et al*., 2010). This can result in opportunities to save costs through timely or targeted action (TEEB, 2010).

Tropical forests are essential to the enhancement and maintenance of water quality worldwide. But just how important are they in doing so? How do changes in land use (LU) and land cover (LC) affect water quality outcomes? What is the opportunity cost of LU/LC changes that significantly affect water quality? How do water treatment costs increase with deteriorating water quality? How much does it cost to get the water elsewhere? Answers to such questions are critical to design effective watershed management measures and policies and eventually determine where a PES scheme can enforce this objective. Yet there is still little empirically based knowledge to answer such questions satisfactorily.

Valuation of ecosystem services which compare the benefits associated with conservation of forest areas versus conversion in other land uses can give essential information to make a prioritisation in several situations (TEEB, 2010b). Studying the opportunity costs of land use change as well as the demand for watershed services can help decision makers to evaluate the scope and economic feasibility of PES and alternative management options.

2. State of the Art

2.1 Watershed services

Forests have an important role in hydrological processes such as stream flow regulation and water quality maintenance (MMA, 2011). These and other watershed services are valuable for society (Landmills & Porras, 2002; World Bank, 2011). Stream flow regulation includes maintaining flow during dry season or drought years and controlling floods, while maintaining water quality comprises the control of sedimentary, nutrient (e.g. phosphorus and nitrogen), chemical load and salinity (Bohlen *et al*., 2009).

Forests, wetlands and protected areas that are subject to management actions frequently supply with clean water at a significant lower cost than anthropogenic replacements such as water treatment plants. For instance, payments to maintain services of water purification in the Catskills watershed, New York, represent (US$ 1-1.5 billion) in comparison to the much higher estimated cost of a filtration plant (US$ 6-8 billion plus US$ 300-500 million yearly for operating costs) (Wunder, 2008; Pagiola *et al.*, 2004). Another example is in Venezuela, where a national protected area system avoids sedimentation. If this would not be tackled it could reduce farmer´s income by approximately US$ 3.5 million yearly (Pabon-Zamora *et al.*, 2008).

When comparing the market share of water related environmental services with other environmental services, it is noticeable that the market for water quality is the second largest in value after the regulated carbon (Stanton *et al.*, 2010). Compared to carbon sequestration and several biodiversity conservation services, watershed protection services are mainly of concern to local and regional users (Landell-Mills & Porras, 2002).

From all PES programmes worldwide, Latin America has the highest number of them with a contribution of US$ 31 million for the conservation of watersheds affecting about 2.3 million hectares (Stanton *et al.*, 2010). PWS programs are growing rapidly in this region from 7 in 2000 to 36 active programs in 2008. PES used to fund conservation of upstream from downstream users was being developed first in Ecuador, Colombia, Brazil and now Peru especially (Stanton *et al.*, 2010).

2.2 PES for watershed services (voluntary interests, national states, regulations, legal framework and other relevant economic incentives)

PES might be induced by voluntary interests of watershed services that are supplied to discrete beneficiaries. In these cases, individual private buyers of PES might pay providers so that the continuous provision of the service is secured. An example of this is the case of Vittel, a water company in France, where actions have been taken to decrease water pollution resulting from livestock production. This company dealt with farmers to incentive them to change their land management practices for the reduction of nitrates in the water springs (Perrot-Maître, 2006). The changed practices by farmers included the elimination of maize cultivation for animal fodder and application of agrochemicals, the use of extensive cattle ranching with smaller number of animals and the modernization of farm constructions to minimize nutrient runoff (FAO, 2007).

There are other examples of watershed PES that are carried out by national states in Latin America. Examples of such schemes are the PES Programme in Costa Rica, which pays landowners in the watershed to maintain their forests intact for the control of erosion (FAO, 2007). Another example is the PSAH Program in Mexico and the Brazilians´ Socio-environmental Development Program of the Rural Production (Proambiente) (FAO, 2007; Wunder, 2008). Proambiente is a federal programme that provides farmers with subsidized credit for farming practices that are believed to enhance ecosystem service flows coming from agriculture (Börner *et al*., 2006).

Watershed PES schemes are being promoted in several forms worldwide coming from voluntary interests, economic incentives, regulations and legal framework. The latter can also be essential instruments to aid creating demand for ecosystem services (MMA, 2011).This results in arising opportunities and favourable conditions to make steps in the direction of sustainable watershed management.

2.3 Relevant policy tools for watershed services management in Brazil

Relevant legislation to assess watershed services can be found in the Brazilian National Law on Water Resources (Law No. 9433/97), which is the potential base for the establishment of watershed service markets and permits charging for water use practiced already in several states (Da Veiga, 2008). This is based on the polluter pays principle to transfer payments from the users/polluters to the protectors of springs and riparian forests.

Another important tool that allows the assessment of the relation between forest and watershed services is foreseen in the Articles 47 and 48 of the SNUC[5]. This is the Brazilian law governing protected areas and foresees payments to conservation units for ecosystem services. Unfortunately, there is still a lack of regulation of such articles for the implementation of Articles 47 and 48 of the SNUC (Strobel *et al.*, 2007).

