Optimal ecosystems for water regulation of the Mantasoa watershed

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Abstract

Climate change poses significant threats to water resources worldwide, impacting hydrological cycles and exacerbating extreme weather events. In response, Nature-Based Solutions (NBS) have emerged as effective strategies to address these challenges by integrating natural ecosystems into water management practices. This study focuses on the Mantasoa watershed in Madagascar, a region heavily affected by climate change-induced disruptions in rainfall patterns and increased erosion. By employing a multi-faceted approach encompassing field observations, hydrological analyses, and ecosystem characterization, the study aims to identify sustainable solutions for water resource management in the watershed. The research delineates the hydrological characteristics of the Mantasoa watershed, emphasizing its rugged terrain, diverse ecosystems, and reliance on Lake Mantasoa for water supply. Through meticulous analysis of rainfall data, soil erosion parameters, and land use patterns, the study quantifies the extent of erosion and identifies areas susceptible to degradation. Furthermore, it explores the potential of Nature-Based Solutions, particularly the establishment of green infrastructure, to mitigate erosion, enhance infiltration, and preserve water quality. Results highlight the pivotal role of natural forests in regulating water flows and reducing soil erosion, underscoring the importance of preserving these ecosystems amidst pressures from human activities such as bushfires and land conversion. Additionally, the study proposes the implementation of buffer zones around Lake Mantasoa to safeguard water resources and mitigate land loss. In conclusion, the study underscores the urgency of adopting holistic and sustainable approaches to water resource management in the Mantasoa watershed. It advocates for integrating Nature-Based Solutions into conservation strategies. It emphasizes the importance of stakeholder engagement and interdisciplinary collaboration in ensuring the long-term resilience of the watershed. By prioritizing ecosystem preservation, informed land use planning, and community involvement, the study endeavors to foster environmental sustainability and enhance water security in the face of climate change challenges.

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1 Introduction

Climate change is a major concern of our century. Indeed, the report of the Intergovernmental Panel (IPCC) in 2018 induces irreversible alterations in seasons and rainfall regimes (Woillez & Ourbak, 2018) (Valentin Brice, Gil, Jean-Guy, & Romain Armand Soleil, 2020). Hydrological cycles are disrupted as are the production systems that depend on them. These impacts will be amplified by demographic pressure through increased demand and disruption of the water cycle through land use change. The impacts of climate change are also more intense continental flooding (Bates, Kundzewicz, Wu, & Palutikof, 2008). Due to the increasing number of urban areas, the interaction of many factors such as demographic, economic, political, environmental, cultural, and social factors creates challenges related to the use and management of water resources. Many of these problems can be solved with nature-based solutions (NBS). To address these problems, Nature-Based Solutions (NBS) are emerging as effective and adaptive approaches, offering benefits for both biodiversity and human well-being (IUCN, 2018). They are also seen as potential support for sustainable water management (FAO, 2018). To reduce the impacts of climate change on water resources and limit extreme phenomena, SNB and more particularly, green infrastructure have been put in place in many countries (COALITIONEAU, 2014). Green infrastructure is composed of natural or semi-natural structures (Meerow & Newell, 2016)(EUROPEAN COMMISSION, 2014). These infrastructures, composed of natural or semi-natural ecosystems, offer an alternative to hard structures by reinforcing dams, dikes, and canals (Randriamaherisoa & Grondin, 2014).

In Madagascar, disruptions to the hydrological regime have been palpable in recent years (USAID, 2018). The impacts of climate change have been severe over the past two decades: prolonged periods of drought, increased precipitation variability, intensification of cyclones, and flooding associated with cyclonic disturbances (United Nations Framework Convention on Climate Change, 2015) (Wu, Zhao, Wang, Cao, & Liang, 2022). The current situation ranks Madagascar among the most vulnerable countries to climate change and extreme weather phenomena (Eckstein, Künzel, Schäfer, & Winges, 2020). For good reason, gray infrastructures do not adapt well to unplanned fluctuations in water resources (Rasolofomanana, 2012) (Mark, et al., 2020). Locally, the Mantasoa watershed in Madagascar, faced with a drop in rainfall since 2016, is experiencing accentuated effects of climate change, exacerbated by significant erosion leading to siltation of the lake (Randriamamonjy, 2011) (Rasoarinoro, 2019). (Setaniera*, 2016). The importance of this lake for the population and production activities led to the search for a lasting/sustainable solution (PCD Mantasoa, 2017). It was planned to support the gray infrastructures that exist there. Due to the dilapidation of the gray infrastructure consisting of retention dams and canals, they could no longer fulfill their role of storage and adequate distribution of water. This study proposes to identify the ecosystem allowing the establishment of green infrastructure at the watershed level to support the retention dam in order toto improve infiltration and reduce erosion. Existing ecosystems were identified, forms of erosion were observed, and measurements of the infiltration speed were undertaken. Finally, statistical analyses, notably analysis of variance, were carried out to compare the infiltration speeds of the different ecosystems.

