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An irrigation system for domestic vegetable gardens: application to a case study of subsistence farming in Madagascar

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Contents

Abstract

In 2021 the lack of safe water for the human being needs is still an issue, especially in the developing countries. To overcome this problem, the United Nations establish the SDG 6 “Ensure availability and sustainable management of water and sanitation for all” with the purpose to give safe water to all the people in need within 2030. The present work follows the purpose of the Goal 6 and it focus on the case study of the Nosy Mitsio island in the North of Madagascar. In the island the local population suffers the absence of a water supply system for irrigation of vegetable gardens: for now, the locals practice a subsistence farming, changing the location of the vegetable gardens when the soil loses its fertility and stopping the farm during the dry season. With this method, the population is unable to sustain itself with the vegetables of the gardens which are not constantly produced, and their stocks are insufficient for the entire population. With the aim to design a basic water supply system, different aspect about the island have been investigated: first of all, both the social and economic situation and the water facilities present on the island have been studied . On the other hand, data about the weather and the hydrogeological characterization have been collected, in order to create a literature data about the island. Thanks to an expedition on Nosy Mitsio, it has been possible to study the result of water sample analysis and performing laboratory test on soil samples. At least, a simple water supply system has been designed, to bring water from the selected spring to the area addressed to the gardens, finding the best configuration to assure the required irrigation water amount. This work has been carried out thanks to the partnership between the Politecnico di Torino, the H4O Help for Optimism Onlus, and the Kukula Onlus. Working on a project on international cooperation during the Covid 19 pandemic has given rise to a new way of working together, where the mutual exchange of information between different parties and the help of the local population is crucial to overcome the impossibility to go on the site.

1 Introduction

The lack of water in developing countries is one of the biggest issues of our century. Safe water is necessary to human life as it is used as part of alimentation, for agriculture, livestock, cooking, and hygienic-sanitary purposes. The United Nations Agenda 2030 with the SDGs (Sustainable Development Goals) supports the water supply for everyone. These goals are also sustained by "Non-profit organization of social utility" (Onlus), locals or internationals, which help developing countries to achieve good standards of living.

1.1 The 2030 Agenda and the Onlus' contribution

"Transforming our world: The 2030 Agenda for sustainable development" is a document written by the United Nations in 2015 declaring the new goals for humankind. The main Agenda's purpose is to end poverty under the sustainability and the resilience of Planet Earth. In this document are described 17 goals to reach until 2030 in Figure 1.1, that are based on five pillars: People, Planet, Prosperity, Peace, and Partnership (United Nations, 2015). Onlus play an important role in reaching the SDGs. Many of them make the Agenda's goals their guide and their main reference points, choosing some specific goals to contribute to and to be transformed into tangible actions.

Figure 1.1: Sustainable Development Goals of United Nations (*Sustainable Development Goals*, 2021)

This dissertation aims to investigate on a Madagascar island, called Nosy Mitsio, where is not practice a permanent agriculture due to the lack of a water supply system for the irrigation; the SDG that inspired the present work is the Goal 6: "*Ensure availability and sustainable management of water and sanitation for all*". Worldwide, one in three people do not have access to safe drinking water, 673 million of people still practice open defecation, and two in five people do not have a basic hand-washing facility with soap and water. Also, the water quality is relevant: each day, nearly 1000 children die due to preventable water and sanitation-related diarrheal diseases. The Covid -19 pandemic, highlighted the link between health and water: sanitation, hygiene and the right access to clean water are the only effective weapon to contrast the spread of infections (Sustainable Development Goals, 2021). The Goal 6 consist of providing Water, Sanitation and Hygiene (WASH) for all and is subdivided into sub-points (United Nations, 2015):

- universal access to safe and affordable drinking water;
- access to sanitation and hygiene for all, including end of open defecation, with particular attention to women and girls;
- more efficiency in the water used to face water scarcity and to reduce the volume of wastewater and water pollution;
- protecting water environments;
- international cooperation for water activities and the building of hygienic plants in developing countries supporting the local population collaboration.

Through the reaching of Goal 6 it will be possible to realize some of the other Agenda's Goals:

Goal 1. *End poverty in all its forms everywhere.* The concept of poverty is intrinsically linked to the availability of water. Water available for all is the first step towards collective well-being.

Goal 2. *End hunger, achieve food security and improved nutrition and promote sustainable agriculture.* Water is at the basis of all livelihoods and must come from sources free of contamination.

Goal 5. *Achieve gender equality and empower all women and girls.* In low-income countries, girls and women are the primarily responsible for collecting water, and that precludes they participation in education; often, providing water is arduous and dangerous. Women and girls are more vulnerable when they use public toilet or open defecation. At least, women have specific hygiene needs during the difference phases of their lives (Unwater - Water and Gender, 2021).

Goal 8. *Promote sustained, inclusive, and sustainable economic growth, full and productive employment for all*. Water is at the basis not only of alimentation but also of economic activities: agriculture, farming and industry activities need water for they maintenance.

Goal 10. *Reduce inequality within and among countries.* Water availability for those people that cannot access to safe water is a step forward to give to everyone the same opportunities and move close to the equality.

Goal 11. *Make cities and human settlements inclusive, safe, resilient, and sustainable.* Bringing safe water available for all in a community is the first step to reduce inequalities and face difficult situations as period of drought.

Goal 15. *Protect, restore, and promote sustainable use of terrestrial ecosystems sustainably manage forests, combat desertification, and halt and reserve land degradation and halt biodiversity loss.*

Goal 16. *Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable, and inclusive institutions all levels.* If water were available to all, general well-being would be ensured and conflicts over water supply would end. Water conflicts happen nowadays, and the water could be the trigger of conflict, due to the water control. Water can be also used as a weapon of conflict, where is used as a tool in a violent conflict, or water can be a casualty of conflict (World's Water - Pacific Institute, 2021). The water conflicts happened in the world since 2019, and classified in this way, has been tracked by the Pacific Institute (World's Water - Pacific Institute, 2021), and can be consulted as a map or as a chronological events.

Goal 17. *Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development*. Non-profit organisations working in developing countries contribute to the achievement of the SDGs through international cooperation and by helping the local population.

The present thesis is the result of the collaboration between the Onlus H4O Help for Optimism and the Politecnico di Torino. H4O is an Italian no-profit organisation; it was founded in July 2014 with the aim to improve the lifestyle of the rural population in islands of northwest Madagascar. H4O based its work on the SDGs and follow three pillars following the Agenda's aim: health, education, and sustainability. Without health, the development cannot be reached. Health starts with open access to safe water and hygienic-sanitary services for all. The education is necessary to create work and H4O gives tools and know-how information to help the local population to take advantage of their natural resources. Sustainability is necessary for a long-term vision. Economic activities are launching to self-finance their projects (H4O - Help for Optimism Onlus, 2021).

The thesis is placed in an international project, called Tany Vao, New Earth in Malagasy. The project should guarantee access to WASH (Water, Sanitation & Hygiene) facilities and services in the island of Nosy Mitsio in the North-West of Madagascar. Moreover, should give facilities and competence to develop and maintain an integrated agricultural production cycle, to end malnutrition, and improve the air quality near the cooking area and raise awareness about the health impact linked to traditional cooking methods (H4O Help for optimism Onlus, 2020). The promoters of this project are H4O Help for optimism Onlus and Kukula Onlus in partnership with:

- University of Pavia - Laboratory of Dietetics and Clinical Nutrition, Department of Public Health, Experimental Medicine and Forensic Medicine;
- Politecnico di Milano –Course of Environmental Engineering;
- NGO Associazione ELPIS Nave Ospedale;
- V.I.M. Volontari per il Madagascar NGO.

Providing water to an insular population of South Africa is in accordance with the Agenda's aim. With the present work, it is hoped to achieve Goal 6 and all other related goals. First, the correct use of water can reduce malnutrition and permits to practice agriculture despite the dry season and drought periods. In this way, local agriculture can provide the right daily food amount for each person. (Goal 2); in addition, guaranteeing water supply for irrigation for the entire year can help the local population have stable work and it could represent a work opportunity for women. Also, producing food for all, will reduce the gender gap in alimentation and will support the local economy. (Goal 1, 5, and 8). Furthermore, Madagascar is a notorious touristic destination, famous for its uncontaminated environment. The presence of luxury resorts in the country is in strong contradiction with the lack of safe water, healthcare, and food in some areas of Madagascar. The project exposed in the present dissertation will reduce this social gap, providing the basic necessities to the population (Goal 10). Moreover, the presence of water inside the village will avoid the island depopulation; will permit a settlement inclusive and safe; water availability for all will avoid conflicts for its supply and will permit the local population to developing in the optic of environmental respect (Goals 11 and 16). In conclusion, there cannot be progress if knowledge, technologies, and financial resources are not shared. Thanks to international cooperation it's possible to help developing countries in their social and economic growth and the reaching of SDGs (Goal 17). At last, the Tany Vao project and the present thesis work will be done in the respect of nature and the good management of environmental resources (Goal 15).

Due to the Covid-19 pandemic, go to the island and record data in first person was not possible. Only one volunteer of the Kukula Onlus has had the opportunity to reach Nosy Mitsio and collect information and sample (see Chapter 3.3). The pandemic situation has changed the way in which Onlus can operate in the development countries: if the NGO staff cannot be physical present to give indication or to required information, these actions can be done in a remote way, and the locals can provide to them. But the "remote cooperation" can succeed only if the local staff has been trained and know how to operate. This way to proceed has been defined has *Smart Cooperation* (Zara et al., 2021). Smart cooperation would make each project more resilient and participative, mitigating the risk due to infections , but allowing the project to the keep going on. Smart cooperation approach, also, contribute to educate local people, making them more independent and sharing knowledge. To overcame impossibility to go on the island of Nosy Mitsio, the program *Google Earth* has been used to investigate the island and understand the geographical conformation. The images present in the thesis have been taken from internet websites or have been given by H4O photos collection. Moreover, part of the information about the population and the elements in the island are local knowledge. These ways of conveying information and material made the present thesis possible, even without its author ever having gone to the island himself. This way of proceeding also falls within the concept of *Smart Cooperation.*

2 The island of Nosy Mitsio

Mitsio archipelago is situated in the Northwest of Madagascar, 72 km northeast of the near island Nosy Be and about 30 km from the Madagascar coast (Figure 2.1). Nosy Mitsio has a latitude of -2.90 and a longitude of 48.60 and has a tropical monsoon climate (sign with Am) according to the Köppen–Geiger climate classification system.

Figure 2.1: Nosy Mitsio geographical position

The Mitsio archipelago is composed of the islands Tsarabanjina, The four brothers, Nosy Tolholo and Nosy Mitsio, the biggest and the only inhabited one of the archipelagos. Nosy Mitsio has an area of 29.7 km^2, a length of 12 km, a width of 3 km, and an elevation above sea level of 206 m. On this island there is a particular phenomenon: an organ pipes like a wall of basalt starts from the sea and continues vertically for some tens of meters (Figure 2.2) (Office Régional du Tourisme de Nosy Be, 2019). The coast is mainly sandy, with white sand and a crystalline sea. The vegetation is composed of coconut palms, spontaneous plants, and some rice and corn fields cultivated by the population. On the island neither rivers nor lakes are present, but there are some natural ponds (Figure 2.3) dislocated on the ground generated by water, which rises from local underground water accumulations.

Figure 2.2: Basalt wall in Nosy Mitsio

Figure 2.3: Example of natural ponds in Nosy Mitsio

2.1 The social, economic, and political situation

In Nosy Mitsio there are approximately 2000 inhabitants divided into five villages as in Figure 2.4: Ampanitsoha, Bevaoko, Amparimilahy, Marimbè, Andravorona, Ratapenjiky and Ampasindava (H4O - Help for Optimism Onlus, 2021).

Figure 2.4: Villages in Nosy Mitsio.

On Nosy Mitsio the health and hygiene situation of the population is precarious: until 2017 the island lacked both the presence of bathrooms and access to safe water. The population was obliged to open-defecation; the water was taken from natural pods where was not safe. Thanks to the intervention of H4O, two aqueducts were built, and the medical dispensary was improved. Also, one school with bathrooms was built to allow the children of the island to attend the lessons and reduce the high level of illiteracy of the locals. All these facilities implemented the social conditions of the population, even if different issues remains, as the open-defecation practice, and the food supply. One of the main population’s need is the creation of an irrigation and livestock system which allow the locals to sustaining themself and not depend on the expensive food from the outside of the island. The only economic activity on the island is the livestock of goats and zebus, and the only subsistence activity is the plantation of rice and corn during the wet season. A subsistence agriculture is already practice in Nosy Mitsio. The subsistence agriculture is a practice where smallholders produces essentially for own consumption and with little or no capacity to generate surplus production for the market (FAO Statistics Division, 2017). On the island, fields are made in flat terrain areas; if these ground portions are covered by forest, the trees are removed to make room for the agricultural fields, clearly visible from satellite images as in Figure 2.5. This practice is called "slash and burn" agriculture and it is often practice in areas where local farmers are not well trained in agricultural practices. Subsistence agriculture is responsible of 33% of deforestation worldwide and 40% of deforestation in Africa and Asia (Mabee, 2020).

Figure 2.5: the red arrows indicate the gardens, visible from satellite images on Nosy Mitsio

The field preparation occurs when the rainy season is nearby: in the first rain, fields are sowed. The cultivation lasts until there is the rainy season; once arrives the dry season, high temperature and lack of water for agriculture, determine the destruction of cultivation. For this reason, every year is necessary to re-make the fields and the cultivation. The fields are delimited by palm trees and leaves to protect plants from goats, which would eat the cultivations. On the island rice and corn are the only cultivated plants. They represent an important part of the local alimentation, and they are stocked to be consumed also during the dry season. Unfortunately, in the last years, the dry season is no longer as was before: rains are less and more intense. This causes a shorter time to cultivate, and the stocks are not sufficient for the entire dry season. The demand to have food all year round for the entire population, highlighted the need of permanent gardens and the availability of water for their maintenance. The lack of a constant food source, causes a non-diversified alimentation, resulting in malnutrition in the entire population. According to the Human Development Reports, (2020) and The World Bank - Data, (2021), Madagascar has the world's fourth highest rate of chronic malnutrition, and the percentage of children under the age of five in a condition of malnutrition and stunting are 41.6%. These data, reflect the condition of children in Nosy Mitsio: until the children are too young to get something to eat, they are under the responsibility of the family and their alimentation is mainly composed of rice, bananas, and coconut milk, which are food with a low caloric intake. When the children are capable to get food, for example fishing or climbing coconut palm to reach the fruits, they are allowed to eat more and their caloric intake increase. This happens at the age of about thirteen years. This condition is linked to the poverty situation present in the island and in the country. The Madagascar has the Multidimensional Poverty Index equal to 0.384, which is the "percentage of the population that is multidimensionally poor adjusted by the intensity of the deprivations". In Madagascar, the 70.7% of the population lives below the income poverty line, and the percentage of the population living on less than $1.90 a day is 78.8% (United Nations Development Programme, 2020).

Moreover, on Nosy Mitsio there are not public lightning systems and mobile cover GSM, forbidding communication with other localities. Few families in Ampanitsoha and Bevaoko have domestic lightnings thanks to solar panels of 12 V and only the medical dispensary has a 220V solar panel. The isolation of Nosy Mitsio is incremented by the absence of motorboats and ground transportation. From a political point of view, the situation is very critical: most of the population doesn't have identity documents and ballots, and public institutions are absent except for the school of Bevaoko. The only figure that represents the population is President Mamohodo, elected 20 years ago, who takes care of buying and selling livestock on the island. Despite these conditions, each village discusses its problems and needs in small meetings moderated by the village relevant figure. When H4O started its project, supported this organization and the population participated actively in the works (H4O Help for optimism Onlus, 2020). This behaviour, underline the will of the population to improve their condition.

From a religion point of view, in Madagascar, the 52% of the population believes in indigenous religion, 41% is Christian, and 7% Muslim. Islam is popular in the northwest, while Christianism in the highlands. The practice of both Islamism and Christianism is mixed with the traditional religion (United States Department of State, 2019). The local inhabitants of Nosy Mitsio are 100% Muslim but, as well as the rest of Madagascar, many animist beliefs coexist with the local religions.

2.2 Water facilities in Nosy Mitsio

In Madagascar, 88% of the population doesn't have bathrooms and 4.000 children die every year due to dirty water and lack of hygiene (H4O - Help for Optimism Onlus, 2021). From these data is very clear the relevance of free hygienic-sanitary services to the local inhabitants. H4O has completed different missions in Nosy Mitsio and the near islands, Nosy Komba and Nosy Iranja. All its projects are based on the life conditions improvement of the local population and the local economy sustainment. As an example, in Nosy Komba was created a lab to produce chocolate with locally-sourced cocoa beans managed by a sustainable enterprise; in Nosy Komba and Nosy Iranja were done hygiene promotion activity for children and their mothers. (H4O - Help for Optimism Onlus, 2021). The two activities are clear examples of respectively of "development cooperation" and "awareness campaign". This two attitudes, are in the optic of the *Smart Cooperation* (Zara et al., 2021). Also, this thesis and the project *Tany Vao* (H4O - Help for Optimism Onlus, 2020) is focalised on the *Smart Cooperation*: after the aqueduct construction, the local population will be followed in the garden's plantation and their alimentation.

In Nosy Mitsio the H4O intervention started in 2017. Before it, the hygienic-sanitary conditions were critical: public services were absent, and the open defecation was done by 100% of the population; there wasn't access to potable water and the level of analphabetic was 90%. The Onlus has worked in two villages, Bevaoko and Ampanitsoha, with respectively 400 and 300 inhabitants (H4O Help for optimism Onlus, 2020). In each village, was built an aqueduct to bring safe and potable water from the springs to the residences, to the schools, and to the hospital in Bevaoko. The aqueduct starts from a water catchment, which is a point in which there is a spring, and the water is channelled into a pipe. From the water catchment, a series of underground pipelines were laid to conduct water to different taps, dislocated on the territory near the villages, as the schools and the hospital in Bevaoko. In Bevaoko (Figure 2.6) the pipes connect the water catchment with four taps dislocated on the coast. The first (Tap 1) provide water to the hospital implemented by H4O, the second (Tap 2) brings water to the school hygienic services; the third and the fourth taps (Tap 3 and Tap 4) are near to the residences.

Figure 2.6: Bevaoko water facilities

2.2.1 Water facilities in Ampantisoha

The present dissertation is focused on the village of Ampanitsoha (Figure 2.7). Here, from the water catchment (WS01) located on a hill, the water arrives in a water tank. From it, the pipelines conduct the water to the "Main Tap" that is open every day only in the morning and in the late evening and allows the water passage to the other three taps. The opening is regulated to avoid water waste. Water from taps is used by the population to cook, do housework and as drinking water. Tap 1 gives water to the east part of Ampanitsoha; from here the pipelines continue until they arrive in a coconuts forest and then are divided into two branches: one goes to the school (Tap 3), one to West Ampanitsoha (Tap 2).

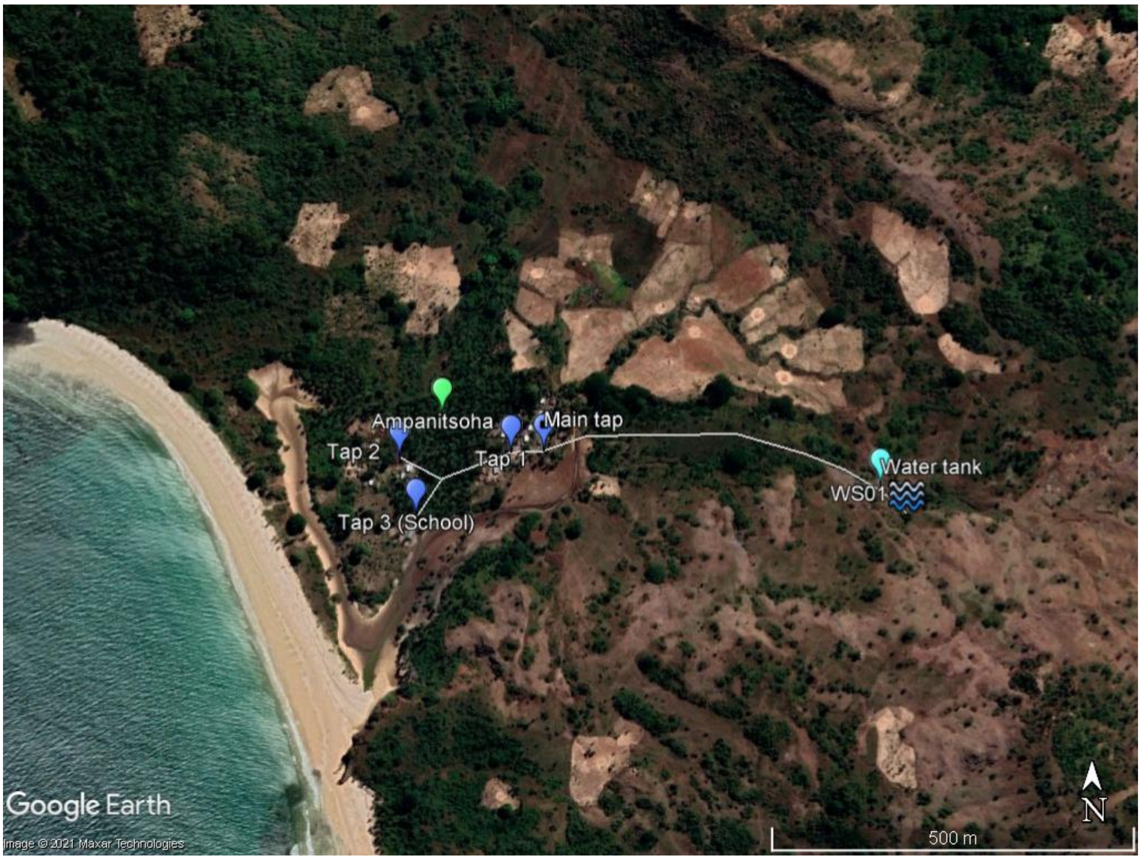


Figure 2.7: Ampanitsoha water facilities

The water tank is necessary for three reasons. First, during the day there are moments in which the water request is higher than the water availability. Through the water tank the water is collected, so when the main tap is opened all the water request is satisfied. Second, the tank has the function to guarantee the right pressure to the entire aqueduct. Without the tank, would be created a vacuum in the pipelines, due to the island's altimetric profile. Third, in the water tank, the water has a sedimentation process: suspended particles in water, sediment to the tank bottom. A pipeline at 10-15 cm from the tank bottom picks up the water to introduce it in the aqueduct. In this way, the water taken from the spring arrives clear to the taps. Because all the sediments are accumulated to the bottom of the tank, every three-four months the water tank is emptied to be cleaned. This operation causes a big delta in pressure to the inside of the tank, which is visible by cracks. For that, once a year the inside of the tank is reinforced with concrete. Figure 2.8 is a photo taken from the water catchment point of view and Figure 2.9 shows the water catchment construction in Ampanitsoha and the water tank in the background

Figure 2.8: Water catchment point of view

Figure 2.9: The water catchment in Ampanitsoha and the water tank (in the black circle).