The "ecological" or "green" ICMS[6] is another relevant economic incentive that is being used for supporting the management costs of the Private Natural Heritage Reserves. With this policy tool, it is intended to increase the economical attractiveness to create new protected areas as well as to improve the management of those already existing (Marques Fernandes, 2009; Da Veiga, 2008). The green ICMS has already been implemented in 11 Brazilian States. Those include the states of Paraná, Minas Gerais, São Paolo, Rio de Janeiro, Mato Grosso do Sul, Amapá, Mato Grosso, Rio Grande do Sul, Pernambuco, Rondônia and Tocantins (Da Veiga, 2008). Each state has specific environmental criteria that define the handing over of the 25% that the municipalities can obtain from this tax (Da Veiga, 2008). For instance, the state of Paraná was the pioneer using this type of tool and since then, the number of protected areas within the state increased by 165% (Marques Fernandes, 2009).

All these tools are important to consider because they feed the process of decision-making by providing several means to be used towards a sustainable management of water resources in

[5] Lei do Sistema Nacional de Unidades de Conservação (SNUC): Lei 9985/ 2000. This law works under the protector-receiver principle indicating that those protecting resources should receive a financial reward for their stewardship (Strobel *et al.*, 2007).

[6] ICMS (Imposto sobre a Circulação de Mercadorias e Serviços): Tax for the circulation of merchandise and services

Brazil. For instance the next point shows several examples of charging of water use in Brazil at the federal, state and municipal level.

2.4 Brazilian examples for the assessment of watershed services

At the federal level, the watershed of the river Paraíba do Sul that comprises part of the states of São Paulo, Rio de Janeiro and Minas Gerais collected around R$6 million (US$ 3.5 million) yearly through the charging of water use and with the expectation to be increased in the following years (Da Veiga, 2008). The second federal watershed of the rivers Piracicaba-Capivari-Jundiaí in 2006 obtained around R$10 million (USD 5.8 million) yearly from with the expectation to be doubled until 2008 (Da Veiga, 2008).

At the state level, Ceará is a pioneer having implemented a charging for water since 1996. Rio de Janeiro implemented initially only charges for water in the area of the Paraíba do Sul watershed in 2004. After this point and with the approval of the state Law 4247/03, the state of Rio de Janeiro extended the charges for other watersheds such as Guandu and others. For São Paulo the state charges started in 2007 for the waters of rivers Piracicaba-Capivari-Jundiaí and Paraíba do Sul (Da Veiga, 2008). At this level, several examples of PES for watershed services are carried out by states such as Minas Gerais, Espírito Santo and São Paulo with their programmes[7]: “Green Bag”, “Water Producers” and “Water Mine” (MMA, 2011). For instance, the Water Producer´s Programme pays rural producers through conservation and management practices of vegetation cover, that contribute the effective erosion and sedimentation control and for the increasing infiltration of water. Later the programme was modified considering also payment for the recuperation and protection of springs and re-forestation (Kfouri & Favero, 2011).

There are also initiatives that have been promoted since the entering into force of Municipal Laws such as the case of the Programme “Water Conserver” in the Municipality of Extrema in Minas Gerais. This has been promoted with the taking into force from the Municipal Law 2.100/2005. In this case, it is predicted that the project uses municipal funding for the payment to rural producers. The producers that are considered in this project are those who are willing to adapt their properties with the objective of gaining improvements in water quality and widening their supply (Kfouri & Favero, 2011).

2.5 PES for watershed services in the Brazilian Atlantic Forest

When comparing the number of initiatives of PES related to watershed services in the Atlantic Forest region with other PES schemes related to carbon or biodiversity, it is evident that their share is today much higher and increasing rapidly (table 1). In these schemes, rural producers are compensated for the protection and/ or restoration of natural forest ecosystems located in strategic areas for the production of water (springs, riparian forest or captivation areas) (Veiga & Galvadão, 2011).

Table 1. Initiatives of PES in the Atlantic Forest (Becker Guedes & Seehusen, 2011)

Implementation stage	PES - Carbon	PES - Water	PES - Biodiversity
Implementation stage	15	8	1
In execution	15	20	0
In articulation	3	12	4

[7] “Bolsa Verde”, “ProdutorEs de Água” and “Mina D’água” Programmes

Total	33	40	5

PES water schemes in Brazil are expanding and there are already 848 ecosystem service sellers in the Atlantic Forest region, who are receiving payments ranging from R$ 10 per ha yearly to R$ 577 per ha monthly. 40 PES projects related to hydrological services were identified until 2010, covering an area of around 40 000 ha. Those projects are in different phases: 8 are in the implementation stage; 20 in development stage and 12 are in articulation (Veiga & Galvadão, 2011).

The majority of projects are concentrated in Southeast Brazil (28 projects), another seven in the South and just five in the North and Northeast of the country. It is important to point out that several projects are strategically located in priority areas for the conservation of the Atlantic Forest or close to significant urban settlements (Veiga & Galvadão, 2011).

2.6 Payments related to PES for watershed services

The PSAH Programme in Mexico, financed from water fees, pays around US$ 24-38 $ha^{-1}yr^{-1}$ depending on forest type. The price paid has been determined by the opportunity cost of land with the assumption that corn production would be an alternative use to conservation. Therefore, cloud forests/mesophilous forests receive superior payments of around US$ 36 per ha and temperate forests receive about US$ 30 per ha (Ecosystem Marketplace, 2010).