2 Materials and methods

2.1 Description of the study area

A watershed is defined by a portion of territory delimited by ridge lines (or watershed lines), irrigated by the same hydrographic network (Meziani, 2011). The watershed is the support for development aimed at managing water resources. The study focused on the Mantasoa watershed which is located between 21°00' and 21°20' South latitude and between 47°50' and 47°85' East longitude. It is located on the edge of the first recess of the eastern cliff (Angavo Cliff), near the watershed, between the Ikopa and the Mangoro basin watershed. Lake Mantasoa, the outlet of this basin, is located in the eastern part of the Central Imerina region, more precisely in the commune of Manjakandriana and Mantasoa, District of Manjakandriana, Analamanga Region (Setaniera*, 2016).

The climate of Mantasoa is a tropical highland one (JICA, 2000). The watershed is subject to the Monsoon regime with an alternation of a dry season corresponding to a southern winter and a rainy season corresponding to summer. The annual rainfall is around 1350mm (Rasoarinoro, 2019). The temperature is relatively mild, with an annual average of 16.5°C, a maximum of 20°C in January, and a minimum of 12°C in July (Botomanovatsara, 2019).

The Mantasoa area is rugged with lateritic hills. The largest differences in altitude (500 m over 4 km) are observed in the Anjiro area. The average altitude is between 1300m and 1500m, and the highest parts of the area peak at over 1600m (Andrianiaina M. S., 2006).

Lake Mantasoa is fed by the Varahina Nord (Setaniera*, 2016)River. Its estimated surface area is 20.05 km or 2005 Ha with an average depth of 8 to 12 m and a maximum depth of 40m at the retention dam (FANOMEZANTSOA ML, 2017) (Rasoarinoro, 2019). The reservoir dam was built in 1938 to regulate the low flow of the Ikopa. And, this dam feeds the Ampasipotsy dike and the Mandraka hydroelectric power station. Lake Mantasoa is made up of retained water from the dam of which it is the outlet. In recent years, we have observed siltation of the lake and a considerable drop in the water level.

2.2 Study of the current hydrological characteristics of the watershed

Mantasoa watershed was broken down into two parts: estimation of land loss and sizing de green infrastructure.

The estimation of land loss was based on the RUSLE equation.

$$A = R * K * LS * C * P$$

Which: A represents the soil losses due to erosion in tonnes/ha/year and depends on the five (05) factors, namely: R (rain erosivity in MJ mm/ha/d), K (soil erodibility), LS (the slope factor or topographic factor), C (the effect of the vegetation cover of the soil) and P (the correction factor)

The R factor relating to rainfall or more precisely to the aggressiveness of rain was calculated from rainfall data collected by the companies ACIPENSER and JIRAMA. The data collected made it possible to present the evolution of the annual rainfall amount from 1990 to 2018.

The R factor will be calculated from annual precipitation. Three methods can be proposed:

- The one developed by Lo et al. (1985), which was applied in Mauritania: $R = (38{,}46 + (3{,}48 * PA)) * 0{,}1$
- That developed by Roose (1997) in the United States and applied for Shama $R = 0{,}5 * PA * 1{,}735$

And, that of Renard and Freimund (1997) in the United States and applied for Shama $Si\ PA < 850\ mm, R = 0{,}0483 * PA^{1{,}61} * 0{,}1 \quad et\ Si\ PA > 850\ mm, R = (587{,}8 - 1{,}219PA + 0{,}004105PA^{2})0{,}1$

The values of wet and dry five-year precipitation as well as those of wet and dry ten-year precipitation were integrated into the evaluation of rainfall erosivity.