Figure 2.10 shows how was the spring before H4O started its work. The local population used to consume and use water as it was, without any treatment: it was very dangerous for their health because water could be contaminated also by animal carcasses.

Figure 2.10: artesian spring: water arrives naturally on the ground surface. Situation before H4O intervention.

Water from the aqueduct is employed by the population for any kind of use. At the main tap, a counter was placed on 20 December 2019; from this data to 27 September 2020, it measured water consumption of 550 m^3. Despite this, the well never had a significant lowering in the piezometric head. This suggests that the aquifer has good productivity.

In Ampanitsoha are present some natural water risen. Some of them are natural ponds, where the water rises until the ground level as in Figure 2.3. In other points the population has dug in the ground and reached the water; in this way has been created some rural wells, with no internal protection between the water and the soil, and with rural protection at the top of the well to avoid that something as objects or animals can fall in the water. The rural wells have a small diameter and a low depth (some meters), and the water level inside changes with the season. One of these rural wells (from this point called only "well") is in Figure 2.11. These wells are used by the population to wash themselves directly at the pond and the water is collected to wash clothes; in Figure 2.12 their position is indicated with the name "Rural well".

Figure 2.11: rural well in Ampanitsoha

It is also presented a private well used by a family of eight-ten members (in Figure 2.12 indicated as VMASK) with a height water column inside with a range of 3-5 m. It is supposed that the amount of water collects from this well is around 200 l/day (10-15 l/day per person, 73.000 l/year). Family members use this water throughout the year and for any purpose: to wash themself, to cook, to wash their clothes, etc., and especially to drink. It is present another pond, at a distance from the sea of 230 m. From this pond, the population does not use the water to drink because has not a good taste (in Figure 2.12 indicated as VMM). The position near to the sea and the opinion of the population, presume a possible seawater infiltration.

Figure 2.12: Rural wells and ponds in Ampanitsoha: VMASK is a private well, VMM natural pond near the sea, Rural well a public well.

3 Data analysis

The lack of information about the island of Nosy Mitsio was one of the first difficulties encountered when this thesis has been writing. For this reason, it was decided to collect as much information as possible about the island and to create literature about Nosy Mitsio. In many cases, it was not possible to find specific data about the island, so it was necessary to look for information about neighbouring areas such as the island of Nosy Be or the coast to the east of the island. The topics on which it was decided to carry out further research were climate and hydrogeological characterisation. For the climate, it was essential to study the temperature and rainfall trends, as these are elements that will directly influence the construction and maintenance of the vegetable gardens. This part involved researching the data and manipulating them to find synthetic, island-specific results. The hydrogeological characterisation, on the other hand, consisted of two parts: a bibliographic search and an analysis of the samples in the laboratory. With the bibliographic research, the characteristics of the soil, such as its stratigraphy, and the possible presence of water tables on the island were searched for. Thanks to an expedition to the island in December 2020, it was possible to have samples analysed in Madagascar and to bring soil and water samples back to Italy. The results of the water analysis in Madagascar were compared with the limit values for irrigation water. The soil samples, on the other hand, were analysed in the laboratory of the DIATI Department of the Politecnico di Torino by performing a granulometric analysis.

3.1 The weather

In Madagascar, there are two main seasons: the hot season in which there is heavy rainfall from November to April with high levels of humidity, and the cool and dry season, from May to October. The average temperature along the coasts is between 23 – 27 °C while in the internal area is between 16 – 19 °C, as it's reported in Table 3.1. The same data are shown in Figure 3.1 (World Bank Group, 2020).

Table 3.1: Monthly average temperature and rainfall in Madagascar from 1901 to 2016

Month	Average Temperature (°C)	Average Rainfall (mm)
January	24.74	276.18
February	24.57	274.61
March	24.41	185.66
April	23.41	90.01
May	21.65	51.77
June	19.81	45.33
July	19.09	46.82
August	19.75	42.76
September	21.18	31.76
October	22.85	52.69
November	23.94	103.69
December	24.36	218.21

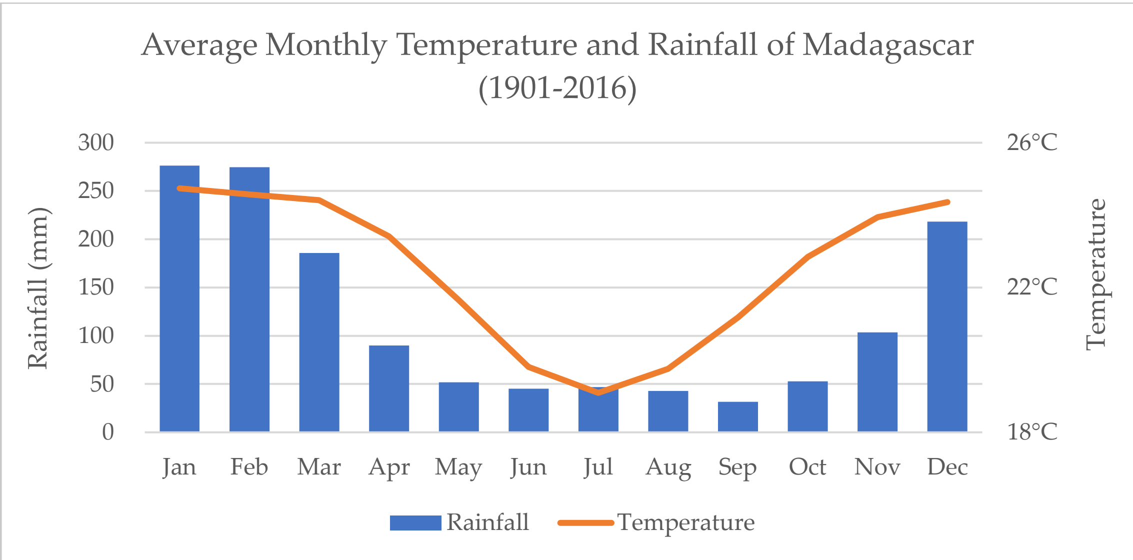


Figure 3.1: Temperature and rainfall trend in Madagascar from 1901 to 2016

To study the rainfall variation in Madagascar over the last six decades, rainfall data from the *World Bank* (2020) website were analysed. The website gave the average monthly rainfall for each year from 2016 to 1901. The period from 2016 to 1957 has been chosen to be analysed and it has been divided into six decades. For each decade, the average monthly rainfall has been calculated and the results are reported in Table 3.2. Also, the average yearly rainfall for each decade has been reported. The data analysed in this way reflect the presence of two seasons, the dry and the rainy ones. The rainiest month is January in 2006-1997 and January in 1976-1967, when the precipitation overcame 300 mm of rain. From April to November there is the dry season, and the driest month is September in the decade 2016-2007 and 1996-1987, when the rain fell was less than 23 mm. In general, rainfall data vary a little and each decade follows around the same trend.

Table 3.2: Average monthly rainfall for six decades from 2016 to 1957

Average Monthly Rainfall (mm)						
	2016-2007	2006-1997	1996-1987	1986-1977	1976-1967	1966-1957
Jan	276.25	318.98	285.88	270.79	326.25	246.07
Feb	266.70	254.17	287.66	273.99	268.58	248.48
Mar	179.73	184.39	156.13	202.63	195.70	193.32
Apr	92.74	73.59	93.55	110.62	88.95	71.79
May	49.98	48.27	45.02	50.49	61.81	49.97
Jun	47.73	38.95	33.32	42.46	60.24	48.19
Jul	46.60	52.82	44.30	46.62	49.63	64.47
Aug	36.44	43.86	31.14	37.38	48.31	54.72
Sep	22.84	36.73	22.93	35.86	31.69	28.48
Oct	55.60	45.88	49.10	79.86	57.61	51.52
Nov	113.68	98.52	69.67	126.10	118.98	111.08
Dic	183.09	253.80	188.56	213.77	241.94	255.72
Tot	1371.39	1449.95	1307.25	1490.55	1549.68	1423.79

Figure 3.2 represents the average total rainfall for each decade. The period from 1996 to 1987 was particularly dry, while the other total average rainfall values are similar, except for the decade 1976-1967 that was very rainy with a peak of 1550 mm. It can be assumed that the ten-year mean value of rain it's about 1400 mm. The data of the single decade are in Appendix 1.

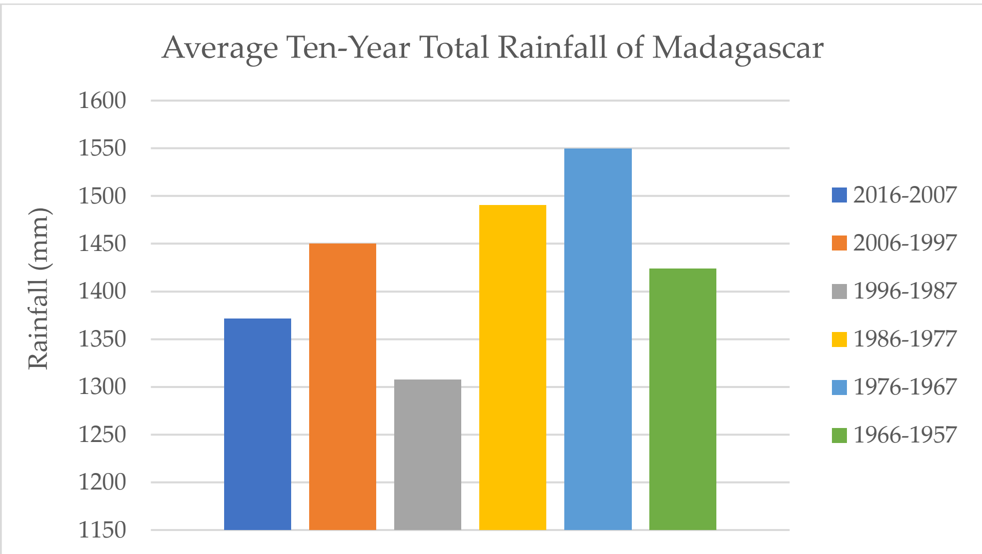


Figure 3.2: Average total rainfall of Madagascar for decades from 2016 to 1957

Since there isn't a weather station in Nosy Mitsio, rainfall, rainy days and temperature data have been considered from four different sources. Climates to travel, World climate guide, (2019), Go-viaggio, (2020), My Madagascar, (2020) websites report approximative data of Nosy Mitsio while Weather and Climate, (2020) accounts for data of the near Island Nosy Be. To obtain an approximated trend of temperature and rainfall, the average of the data given by these websites has been done.

Average maximum and minimum temperature, average rainfall, and average rainy days data are reported in Table 3.3, Table 3.4, and Table 3.5, while the corresponding charts are shown in Figure 3.3, Figure 3.4, and Figure 3.5.

Table 3.3: Table of average monthly maximum and minimum temperature in Nosy Mitsio.

Month	Average Tmin (°C)	Average Tmax (°C)
January	22.25	30.00
February	22.25	30.25
March	22.50	30.38
April	21.98	30.33
May	20.75	30.50
June	18.75	29.13
July	17.75	28.88
August	17.75	28.75
September	18.75	30.00
October	20.50	30.83
November	21.81	31.08
December	22.19	30.50
Average T (°C)	25.33	

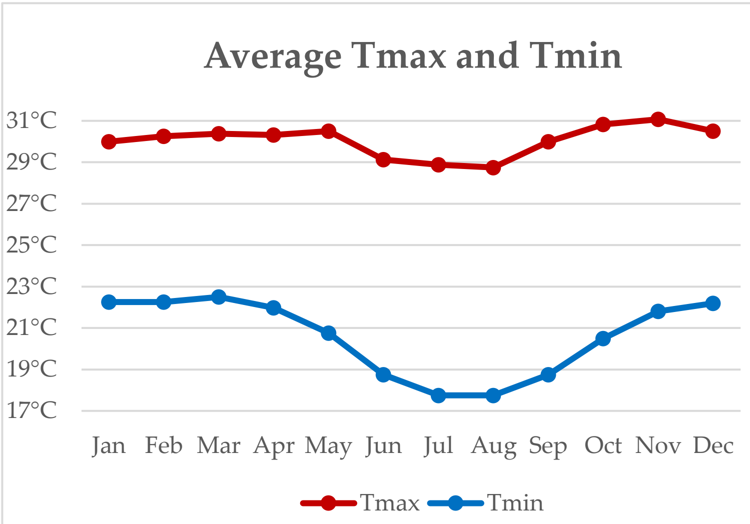


Figure 3.3: Average maximum temperature and average minimum temperature during the year in Nosy Mitsio.

Table 3.4: Average rainfall in mm for month annual rainfall in Nosy Mitsio

Month	Average Rainfall (mm)
January	487.5
February	404
March	278
April	153
May	53
June	43
July	34.5
August	34
September	39.5
October	95
November	156.5
December	345
Total/year	2123

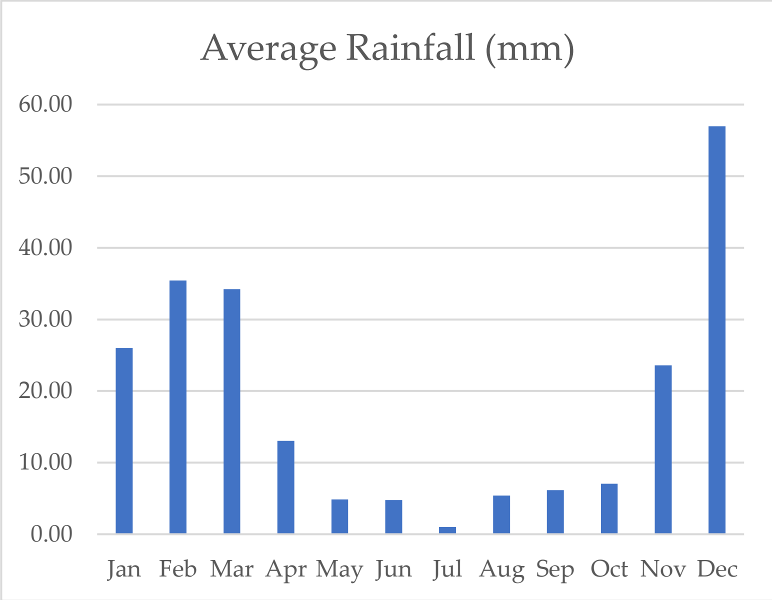


Figure 3.4:average rainfall in mm per month in Nosy Mitsio

Table 3.5: average rainy days for month in Nosy Mitsio

Month	Average Rainy Days
January	21
February	18.5
March	16
April	10
May	6
June	6
July	4.5
August	5
September	5
October	7
November	12
December	17
Total/year	128

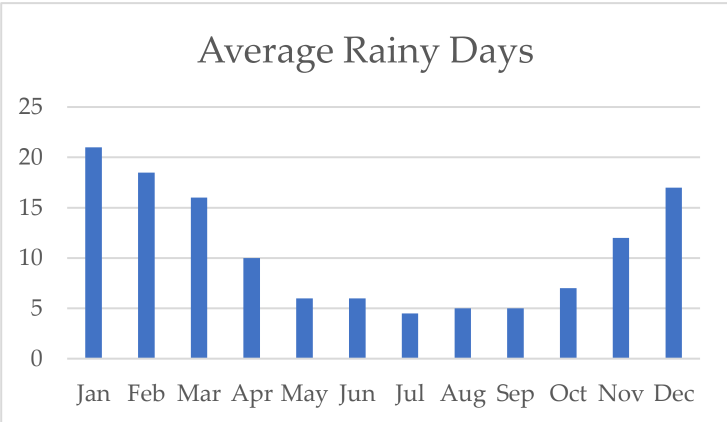


Figure 3.5: Average monthly rainy days in Nosy Mitsio

From Table 3.3, Table 3.4, Table 3.5, and the respective Figure 3.3, Figure 3.4, and Figure 3.5 it is possible to assume that:

- The maximum temperature fluctuates from 31°C in November to a minimum of 29°C in August while the minimum temperature goes from 22°C in December to 18°C in June and July. Comparing Figure 3.1 and Figure 3.3 it can be observed that temperatures in Nosy

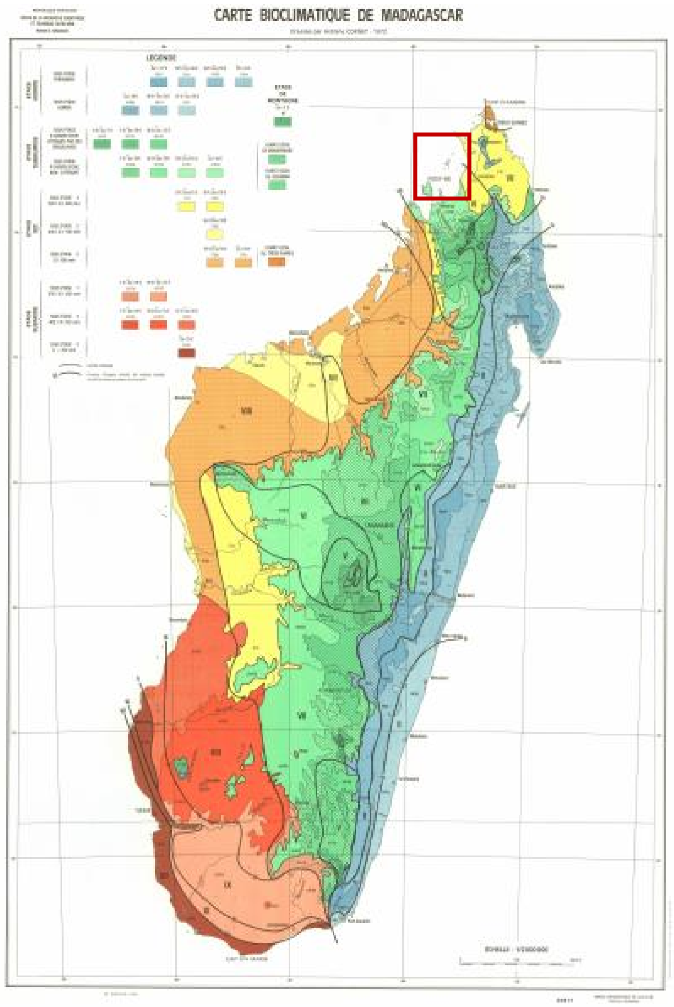
Mitsio are higher than the average temperatures in Madagascar, but they have the same trend.

- Rainfalls are concentrated between October and April (rainy season) while are scarce from May to September (dry season). Rainfall peak is in January with 485.5 mm of rain and the minimum is 34 mm of rain in August. Also, in this case, rainfalls in Nosy Mitsio follow the Madagascar rainfall trend but, during the rainy season, rainfalls are heavier and, in the dry season, are lower than the average. The total amount of rainfall in a year is about 2000 mm, but to be conservative, the rainfall in a year in Nosy Mitsio will be considered in a range of 1000-1500 mm.
- Rainy days trend follows the rainfall trend. During the rainy season, it rains for more than half a month, and in the dry season, it rains only for about 5 days. The total rainy days are 128 days, more than 1/3 of the days in a year.

Comparing the temperature and the rainfall in Madagascar in Figure 3.1with the temperature and rainfall in Nosy Mitsio in Figure 3.3 and Figure 3.4 it's possible to notice that the meteorological events in Nosy Mitsio are accentuated compared to the rest of Madagascar. It can be explained by the fact that Nosy Mitsio is an island in the tropical range: rainfalls are consistent, and temperatures are higher than temperatures in the highland (e.g., Antananarivo area). Besides, temperatures are moderately hot all year long thanks to the mitigation effect of the sea. The huge amount of rain during the rainy season causes several mudflows all over the island. They are clearly visible from the satellite images. In Figure 3.6 is shown as an example of the area interested by mudflow in Ampanitsoha village.

Figure 3.6: Area interested by the mudflow in Ampanitsoha

The cartography of Madagascar has been investigated to found more information about climate and to confirm the previous assumptions. The result is a Bioclimatic map of Madagascar in Figure 3.7 (Cornet, 1972). In this map, Madagascar is divided into four climatic areas, from the most humid area to the most arid one: the sub-arid zone, the dry zone, the sub-humid zone humid one. Each area is also divided into subareas according to the range of average temperature and average rainfall. On the map, some curves indicate the numbers of the rainy month. Nosy Mitsio is not classified, but its subarea can be assumed the same as the near island, Nosy Be. In this way, it is recognised that Nosy Mitsio is in a sub-humid region with a not attenuated dry season, with an average temperature of over 16°C, and rain for six months a year. Comparing the near island of Nosy Be to the coast area at East of Nosy Mitsio, can be noticed that the coast is classified as an arid region with average yearly rainfall in the range of 400-700 mm and with an average temperature between 16 and 18 °C. From this data, can be assumed that the average yearly rainfall in Nosy Mitsio is higher than the average rainfall on the coast. This consideration supports the assumption of an average yearly rainfall of about 1000-1500 mm in Nosy Mitsio.