The Ecuadorian case in Pinampiro PWS (payment for watershed services) programme pays landowners around US$ 6-12 $ha^{-1}yr^{-1}$ (Wunder & Albán, 2008), while Los Negros programme in Bolivia pays in-kind with beehive box for honey production (Asquith & Wunder, 2008). The extent in which such payments are “appropriate or not” depends on the alternative uses in each given area (Pagiola *et al*., 2010).

An overview of all actual PES –water initiatives in the Atlantic Forest that are already in execution considering the valuation method used and the value paid is summarised in table 2. Payments in certain cases might appear low; however change perception about the importance of forest are perceived as symbolic and are necessary to promote environmental conservation and to value rural producers as a beneficiary. Payments are more explicit when linked to the worked area; because in this way the relationship between the loss of the productive area and the payment for the ecosystem service is clear (Veiga & Galvadão, 2011).

This information indicates willingness to pay for the watershed services at different levels and areas. The payment values have been based on differentiated criteria in each case. However, for our case, being aware of these values and methods, especially of those in Latin America and Brazil is essential to be able to make comparisons and to gain knowledge from their lessons learned.

2.7 Methodological approaches to value watershed services for PES schemes

Several methodological approaches for valuating watershed services as a base for PES schemes have been developed. In Latin America, there is the case of Nicaragua and Honduras with the contribution of the PASOLAC programme which developed a methodology for implementing PES at the municipality level.

In Honduras, a GIS Cost-Benefit Analysis was used as base methodology to establish a PES scheme in watersheds (Martinez de Anguita *et al*., 2011). This study identified key areas where a change in land use or other sanitary practice would improve water quality significantly; estimated the costs of conversion in land use patterns and estimated local resident´s willingness to pay for water and analysed the legal structures under which such a project might be like in Honduras

(Martinez de Anguita *et al*., 2011). In this case, land restoration and opportunity cost valuation techniques were used combined with GIS analysis, which was considered as a component that enabled a broader land planning. With GIS techniques one can also identify the critical areas where land use changes might improve the degree of forest conservation and in this way result in gains regarding water quality. However, this study had the specific application in the watershed of the Calan River (Martinez de Anguita *et al*., 2011).

Another approach was followed in a study carried out by Quintero, Wunder & Estrada (2009) who showed how hydrological modelling combined with an economic analysis of land-use alternatives could be useful to report to decision makers on the cost for different intervention at different spatial locations. Two watersheds in the Andean region (Moyobamba-Perú and Pinampiro-Ecuador) were subject to this research. The application of the SWAT[8] model permitted the identification of biophysically critical areas for the delivery of the service. The model enabled also the comparison of services for actual land-uses with change scenarios: deforestation, reforestation, live barriers and agroforestry (Quintero, Wunder & Estrada, 2009). Subsequently an economic analysis and opportunity costs optimization model was used to predict net economic benefits for service providers.

Pagiola *et al*. (2010) assessed the degree to which areas of interest for conservation of water services overlap with areas of interest for conservation of biodiversity at the country level in Guatemala. These authors considered as important to overlay water supply areas with areas of high priority for biodiversity conservation using for instance cartographical information on protected areas. In this way, Pagiola *et al*. (2010) identified where payments for watershed services can have a major contribution to biodiversity conservation.

These studies show important methodological approaches used with similar objectives to the ones in this study. Therefore now in the methods section, we describe how our methodological procedure is and the characteristics of our study area.

[8] Soil & Water Assessment Tool (SWAT)

Table 2. Overview of all projects in execution involved in PES for water services in the Atlantic Forest (Based on: Veiga & Galvadão, 2011)

Project	FU[1]	Valuation Type	PES Value
Environmental Department of Extrema – "Water Conserver"	MG	Total valuation comprises the local opportunity costs (OC) and the total property size	R$ 176 $ha^{-1}yr^{-1}$ Value based on a UFEX (Fiscal Unit of the Extrema Municipality) in March 2010
ANA/TNC – "Water Producer"	SP	According to model of the Programme "Water Producer of ANA": PAE = 100 (1- Z1 / Zo) where: PAE varies depending on soil management Z = are reference values for erosion abatement	R$ 25 - 125 $ha^{-1}yr^{-1}$ Three payment categories: • conservation practices (R$ 25 - 75 $ha^{-1}yr^{-1}$); • restoration of riparian forest with two classes (R$ 83 - 125 $ha^{-1}yr^{-1}$); • conservation of riparian forests (R$ 42 - 125 $ha^{-1}yr^{-1}$) according the level of engagement of the producer and the succession stage of the forest
Instituto Terra – Producers of Water and Forests – Guandu watershed	RJ	Variables considered for the payment calculation: 1) Areas to be restored (APPs and water interception areas in two states) 2) Conservation areas (areas surrounding the conservation units; succession stage of vegetation; level of engagement of producers in the restoration and fitting within the priority areas for the water service Local opportunity cost served as basis for the determination of the above mentioned weighed factors.	R$ 10 - 60 $ha^{-1}yr^{-1}$
Instituto BioAtlântica/ IEMA – "Water Producers" – Benevente watershed	ES	Formula comprises the criteria: slope, regeneration stage of the forest and opportunity cost: VSrh = 200 x VRTE x (1-Z) x Kt, where: VSrh = ecosystem service value of the conservation and improvement of water quality and availability in R$ ha yr^{-1}; VRTE = unit for the reference values of the State Treasury Z = coefficient of erosive potential referred to the stage of development of the forest defined by: the stage of initial regeneration, secondary initial, primary, secondary media advanced; Kt = coefficient of topographic adjustment defined by the slope ranges	R$ 80 - 340 $ha^{-1}yr^{-1}$ (max. values established in 510 VRTEs[2] (Article 3° of Law 8.995/2009)