The K factor of soil erosivity depends on the nature of the parent rock. Wischmeier and Smith (1978) developed an equation that relates the K factor to texture, organic matter content, structure, and permeability. And, studies have already evaluated the value of this factor depending on soil types. Clay-rich soils have low K values, around 0.05 to 0.15, because they are resistant to detachment. Coarse-textured soils, such as sandy soils, have low K values, around 0.05 to 0.2, due to low runoff, although these soils loosen easily. Medium-textured soils, such as loamy soils, have moderate K values, about 0.25 to 0.4 because they are moderately sensitive to detachment and produce moderate runoff. Soils with high silt content are the most erodible of all soils. They come off easily; tend to crust and produce high runoff rates. K values for these soils tend to be greater than 0.4. Then, the texture of the soils under each ecosystem was identified and assigned according to the table below:

Types of ecosystems	Texture observed	K
Built-up land and cultural mosaic	**Sandy-loamy**	**0.2**
reforestation forest	**Loamy-loamy or loamy-sandy**	**0.02**
natural forest	**loamy**	**0.02**
savannah	**Sandy loam**	**0.1**

The LS factor translates to the slope factor or topographic factor. It is more precisely the length of the slope and its inclination. The subfactor L relates to the length of the slope, and the subfactor S is the steepness of the slope representing the effect of the slope on erosion. The formula used to estimate this factor was: LS= (/22.13) 0.4 × (0.01745 Sin Ө /0.0896)1.4 × 1.4.

The C factor is determined by plant cover, cropping systems, and land use. Indeed, these have a significant impact on runoff and erosion. The different types of land use were identified through the map available at the commune level, from the FTM. And, the land use maps were supplemented by field observations. In the Mantasoa watershed, six types of land use were observed. The C factor is estimated at 1 on bare soil, 0.001 under dense forest, or 0.01 on undercover plants (Payet, Dumas, & Pennober, 2012).

Type of land use	Factor C
Bare ground	1
Degraded forest	0.7
Tree and shrub savannah	0.3
Degraded grassy savannah	0.6
Mosaic of culture	0.5

Reforested area	0.18
Dense forest	0.001
Body of water	0

The P factor represents soil protection and anti-erosion practices reducing runoff speed and thus reducing the risk of water erosion. Land uses in the study area vary from natural forests and reforestation forests to bare soil. P = 1 for the undeveloped areas and 0.1 for the gently sloping area developed with retention benches.

Types of occupation	P
Watercourse	1
Rainfed cultivation	0.5
Forest Gallery	1
Housing area/bare land	1
Tree savannah	1
Wooded savannah	1

The measurement of infiltration was made at the field level. The measurement points were identified using GPS. 37 measurement points were subjected to measurements of the infiltration speed using the mono-cylindrical method of ROOSE (1997) (Boughalem & al., 2016)(Boughalem M. , 2014). It is a cylinder 10 cm in diameter and 50 cm in height. 2 cm of the tube is buried in the ground. This device is equipped with a ruler and the speed of soil infiltration is measured. To test the dependence of infiltration and plant cover, the measurements were repeated 5 times on each plot and the average value was taken.

2.3 Data analysis

The analysis methods are broken down into silvicultural analyses and statistical analyses.

The silvicultural analysis aims to judge the potential of natural populations, of these characteristics to judge the most widespread species but also to define the development necessary for its use (as ecological infrastructure). The structural analysis of a stand, according to Rajoelison (1997), (Andriaharimalala, Roger, Rajeriarison, & Ganzhorn, 2011)(Ramananjatovo, 2013) makes it possible to obtain indications respectively on the characteristics of the species that compose it. And, the floristic structure was defined from the floristic composition and richness.

For the study of the spatial structure, two parameters were calculated:

- Abundance is calculated by the number of stems of a species per surface unit and is expressed by N/ **ha**
- Dominance evaluates the basal area G of a stand and **is** calculated by the following formula: $G = \Sigma g_i = \Sigma \pi/4 \; d_{i\,1,30}^{2}$. With G: basal area of the stand (in m2/ha); gi: basal area of each foot (of tree i) and di 1.30: diameter at 1.30m from the ground (of tree i).