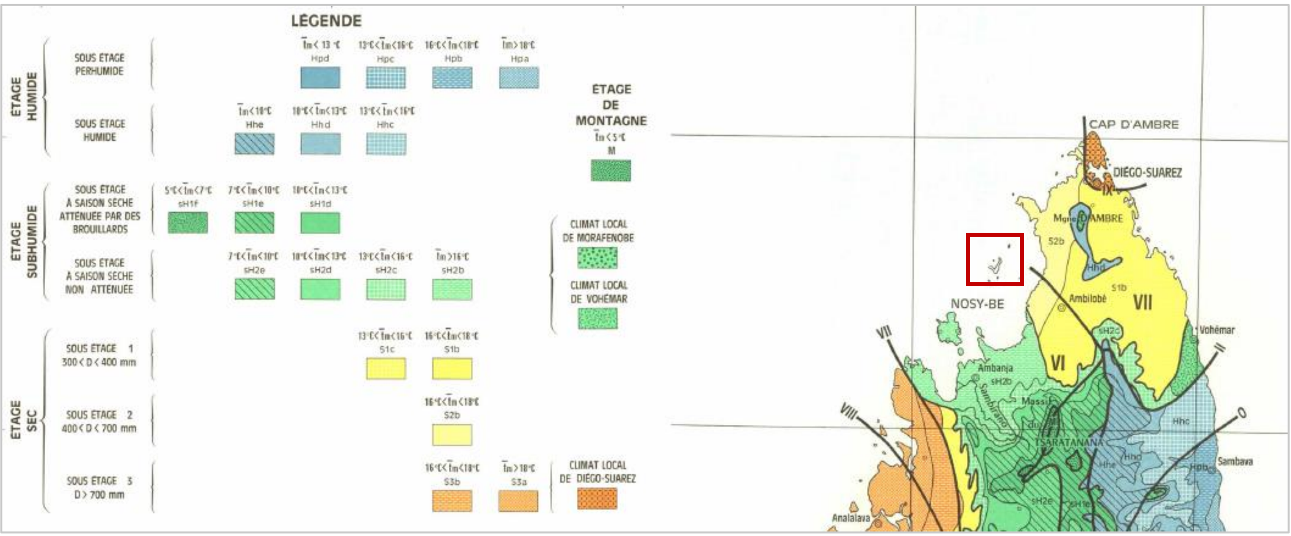


Figure 3.7: Bioclimathic map and focus on Nosy Mitsio (Cornet, 1972)

3.2 The hydrogeological characterization

The geological composition of Nosy Mitsio consist of:

- a volcanic bedrock (Groundwater resources in Africa, 2019);
- an Acid and Basic Plutonic rocks (intrusive igneous rocks) and Mixed sedimentary rock as lithological composition, as supposed by the lithology of Nosy Be and the other areas with a volcanic basement (Igrac International Groundwater Resources Assessment Centre, 2020);
- a lateritic coverage (Igrac International Groundwater Resources Assessment Centre, 2020)

The same information has been found in the historical cartography of Madagascar (Vieillefon and Bourgeat, 1965) in Figure 3.8.

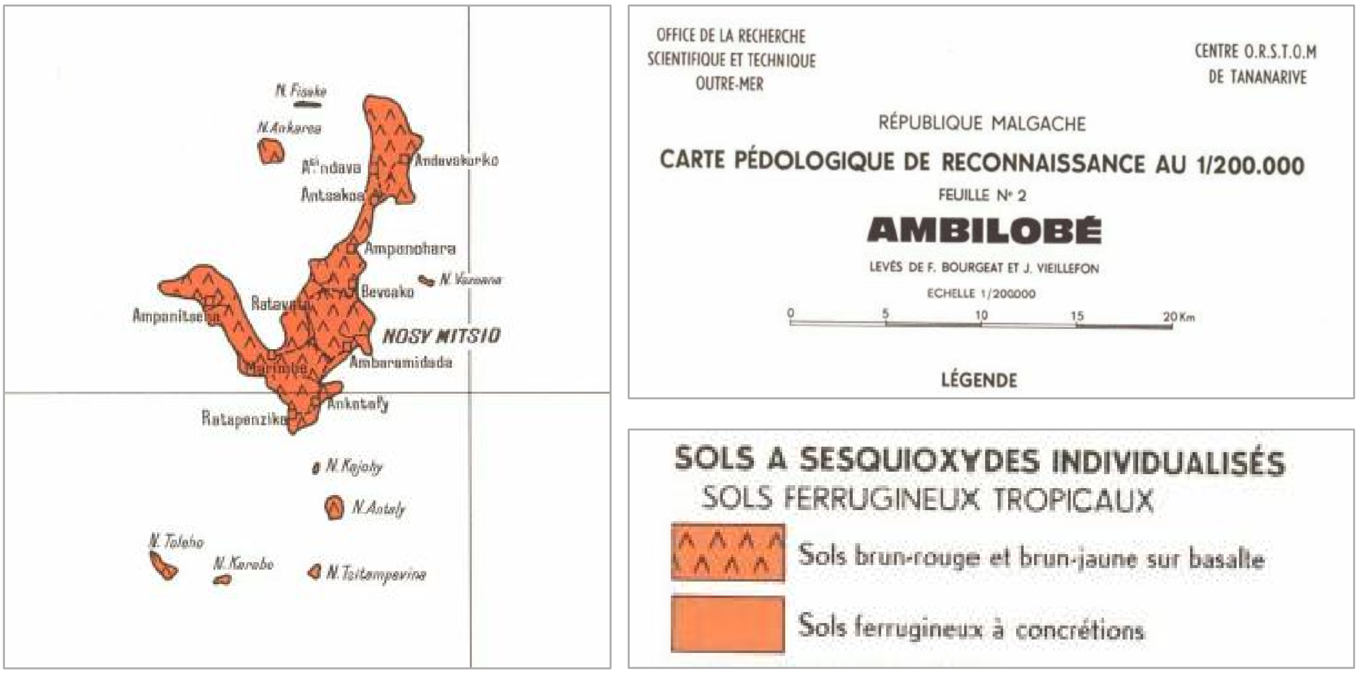


Figure 3.8: Carte Pédologique de Reconnaissance au 1/200.000 Feuille no. 2: Ambilobè (Vieillefon and Bourgeat, 1965).

Ferralsol, also known as ferralitic or lateritic soil, is soil with a low nutrient content due to the rainy regions weathering. The ferralsol covers around 10% of Africa and it is widespread in Central, Eastern, and Southern Africa, besides the north and east coast of Madagascar. Because of weathering, ferralsol is a leached soil with a very low content of nutrients, as calcium and magnesium, and a high content of aluminium and iron oxides (European Commission, Joint Research Centre, European Soil Data Centre (ESDAC), 2020). The quartz is the only primary mineral present and as secondary minerals, there is a combination of kaolinite, gibbsite, goethite, and hematite. This type of soil has a low cation exchange capacity and a high anion absorptive capacity. The ferralsol appears red and patchy yellow-red, but in the upper layer is present a humus horizon (IUCN/UNEP/WWF, 1987), thanks to luxuriant vegetation, with a percentage of humus in the range from 1-1.15 to 8-10; this confers a black colour to the soil. In general, the structure of the middle zone shifts from the humus to the parent (The Great Soviet Encyclopedia, 2021).

In this soil can be very commonly found fluorine and arsenic in high quantity, which can be transferred to the water (Emeh et al., 2019). Fluorine can be very dangerous for the skeletal apparatus and the teeth. Arsenic can have a cancerogenic effect on humans because of long-term exposition. For the WHO (World Health Organization) the maximum concentration of arsenic in water is 10 μ/L. To know fluorine and arsenic concentration in water and soil, it will be necessary to do a water and soil laboratory analysis. The leaching process needs a low pH and basic parental material (as basalt) with a high content of aluminium and iron oxides but with a low content of silica. The binding of soil particles with iron oxides makes the soil apparently sandy or silty (pseudo sand). Clay content and texture are relatively constant thanks to the mixing done by biological activity (Emeh et al.,2019).

Ferralsol is a good soil for the growth of local vegetation as coconut palms, but its plantation can be difficult. In fact, this soil has a low pH, which combined with iron and aluminium oxides, fixes the phosphorus fertiliser, and doesn't allow the phosphorus plant consumption. The natural vegetation grows thanks to a self-sustaining nutrient cycle. If the cycle is modified with, for example, caused by deforestation or the exportation of agricultural products, the soil loses its fertility and can be subjected to degradation as erosion (European Commission, 2013).

The dissolution of aluminium and iron oxides in lateritic soils mainly depends on the rainfall and/or runoff water pH. If the pH becomes basic or acid the dissolution of these oxides increases. Water percolation from the ground surface to the aquifer level can pollute the groundwater, compromising its use as a source of potable water (Emeh et al., 2019). Water contamination is caused by two main anthropogenic activities:

- Industrial activities that release sulphates and nitrates (SO4- e NH3-); these substances make the water acid;
- Production and usage of fertilizers disperse ammonium (NH4+) that makes the water basic.

The study of Emeh et al. (2019) results that Al and Fe are more soluble in a basic solution than in an acid solution and iron is more soluble than aluminium; moreover, on Nosy Mitsio there are no industrial activities. For that, it is important to understand if fertilizers will be used in vegetable gardens and, in case, which types. The EPA (Environmental Protection Agency of the United States) allows a limit of 0.2 mg/dm^3 of Al and a limit of 200 μm/L of dissolved Fe in drinking water. If these limits are overcome, the consequences for human health are Alzheimer, memory loss, Iron toxicosis. Also, it has been found that a high level of aluminium induces the stunted growth of plants and the death of fish. To understand if the aquifer is polluted, it can be useful to investigate if diseases and plants' and fishes' intoxications have never occurred, thanks to the help of the local population.

From the European Commission, Joint Research Centre, European Soil Data Centre (ESDAC) (2020) it is possible to give a first approximated value of the main Nosy Mitsio's soil characteristics:

- Soil pH from acid to very acid; would be useful doing a field test on water pH;
- Clay content of 20-30%;
- Silt content of 30-40%;
- Sand fraction of 45-60%
- Gravel content 1-10%
- CaCO3 (calcium carbonate) content of 0%; this data indicates the distribution of lime bearing rocks. The application of lime to acid soils can raise pH values and allow the cultivation of additional crops.
- CEC (Cation Exchange Capacity) from 4 to 20 cmol/kg;
- Base saturation of 20-50%; measures the sum of exchangeable cations as a percentage of the overall exchange capacity of the soil. It often shows a near-linear correlation with pH;
- WSC (Water Storage Capacity) > 150 mm/m;
- Water infiltration moderate well-drained;

The aquifer category is supposed to be igneous; the aquifer type could be an igneous extrusive aquifer composed of basalt (Groundwater resources in Africa, 2019) (Earthwise, British Geological Survey, 2020). This aquifer type is common in the north of Madagascar, where the basalts compose fractured aquifers usually unconfined and can support very large springs. The approximated productivity could be moderate to high which means productivity is in the range of 2-20 l/s (moderate 2-5 l/s, high 5-20 l/s). The borehole yield depends on the local distribution of fractures, but generally, the maximum yield observed is 7 l/s. Volcanic aquifers' groundwater is typically low in mineralisation but occasionally can be brackish to salty (British Geological Survey, 2019). More data about the aquifer can be kept from geological maps of the BGS British Geological Survey (2020). Because Nosy Mitsio is a little island and very often is not represented in the maps, information about the aquifer was given by the near Antsiranana area (north of Madagascar), which has the same type as Nosy Mitsio's aquifer. The groundwater storage could be about 10.000-25.000 mm water depth (10-25 m of water depth). The estimated depth of the aquifer is 7-25 mbgl (meters below ground level), like countries in the sub-tropical band. The aquifer saturated thickness could be about 25-100 m (Figure 3.9).

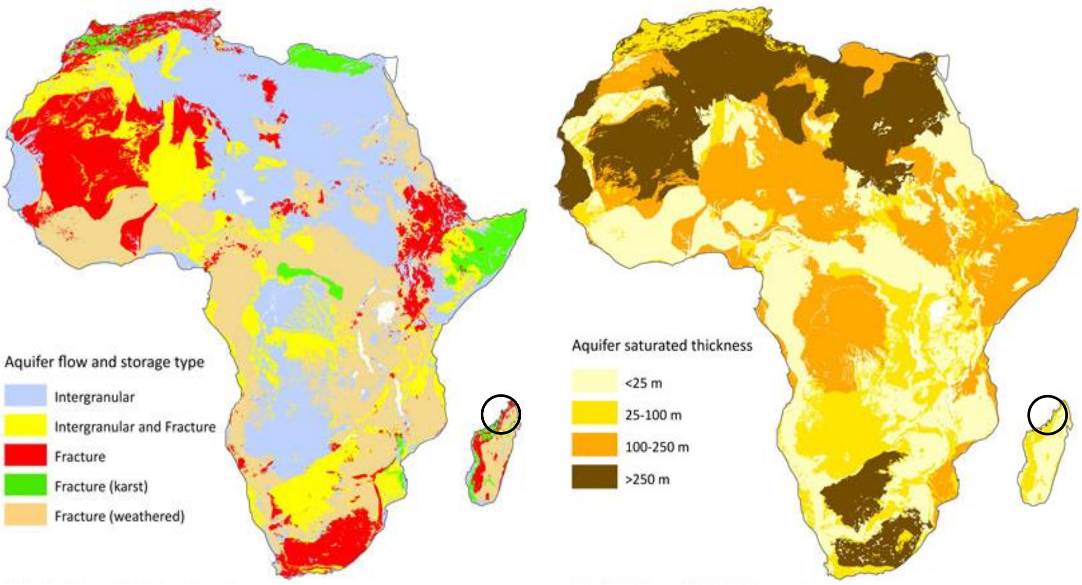


Figure 3.9: African thematic maps: Aquifer flow and storage type (on the left) and Aquifer saturated thickness (on the right) (BGS British Geological Survey 2020)

The hypothesis that the bedrock may be composed of fractured basalt in which water accumulates can be partially confirmed by photos from the island and the various natural water rises scattered throughout the area. The presence of basalt on the island is confirmed by the basalt wall shown in Figure 2.2. As far as the accumulation of water is concerned, it can be assumed that due to the heavy rainfall in the wet season, water enters through the first layer of soil until it reaches the fractures created by the basalt, where thanks also to the possible presence of clay, the water tends to accumulate and does not descend any deeper. Once accumulated underground, the water is likely to be in a pressure layer that causes it to rise to the surface. It has also been found that the wells on the island, although shallow, have always had a certain level of water in them and the water supply system has always been able to carry the required water even during the dry season. These observations suggest that there is a significant accumulation of water due to both heavy rainfall (1000-1500 mm/year) and good fracturing of the rocky substrate. Figure 3.10 represents some fractured basaltic rocks with a clay cover from which water escapes, near to the water catchment in Ampanitsoha.

Figure 3.10: Water escapes from fractured basaltic rocks with the presence of clay near the water catchment in Ampanitsoha.

3.3 Sample analysis

At the start of December 2020, there was an expedition in Nosy Mitsio, conduct by a volunteer of Kukula. The original reason for the expedition was to make a census of the local population, to know how many families there are in Bevaoko and Ampanitsoha and the physical characteristics of members as age, gender, height, and weight. These data will be used to understand if the population is malnourished and to decide at which families giving the management of the garden. The expedition also represented the opportunity to collect other information about Nosy Mitsio. With the team of Kukula and H4O has been decided to taken GPS data and water and soil samples, and was planning how and when to collect data and samples. At first, to identify the right source which will provide water for the gardens in Ampanitsoha, different water sources were identified. At the start of the water source research, the well named VMASK was the favourite one because it was near the gardens area and because the water of this well was already used by a local family of ten people as drinking water and other purposes: this was a first indicator that the water could be used as irrigation water. Unfortunately, the well owner was not favourable to share the well with the rest of the village, and for this reason, the well VMASK was not selected. Instead, another water source was considered, located near the village. It is a natural spring, and its water is already used by the population for any use. At a local level, the spring is known by the name of "Plastic", but in this work, it was renamed as Water Source 2 (WS02). The WS02 is in direction north-east respect to Ampanitsoha East, and it is about 466 m of distance from the village.

The local population participated actively in the data collection. The local collaborators of H4O went with the Kukula volunteer along the paths taking the GPS data; they also indicated the different wells and ponds for the samples collection. The locals were fundamental to get in touch with the Institute Pasteur, where the water sample analysis was done, and to communicate with the institute. The locals participated in the census, giving the necessary data for the vegetable gardens design.

3.3.1 Nosy Mitsio expedition

With the team of H4O and Kukula was discussed which kind of sample could be taken on the island. The first requirement was that the samples had to be easy to collect and to transport. To know the altimetric profile of Ampanitsoha and the area around the village, were collected GPS data with a simple GPS electronic device. The altitude was recorded along some specific paths: from the WS01 to the village, from the WS02 to the village, and around different areas as in Figure 3.11. The area in yellow was the first selected for the gardens before the expedition, but, during the expedition, was thought that the area with the perimeter in light green another area could be more suitable to host the gardens. The area in dark green, defines the position of the coconut forest where Ampanitsoha is placed.

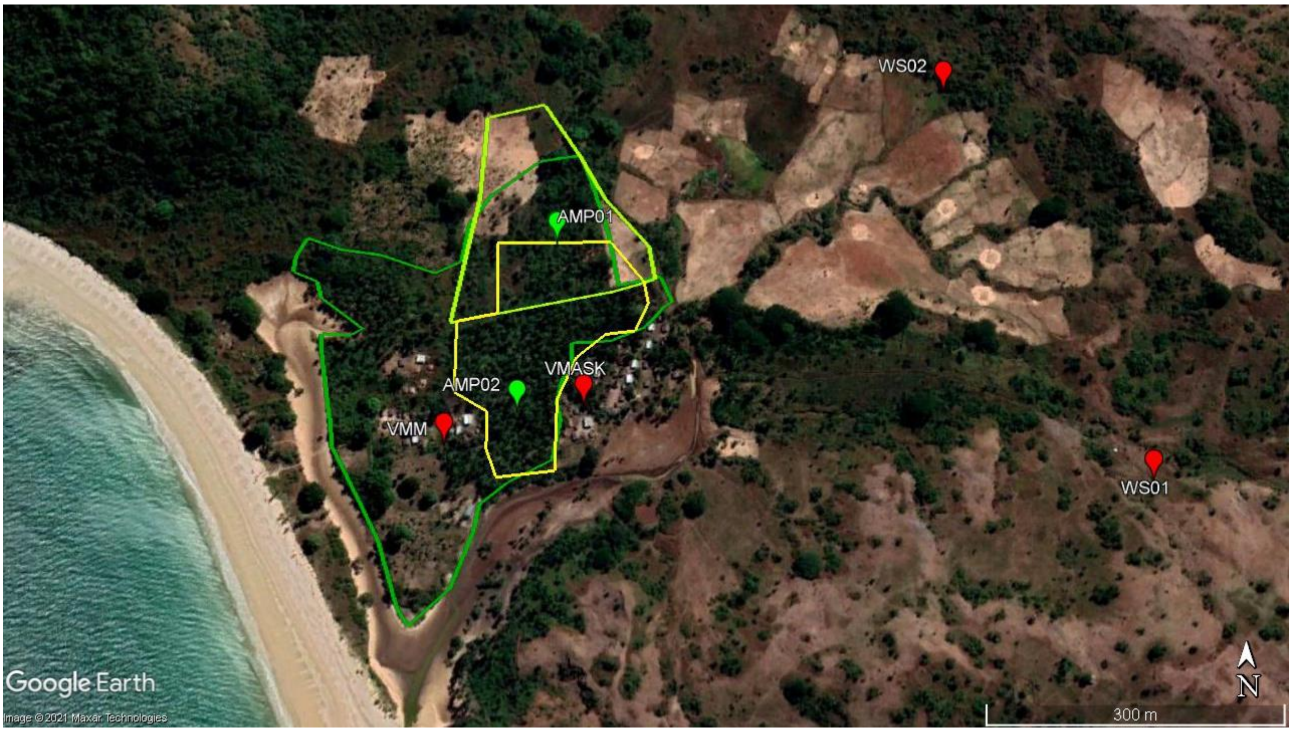


Figure 3.11: The data and samples kept in Ampanitsoha: VMM, VMASK, WS02, WS01 water samples (in red), AMP01 and AMP02 for the soil samples (in green); the first and the second area for the gardens (in yellow and light green) and the coconut forest (in dark green)

Also, were collected samples of water and soil. Water samples have been taken in four points in Ampanitsoha: WS01, WS02, VMM and VMASK (Figure 3.11). These points were chosen because they are strategic in providing water to the population. The VMASK provides water to a family of ten members; the VMM well is not used by the population; the WS01 provides drinking water and the WS02 has been identified as the possible water source for the gardens. For each point, were collected two samples of 0.5 l: one to be analysed at the Institute Pasteur de Madagascar, one to be brought in Italy, and analysed at the Politecnico di Torino. The water analysis was done to know its quality as drinking and irrigation water. The drinking water from WS01 and VMASK has never been analysed, and it is important to know if it respects the threshold values. The water analysis of the VMM, was done to understand if the water is not consumed because some parameters are over the threshold values or for the superstition of the population. Finally, the water of WS02 was analysed to evaluate its suitability as irrigation water. Together with the water sample, at each point were recorded the pH, the temperature, and the Total Dissolved Solids (TDS). Soil samples were collected taking 0.5 kg of the first 20-30 cm of soil in four points, two in Ampanitsoha (identified as AMP01 and AMP02), two in Bevaoko (identified as BVK01 and BVK02), in the area in which the gardens should be located. Soil samples are necessary to know the granulometric composition of soil and its behaviour in contact with water. This information will be useful to decide in which areas will be made the gardens. At least, was asked to measure the depth of the wells VMM and VMASK and the water depth level inside of them to give an idea of the underground water distribution.

3.3.2 Water analysis

TDS and pH parameters and the corresponding temperature were collected at the points WS01, WS02, VMM, and VMASK. Each parameter was recorded three times to obtain a mean value. TDS and pH values were recorded with a conductivity meter and a pH meter respectively. In Table 3.6 is reported, as an example, the value of pH, temperature, and TDS for the Private well. The parameters of the other points are in Appendix 2.