IEMA – "Water Producers" – Guandu watershed	ES	Formula comprises the criteria: slope, regeneration stage of the forest and opportunity costs	R$ 80 - R$ 340 $ha^{-1}yr^{-1}$
Fundação Boticário de Proteção à Natureza - Oásis	SP	Valuation for the reposition cost considering the conservation of the areas and an index for the springs valuation	R$ 75 - R$ 370 per ha of conserved natural area Payment with greater value for the preserved areas. Three criteria are used: • Water production and storage (R$ 99 $ha^{-1}yr^{-1}$); • Erosion control (R$ 75 $ha^{-1}yr^{-1}$) and • Water quality maintenance (R$ 196 $ha^{-1}yr^{-1}$) – max. value R$ 370 $ha^{-1}yr^{-1}$)
Fundação Boticário de Proteção à Natureza - Oasis	PR	Valuation defined by the OC of land and for the environmental quality of the properties. The valuation of the environmental quality is done through a punctuation, checking characteristics such as: • existence of RL (legal reserve) and APP (area of permanent protection) and their conservation status; • connectivity level of the RL with the RL and APPs from neighbours; • existence of areas of native forests that surpass the legal limit; • existence of wind breaking lines or live barriers made exclusively with native species; • quantity of springs with their riparian forests protected that are located in the property These and other factors will produce an index of valuation for the rural property that will define the value each landowner will receive per month.	R$ 93 – 563 yearly, adjusted every year according to (UFM)[3]
Fundema – Programme for the Environmental Management of Springs	SC	Until 2005, the size of areas involved in the project was of 180m² to 32.616m². Since 2006, the minimum area is 900m² and the maximum of 30 000m².	R$ 175 (min. area size) and 577 (max. area size) per ha monthly of worked area. The payment value is established as a percentage of the minimum salary and last for a period of 36 months.

[1] FU: Federal Unit: ES (Espiritu Santo); MG (Minas Gerais); MS (Mato Grosso do Sul); PR(Paraná); RJ (Rio de Janeiro); SC (Santa Catarina); SP(Sao Paolo)
[2] VRTEs: Reference values of the State Treasury
[3] UFM: Fiscal Unit of the Municipality

3. Materials and Methods

3.1 Study area

The study area lies within the Guapi-Macacu watershed (1.263 km²), which is located within the Serra do Mar corridor (a priority conservation area within the Atlantic Forest biodiversity hotspot for Brazil and worldwide) in the state of Rio de Janeiro (CEPF, 2001). Springs from this watershed come mainly from the State Park "Três Picos" but also from the PARNA[9] Serra dos Órgãos and ESEC[10] Paraíso and resulting in the eastern side of the Guanabara Bay. Within the Guapi-Macacu watershed (figure 1), three sub-watersheds: Manuel Alexandre, Batatal and Caboclo were selected for this study (figure 2).