Statistical analyses were applied to inventory data regarding dominance and abundance in each compartment. Variance analysis made it possible to determine the similarity in the inventory plots. Apart from the compartment characteristics per plot, we also compared the mixing coefficient and the regeneration rate. The tests were carried out by using XLSTAT2014. The null hypothesis is that the averages of the characteristics between the different plots are not important; therefore, they are more or less equal. The significance level was set at 95%.

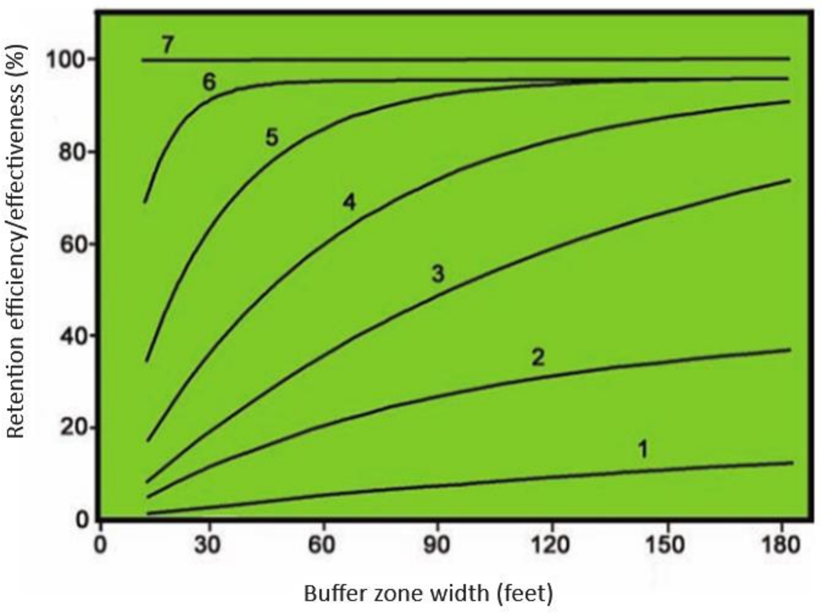
The study of the vegetation effects on the infiltration values was subjected to variance analysis by using XLSTAT2014. In the present case, the value of infiltration under the different soil covers was compared. These different covers are bare soils, reforestation forests, shrub savannahs, grassy savannahs, and secondary forests. Analysis of variance was carried out to analyze the dependence between infiltration and vegetation cover. 37

samples corresponding to 37 measurements under the different soil covers were compared. The null hypothesis is that there is no difference in the means between the infiltration measurements under the different covers.

2.4 Sizing green infrastructure

The dimensioning of the infrastructure was based on the methodology applied for the development of buffer zones, wooded corridors, and green networks. It was first necessary to identify the objectives of the green infrastructure and the priority functions to be assigned to the green infrastructure. The latter needed to protect Lake Mantasoa 's water resources must reduce runoff and siltation and increase water infiltration into the ground. These objectives led to the choice of buffer zones.

The width of the buffer zone was calculated using the following tool.



3 Result

3.1 Characteristics of Existing Ecosystems

Field observations made it possible to determine 5 types of land use and their management method: reforestation, savannah ecosystems, natural forests, cultural mosaics, and built-up lands.

Reforestation stands are mainly Eucalyptus and Pinus plantations. The plots under Eucalyptus in which infiltration measurements were made are mainly composed *of Eucalyptus robusta*. *Pinus paluta* and *Pinus keshyia* dominate Pinus plantations. The populations observed are around 3 to 5 years old. The exploitation of these forests mainly results in the production of firewood (charcoal and firewood) but also construction wood (round wood, planks, square wood, and planks). According to our interviews with forest operators, the rotation duration is not fixed.

Savannas are broken down into tree savannah and grassy savannah. Tree and/or shrub savannahs are mainly composed of *Phillipia sp*, *Eugenia emirniensis*, and *Psiadia altissima*. These ecosystems often result from bushfire activities or clean-up fires. These soils have often become unusable and left in abundance according to the populations upstream. *Phillipia sp* are used for the roofing of stables, firewood, and fencing of living areas.