Table 3.6: values of pH, TDS, and temperature at Private well

Private well (Pozzo Mamatsiaka) (VMASK)			
Hour and date: 9.56 03/12/20			
Ph1	8.16	T1 (°C)	30.9
Ph2	8.1	T2 (°C)	31.1
Ph3	8	T3 (°C)	34.5
Mean	8.09	Mean	32.17
St. Dev.	0.08	Dev.st.	2.02
TDS1 (ppm)	335	T1 (°C)	32.3
TDS2 (ppm)	319	T2 (°C)	32.4
TDS3 (ppm)	331	T3 (°C)	32.7
Mean (ppm)	328.33	Mean (°C)	32.47
St. Dev.	8.33	Dev.st.	0.21

At the Institute Pasteur were analysed the following parameters: temperature of conductivity with a probe, electrical conductibility, and nitrite, following the french standard NF EN 27888 and NF EN 26777 respectively. Chloride, iron, fluoride, calcium, magnesium, potassium, and sulphite were measured with the method of visible spectrophotometry. Hydrogen carbonates were derived through calculations. The threshold values reported in "Water quality for agriculture" (FAO, 1994) were used to evaluate the quality for the most parameters; also was considered the limits in "Metodi di analisi delle acque per uso agricolo e zootecnico" (Ministero agricolo delle politiche forestali, 2011) for nitrate.

Table 3.7: Results of water analysis at the Institute Pasteur and threshold values

Parameter	Well				Degree of Restriction to use			Usual range in irrigation of water	Recommended Max Conc. (mg/l)
	WSO1	WSO2	WMM	VMASK	None	Slight to Moderate	Severe		
T of conductivity (°C)	20.50	20.50	20.70	20.50	-	-	-	-	-
EC at 25°C (µS/cm)	307	258	599	676	<700	700-300	>3000	0-3000	-
TDS (ppm)	180.83	82.60	238.67	328.33	<450	450-2000	>2000	0-2000	-
Chloride (meq/l)	0.584	0.327	0.623	1.416	surface irr. <4	4-10	>10	0-30	-
					sprinkler <3	<3	-	-	-
Iron (Fe) (mg/l)	<0.05	<0.05	<0.05	<0.05	-	-	-	-	5
Fluorides (F) (mg/l)	1.1	1.0	2.5	1.1	-	-	-	-	1
Hydrogen carbonates (in HCO3-) (meq/l)	2.10	1.40	3.99	3.89	<1.5	1.5-8.5	>8.5	0-10	-
Nitrite (mg/l of NO2)	0.2	0.4	<0.1	<0.1	-	-	-	-	2
Arsenic (mg/l)	<0.01	<0.01	<0.01	<0.01	-	-	-	-	0.1
Calcium (mel/l of Ca)	1.337	0.938	3.833	4.851	-	-	-	0-20	-
Magnesium (meq/l of Mg)	0.58	0.004	2.39	0.58	-	-	-	0-5	-
Potassium (K) (mg/l)	1.5	3.6	0.2	3.4	-	-	-	0-2	-
Sulphite (mg/l of SO3)	11.3	8.2	9.5	5	-	-	-	-	-
pH (mean value)	8.60	9.21	8.30	8.09	<1.5	1.5-8.5	>8.5	6.5-8.4	-

In Table 3.7 the results of water analysis are compared with the limit values. The colours yellow and red, indicate if the parameter is near or over the irrigation threshold value. The only values that overcome the limits are the fluorides at the VMM, the potassium at the WS02 and the VMASK, and the pH at the WS01 and WS02. If parameters overcome the limit values in the section "Restriction on use" in Table 3.7, it doesn't mean that water is unsuitable as irrigation water. A change of 10 to 20 percent above or below the guideline limits has little significance because other factors can affect the yield. Moreover, guideline values are suitable for a semi-arid to arid climate with low rainfall.

For monsoon climate areas, as Nosy Mitsio where precipitation is high, the guidelines restriction is too severe (FAO, 1994). This can justify the value of fluoride and potassium. These values are a little bit over the recommended maximum concentration or usual range, so they don't represent a hazard for irrigation water. Also, the water source chosen to be the source for irrigation water (WS02) overcame only the limit value of potassium.

For what concerns the high value of pH, it can be justified by the low salinity water (ECw < 200 μs/cm). Low electrical conductivity can cause pH values outside the normal range since water has a very low buffering capacity. In this case, water doesn't cause problems to the crops but can be corrosive for the pipes and other irrigation equipment. For WS01 the EC is slightly over 200 μS/cm (307 μS/cm) but the pH value is very near to the threshold value (8.6 instead of 8.5). At WS02, EC is very near to the limit value of 200 μS/cm and that can justify the high value of pH (9.21). Instead, the EC values of VMM and VMASK are higher than 200 μS/cm and the pH is in the usual range for irrigation water. So, it is possible to assume that these abnormal values of pH don't represent a problem for irrigation. In any case, water with abnormal pH can affect slowly the soil. It is easier to correct the soil pH instead of correcting the water pH: for pH high value, it is recommended the use of sulphur or other acid material to correct the soil pH. Gypsum can be very effective in reducing high soil pH (FAO, 1994).

The water sample has been analysed in Turin. The parameters analysed were the metals and the major elements. The major elements are and shown in Table 3.8 and Table 3.9 and in Figure 3.12 the result are shown graphically.

Table 3.8: Major elements analysis results in mg/l

Sample	Sodium	Potassium	Calcium	Magnesium	Chloride	Sulphate	Carbonate	Nitrate
				mg/l				
VMASK	27.857	2.452	50.323	10.470	48.248	16.372	169.098	10.771
VMM	13.748	0.404	30.915	25.766	19.544	14.529	183.973	24.909
WS01	20.467	0.605	11.611	13.128	18.709	1.319	121.788	0.864
WS02	24.918	1.599	9.816	4.666	10.394	2.078	96.883	4.599

Table 3.9: Major elements analysis results in meq/l

Sample	Sodium	Potassium	Calcium	Magnesium	Chloride	Sulphate	Carbonate	Nitrate
				meq/l				
VMASK	1.212	0.063	2.511	0.861	1.361	0.341	2.771	0.174
VMM	0.598	0.010	1.543	2.120	0.551	0.302	3.015	0.402
WS01	0.890	0.015	0.579	1.080	0.528	0.027	1.996	0.014
WS02	1.084	0.041	0.490	0.384	0.293	0.043	1.588	0.074

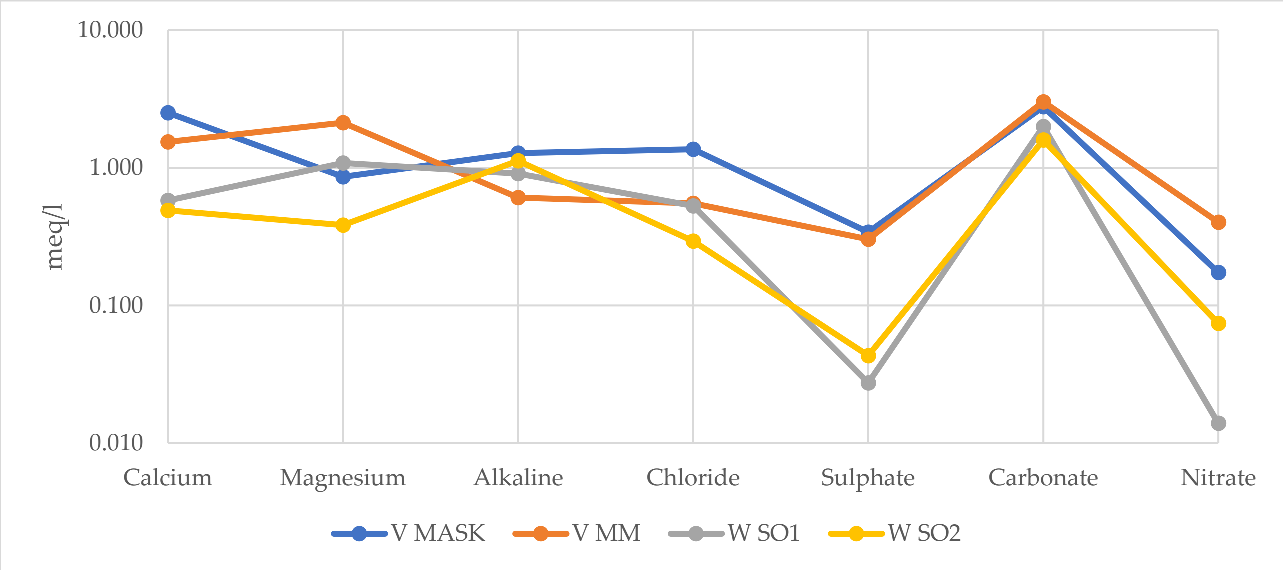


Figure 3.12: Major elements trend per sample

Looking at Figure 3.12 is possible to assume that:

- VMASK has a facies calcium bicarbonate with sub-facies alkali-chloride. This is the sample with the higher alkali-chloride component: it indicates a consistent sea-water intrusion. This well is one of the rural well more used by the local population: the huge water extraction could be responsible for the water-sea intrusion.
- VMM has a facies calcic-magnesic bicarbonate with an alkali-chloride component. It is present a sea-water intrusion, lower than the intrusion in VMASK. It can mean that the population doesn't use the water of this well as potable drink water for a local belief. Have to be taken into account that if the water will be extracted by this well, a sea-water intrusion can be induced, reaching the level of VMASK.
- WS01 has a facies calcic-magnesic bicarbonate with alkali-chloride component and a low amount of sulphate. Also, in this case it is present a sea-water intrusion;

- WS02 has a facies magnesic-calcic-alkali-bicarbonate. There is a presence of sodium chloride but can be attribute to the sea aerosol and not a sea-water intrusion.

Looking at Table 3.10 can be noticed that the arsenic is over 10 μg/l for all the samples except for WS02, which has a value very near to 10 μg/l. The strontium is elevated in VMASK and VMM. There is no presence of cadmium, cobalt, chromium, molybdenum, nickel, antimony, zinc in any sample. There is no presence of iron, except for the sample WS01 , probably due to the iron precipitation before the samples analysis. Comparing the limit values in the major elements and the metals don't overcome the limit value in Table 3.7 so it is confirmed that the water is suitable for the irrigation use.

Table 3.10: Metal analysis results for the samples.

Element	VMASK	VMM	WS01	WS02
	μg/l			
Al	22.245	3.266	6.337	0.000
As	10.453	10.358	10.704	9.785
Ba	12.650	5.044	18.880	11.771
Be	0.000	0.000	0.000	0.000
Cd	0.000	0.000	0.000	0.000
Co	0.000	0.000	0.000	0.000
Cr	0.632	2.295	0.682	0.106
Cu	0.000	0.000	0.000	1.548
Fe	0.000	0.000	0.885	0.000
Hg	7.122	7.477	7.892	7.619
Mn	0.224	0.011	0.164	0.304
Mo	0.000	0.000	0.000	0.000
Ni	0.000	0.000	0.000	0.000
Pb	0.380	3.450	0.000	0.000
Sb	0.000	0.000	0.000	0.000
Se	22.687	24.994	30.524	31.272
Sn	1.090	1.245	0.721	0.783
Sr	2377.990	9583.961	256.392	162.342
Te	11.245	16.078	13.679	27.515
Tl	27.781	0.000	3.986	13.994
V	0.000	0.000	9.521	0.000
Zn	0.000	0.000	0.000	0.000

For what concern the well and the water level depth the measures were kept at the well VMM and WMASK. The results are in Table 3.11. The measures were kept from the opening of the well, where there is a wall in plastic or in metal, indicated as the well height in the table as in Figure 3.13; the measure of the well depth and the water level depth are considered from the ground level. The thickness of the water inside the well has been calculated as the difference between the well depth and the water level depth.

Table 3.11: Measures kept at the wells VMM and VMASK

Measure	VMM	VMASK
Wall height (m)	0.3	1
Well depth (m)	2.5	1.8
Water level depth(m)	2.2	1.5
Water thickness (m)	0.3	0.3
Altitude (m)	12	14

This data demonstrate that the underground could have a good capacity in water storage. The measures were kept in December, at the start of the rainy season, so the water accumulation due to the new rains was not so consistent, and could be present a water accumulation from the last rainy season. In any case, the water thickness inside the wells was not zero so it could mean that the fractures in the basalt bedrocks are shallows and the underground capacity in store a good amount of water. These observations can in part confirm the literature data in paragraph 3.2.

Figure 3.13: A local keeps the deep of a well

3.3.3 Soil analysis

Soil samples collected in Nosy Mitsio were brought to Italy and analysed at the DIATI laboratory at the Politecnico di Torino. To know the soil composition was made a granulometric analysis of the dry and wet samples.

The procedure started with the samples drying in oven for 30 hours at 100°C and then their cooling to room temperature. After this operation, the first sample was passed in the mortar to reduce the size of the biggest part, composed to the union of the finest material (Figure 3.14).

Figure 3.14: The four soil samples after the drying in oven

The single sample was divided into four smaller samples, through the quartering operation (Figure 3.15). The sample in the top right-hand corner was used for the dry granulometric analysis, the sample in the left-hand corner was used for the wet granulometric analysis, and the two other quarters were put together and set aside in a plastic bag.

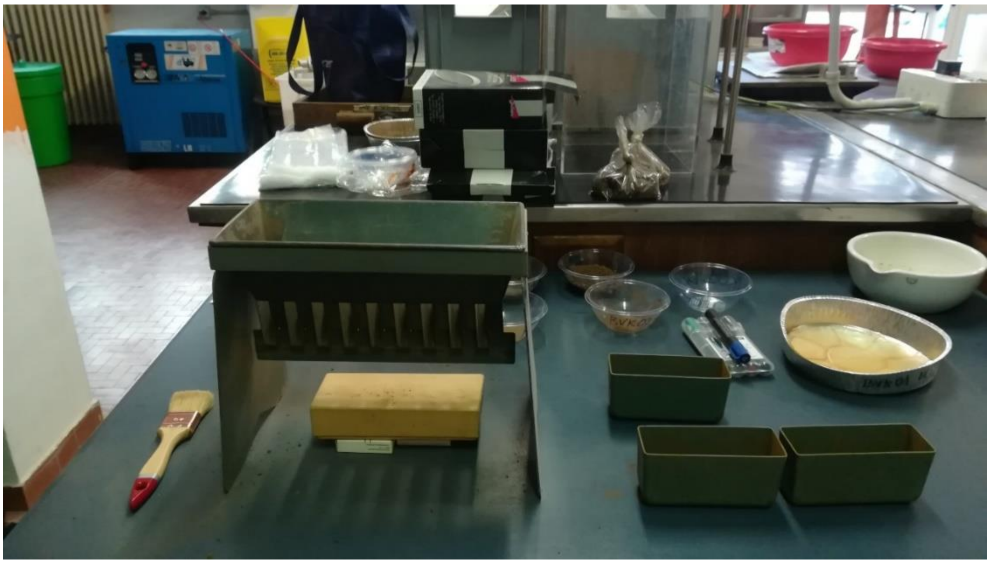


Figure 3.15: The quartering operation

The samples for dry and wet analysis were put in two different plastic bowls. The plastic bowls were previously weighted and then was weighted the sample inside the bowl. In this way was obtained the net weight of the sample.

Figure 3.16: The samples weighing

For the dry granulometric analysis, the soil sample must pass through a set of sieves with different mesh sizes. The sieves are placed one on top of the other, so the sieve with the biggest mesh is on the top and the sieve with the lowest mesh is at the bottom. The sieves, in order from the top to the bottom, are reported in Table 3.12.

Table 3.12: Type of sieves used for the granulometric analysis

Order of sieves	Dimension (μm)	n° of mesh
1	4750	4
2	2000	10
3	850	20
4	425	40
5	250	60
6	106	140
7	75	200
Receiver	<75	<200

The last element in Table 3.12 is a pan called receiver, which collects the soil portion with a size lower than 75 μm. At this time, the sample was poured on the first sieve and the pile of sieves was put and fixed on the plane of a mechanical shaker as in Figure 3.17. The shaker was set for 10 minutes.

Figure 3.17: The sieves on the mechanical shaker

With this system, the vibration from the plane passes to the sieves, and the soil is induced to pass through the mesh. At the end of 10 minutes, was waited some minutes to allow the soil inside the sieves to settle. Then, the portion of soil hold by the sieve was collected and weighted. In this way, was known the retained fraction and the passing fraction. The same procedure was done for the other three samples. In Table 3.13 are reported the sample weights: the total weight is the sum of the sample and the bowl weights, which are both reported in table.

Table 3.13: Weight of the samples before the dry sieve.

Dry granulometric analysis			
Sample name	**Total weight (g)**	**Bowl (g)**	**Sample (g)**
AMP01	125.96	6.93	119.03
AMP02	89.73	6.98	82.75
BVK01	107.67	6.98	100.69
BVK02	100.48	6.93	93.48

Here there are the results for the four soil samples. In each table, and for each sieve, is written the total weight which is the sum of the plastic bow and the sample weight, the plastic bowl weight and the amount of retained and passing fraction. For the sample AMP01 there was some problems during the weighing and the sum of the sample in each sieve was bigger than the sample weigh in Table 3.13. For that the difference between the two weights was divided in three and subtracted from the three bigger samples.

Table 3.14: Results for the sample AMP01 in dry condition

AMP01 – DRY					
n° of Mesh	**Total weight (g)**	**Bowl (g)**	**Retained (g)**	**Retained cumulative (%)**	**Passing (%)**
4	17.15	6.73	10.42	8.75	91.25
10	42.13	6.71	35.29	38.40	61.60
20	38.21	6.9	31.18	64.60	35.40
40	26.8	6.86	19.81	81.25	18.75
60	14.8	7.14	7.66	87.68	12.32
140	15.23	7.1	8.13	94.51	5.49
200	8.42	7.09	1.33	95.63	4.37
F (<200)	12.24	7.04	5.2	100.00	0.00

Table 3.15: Results for the sample AMP02 in dry condition

AMP02 – DRY					
n° of Mesh	**Total weight (g)**	**Bowl (g)**	**Retained (g)**	**Retained cumulative (%)**	**Passing (%)**
4	23.11	6.74	16.37	19.79	80.19
10	29.21	6.71	22.5	46.98	53.00
20	27.67	6.91	20.76	72.08	27.92
40	19.96	6.88	13.08	87.89	12.11
60	12.64	7.3	5.34	94.34	5.66
140	11.03	7.28	3.75	98.88	1.12
200	7.59	7.13	0.46	99.43	0.57
F (<200)	7.43	6.96	0.47	100.00	0.00

Table 3.16: Results for the sample BVK01 in dry condition

BVK01 – DRY					
n° of Mesh	**Total weight (g)**	**Bowl (g)**	**Retained (g)**	**Retained cumulative (%)**	**Passing (%)**
4	33.91	6.73	27.18	27.04	73.01
10	42.67	6.71	35.96	62.81	37.29
20	26.88	6.9	19.98	82.69	17.45
40	15.13	6.86	8.27	90.92	9.24
60	10.95	7.14	3.81	94.71	5.45
140	10.47	7.12	3.35	98.04	2.13
200	7.79	7.1	0.69	98.73	1.44
F (<200)	8.34	7.06	1.28	100.00	0.00

Table 3.17: Results for the sample BVK02 in dry condition

BVK02 – DRY					
n° of Mesh	**Total weight (g)**	**Bowl (g)**	**Retained (g)**	**Retained cumulative (%)**	**Passing (%)**
4	19.4	6.73	12.67	13.55	86.45
10	39.58	6.72	32.86	48.71	51.29
20	31.13	6.9	24.23	74.63	25.37
40	16.94	6.85	10.09	85.42	14.58
60	12.12	7.13	4.99	90.76	9.24
140	12.31	7.09	5.22	96.34	3.66
200	8.29	7.11	1.18	97.60	2.40
F (<200)	9.04	6.89	2.15	100.00	0.00

The wet granulometric analysis consists of a similar procedure. After the quartering, the sample was wetting and leave four days to re-hydrating (Figure 3.18). During this time, the samples were mixed and were eliminated the residual water on their surface.

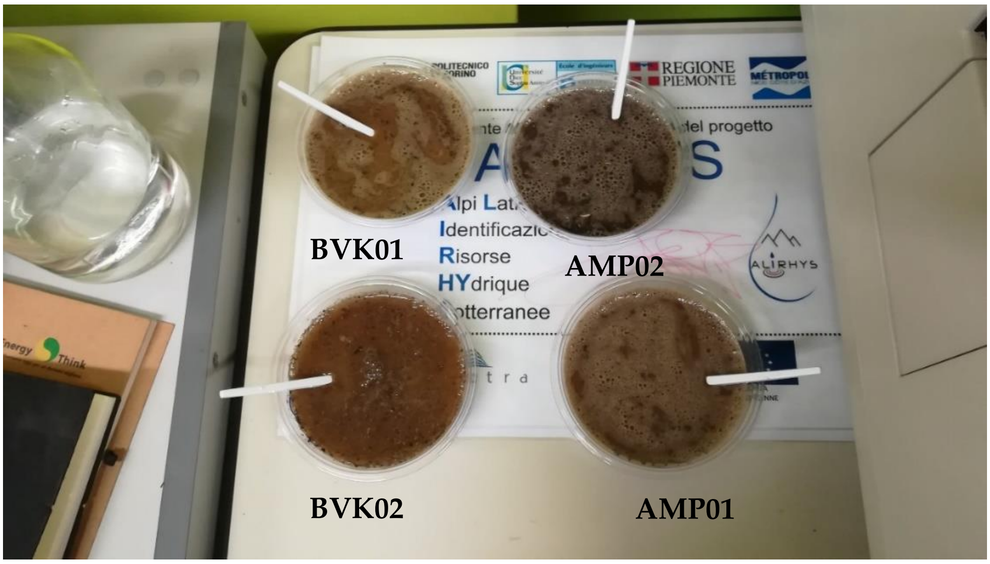


Figure 3.18: the hydrated soil samples for the wet granulometric analysis.

The sieves used were the same as the dry analysis except for the first sieve (4750 μm and 4 mesh) which wasn't used. Sieves were placed as in the dry analysis, but was not used the mechanical shaker. The sample was poured on the first sieve and with water and thanks to a manual mechanical action, the wet soil passed through each sieve. Also in this case, the hold fraction was collected from each sieve and weighted. The fraction which passes through the last sieve (minor than 75 μm) wasn't held. In Table 3.18 are reported the weights of the examined soil samples, while in Table 3.19, Table 3.20, Table 3.21, and Table 3.22 there are the results of the wet granulometric analysis.

Table 3.18: Weight of the samples before the wet sieve.