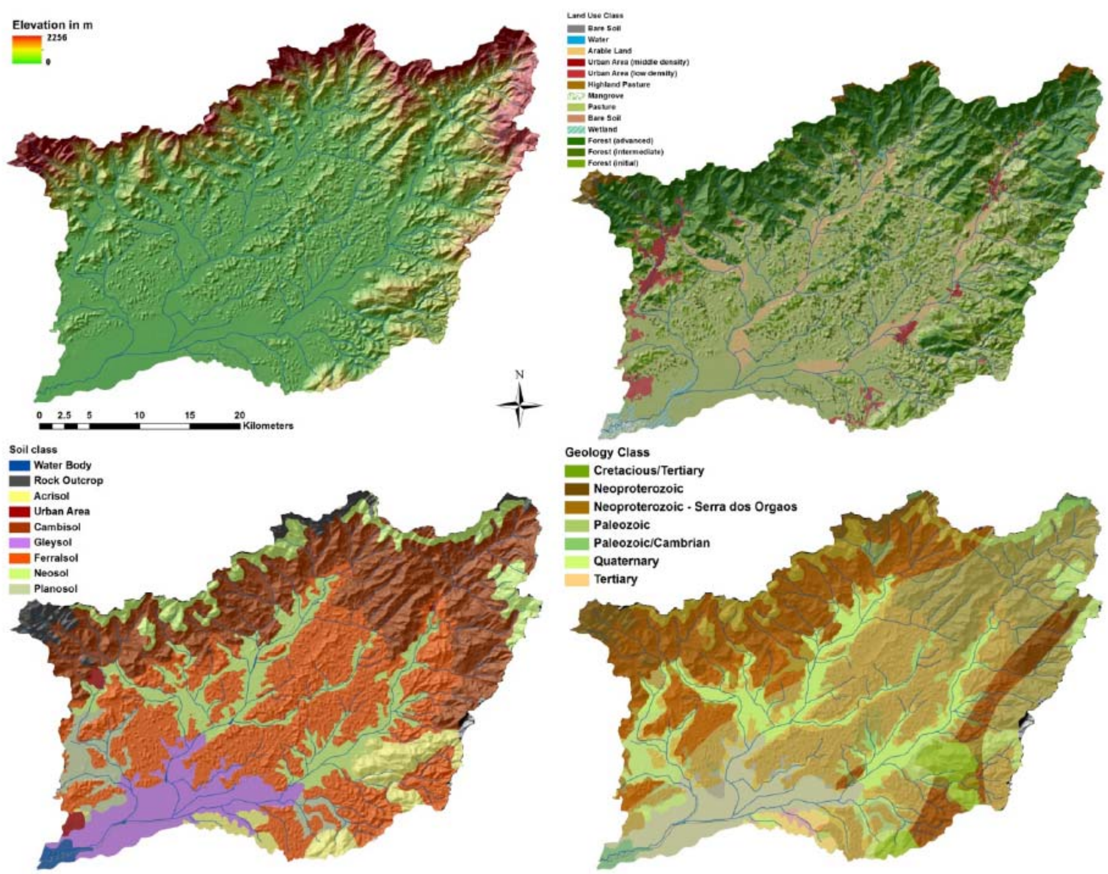

Figure 1. Overview of different environmental conditions of the studied Guapi-Macacu watershed. Top right: land use classification (Cardoso Fidalgo *et al.*, 2008), top left: elevation (Fidalgo *et al.*, 2009), bottom right: geology classes (Projeto Macacu, 2010) and bottom left: soil classes (Lumbreras, 2010)

[9] National park
[10] Ecological Station: a conservation unit with Brazilian´s system of protected areas

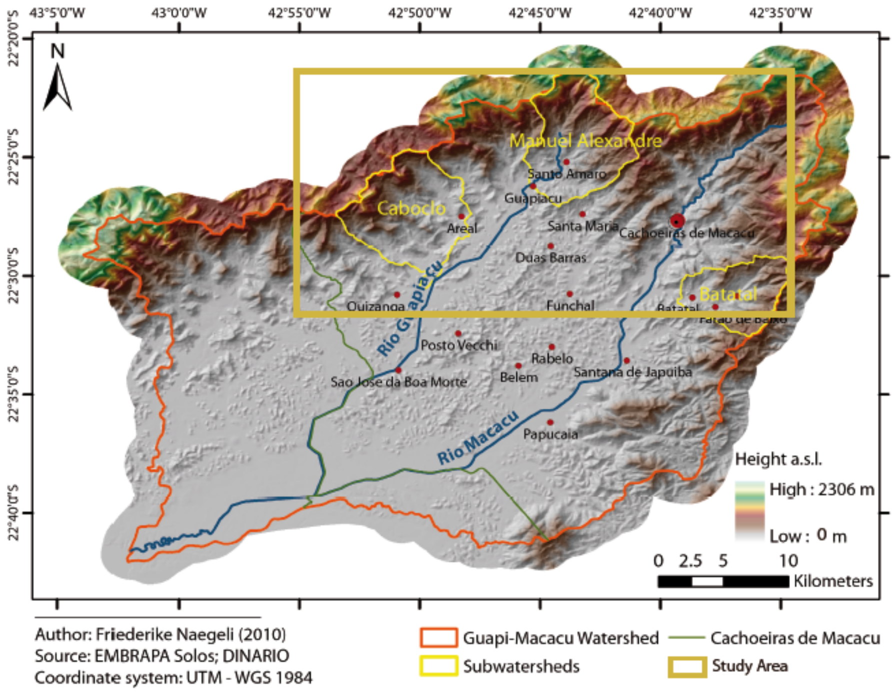

Figure 2. Sub-watersheds subject to this study within GMW (Naegeli, 2010)

All sub-watersheds are subject to different land use patterns, where:

- Manuel Alexandre in "Regua[11]" is an area dominated by forests, which are partly protected. The anthropogenic influence is considered as low. Therefore the sub-watershed is the "reference watershed" for hydrological studies.
- Batatal, which presents a mixed system of the most relevant land uses with a mosaic of forest fragments, pastures and intensive agriculture.
- Caboclo, which has forest as the predominant land use type, but where higher intensity agricultural systems are found mainly along the floodplain. Additionally the percentage of cultivated surface is higher than the average for the GMW.

These sub-watersheds were selected because each presents a highly dominance or a combination of the most relevant land uses including forest, agriculture and pasture, which account altogether for around 95% of the total area of the watershed. By selecting these three sub-watersheds it is possible to compare sub-watersheds with different land use intensities. Furthermore, Penedo *et al*. (2010) have established a water quality monitoring network in this same area measuring water level, climatic variables and various water quality parameters.

On the one hand, relatively well preserved landscapes in REGUA with a high proportion of forest land are regarded as landscapes at the initial stage of transformation. On the other hand, highly degraded landscapes with a considerable loss of forest area and recuperation potential can be found in Batatal and Caboclo. They have undergone a long period of agriculture and pasture utilisation on forest land resulting in erosion and an advanced status of landscape deterioration (Nehren *et al*., 2011).