The study of the silvicultural characteristics of natural forests was carried out at the level of 3 plots which are located at the bottom of the slope, mid-slope, and near the ridges. The analysis of variance demonstrated a small difference between these three inventory plots. Although the second plot does not have any trees exceeding 30 cm, the abundance in compartments B and C are similar. Indeed, the abundance in the three plots of all species combined and all diameters combined is 6240 ± 160 N/ha. The diameter of the trees between the three plots is 15.7 ± 3.7 cm and the height is 10.8 ± 2.18m. The mixing coefficient of the plots is 9/44 ± 0.04, which suggests a fairly poor population. The stand is mainly composed of regeneration stands. However, the regeneration rate varies significantly between plots. It reaches its maximum at the level of plot A which also corresponds to the plot with a maximum abundance value of compartment A. This plot could be the one that is subject to minimum pressures. The most abundant species are: *Aphloia theiformis* (APHLOIACEAE), *Eugenia emirniensis* (MYRTACEAE), *Vaccinium secundiflorum* (ERICACEAE) and *Wennmania minitiflora* (CUNONIACEAE)

Forest fire as a procedure for clearing or acquiring land reduces the surface area of natural forests for the benefit of Eucalyptus plantations: bush fire at the level of Triage of Environment, Ecology, and Mantasoa Forests records 20Ha burned per year, and according to the head of Triage could reach 40Ha/year. The population uses it as land development to enable land acquisition. There are also fires to clean the savannah and to allow the establishment of crops or Eucalyptus reforestation.

3.2 Mantasoa watershed

Each parameter of the land loss formula was evaluated.

$$A = R * K * LS * C * P$$

The first parameter concerns the erosivity of rain. The evolution of the annual rainfall amount from 1990-2018 shows an average rainfall amount of 1216.08mm per year, with a standard deviation of 480.69mm. The linear trend determines a negative regression, therefore a decrease in precipitation over time. However, the values observed in 2016 and 2017 are the most alarming with respective values of 28.19 mm and 46.42 mm.

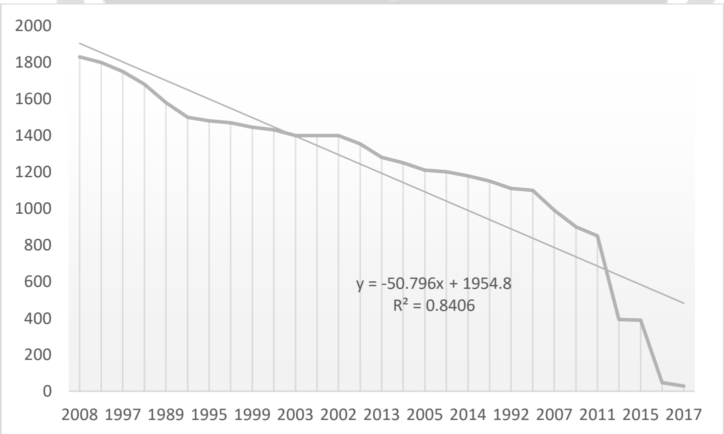
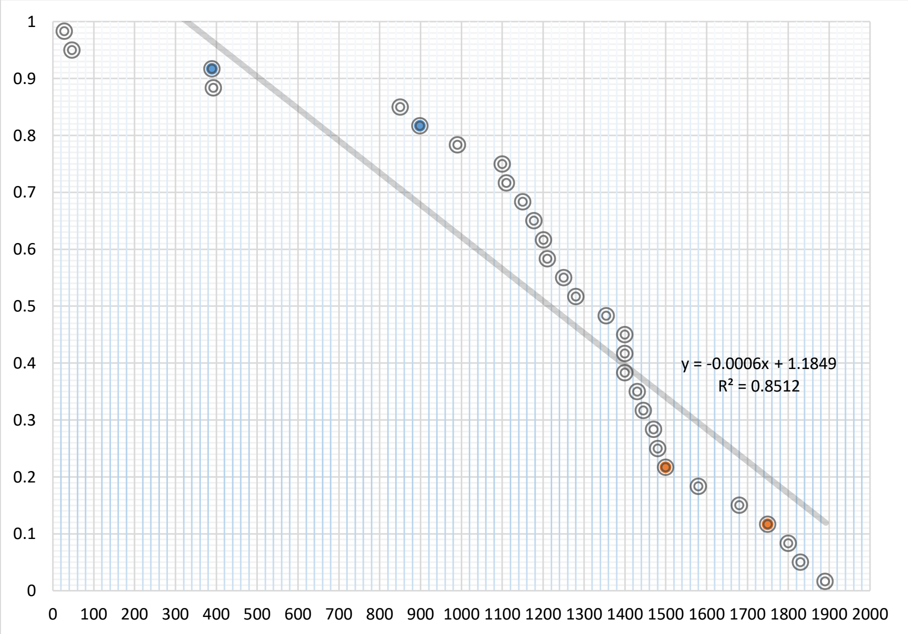