Wet granulometric analysis			
Sample name	**Total weight (g)**	**Bowl (g)**	**Sample (g)**
AMP01	124.2	6.86	117.34
AMP02	139.73	6.9	132.83
BVK01	146.83	6.9	139.93
BVK02	133.77	7	126.77

Table 3.19: Results for the sample AMP01 in wet condition

AMP01 – WET					
n° of Mesh	**Total weight (g)**	**Bowl (g)**	**Retained (g)**	**Retained cumulative (%)**	**Passing (%)**
10	3.58	3.22	0.36	0.31	99.69
20	4.09	3.22	0.87	1.05	98.95
40	4.99	3.24	1.75	2.54	97.46
60	5.21	3.24	1.97	4.22	95.78
140	6.01	2.1	3.91	7.55	92.45
200	2.87	2.11	0.76	8.20	91.80

Table 3.20: Results for the sample AMP01 in wet condition

AMP02 – WET					
n° of Mesh	**Total weight (g)**	**Bowl (g)**	**Retained (g)**	**Retained cumulative (%)**	**Passing (%)**
10	5.29	3.23	2.06	1.55	98.45
20	6.2	3.23	2.97	3.79	96.21
40	5.83	3.24	2.59	5.74	94.26
60	4.9	3.23	1.67	6.99	93.01
140	8.06	3.23	4.83	10.63	89.37
200	7.13	3.23	3.9	13.57	86.43

Table 3.21: Results for the sample BVK01 in wet condition

BVK01 – WET					
n° of Mesh	**Total weight (g)**	**Bowl (g)**	**Retained (g)**	**Retained cumulative (%)**	**Passing (%)**
10	5.77	2.13	3.64	2.60	97.40
20	4.48	2.11	2.37	4.30	95.70
40	4	2.12	1.88	5.64	94.36
60	2.79	2.07	0.72	6.15	93.85
140	3.71	2.14	1.57	7.28	92.72
200	3.49	2.09	1.4	8.28	91.72

Table 3.22: Results for the sample BVK02 in wet condition

BVK02 – WET					
n° of Mesh	**Total weight (g)**	**Bowl (g)**	**Retained (g)**	**Retained cumulative (%)**	**Passing (%)**
10	5.13	2.16	2.97	2.34	97.66
20	3.56	2.09	1.47	3.50	96.50
40	4.09	2.13	1.96	5.05	94.95
60	3.18	2.12	1.06	5.88	94.12
140	4.8	2.16	2.64	7.97	92.03
200	4.37	2.11	2.26	9.75	90.25

3.3.4 The soil samples results

From the laboratory analysis were derived the following data:

- The weight of the soil sample;
- The retained weight at each sieve;
- The percentage cumulative retained at each sieve;
- The passing weight at each sieve;
- The percentage passing at each sieve.

The results obtained from the dry and wet sieve are different. In soils where the fine fraction is prevalent, it tends to aggregate in bigger particles. If it happens, during the dry sieve the soil distribution will not be correct, because the particles composed of fine material aggregate closing the space of the mesh and don’t pass to the next sieve. With the wet sieve, thank to water and the manual mechanical action, the biggest particles disaggregate in the finest particles, and the soil shows its real composition. The comparing results of the dry and wet sieve are in Figure 3.19, Figure 3.20, Figure 3.21, and Figure 3.22.

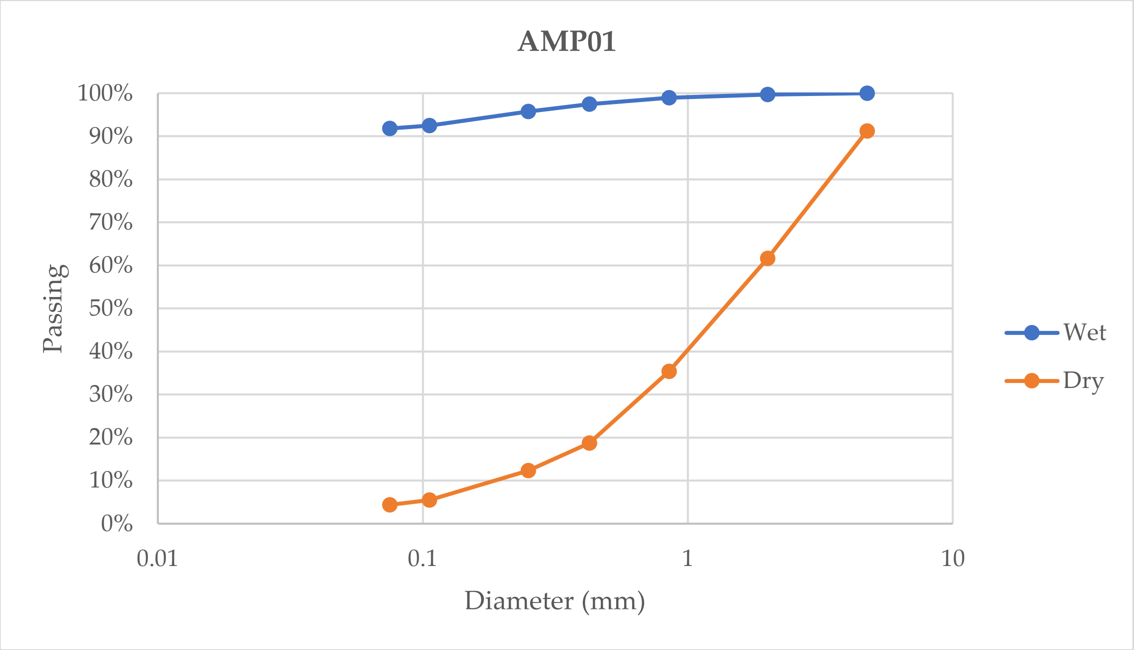


Figure 3.19: Passing fraction at different diameters in dry and wet condition for the sample AMP01

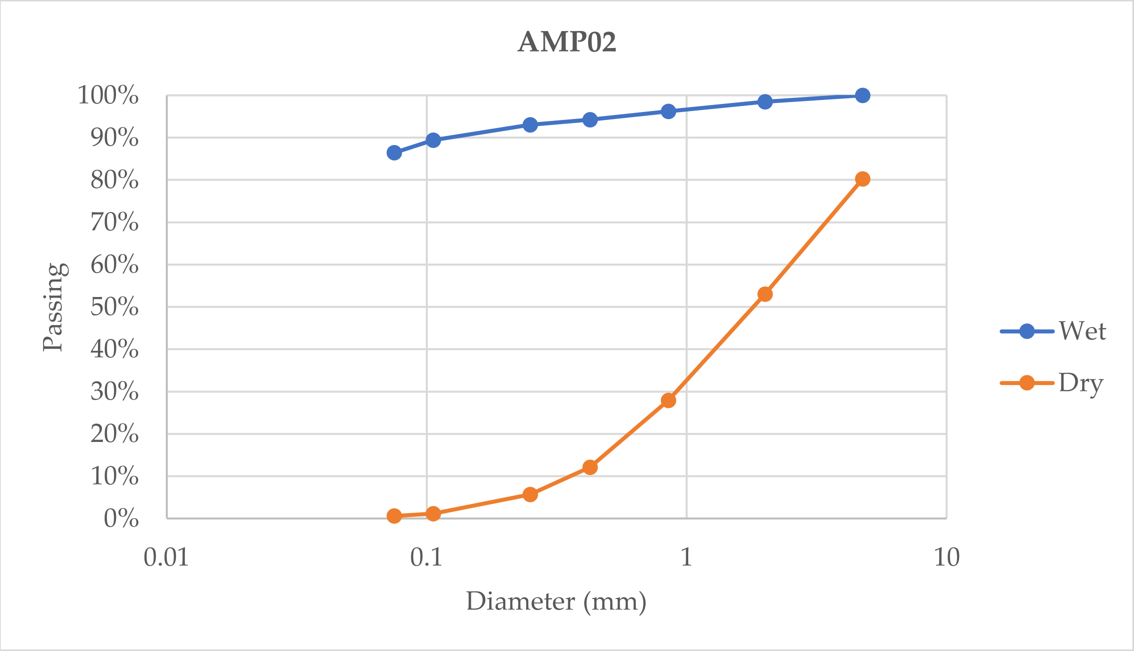


Figure 3.20: Passing fraction at different diameters in dry and wet condition for the sample AMP02

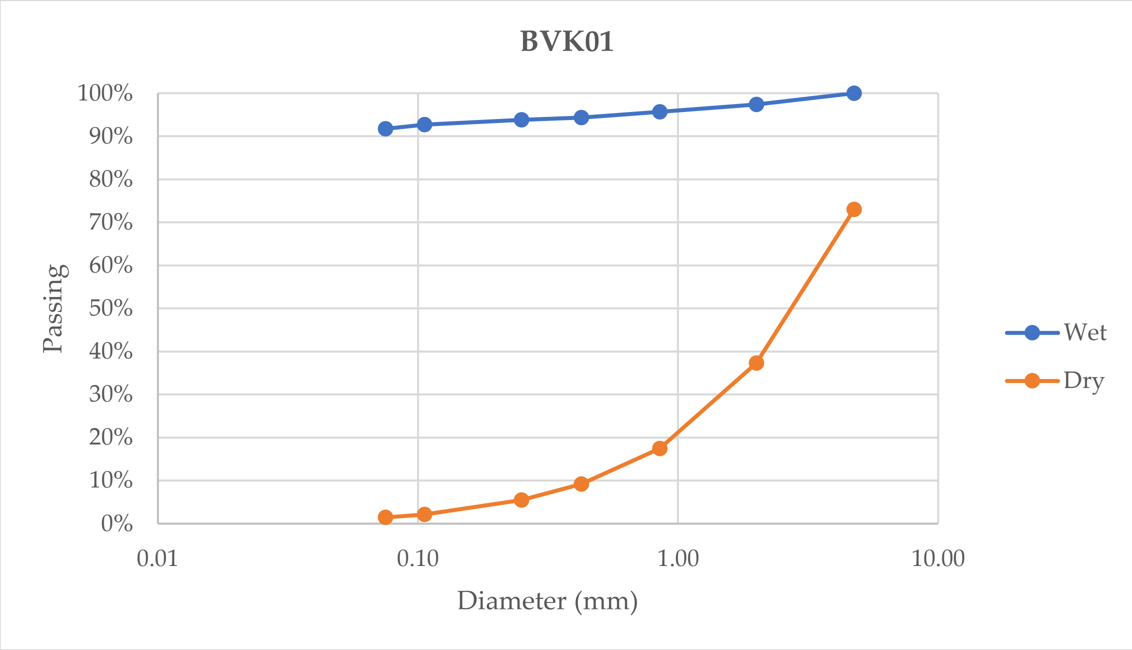


Figure 3.21: Passing fraction at different diameters in dry and wet condition for the sample BVK01

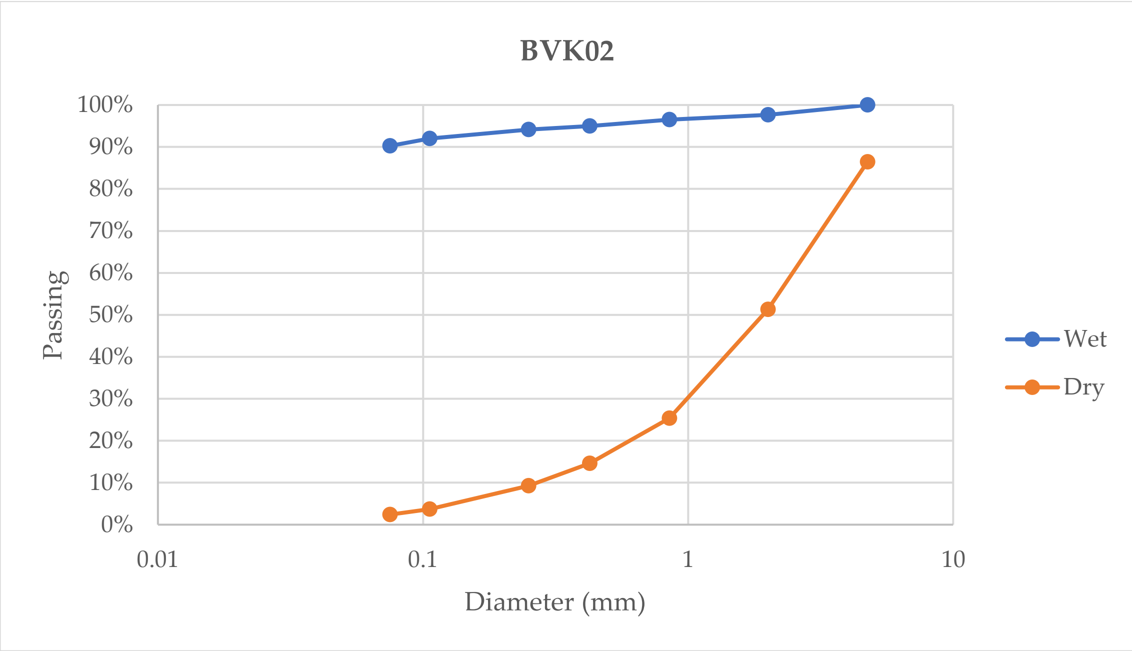


Figure 3.22: Passing fraction at different diameters in dry and wet condition for the sample BVK02

As the figures shows, the wet analysis is more sensitive to the fine particles: as an example, the amount of fine material of the sample AMP01 that passes through the last sieve (0.075 mm) is equal to 91.80% against the 4.37% of the dry sieve. This behaviour was observed also for the other samples as shown in Table 3.23.

Table 3.23: fraction passing the last sieve of 0.075 mm

Fraction passing the sieve of 0.075 mm		
Sample name	**Dry (%)**	**Wet (%)**
AMP01	4.37	91.80
AMP02	0.59	86.43
BVK01	1.44	91.72
BVK02	2.40	90.25

In general, it's possible to assume that if the soil is dry, it can be classified as a sandy soil with a fine material fraction lower than 10% (dimension <0.0 75 mm). If the soil is wet, the fine fraction, composed of clay and silt, is over 90% (except for the sample AMP02 where the clay and silt fraction is the 86.43%). The soil in contact with water has a muddy texture and becomes very compact due to the high amount of silt and clay. For that, it is possible to say that water leaks into the soil for a short time, until the fine fraction absorbs the water, and the soil becomes impermeable. This behaviour explains the occurrence of mud flow during the rainy season.

4 The water supply system design

The last part of this dissertation consists of the basic design of the water supply system which could transport the water from the spring to the gardens. The selected water source is the WS02. The project provides for seven gardens: each garden should be for three-families and with an approximate area of 1635 m^2, for a total area of 11447 m^2. The gardens should be located near the village of Ampanitsoha in an area with coconut forest; the area which respects these characteristics is at the north of the village (Figure 4.1).

Figure 4.1: The selected area for the vegetable gardens and the water source WS02.

The area was selected during the expedition in Nosy Mitsio, and its perimeter was defined keeping GPS points. The selected area is 27600 m^2, bigger than the required area for the seven gardens, because the position of the single garden has not already been chosen. For this, it is an indicative area of reference. Also, in this area was kept the soil samples AMP01. This area is different from the area previously designed to the vegetable gardens, which was bigger and nearest to the village. Thanks to the island expedition it was possible to identify this second better area. For this reason, sample AMP02 falls outside this area.

The vegetables gardens have been designed by the team of Kukula Onlus. The gardens will be located under the coconut forest near Ampanitsoha; the practice of cultivating in fields in which crops, and trees live together is called agroforestry. Agroforestry is a technique known and practiced in the Mediterranean area, Africa, Asia, and South America. It has a lot of advantages with respect to intensive agriculture: sequestering carbon from the atmosphere, bringing up nutrients from deep in the ground, and making agricultural landscapes more resilient. (World Agroforestry, 2021). Agroforestry has different advantages. First, increase the concentration of various nutrients or enhances nutrient cycling improving overall soil quality. This happens especially in tropical areas, where high temperature and rainfall accelerate soil processes, and the soil lost in nutrient. The presences of trees is vital for the realising of nutrient, because fallen leaves and branches contribute to the decomposition of organic matter, re-introducing particles like potassium, calcium, and magnesium in soil. Moreover, tree roots can extract nutrient at deeper soil level and can improving the storage and retention of rainwater in soil (Ospina, 2017). in In the case of Ampanitsoha gardens, the crops could be damaged by the heavy rains during the rainy season and the excessive heat in the dry season, but the coconut forest will protect the crops from both risks. Moreover, it has been noticed that when trees are removed to make room for gardens, the soil loses its layer of humus and loses its natural fertility and humidity. In addition, the rains in the wet season destroy the crops of rice and corn. These facts, bring the local people to abandon the fields to occupy a new piece of land not yet cultivated. Agroforestry can resolve these problems allowing the creation of permanent gardens. Agroforestry provides an opportunity to restore soil quality and nutrient cycling, helping the local farmer to increase the crop production (Ospina, 2017).

The gardens water demand was given by the agronomist of Kukula in collaboration with the nutritionist of the University of Pavia - Laboratory of Dietetics and Clinical Nutrition, Department of Public Health, Experimental Medicine and Forensic Medicine. The data was obtained through the census of four different families in Ampanitsoha: each member gave its gender, age, height, and weight. Thanks to the data, the nutritionists calculated the daily Required Energy Intake (REI) for each family and was supposed that the gardens could provide for 20% of the REI for each person. It was assumed that the REI was composed of macronutrients in the proportion of 55% of carbohydrates and 15% of proteins, and in this way were calculated the grams of each macronutrient that each garden could provide for each family. Knowing the total amount of vegetables that the gardens should give, different crops were selected, and the total water demand was calculated. As a first approximation, it was calculated that each garden requires 668 m^3 of water in one year, and the total amount of water for the seven gardens is 4675 m^3 in one year; the required water in one day is 12.81 m^3, approximated to 13 m^3/day. The data are reported in Table 4.1.

Table 4.1: Gardens data and water demand.

Number of gardens	7
Families served	21
Area of each garden	1635 m^2
Gardens total area	11447 m^2
Water demand for one garden in one year	668 m^3/year
Water demand for all gardens in one year	4675 m^3/year
Water daily demand for all gardens	13 m^3/day

The water amount was calculated considering that gardens required water in the same way for all the year. That is not the real situation, indeed during the six months of the rainy season, the gardens will not demand water. For this reason, the water demand was converted from annual to daily demand, in order to take into account only the day of the year in which is required the water.

The water supply system was divided into three parts:

- The pipes from the water source WS02 to the perimeter of the gardens. The pipe will be in plastic material, preferably in PE (Polyethylene), because the plastic is easy to be transported, is economic, and suitable for the transport of water for human use.
- A water tank to accumulate water and provide it when necessary. The water tank will be built on the island with the calculated dimensions.
- A distribution pipe from the water tank to each garden.

Each of these parts has been sizing, providing the diameter of the pipelines and the relative flow, and the dimension of the tank.

4.1 The pipe from the water source to the gardens

The first part of the water system is the pipe that transports the water from the spring to the water tank, which is arranged along the perimeter of the garden area. The starting data for the project were the altitude and the GPS coordinates of the water spring, of the perimeter of the gardens area, and the coordinates of some points from the WS02 to the Ampanitsoha village. These points were imported into a software for GPS points, to have them on a map and measure the relative distances. To find the best position for the water tank two possibilities were considered: one in the middle of the top area, and one on the middle of the east side. The altitude of the two points is quite similar but changes the distance between the spring and the tank: the position of the tank on the top side of the garden is at 16.50 m and has 455 m of distance, while the position of the tank on the lateral side is 16.47 m with a distance of 368 m.

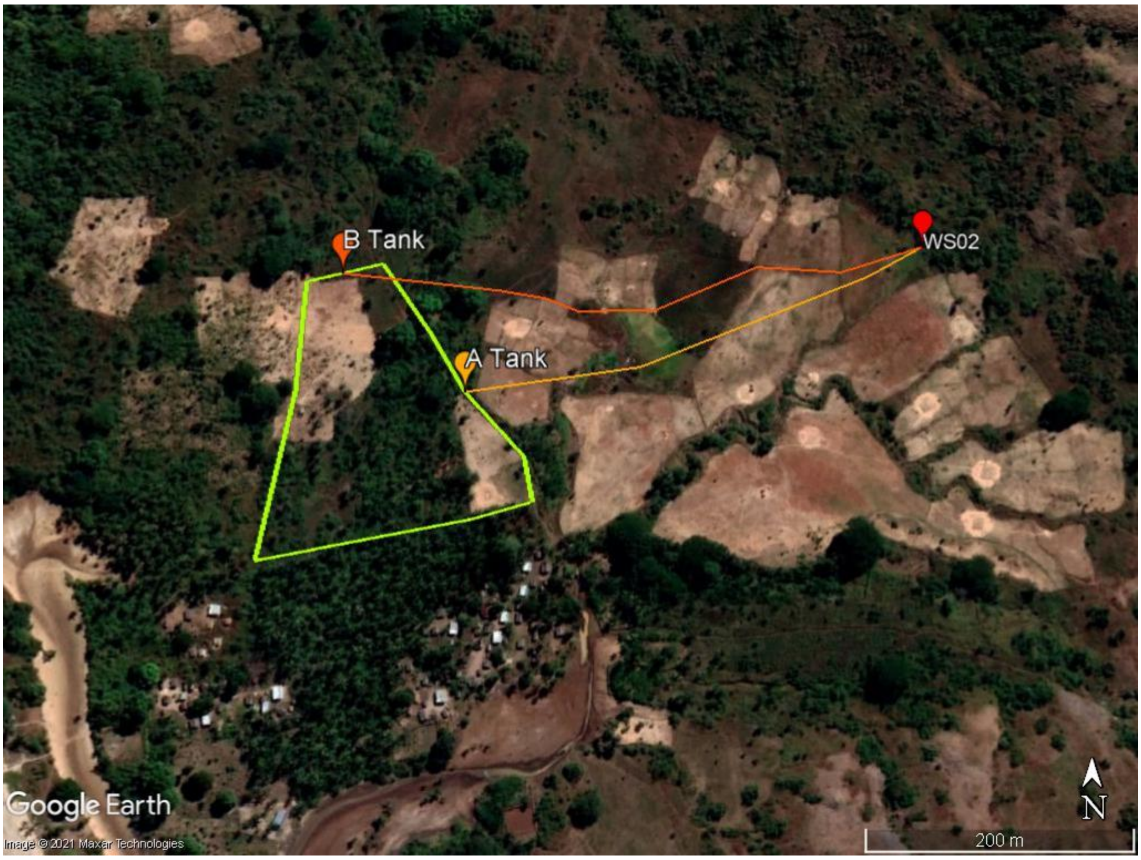


Figure 4.2: The two possible position of the tank, on the top side (B Tank) and on the lateral side (A Tank) of the vegetable gardens area

Since the water will stay at a certain level inside the water tank when it is full, the piezometric level in correspondence of the tank has been considered as the altitude plus 1 m, plus 1.5 m, and plus 2 m. Through these combinations, it is possible to choose the best tank position and its height. Was also considered that the water at the WS02 could be channelled inside the pipeline thanks to a tank; the water level inside this tank is supposed to be 0.5 m high. Knowing the piezometric level at the start and at the end of the path of the pipeline, the difference of hydraulic head (ΔH) has been calculated. The hypothesis of long pipes was applied and for that has been considered only the distributed head losses, calculated as in Formula 4.1.

$$\Delta H = (h1 - h2) = J * L \rightarrow J = \frac{h1-h2}{L} \tag{4.1}$$

Where:

- $h1$ is the piezometric level at the spring WS02;
- $h2$ is the considered piezometric level at the tank;
- ΔH (m) is the difference of hydraulic head calculated as the difference of the piezometric level $h1$ and the altitude of water table inside the tank $h2$;
- J (m/m) as the lowering of the piezometric head line due to the distributed head losses;
- L (m) as the length of pipe.