[11] Reserva Ecológica Guapiaçú: Ecological Reserve of Guapiaçú

The selection of those sub-watersheds is also supported by the information available resulting from different disciplinary scientific groups within the DINARIO[12] project. Especially synergies with the group working with water quality monitoring and modelling are being gained. Besides that, within this project several studies on land use change, biomass production, water issues, biodiversity and soil development are being conducted.

3.2 Methods

To understand how changes in LU and LC affect water quality in every sub-watershed and the whole watershed, we rely on a hydrological component, as well as a land use assessment component. The next point intends to assess the hydrological data that will be used in the scope of this study. The hydrological data comes from two sources: 1) a water quality monitoring network implemented specifically for the GMW, and 2) a model on hydrology and water quality using the J2000 and J2000-S hydrological models respectively adapted for the GMW (Penedo *et al*., 2010).

3.2.1 GIS based watershed characterisation and hydrological modelling

This study concentrates on valuing the watershed's services in terms of regulating sediment and nutrient load. Nutrient load includes Nitrogen (N) and Phosphorous (P) found in surface water, whereas sediment load is measured in terms of total solids and turbidity. Those parameters were selected based on the availability of *in-situ* monitored water quality data along each studied sub-watershed within the Guapi-Macacu watershed. Additionally N and P transport on surface water in this region is subject to water quality modelling by Penedo[13] (2012).

Relative impacts of diverse land uses on water quality are to be quantified from this modeling exercise. This is based on the concept of "hydrological response units" (HRUs) which are the modeling units that are defined as a result of the overlapping of different layers (such as topography, soil, land use, geology, among others) treated with the aid of GIS Software (ArcView).

An important limitation of this modeling exercise is the use of coarse categories of land use based on a land use map that differentiate categories such as agriculture, pasture, forest, etc. In this way, it is difficult to assess the impacts of different intensities of production systems in each land use that are not mapped. Therefore, to improve accuracy of the findings in this study by Penedo (2012), detailed information on the different production (farming) systems located within the coarse categories and their respective management practices will be provided. In a later step, it is summarised how this information is obtained through semi- structured interviews to local producers.

The hydrological modelling component permits the comparison of the studied watershed service for actual land uses with change scenarios. This means, it allows determining the effect of a given change in land cover or/and land use intensity in each HRU in terms of the studied water quality parameters. Those include contents of N and P transported on surface water considered to be influenced by agricultural practices.

GIS analysis to determine the percentages of each land use category, considering additionally layers on spring sources, riparian forest deficit according legislation, priority areas of environmental preservation (APP) and slope will be carried out. This is done to identify spatially differences in the provision of the studied service in correlation to the water quality monitored data.

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[12] DINARIO Project: "Climate Change, Landscape dynamics, Land use and Natural Resources in the Atlantic Forest of Rio de Janeiro" is a multi-disciplinary German-Brazilian cooperation project financed by the German Ministry of Education and Research (BMBF)

[13] Pers. Conversation with Penedo, 2012 (Dinario Project), who is using the J2000-S model developed by the Friedrich Schiller University of Jena able to simulate watershed hydrology (water quality) and nutrient transport (in this case N and P transport) for the GMW

3.2.2 Land use systems classification

With the aim of characterising the farming systems' form, intensity and management practices and relations to water quality, an intensive on-farm survey process was carried out. At a first moment, a random sampling of farm units within each sub-watershed was selected, where a first survey to local producers was started. This surveying had the objective of determining the main characteristics of the principal farming systems found within the 3 areas, which are also being assessed by the hydrology scientific group of the DINARIO project. The design of this semi-structured survey is aided by experiences gained from Forero Álvarez (2002), Rodríguez Osuna (2009), World Bank (2011), the PEN – RAVA Project about Amazon Livelihoods and Environmental Network (Porro, 2011) and Instituto Terrra Mater (2009). In this process, information on farming system´s form, agricultural management practices and local perception on changes in land use and water quality was gathered.

Once the typical farming systems were identified, a second-in depth survey enabled to determine the intensity of farming systems as well as specific agricultural practices carried on. From this analysis, it was possible to select where the most significant agricultural products are mainly produced, what the structure of a typical farm unit in this region is (size, production program), with which production systems are the agricultural products produced (intensity, technologies, labour input, etc.) and which costs and output are relevant and how is the profitability from each significant product and from the farm unit.

The resulting analysis in this component indicates differences between production systems along the upper, middle and lower part in each sub-watershed. This is in terms of agricultural inputs, management practices, land cover, land use, etc. to compare it later on with the water quality parameters monitored also in a collection point at the upper, middle and lower part of each sub-watershed.

With the data obtained as a result of the surveying process, cost-benefit and opportunity cost analysis were carried out. This process was aided by a strong coordination with scientists, agricultural extensionists, local experts and local governmental institutions.

3.2.3 Cost-benefit and opportunity cost analysis

Opportunity cost is an important concept used for PES programmes. For the cases where high benefits can be gained with small reduction (or even gain) in agricultural production or income, low payments can trigger significant supply response. Therefore are PES schemes here likely to be cost-effective (FAO, 2007). To calculate the opportunity costs related to the provision of such watershed service under varying land-use systems, it was necessary to the data including cost-benefit analysis of typical farming systems in the region.