Figure: evolution of precipitation from 1990-2018

A statistical study of the annual rainfall of Mantasoa made it possible to demonstrate the normality of the rainfall amount. Precipitation frequency analysis during these 30 years made it possible to determine the dry and wet five-year rains as well as the dry and wet ten-year rains. These values correspond to a frequency greater than or equal to 1/10 or 1/5. These values correspond to 898.5mm, 1500mm, 389.70mm, and 1750mm.



The three formulas for measuring rain erosivity were applied to the previously estimated rainfall amounts. The Roose formula provides the maximum value for all rain depth values.

	P.A.	Lo et al. (1985)	Rose (1997)	Fox and Freimund (1997)	Average
Average rainfall	1216.0 8	427.04	1054.95	517.61	**666.53**
Wet quinquennial	1500	525.84	1301.25	799.55	**875.55**
Five-year dry	898.5	316.52	779.44	280.65	**458.87**
Wet decadal	1750	612.84	1518.12	1102.61	**1077.86**
Ten-year dry	389.7	139.46	338.06	716.18	**183.71**

Erodability was integrated into each formula in order to determine the impact of rainfall height values on soil loss.

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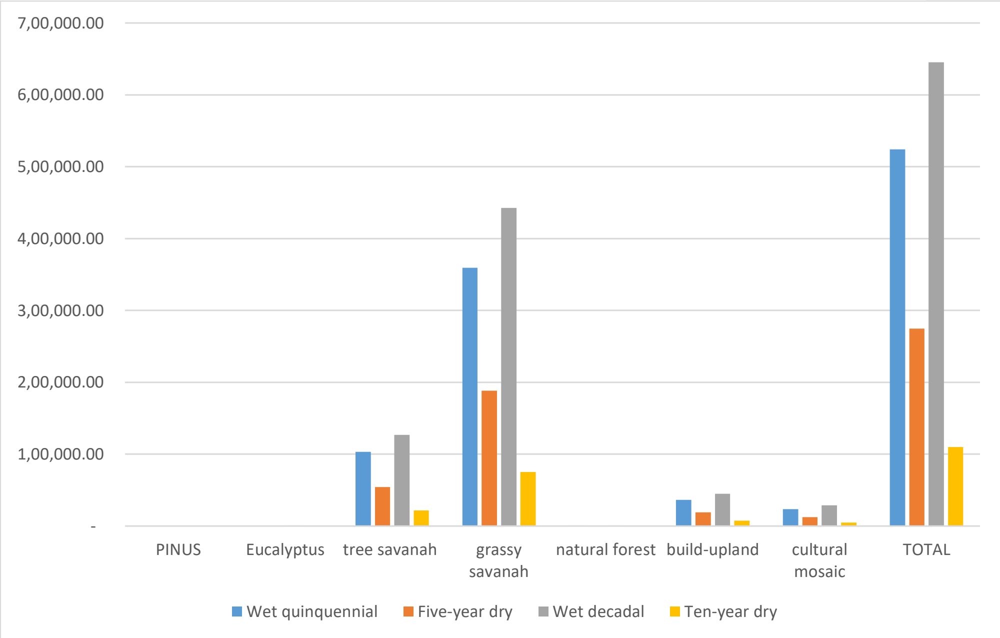
The LS factor was identified from 39 points. When descending into the field, the slopes and slope length could not be assigned to each ecosystem. The calculation was therefore based on the average slope and the slope length.

Average in % Slope	**6**
Average slope length	**92**

The formula was applied to these values: LS= $(0.0065+0.0456\ S+0.006541S^2)\ (L/72.5\ )^{nn}$

The calculated LS factor is 1.88.

The C and P factors applied were those of previous studies.