The unknown of the problem was the diameter of the pipes, necessary to bring the required flow to the gardens: this is known as the design problem. To calculate the theoretical diameter, the pipes were considered in a condition of roughness. Then was found the commercial pipe with a diameter similar to the theoretical and was verified that the flow demand was satisfied. At last, the system has been verified in a condition of smooth pipes, to observe how much water the system could transport when the commercial pipes are new (verification problem).

4.1.1 The design problem

The design problem has been resolved using the Colebrook - White formula with an iterative process.

The Colebrook – White formula is expressed in Formula 4.2:

$$\frac{1}{\sqrt{\lambda}} = -2\, log_{10}\left(\frac{2.51}{Re\,\sqrt{\lambda}} + \frac{\varepsilon/_D}{3.71}\right) \tag{4.2}$$

Where:

- λ (-) is the friction factor;
- Re(-) is the Reynolds number (Formula 4.3)

$$Re = \frac{v\,D}{\nu} \tag{4.3}$$

  With:

  - v (m/s) as the velocity of the fluid inside the pipe;
  - D (m) the internal diameter of the tube;
  - ν (m^2/s) the kinematic viscosity, equal to 10^{-6} m^2/s for water;
- ε (m) is the absolute pipe roughness and the ratio $\varepsilon/_D$ is called relative pipe roughness. The absolute pipe roughness for plastic is assumed equal to 0.02 mm.

The Colebrook – White formula can be applied only if Re > 2000 (Citrini and Noseda, 1987) because for Reynolds number minor than this value the flow is in a condition of laminar flow, where the friction factor is (Formula 4.4).

$$\lambda = {}^{64}/_{Re} \tag{4.4}$$

Formula 4.2 is an implicit equation because the frictional factor appears at the two sides of the equation. In this case, there are two unknowns: the pipe diameter and the frictional factor. To resolve the formula, it's possible to proceed with an iterative procedure. For the first interaction, the frictional factor has been imposed. Then the diameter has been calculated through the inversion of the Darcy – Weisbach formula (Formula 4.5), where the velocity is expressed in function of the diameter and the flow, from the continuity equation (Formula 4.6).

$$J = \frac{\lambda\, v^2}{2\, g\, D} \;\rightarrow\; D = \left(\frac{8\, \lambda\, Q^2}{\pi^2\, g\, J}\right)^{1/5} \tag{4.5}$$

$$Q = \frac{\pi\, D^2}{4} v \;\rightarrow\; v = \frac{4\, Q}{\pi\, D^2} \tag{4.6}$$

The third step has been the calculation of the velocity (Formula 4.6).

With the diameter and the velocity is calculated the Reynolds number (Formula 4.3) and it is verified that is bigger than 2000. Finally, has been calculated the relative pipe roughness. At this point, all the parameters of the Colebrook – White formula are determined, and the new value of lambda has been calculated with Formula 4.2. The process has been repeated until the convergence of lambda.

The values of the project parameters are resumed in Table 4.2. The parameters are the flow rate *Q*, the absolute pipe roughness ε, the kinematic viscosity υ, the gravity accelaration *g*, the altitude of the spring WS02, and piezometric level *h* at the spring.

Table 4.2: Project data for the water pipe

Q (m3/day)	**Q (m3/s)**	**ε (m)**	**υ (m2/s)**	**g (m/s2)**	**WS02 altitude (m)**	**h_{WS02} (m)**
13	$1.505 \cdot 10^{-4}$	$0.02 \cdot 10^{-3}$	$1 \cdot 10^{-3}$	9.8	18.39	18.89

The iterative process has been run for the two possible positions of the tank and the three hypothetical water levels inside the tank when it will be full. The values of the tank heights, the length of pipes L, the piezometric levels h, the distributed head losses J, and the difference of total head ΔH are in tables Table 4.3 and Table 4.4.

Table 4.3: the values of the tank latitude, the length of pipes L, the piezometric levels h, the distributed head losses J, and the difference of total head ΔH for the tank on the lateral side of the gardens area.

A Tank					
Water level (m)	**h (m)**	**J (m/m)**	**ΔH (m)**	**Tank altitude(m)**	**L (m)**
1	17.47	0.0038	1.42	16.47	370
1.5	17.97	0.0025	0.92		
2	18.47	0.0011	0.42		

Table 4.4: the values of the tank altitude, the length of pipes L, the piezometric levels (h), the distributed head losses J, and the difference of total head ΔH for the tank on the top side of the gardens area.

B Tank					
Water level (m)	**h (m)**	**J (m/m)**	**ΔH (m)**	**Tank altitude(m)**	**L (m)**
1	17.50	0.0031	1.39	16.50	455
1.5	18.00	0.0020	0.89		
2	18.50	$8.5714 \cdot 10^{-4}$	0.39		

The results are in Table 4.5 and Table 4.6 in which are reported the theoretical internal diameter D, the velocity v, the Reynolds number Re, the relative roughness ε/D, and the friction factor λ final value. The final value of λ has been reached after 15 iterations.

Table 4.5: results for the tank on the lateral side: the theoretical internal diameter (m), the velocity v(m/s), the Reynolds number Re, the relative roughness ε/D and the friction factor λ.

A Tank						
Water level (m)	**ΔH (m)**	**D (m)**	**v (m/s)**	**Re (-)**	**ε/D (-)**	**λ (-)**
1	1.42	0.0280	0.2448	$6.8478 \cdot 10^{3}$	$7.1489 \cdot 10^{-4}$	0.0351
1.5	0.92	0.0306	0.2040	$6.2513 \cdot 10^{3}$	$6.5262 \cdot 10^{-4}$	0.0359
2	0.42	0.0361	0.1466	$5.3001 \cdot 10^{3}$	$5.5332 \cdot 10^{-4}$	0.0374

Table 4.6: results for the tank on the top side: the theoretical internal diameter D(m), the velocity v(m/s), the Reynolds number Re, the relative roughness $^{\varepsilon}/_{D}$ and the friction factor λ.

B Tank						
Water level (m)	ΔH **(m)**	D **(m)**	v **(m/s)**	Re **(-)**	$^{\varepsilon}/_{D}$ **(-)**	λ **(-)**
1	1.39	0.0293	0.2224	$6.5276{\cdot}10^{3}$	$6.8147{\cdot}10^{-4}$	0.0355
1.5	0.89	0.0322	0.1844	$5.9437{\cdot}10^{3}$	$6.2051{\cdot}10^{-4}$	0.0363
2	0.39	0.0384	0.1302	$4.9952{\cdot}10^{3}$	$5.2149{\cdot}10^{-4}$	0.0380

The flow is in a regime of turbulent transition, between the condition of smooth pipes and the condition of flow completely turbulent. This condition is visible through the Moody diagram in Figure 4.3. In the diagram is reported the interval results of the relative roughness and the Reynolds number. The value of Reynold number intersects the curve of the relative roughness, and it is finding the friction factor interval of values.

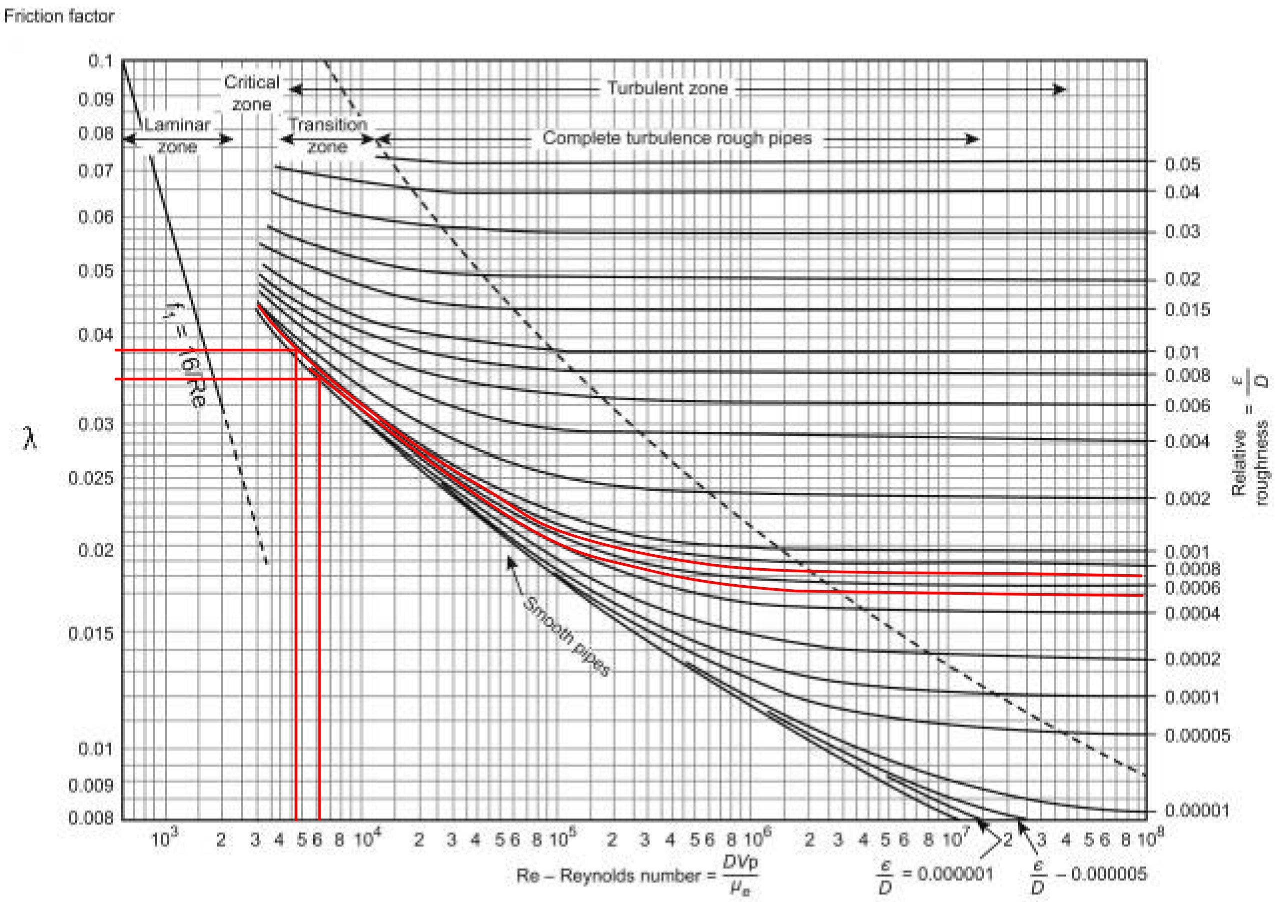


Figure 4.3: Moody diagrams, the interval of solution for Reynolds number, relative roughness and friction factor in rough pipe conditions are represent by the red lines

To find a suitable commercial tube for the system, the theoretical internal diameter has been compared with the dimension of the existing commercial pipes. Each theoretical internal diameter has been associated with the closest value in excess for the relative commercial pipe; has been chosen the value in excess to guarantee the flow rate demand of $1.505 \cdot 10^{-4}$ m^3/s. The results for the tank A and B, are reported in Table 4.7 and Table 4.8 in which is given the theoretical diameter and the corresponding commercial pipe identified with its nominal diameter DN, the internal diameter D_i, the external diameter D_e, the pipe thickness, and the associated nominal pressure PN.

Table 4.7: the theoretical diameter (mm) for the tank on the lateral side and the corresponding commercial pipe identified with its nominal diameter DN (mm), the internal diameter D_i (mm), the pipe thickness (mm), and the nominal pressure PN (bar).

A Tank						
	Theoretical diameter	**Commercial pipe**				
Water level (m)	***D* (mm)**	**DN**	**D_i (mm)**	**D_e (mm)**	**Thickness (mm)**	**PN**
1	28	40	29	34.5	5.5	25
1.5	30.6	40	32.6	36.3	3.7	16
2	36.1	50	36.2	40.22	4.02	25

Table 4.8: the theoretical diameter (mm) for the tank on the top side and the corresponding commercial pipe identified with its nominal diameter DN(mm), the internal diameter D_i (mm), the external diameter D_e (mm), the pipe thickness (mm), and the nominal pressure PN (bar).

B Tank						
	Theoretical diameter	**Commercial pipe**				
Water level (m)	***D* (mm)**	**DN**	**D_i (mm)**	**D_e (mm)**	**Thickness (mm)**	**PN**
1	29.3	40	32.6	36.3	3.7	16
1.5	32.2	40	32.6	36.3	3.7	16
2	38.4	50	40.8	45.5	4.6	16

At least, the water amount transported by each commercial pipe has been verified. The same procedure used to find the internal diameter has been applied to calculate the flow rate and the velocity corresponding to the commercial diameter, but this time the unknown was the flow rate. For that, the velocity in Formula 4.5 has been written as a function of the diameter and the flow rate inside the formula of the distributed head losses J (Formula 4.8). From Formula 4.8 has been obtained the flow rate as a function of the known data(Formula 4.9).

$$J = \frac{\lambda \, Q^2}{2 \frac{\pi^2}{16} g \, D^5} \qquad (4.8)$$

$$Q = \left(\frac{J\,D^5 g\,\pi^2}{8\,\lambda}\right) \quad (4.9)$$

The velocity, the Reynolds number, and the final value of the frictional factor are calculated with the respective Formula 4.7, 4.3, and 4.2. The final values are reported in Table 4.9 and Table 4.10.

Table 4.9: Commercial pipe diameter and the corresponding value of relative roughness ε/D, velocity v, Reynolds number Re, the flow rate Q, and friction factor λ for the tank on the lateral side.

A Tank						
Water level (m)	***D* (m)**	**ε/D (-)**	***v* (m/s)**	***Re* (-)**	***Q* (m^3/s)**	**λ (-)**
1	0.029	$6.8966 \cdot 10^{-4}$	0.2513	$7.2886 \cdot 10^{3}$	$1.6601 \cdot 10^{-4}$	0.0345
1.5	0.0326	$6.1350 \cdot 10^{-4}$	0.2135	$6.9607 \cdot 10^{3}$	$1.7822 \cdot 10^{-4}$	0.0348
2	0.0362	$5.5249 \cdot 10^{-4}$	0.1468	$5.3141 \cdot 10^{3}$	$1.5109 \cdot 10^{-4}$	0.0374

Table 4.10:Commercial pipe diameter and the corresponding value of relative roughness ε/D, velocity v, Reynolds number Re, the flow rate Q, and friction factor λ for the tank on the top side.

B Tank						
Water level (m)	***D* (m)**	**ε/D (-)**	***v* (m/s)**	***Re* (-)**	***Q* (m^3/s)**	**λ (-)**
1	0.0326	$6.1350 \cdot 10^{-4}$	0.2403	$7.8336 \cdot 10^{3}$	$2.0057 \cdot 10^{-4}$	0.0338
1.5	0.0326	$6.1350 \cdot 10^{-4}$	0.1860	$6.0626 \cdot 10^{3}$	$1.5523 \cdot 10^{-4}$	0.0361
2	0.0408	$4.9020 \cdot 10^{-4}$	0.1364	$5.5657 \cdot 10^{4}$	$1.7835 \cdot 10^{-4}$	0.0368

The flow is in a transient turbulent regime also in this case, and the values of Reynolds number and friction factor are bigger than when the considered theoretical diameter.

The final results are Table 4.11 and Table 4.12. Choosing the closest value in excess for the commercial diameter the flow transported to the gardens is bigger than the required 13 m^3/day.

Table 4.11:Top side tank: the final values of diameter, velocity, and flow rate for the different water levels inside the tank.

A Tank					
Water level (m)	**ΔH (m)**	**Commercial *D* (m)**	***v* (m/s)**	***Q* (m^3/s)**	***Q* (m^3/day)**
1	1.42	0.029	0.2513	$1.6601 \cdot 10^{-4}$	14.3432
1.5	0.92	0.0326	0.2135	$1.7822 \cdot 10^{-4}$	15.3984
2	0.42	0.0362	0.1468	$1.5109 \cdot 10^{-4}$	13.0540

Table 4.12: Top tank: the final value of diameter, velocity, and flow for the different water levels inside the tank.

B Tank					
Water level (m)	**ΔH (m)**	**Commercial D (m)**	**v (m/s)**	**Q (m³/s)**	**Q (m³/day)**
1	1.39	0.0326	0.2403	$2.0057 \cdot 10^{-4}$	17.3240
1.5	0.89	0.0326	0.1860	$1.5523 \cdot 10^{-4}$	13.4116
2	0.39	0.0408	0.1364	$1.7835 \cdot 10^{-4}$	15.4093

The flow rate has been verified also for the condition of smooth pipes. To calculate the flow rate transported in smooth pipes, the energy balance has been expressed as in Formula 4.1, and as a function of the flow rate. The components of J in Formula 4.5 have been expressed in the following way:

$$J = \frac{\lambda\, v^2}{2\, g\, D} \tag{4.5}$$

- The velocity has been written as a function of the diameter and the flow rate as in Formula 4.6;
- The friction factor has been calculated using the Blasius formula (Formula 4.10), where the Reynolds number is written as a function of the diameter and the flow rate (Formula 4.11).

$$\lambda = 0.316\, Re^{-0.25} \tag{4.10}$$

$$Re = \frac{v\, D}{\nu} = \frac{4\, Q}{\pi\, D^2}\frac{D}{\nu} = \frac{4\, Q}{\pi\, \nu\, D} \tag{4.11}$$

In this way, the Formula 4.5 of J has become as in Formula 4.12, which is expressed as a function of the flow rate, where the expression composed of the other parameters is grouped in the variable B

$$J = 0.316\left(\frac{4\, Q}{\pi\, \nu\, D}\right)^{-0.25}\left(\frac{4\, Q}{\pi\ D^2}\right)^{2}\frac{1}{2\, g\, D} \rightarrow J = 0.316\left(\frac{4}{\pi\, \nu\, D}\right)^{-0.25}\left(\frac{4}{\pi\, D^2}\right)^{2}\frac{1}{2\, g\, D}\, Q^{1.75}$$

$$J = B\, Q^{1.75} \tag{4.12}$$

Then the Formula 4.12 has been introduced in the Formula 4.2 and expressed as a function of the flow rate (Formula 4.13)

$$Q = \left(\frac{\Delta H}{B\, L}\right)^{1/1.75} \tag{4.13}$$

The different commercial diameters, found in the previous calculous have been inserted in Formula 4.13 and the respective flow rate has been calculated as reported in Table 4.13 and Table 4.14.

Table 4.13:Pipe in smooth condition for the lank on the lateral side

A Tank							
Water level (m)	**ΔH (m)**	**Commercial D (m)**	**v (m/s)**	**λ (-)**	**Re (m)**	**Q (m^3/s)**	**Q (m^3/day)**
1	1.42	0.029	0.2527	0.0342	$7.3292 \cdot 10^3$	$1.6693 \cdot 10^{-4}$	14.3432
1.5	0.92	0.0326	0.2144	0.0346	$6.9898 \cdot 10^3$	$1.7897 \cdot 10^{-4}$	15.4626
2	0.42	0.0362	0.1476	0.0370	$5.3438 \cdot 10^3$	$1.5193 \cdot 10^{-4}$	13.1270

Table 4.14: Pipe in smooth condition for the lank on the top side

B Tank							
Water level (m)	**ΔH (m)**	**Commercial D (m)**	**v (m/s)**	**λ (-)**	**Re (m)**	**Q (m^3/s)**	**Q (m^3/day)**
1	1.39	0.0326	0.2412	0.0336	$7.8624 \cdot 10^3$	$2.0131 \cdot 10^{-4}$	17.3932
1.5	0.89	0.0326	0.1869	0.0358	$6.0942 \cdot 10^3$	$1.5603 \cdot 10^{-4}$	13.4814
2	0.39	0.0408	0.1369	0.0365	$5.5873 \cdot 10^3$	$1.7904 \cdot 10^{-4}$	15.4691

Also in this case, the water flows with a turbulent transition regime. The Reynolds number is quite bigger than the pipe rough condition, due to the lower friction factor that increases the flow rate and consequently the velocity. The flow rate values in the conditions of smooth and rough pipes are compared in Table 4.15 and Table 4.16.

Table 4.15: comparison between the flow rate transported the pipe smooth and rough condition for the three different commercial diameter and piezometric level at the water tank on the lateral side.

A Tank			
Piezometric level in the tank (m)	**Commercial D (m)**	**Rough pipe condition Q (m^3/day)**	**Smooth pipe Condition Q (m^3/day)**
16.47 +1	0.029	14.3432	14.3432
16.47+1.5	0.0326	15.3984	15.4626
16.47+2	0.0362	13.0540	13.1270

Table 4.16: comparison between the flow rate transported the pipe smooth and rough condition for the three different commercial diameter and piezometric level at the water tank on the top side.