This process started with the development of detailed budgets of simple activities also named enterprises within land use systems. Such budgets summarise information of cost and revenue. They generally illustrate the activities that take place within a planting and harvest season (World Bank, 2011). Enterprise budgets for crops that are harvested in more than one year such as cassava, perennial tree crops and animal production require taking into account several years that correspond to all phases of an enterprise (World Bank, 2011). These budgets permit obtaining in the end the average return in every land use. Then, the opportunity costs is calculated based on comparing the profit of a given land use minus the profit of the other. For instance in the case of calculating the opportunity cost of leaving agricultural land to pasture, it would be necessary to calculate the profit of pasture minus the profit of agriculture.

Opportunity costs of actual land uses will be mapped with the aid of GIS Software (Arc View). A physical mapping of areas most relevant to water conservation considering the latter together with layers on land use, slope, amount of spring sources, riparian forest deficit according legislation and priority areas of environmental preservation will be carried out. The spatial mapping of conservation opportunity cost of watershed services maintenance and improvement will permit deriving implications for cost-effective management the basis of scenario analyses.

3.2.4 Theoretical framework

Once the total opportunity costs obtained within every sub-watershed and the water quality results from different monitored points along the area are known, the hydrological model should serve to predict how water quality varies based on changes in LU and LC for the whole watershed. In other words, to be able to determine the opportunity cost of LU/LC changes that significantly affect water quality, we identify the required measures for improving water quality. Then, the hydrological model indicates how these measures result in terms of water quality. Based on this assumption, the red supply curve showed in figure 3 is created.

In a next step, we find out how water treatment costs increase with deteriorating water quality by applying the avoidance cost method. This type of economic valuation of the studied ecosystem service is oriented on the main demander of the service, in this case the Drinking Water and Wastewater State Company (CEDAE) located in the lowest part of the watershed. In this way the other curve named as "water treatment costs" in the figure 3 is obtained. Expert opinion from staff working in CEDAE is asked to find out how much it would cost to get the water elsewhere by using the replacement cost method (also seen in figure 3).

Considering all these elements presented previously, we can determine if we are in a feasible PES opportunity cost range. Furthermore, it is planned to determine under which conditions a PES scheme would be cost-effective considering measuring the identified water quality indicators as policy measure to enhance water quality, related to the preservation or recovery of forest area, as well as to good agricultural practices within the watershed.

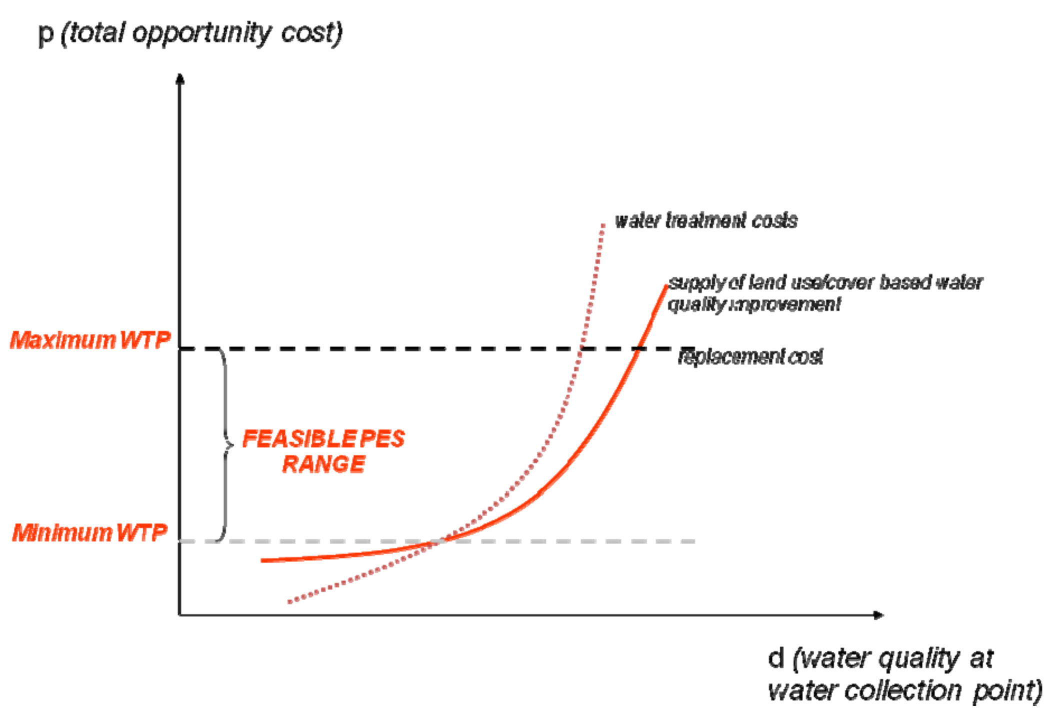

Figure 3. Theoretical model integrating all final components in this study

4. Interim results and discussion

Considering the orientation of this paper to provide an outlook of the methodological approach of this study rather than presenting detailed results that are still in an ongoing phase, this section aims at giving only an insight.