The graph above shows land loss at the watershed level as a whole and by ecosystem type. It also shows the variation in soil loss depending on precipitation. The greatest loss of land corresponds to that of the grassy savannah. The least significant loss of land corresponds to forest areas, whether reforestation forests or secondary forests. The estimated loss of land for the entire watershed is 388,573.53 tonnes, which corresponds to an average of 366 tonnes/Ha.

3.3 Buffer zone sizing

3.3.1 Buffer zone design

The reference curve which approximates the characteristics of the Mantasoa watershed corresponds to curve number 04. This curve 04 corresponds to the greatest length of fields (in feet), to a slope of 2%, to a loamy texture, to a C factor of 0.5, and to the fixation of sediments from runoff. For factors that diverge from the characteristics observed in the field, adjustments were made. The Mantasoa Watershed field length corresponds to 6561 feet, which is twice as long as the reference field length. The average slope observed is 5%, and -1 points have adjusted the slope factor. And, the C factor of the Mantasoa watershed is lower than the C factor of the reference curve, which corresponds to a positive adjustment of 01.

variables	reference curve	site condition (foot)	setting	Observations
field length	1300	6561	-2	2 times double the reference length
Slopes (%)	2	5	-1	2%+2.5 more compared to the reference slope
Textures	LLA	LLA	0	without change
C factors	0,5	0,003	1	C forests and cultivated areas

Types de pollutant	sediment	sediment	0	without change
Curved number	4			

The total of the adjustments corresponds to minus two points of the reference curve, so the curve is retained as curve 02.

Adjustment	**-2**
Final curve retained	**2**

The following figure shows the capacity of the buffer zone:

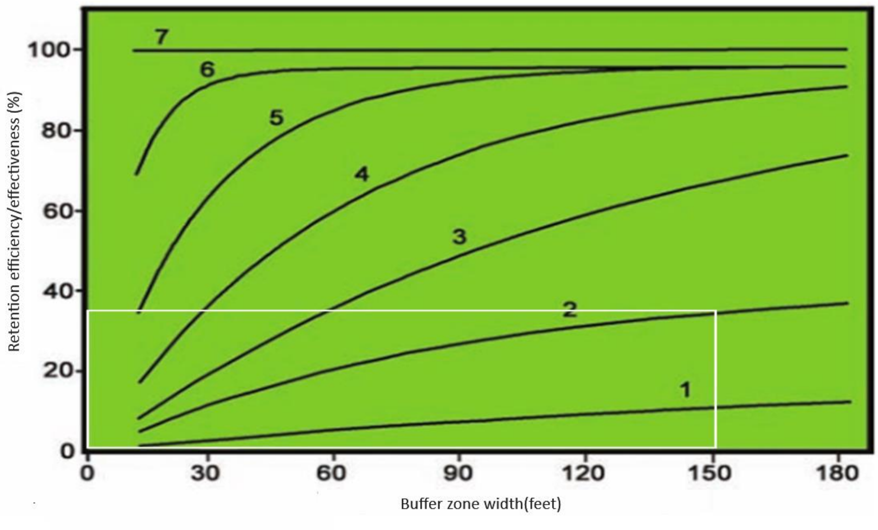


Figure 1: Tools for calculating buffer zones to limit runoff

For curve number 02, the maximum capacity that can be reached is less than 40%. This maximum capacity corresponds to a width of 150 feet of the buffer zone. This width is 45.72 m all around the watershed. The buffer zone will consist of a forest belt of 43.89 m all around Lake Mantasoa, and upstream of the forests, herbaceous formations of 1.82 m which will be developed perpendicular to the slope.

4 Discussion

This study made it possible to characterize the ecosystems of the studied region, focusing on five types of land use and their management methods. Reforestation forests, mainly composed of Eucalyptus and Pinus, are exploited for the production of firewood and construction wood. Savannas, often resulting from bushfires, present soils that are unusable for local population. Natural forests have been studied at different topographic levels, demonstrating a poor species composition, mainly dominated by regeneration stands.

A worrying trend is observed regarding the reduction of natural forests in favor of Eucalyptus plantations, resulting from bushfires used to acquire land. Erosion of the Mantasoa watershed was also analyzed by using the land loss formula, integrating the parameters of rainfall erosivity, slope, slope length, C factor, and soil conservation factor floors.