B Tank			
Piezometric level in the tank (m)	**Commercial *D* (m)**	**Rough pipe condition *Q* (m^3/day)**	**Smooth pipe Condition *Q* (m^3/day)**
16.47 +1	0.0326	17.3240	17.3932
16.47+1.5	0.0326	13.4116	13.4814
16.47+2	0.0408	15.4093	15.4691

The flow rate in the smooth pipe condition is higher than in the rough condition, as was expected. This is because the wall pipe friction is lower in smooth condition than in the rough condition, and that allows the water to flow better and faster on the pipe wall. Indeed, the friction factor has major values in the rough condition while the water has a bigger velocity where the pipes are in smooth condition. The comparison between the flow rate in smooth and rough condition demonstrates that the flow is quite similar in the two conditions. This suggests that the pipe should be able to transport an almost fixed flow rate with little variations over time. Therefore, it can be assumed that the water transport efficiency of the system will remain practically constant over time.

4.2 The water tank

The water tank is the point of union between the water source and the gardens. Thanks to the water tank it is possible to store the water and give it when the gardens require it. The tank will be built in concrete on the island with the dimensions found with the present design. The pipe of in and out water will be positioned in the lower part of the tank, at the ground level or 20-30 cm below it. Design the water tank consists of calculating the tank dimensions and how the water enters and exits in the tank to minimize its volume. The first parameter that must be calculated is the minimum volume of compensation, which is the minimum volume of the water tank to guarantee the water availability when it is required. The design goal is to minimize the tank volume, because the bigger the tank, the more expensive its construction will be. Designing the water tank has meant to consider the volumes of water that enter and exit from the tank. The water that goes in depends on the spring productivity. To simulate the best and the worst condition in which the spring can be, the spring has been considered in a condition in which gives the required water amount (13 m^3/day) and a condition in which the spring can provide only the 20% of the required water, equal to 2.6 m^3/day. This percentage has been chosen because it is the minimum water amount at which the crops can survive. The water that comes out of the tank depends on how much it is necessary to irrigate the crops. In the best case, the crops are irrigated twice a day in the fresher hours, in the morning, and in the late evening. In the worst case, when the water income is only at 20%, the irrigation happens only three times a week. In the middle case, the water is given only once a day, in the morning. To simulate the water in and out of the tank has been considered a timing cycle of tank filling and emptying. Considering irrigating almost one time a day, the cycle is daily, while in the worst case, the cycle is weekly. To design the water tank the transitory phase has not been considered. The transitory phase is the first time at which the tank is filled with water and enters the amount of water necessary to start the cycle. The volume that enters in the transitory moment is the initial volume.

So, the scenarios considered in the water tank design are:

- Case 1: the spring gives 13 m^3/day, the required water amount for the maintenance of the gardens, and the water is distributed two times a day;
- Case 2: the spring gives 13 m^3/day, the required water amount for the maintenance of the gardens, and the water is distributed one time a day;
- Case 3: the spring gives 20% of the required water amount equal to 2.6 m^3/day and the water is distributed three times a week.

For each case has been calculated the minimum volume of compensation, the initial volume, and are being produced the graphs of the flow rate and the volume of water in and out of the tank

4.2.1 Case 1: two times a day for two hours

For the first case, the filling and emptying cycle have been considered as daily, so the day was divided into 24 hours. The flow entering in the tank has been assumed as constant, and the total required flow rate has been converted in cubic meters per hour equal to 0.5417 m^3/h. The flow rate given to the gardens was split into two hours in the morning (from 6 to 8 a.m.) and two hours in the evening (from 6 to 8 p.m.), therefore the flow rate exiting per hour is 3.25 m^3/h. The graph in Figure 4.4 shows the tank flow rate in and out.

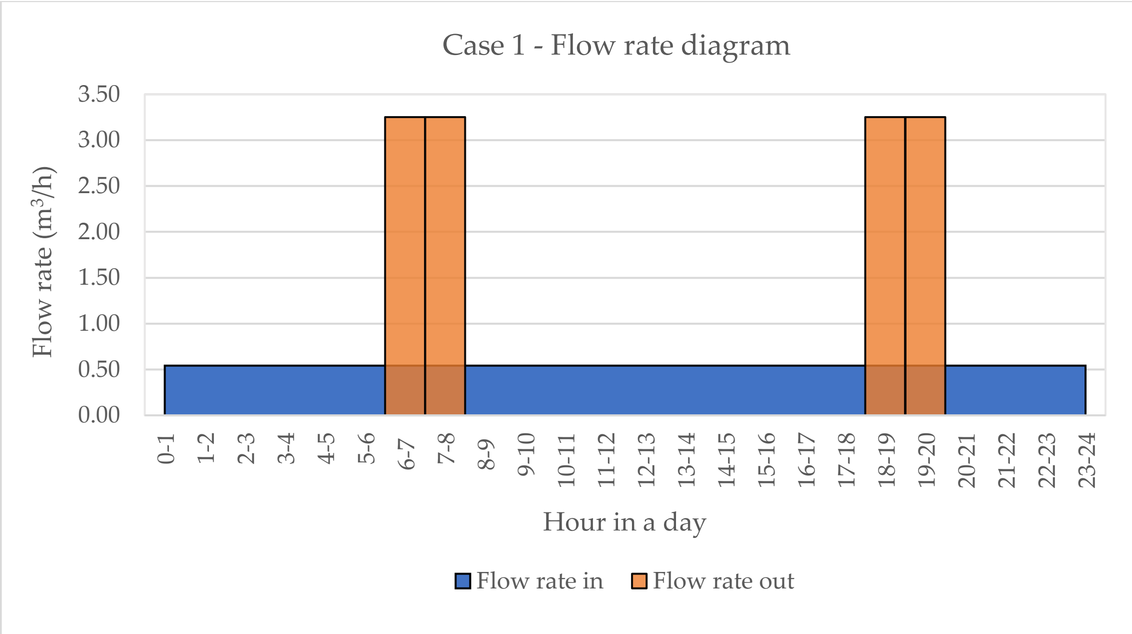


Figure 4.4: Flow rate in and out of the tank for Case 1

In the tank, the income water volume must be equal to the outcome water, indeed, the blue area of the income flow rate (13 m³/day) is equal to the orange area of the exiting water (3.25 m³/h*4). The flow rate can be expressed as the variation of the volume in time as in Formula 4.14:

$$Q(t) = \frac{dV(t)}{dt} \tag{4.14}$$

With

$$Q_{in}(t) = \frac{dV_{in}(t)}{dt} \; and \; Q_{out}(t) = \frac{dV_{out}(t)}{dt}$$

Where:

- Q_{in} and V_{in} are the flow rate and the volume of water which income in the tank;
- Q_{out} and V_{out} are the flow rate and the volume of water which outcome from the tank;

The equation that represents the change of the volume inside the tank in time is Formula 4.15 where $V_0$is the initial volume, and the integral of the in and out flow rate is equal to the respective subtended area in Figure 4.4:

$$V(t) = V_0 + \int_0^t Q(t)dt = V_0 + \int_0^t Q_{in}(t)dt + \int_0^t Q_{out}(t)dt \tag{4.15}$$

If the considered period is the cycle duration, the t will be equal to 24: the difference between the volume in entrance and the exit will be 0 and the total volume will be equal to the initial volume V_0. To observe the volume variation in time, the extremes of the integral should be changed in the time interval inside the daily cycle that would be observed. At first, the initial volume was unknown and was not considered, so the Formula 4.15 became:

$$V(t) = \int_0^t Q_{in}(t)dt + \int_0^t Q_{out}(t)dt$$

The graphic solution of the equation is the volume diagram in Figure 4.5. The volume diagram has been obtained plotting the cumulative volume income and outcome in a daytime. When the water is required, the line of volume out is over the line of volume in. For that, to guarantee water availability, it is necessary an initial volume to start the water filling and leaving cycle. The change in volume is tabulated in Table 4.17.

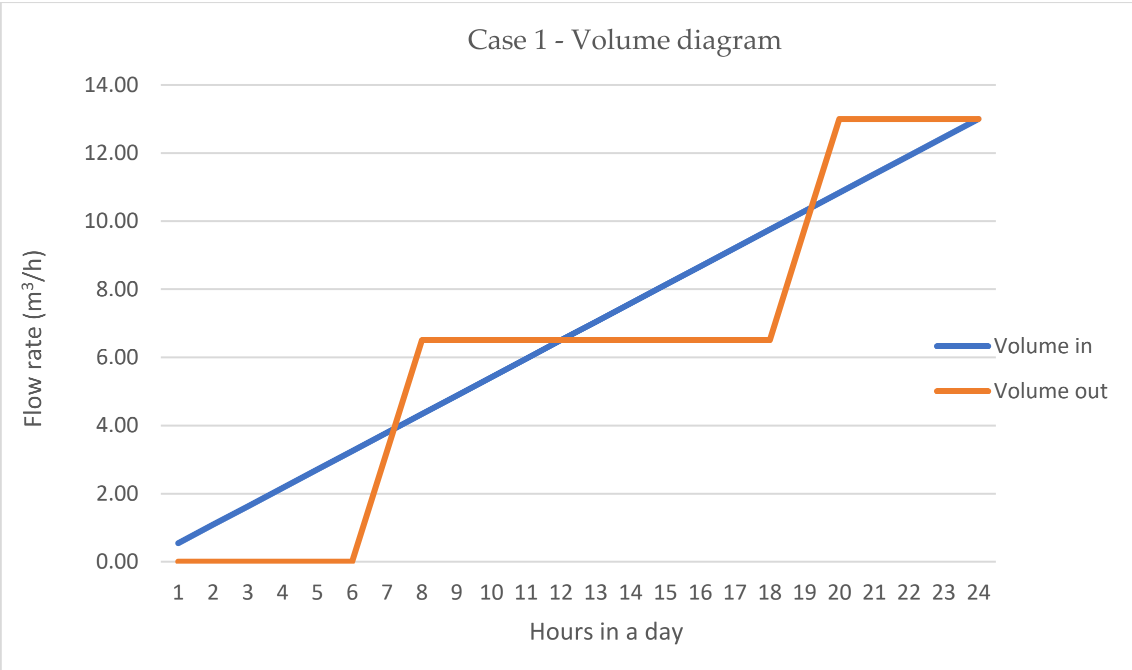


Figure 4.5: Volume diagram, the change of water entering and leaving the tank

Table 4.17: Change in volume tabulated values in Case 1.

Change in volume inside the tank: Case 1					
Time	**Ve**	**Cum Ve**	**Vu**	**Cum Vu**	**Cum Ve-Cum Vu**
h	m^3	m^3	m^3	m^3	m^3
1	0.54	0.54	0	0	0.5417
2	0.54	1.08	0	0	1.0833
3	0.54	1.63	0	0	1.6250
4	0.54	2.17	0	0	2.1667
5	0.54	2.71	0	0	2.7083
6	0.54	3.25	0	0	**3.2500**
7	0.54	3.79	**3.25**	3.25	0.5417

8	0.54	4.33	**3.25**	6.5	**-2.1667**
9	0.54	4.88	0	6.5	-1.6250
10	0.54	5.42	0	6.5	-1.0833
11	0.54	5.96	0	6.5	-0.5417
12	0.54	6.50	0	6.5	0.0000
13	0.54	7.04	0	6.5	0.5417
14	0.54	7.58	0	6.5	1.0833
15	0.54	8.13	0	6.5	1.6250
16	0.54	8.67	0	6.5	2.1667
17	0.54	9.21	0	6.5	2.7083
18	0.54	9.75	0	6.5	3.2500
19	0.54	10.29	**3.25**	9.75	0.5417
20	0.54	10.83	**3.25**	13	-2.1667
21	0.54	11.38	0	13	-1.6250
22	0.54	11.92	0	13	-1.0833
23	0.54	12.46	0	13	-0.5417
24	0.54	13.00	0	13	0.0000

The minimum compensation volume has been calculated as the sum of the maximum deviation in negative and positive of the cumulative income and outcome volume difference. Graphically, the maximum difference between the line of the volume out and the line of volume in, is represented in Figure 4.6, by the red lines. It occurs at 6. a.m. and 6 p.m., as the maximum difference in positive between the in and out cumulative volume, and at 8 a.m. and 8 p.m., as the minimum difference in negative. These values are highlighted in Table 4.17.

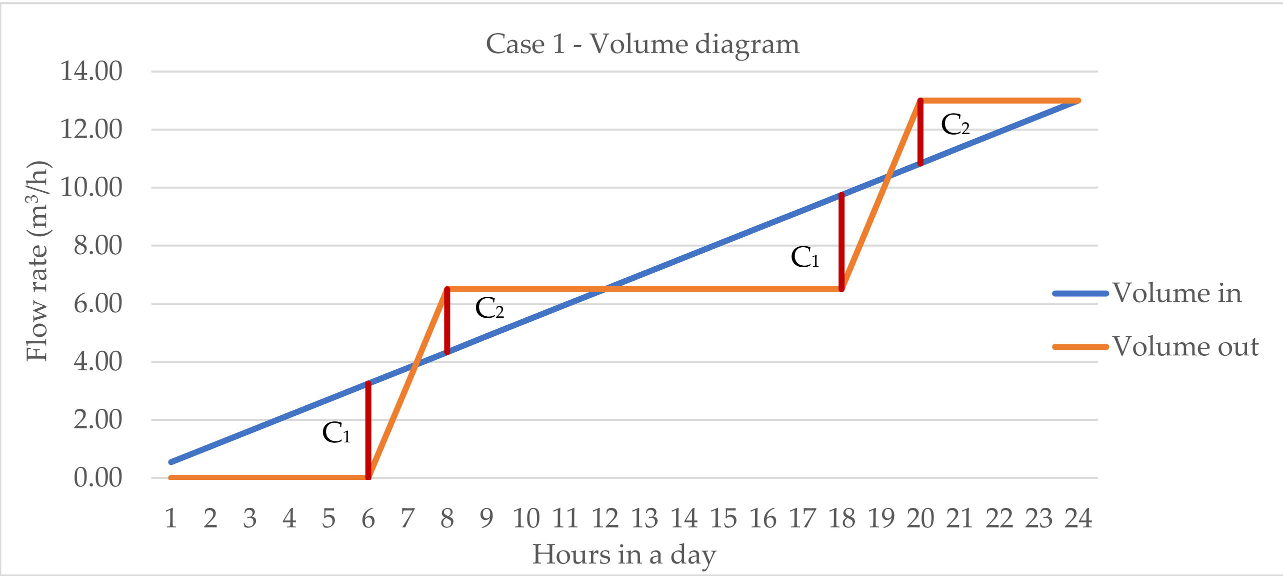


Figure 4.6: The maximum deviations C_1 and C_2 between the volume aout and the volume in.

The formula for calculating the minimum volume is in Formula 4.16.

$$C_{min} = C_1 + |C_2| = 3.25\ m^3 + |-2.17|\ m^3 = 5.42\ m^3 \quad (4.16)$$

The initial required volume inside the tank is equal to the maximum deviation in negative, corresponding to $|C_2| = 2.17\ m^3$.

Considering the initial volume, the line of volume out will stay under the line of volume in. Graphically, it is obtained by moving up the income volume line of the initial volume V_0, and it is represented in Figure 4.7. The dashed area is the variation of water volume inside the tank during the daytime. When the green line (V_0 plus the income volume) and the orange line (the outcome volume) are in touch, it means that inside the tank the water level is zero.

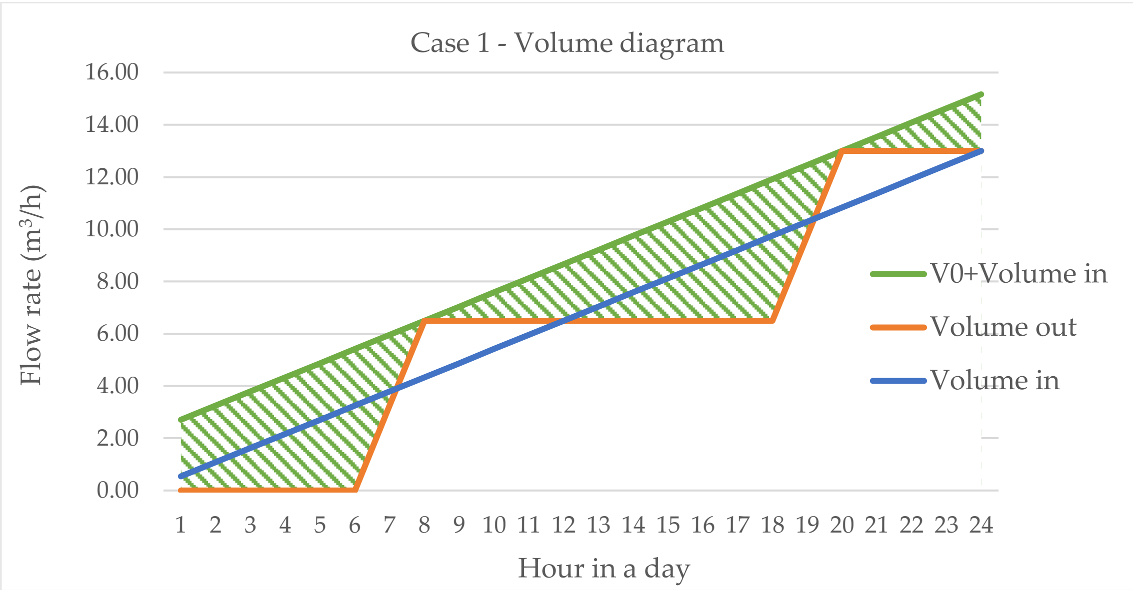


Figure 4.7: Change in volume in the daytime in Case 1. The dashed area in green is the water volume variation inside the tank.

The results are resume in Table 4.18.

Table 4.18: Case 1: water distribution, initial volume V0 and minimum volume Cmin.

Times per day	**Hours per time**	**Volume out per hour (m^3)**	**V_0 (m^3)**	**C_{min} (m^3)**
2	2	3.25	2.17	5.42

4.2.2 Case 2: two times a day for one hour

The same procedure applied in Case 1 for the calculus of the minimum volume and the initial volume has been used in Case 2.

In Case 2 the water is given to the gardens only one hour in the morning (from 6 to 7 a.m.), The flow rate taken from the tank is the total required flow rate equal to 13 m^3, while the income flow rate is assumed constant, equal to 0.54 m^3/hour (as in Case 1). Figure 4.8 represents the flow rate diagram for this scenario. Also has been tried to divide the rate flow in four hours in the morning, with a outcome flow rate of 3.25 m^3/hour (always shown in Figure 4.8).

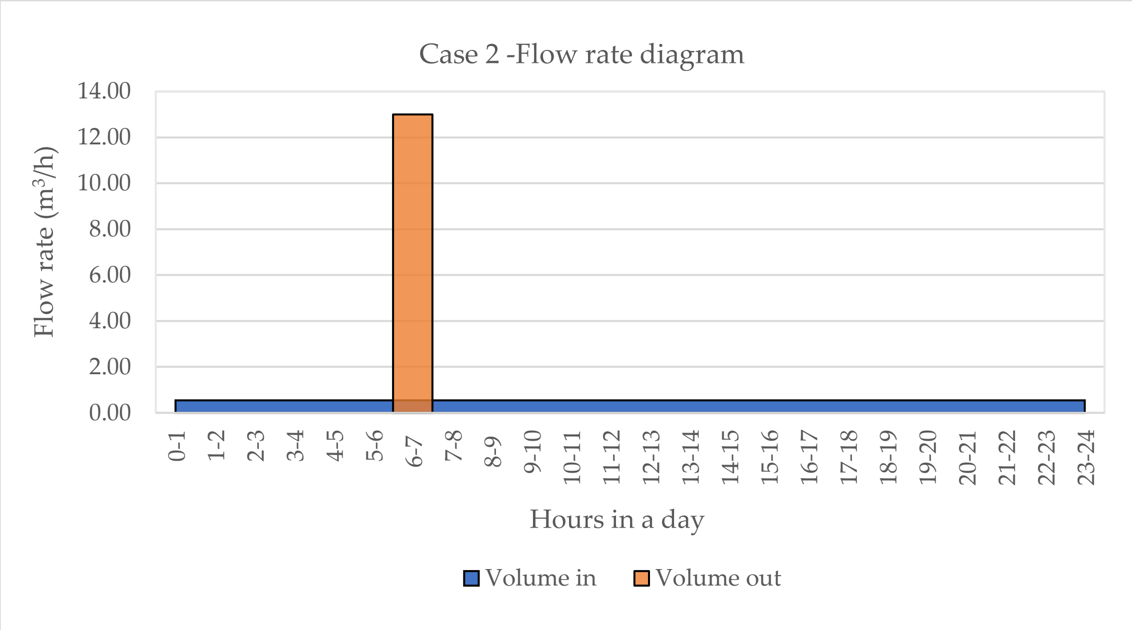


Figure 4.8: flow rate diagram if the water is distributed in one hour a day in Case 2

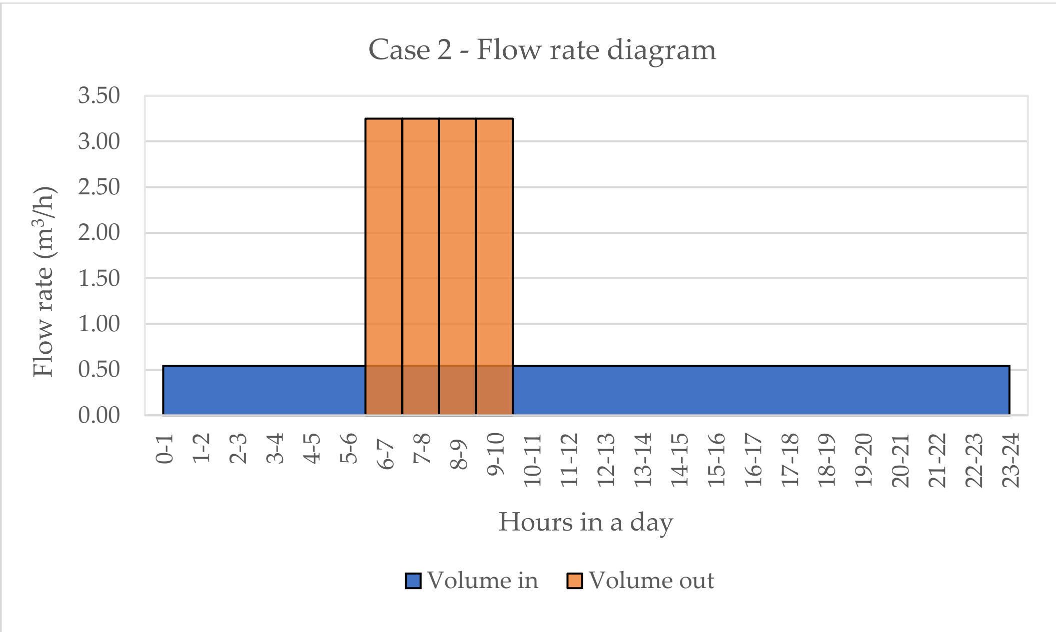


Figure 4.9: Flow rate diagram if the water is distributed in four hours a day in Case 2

The maximum deviation in negative and positive of the difference between the cumulative volume in and out is in Formula 4.17 where has been calculated the minimum volume for the two cases.