The reference sub-watershed with the highest percentage of forest cover is Manuel Alexandre (89%).This area has a private reserve with low anthropogenic interventions in form of ecotourism, particularly for birdwatchers. The sub-watershed of Batatal shows a forest cover of 73.2%, a pasture area of 23.7% and arable land of 3.1%, while the sub-watershed of Caboclo presents a forest area of 83.6%, a pasture area of 7.5% and arable land of 8.9% (table 3).

Table 3. Land use shares and surface area of the studied sub-watersheds and the Guapi-Macacu watershed (Based on: Cardoso Fidalgo *et al*., 2008)

Sub-watershed	Surface (km^2)	Land use (%)			
		Pasture	Arable land	Forest (initial, intermediate & advanced)	Others
Manuel Alexandre (MA)	18.5	0.5		89.0	10.5
Batatal	31.8	23.7	3.10	73.2	
Caboclo	12.5	7.5	8.90	83.6	0.1
Guapi-Macacu watershed	1263.6	41.4	4.40	48.8	5.4

Results from interviews to local producers show that there are some differences in production patterns when comparing the upper and lower area of each sub-watershed where agricultural production takes place (in Batatal and Caboclo). An illustrative example is shown for the case of Batatal, with an average altitude in the upper zone of 344 m.a.s.l. and 83 m.a.s.l.in the lower part.

In the upper part, most production is oriented to banana “extractivism”, which requires fewer agricultural inputs as the productive areas are found on top of the hills at considerable distances accessible only with aid of mules (figure 4). The lower part shows also the predominance of banana plantation, but other temporary crops such as cassava, yam, green maize and some vegetables become important (figure 4). There are several differences regarding the percentage of area dedicated to agriculture and to forest between the lower and upper part of the sub-watershed. Other aspect that is analysed with more detail is the difference in use of inputs for agricultural production, being i.e. low in terms of fertilisation in the upper part and more intensive in the lower part. There is a high percentage of local producers using herbicide for weed control due to shortage and high costs of labour force for this activity. It is also relevant to mention that the Atlantic Forest Law establishes that when a weed grows until certain height, land should be “left out for forest” regeneration and therefore is considered as “lost” for any economic use.

Differences on key water quality parameters such as total solids and turbidity in the sub-watershed show higher values in the lower part of the sub-watershed reenforcing the differences resulting from the interviews. The same occurs when comparing values of nutrients (as total N and total P) presenting higher values at the lower part of the sub-watershed.

Returns for agriculture tend to be higher in the lower part of the sub-watershed, where labour force has become costly and there is a higher use of agricultural inputs, especially fertilisers for cash crops.

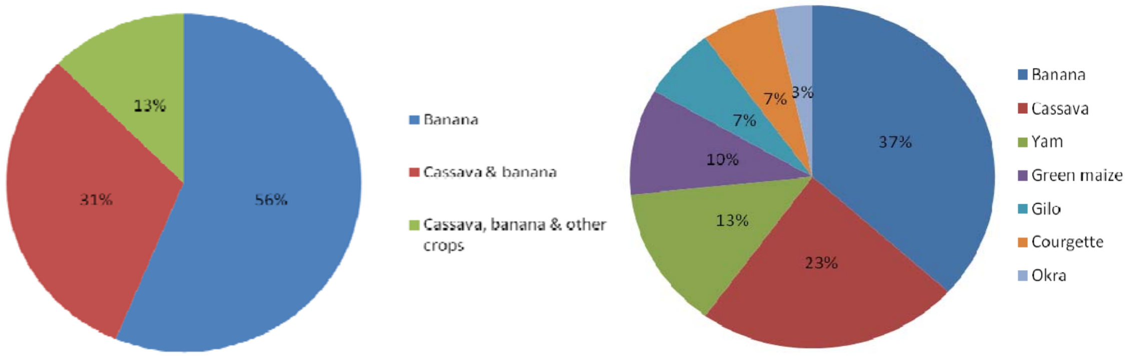

Figure 4. Agricultural production in the upper part (left) and in the lower part (right) of the sub-watershed of Batatal

These previous results show the limitations of using land cover versus land use. The deeper knowledge of difference in land uses and their intensities allow assessing returns for agriculture and pasture in a more cost-effective way.

5. Implications for policy and decision-making

By assessing land use in the manner presented in this paper together with hydrological modelling spatial analysis, cost-benefit and opportunity cost analysis allow us to have a strong baseline. By identifying the measures that are more likely to produce gains in water quality and introducing them into the hydrological model, we can determine the outputs of such changes in water quality. Then, calculating the costs of such changes makes evident which changes count for more gains, targeting in this way actions towards cost-effective watershed management.

Additionally, we ask the willingness to pay coming from the main demander (in this case the water utility) and obtain the costs of taking the water somewhere else. This additional analysis permits to check whether payments to incentive positive changes in terms of gains in water quality are reasonable and where it costs less to do so.

Finally, this approach enables to analyse if the actual situation is situated on a PES feasible opportunity cost range versus other alternative management options.

6. Conclusions

This study focuses only on watershed service provided by forest regarding water quality maintenance and improvement. However other co-benefits from the ecosystem services provided of forests are not assessed in this study.

This paper focused on showing the process which is still taking place; therefore no complete results are presented here. However, the objective of this paper is to show the methodological approach that is being carried out here to contribute to the future implementation of measures for a cost-effective management of this watershed supported with in-depth interdisciplinary scientific results.

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