Analysis of precipitation over 30 years revealed a general decrease, although some years recorded alarming values. The different rain erosivity formulas showed significant variations, with Roose's formula proposing the maximum values. Land loss was estimated for the entire watershed, showing a predominance of grassland savannah in terms of land loss, while forested areas had the lowest losses.

Mantasoa watershed was explored through the design of a buffer zone. By adjusting the parameters of the reference curve, a final curve was retained, suggesting a maximum buffer zone capacity of less than 40%, with a width of 45.72 m around the watershed.

In conclusion, this study highlights the importance of sustainable ecosystem management, emphasizing the pressures exerted by human activities such as bushfires and Eucalyptus plantations. The results could inform conservation and land use planning strategies to preserve the ecological balance of the Mantasoa watershed.

Morphometrically, the watershed has a perimeter of 74 km and an area of 96 km2. The compactness index is 2.114, and the overall slope index is 7 m/km. This value explains the slopes observed in the watershed, favoring low peak flows and a prolonged conveyance time while leading to a mechanism of water stagnation in the lowlands. Geologically, the study area is dominated by lateritic meadow clay which could promote waterlogging of the soil. Recent studies indicate that watershed soils are favorable for erosion and runoff.

This study provided a better understanding of the hydrological responses of soils under different plant covers. A comparison of the results shows a difference in the amount of soil loss depending on the calculation equations used. More in-depth soil studies should determine the impacts of these covers on the quality of the water resources of Lake Mantasoa, which could be of interest to the ACIPENSER company.

On the other hand, the Mantasoa dam, currently facing difficulties in meeting current needs during low water and years of low hydraulicity, will not be able, alone, to cope with growing demands. Depending on the results of this study, two scenarios can be considered. Field measurements show that natural forests are the best options for improving infiltration in the Mantasoa watershed.

The first scenario consists of an extension of natural forests over the entire surface of the watershed, which would increase infiltration by at least 70 mm/day and reduce erosion. However, the use of this type of green infrastructure is difficult due to the decrease in species present there. In addition, this development would require a radical modification of the entire current system, which could be poorly received by the population.

The second scenario values reforestation stands. Although the Eucalyptus robusta population only slightly improves infiltration, their regulatory function can be improved through pH correction or decompaction of the substrate. These methods facilitate the movement of water and air and improve root activities. To protect the remaining natural forests, multi-use species can be provided to divert their exploitation.

For example, the installation of scrub species on crop soils such as Grevillea banksii can reduce pressures from charcoal production. Diversification of species at the level of the reforestation stand through the planting of species with high commercial value such as Tectona grandis, Greveillia robusta or Gmelia arborea would divert loggers from natural forests. The determination of the LS factor takes into account that the slope is uniform, while the shape of the slope (concave or convex) also influences erosion. However, it is difficult to estimate their effect on plot erosion. Plots subject to strong degradation tend to become concave in the middle.

5 Conclusion

In conclusion, this study highlights the urgency of taking measures to preserve the ecological balance of the Mantasoa watershed. The results obtained highlight the significant impact of human activities, such as bushfires and Eucalyptus plantations, on local ecosystems and the availability of water resources.

The in-depth analysis of the watershed's ecosystems, precipitation, and erosion highlights the need for sustainable and informed management of land and water resources. Management strategies, such as the extension of natural forests or the enhancement of reforestation stands, offer possibilities for mitigating erosion and improving infiltration but require an integrated approach taking into account the ecological, social, and economic aspects.

With this in mind, the establishment of a buffer zone around the Mantasoa watershed represents a potential solution to mitigate erosion and preserve water quality. By adjusting design parameters, this buffer zone can play a crucial role in regulating water flows and reducing land loss.

It is imperative to involve local stakeholders, policymakers, and communities in the implementation of these strategies, including the creation and management of the buffer zone, to ensure their effectiveness and social acceptability. Moreover, additional studies on water resource quality and potential impacts of land use changes are needed to guide future actions.

Ultimately, preserving the Mantasoa watershed and its rich and fragile ecosystems requires long-term vision, collective commitment, and concerted action at all levels of society. Only a holistic and sustainable approach will ensure the protection of this precious natural resource for future generations.