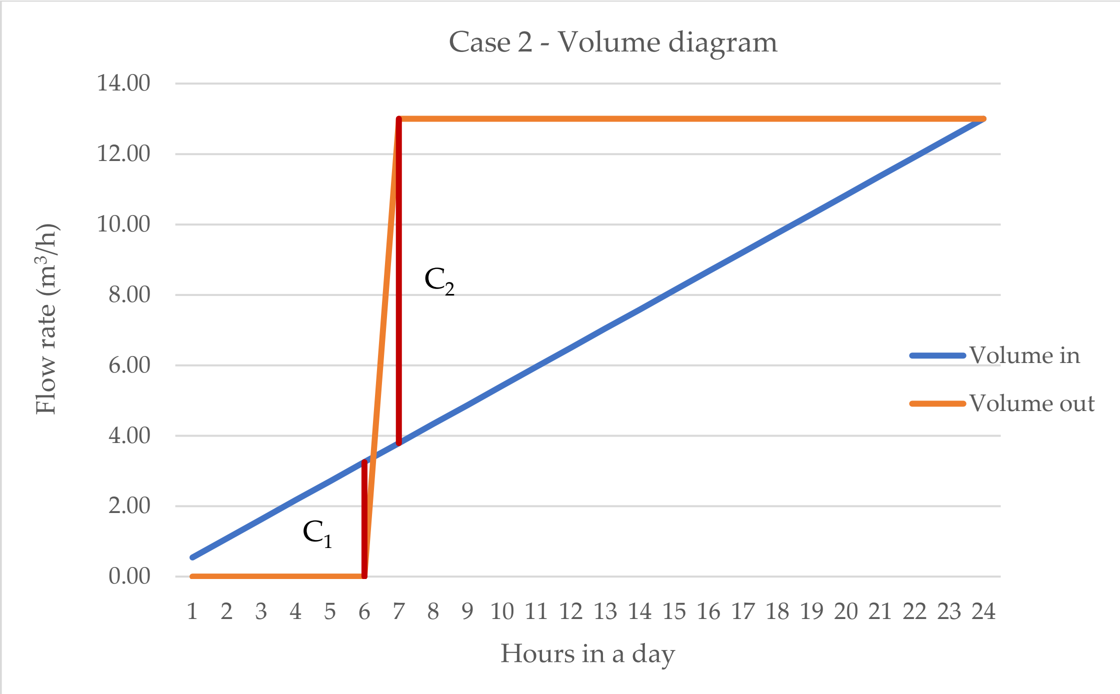


Figure 4.10: Change in volume for the Case 2 if the water is distributed one hour per day and the maximum deviations C_1 and C_2 between the volume aout and the volume in.

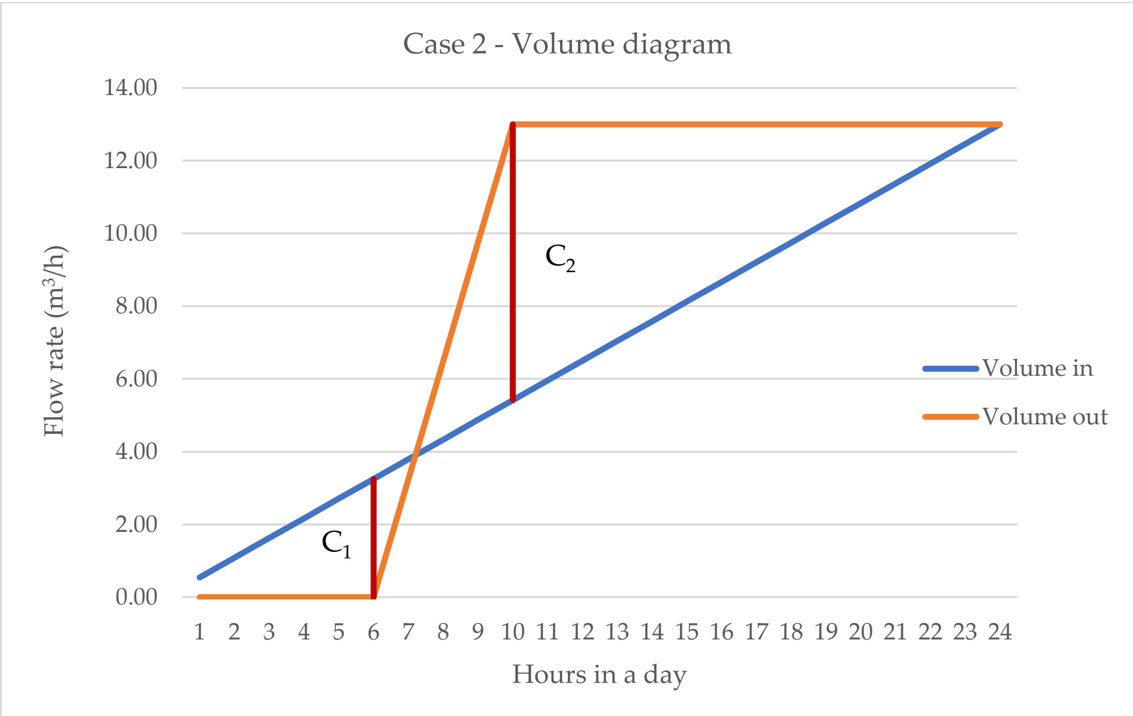


Figure 4.11: Change in volume for the Case 2 if the water is distributed four hours in the morningand the maximum deviations C_1 and C_2 between the volume aout and the volume in.

The minimum volume is calculated with Formula 4.17:

$$C_{min}\,(1\ hour) = C_1 + |C_2| = 3.25\ m^3 + |-9.21|\,m^3 = 12.46\,m^3$$
$$C_{min}\,(4\ hour) = C_1 + |C_2| = 3.25\,m^3 + |-7.60|\,m^3 = 10.83\,m^3 \quad (4.17)$$

The volume diagram for the two cases has been produced and they are in Figure 4.12 and Figure 4.13 using the data in

Table 4.19 and Table 4.20, where are highlighted the income volume in the tank and the maximum deviation in negative and positive of the difference of cumulated volumes.

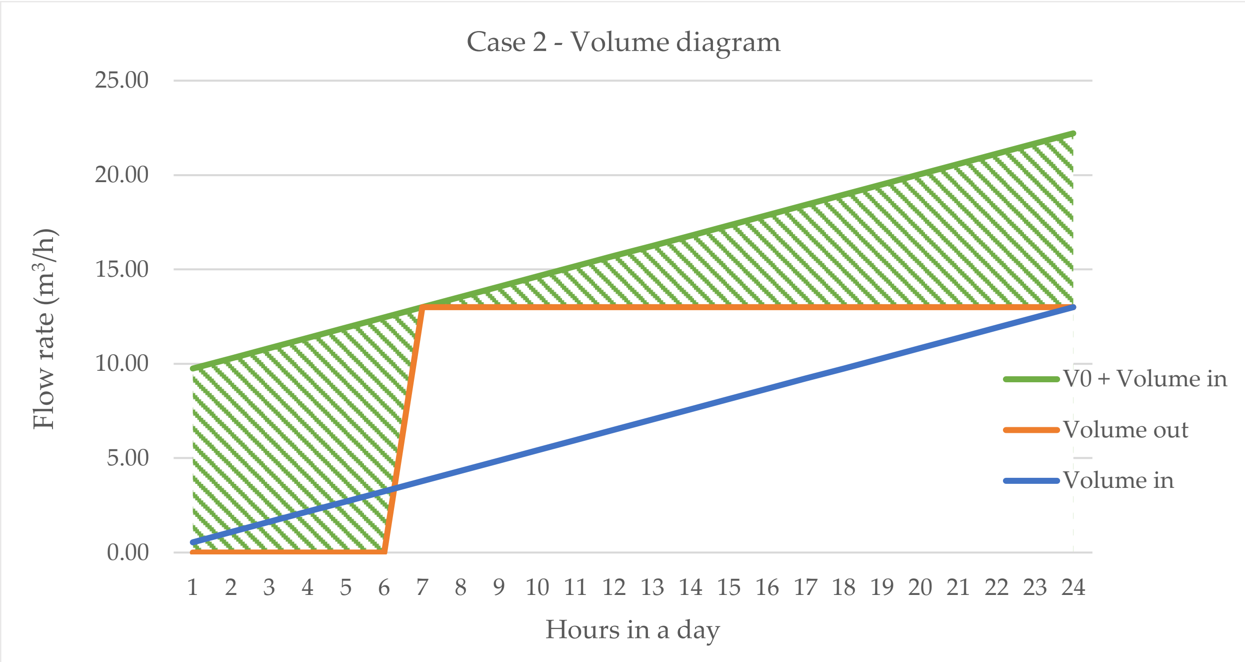


Figure 4.12: Change in volume inside the tank during the day for the Case 2 if the water is distributed one hour per day. The dashed area in green is the effective water volume inside the tank

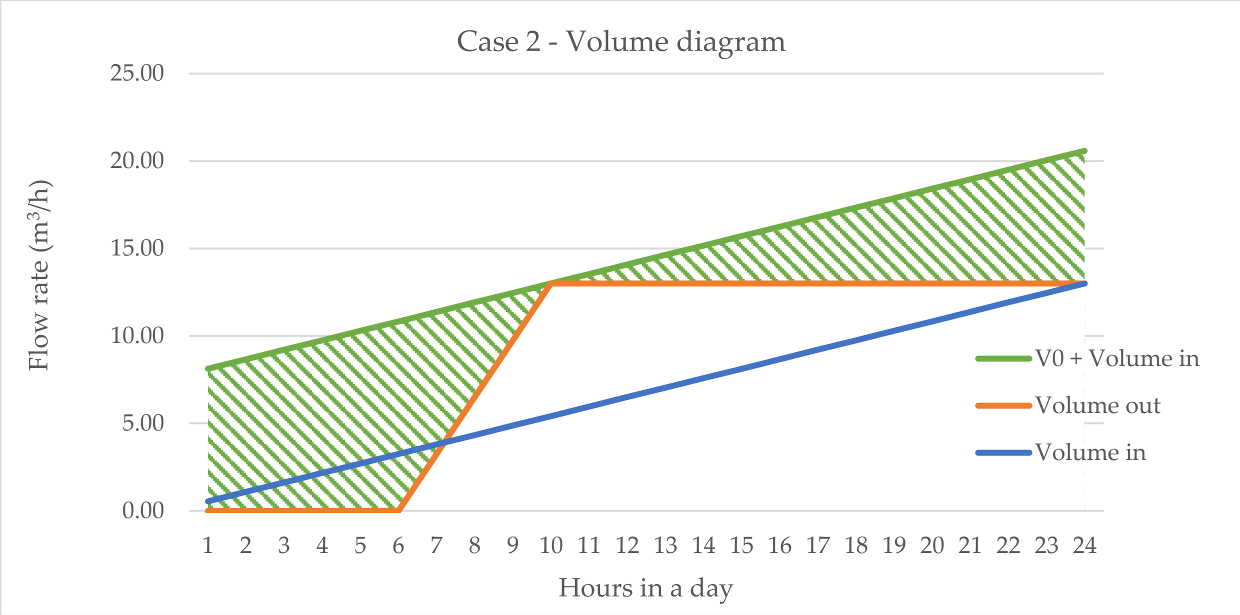


Figure 4.13: Change in volume inside the tank during the day for the Case 2 if the water is distributed four hours per day in the morning. The dashed area in green is the effective water volume inside the tank

Table 4.19: Change in volume inside the tank during the day for the Case 2 if the water is distributed one hour per day. In the table are reported the volume in and its cumulative values, the volume out and its cumulated values, and the difference between the two cumulates.

Change in volume inside the tank: case 2					
Time	**Ve**	**Cum Ve**	**Vu**	**Cum Vu**	**Cum Ve-Cum Vu**
h	m^3	m^3	m^3	m^3	m^3
1	0.54	0.54	0	0	0.5417
2	0.54	1.08	0	0	1.0833
3	0.54	1.63	0	0	1.6250
4	0.54	2.17	0	0	2.1667
5	0.54	2.71	0	0	2.7083
6	0.54	3.25	0	0	**3.2500**
7	0.54	3.79	**13**	13	**-9.2083**
8	0.54	4.33	0	13	-8.6667
9	0.54	4.88	0	13	-8.1250
10	0.54	5.42	0	13	-7.5833
11	0.54	5.96	0	13	-7.0417
12	0.54	6.50	0	13	-6.5000
13	0.54	7.04	0	13	-5.9583
14	0.54	7.58	0	13	-5.4167
15	0.54	8.13	0	13	-4.8750
16	0.54	8.67	0	13	-4.3333
17	0.54	9.21	0	13	-3.7917
18	0.54	9.75	0	13	-3.2500
19	0.54	10.29	0	13	-2.7083
20	0.54	10.83	0	13	-2.1667
21	0.54	11.38	0	13	-1.6250
22	0.54	11.92	0	13	-1.0833

23	0.54	12.46	0	13	-0.5417
24	0.54	13.00	0	13	0.0000

Table 4.20: Change in volume inside the tank during the day for the Case 2 if the water is distributed four hour per day in the morning. In the table are reported the volume in and its cumulative values, the volume out and its cumulated values, and the difference between the two cumulates.

Change in volume inside the tank: case 2					
Time	**Ve**	**Cum Ve**	**Vu**	**Cum Vu**	**Cum Ve-Cum Vu**
h	m^3	m^3	m^3	m^3	m^3
1	0.54	0.54	0	0	0
2	0.54	1.08	0	0	0.5417
3	0.54	1.63	0	0	1.0833
4	0.54	2.17	0	0	1.6250
5	0.54	2.71	0	0	2.1667
6	0.54	3.25	0	0	2.7083
7	0.54	3.79	0	0	**3.2500**
8	0.54	4.33	**3.25**	3.25	0.5417
9	0.54	4.88	**3.25**	6.5	-2.1667
10	0.54	5.42	**3.25**	9.75	-4.8750
11	0.54	5.96	**3.25**	13	**-7.5833**
12	0.54	6.50	0	13	-7.0417
13	0.54	7.04	0	13	-6.5000
14	0.54	7.58	0	13	-5.9583
15	0.54	8.13	0	13	-5.4167
16	0.54	8.67	0	13	-4.8750
17	0.54	9.21	0	13	-4.3333
18	0.54	9.75	0	13	-3.7917
19	0.54	10.29	0	13	-3.2500
20	0.54	10.83	0	13	-2.7083
21	0.54	11.38	0	13	-2.1667
22	0.54	11.92	0	13	-1.6250
23	0.54	12.46	0	13	-1.0833
24	0.54	13.00	0	13	-0.5417

In Table 4.21 there are the resumed results for the Case 2.

Table 4.21: Results for the Case 2

Irrigation	**Times per day**	**Hours per time**	**Volume out per hour (m^3)**	**V_0 (m^3)**	**C_{min} (m^3)**
For 1 hour	1	1	13	9.21	12.46
For 4 hours	1	4	3.25	7.60	10.83

4.2.3 Case 3: three times a week for one hour

The same procedure applied in Case 1 for the calculus of the minimum volume and the initial volume has been used in Case 3.

In this case, it is supposed that the water source WS02 can give only 20% of the total daily required flow rate, equal to 2.6 m^3/day, and the water is given to the gardens only three times a week. This scenario has been chosen because it is not sure that the spring can provide 13 m^3/day for all dry season long and because such water distribution is the worst condition at which the crops can survive. Since the water is provided not every day but three times a week, the cycle water distribution has been considered as weekly. For this scenario different attempts have been done to reach the minimum volume of compensation. As first approach, the flow rate income in the tank has been supposed to be constant every day of the week at 0.0108 m^3/hours, equal to 2.6 m^3/day. The water is given to the gardens on Monday, Wednesday, and Friday, from 6 to 7 a.m. as shown in Figure 4.14. With this configuration, would be very easy to regulate the water distribution, but the minimum volume of compensation would be too much large, about 12.25 m^3. For this reason, the income water flow rate has been modulated with the purpose to minimize the minimum value of the tank.

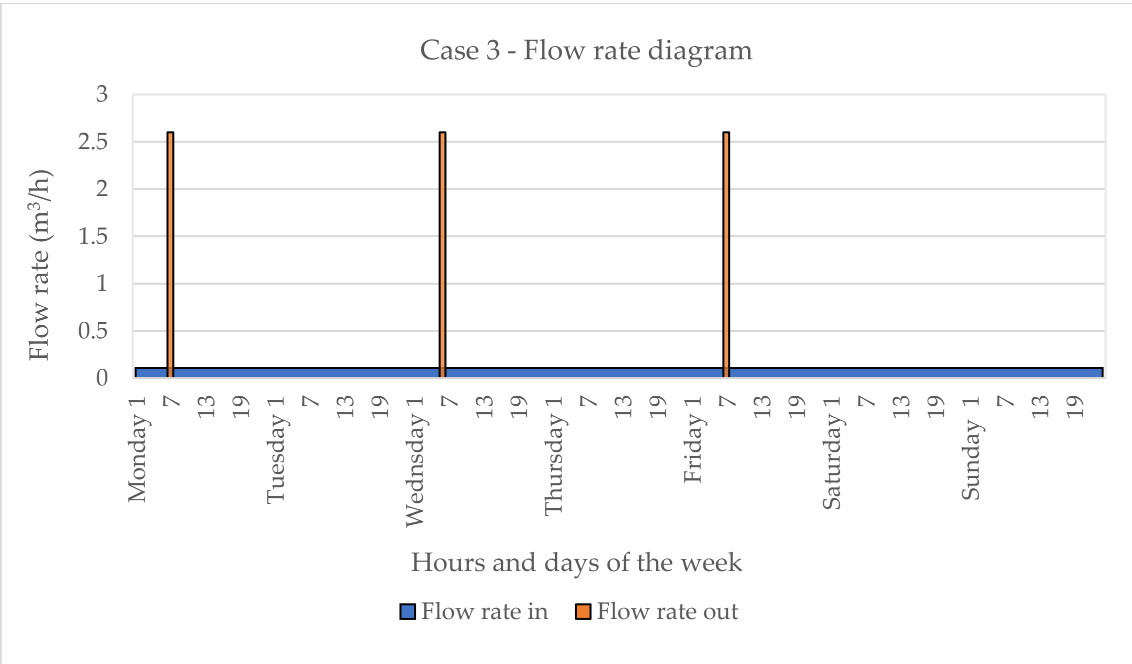


Figure 4.14: Flow rate if the water is distributed three time a week for one hour each day with a constant flow rate income into the tank

The income flow rate has been modulated to be easy for the local people to open and close the valve that will regulate the flow rate in entrance. The final configuration is in Figure 4.15.

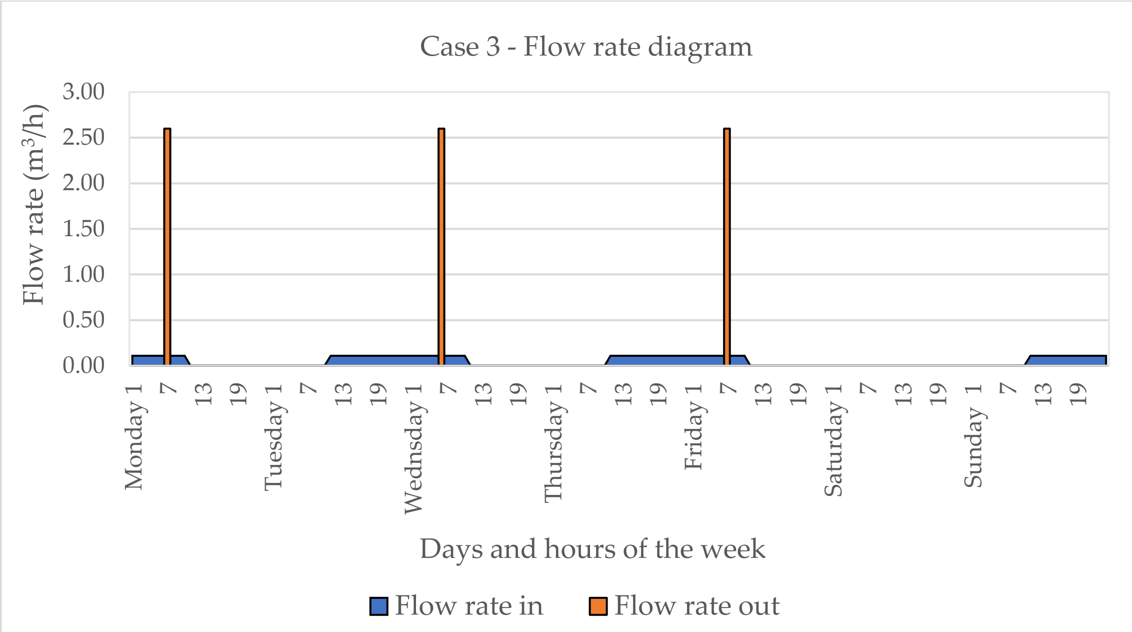


Figure 4.15: Flow rate if the water is distributed three time a week for one hour each day with a modulated flow rate income into the tank

The water will enter in the tank for 24 hours from 10 a.m. of the day before to 10 a.m. of the day after in the days of Monday, Wednesday, and Friday. The volume diagram is in Figure 4.16 and the table in which there are the data is in Appendix 3. In Figure 4.16 are drawn the maximum deviation in minimum and maximum of the difference between the cumulative income and outcome volumes. The maximum deviation in positive occurs twice in a week: on Monday and Friday at 6 a.m. (C_1). The maximum deviation in negative, instead, occurs one time in a week on Wednesday at 6 a.m. (C_2).

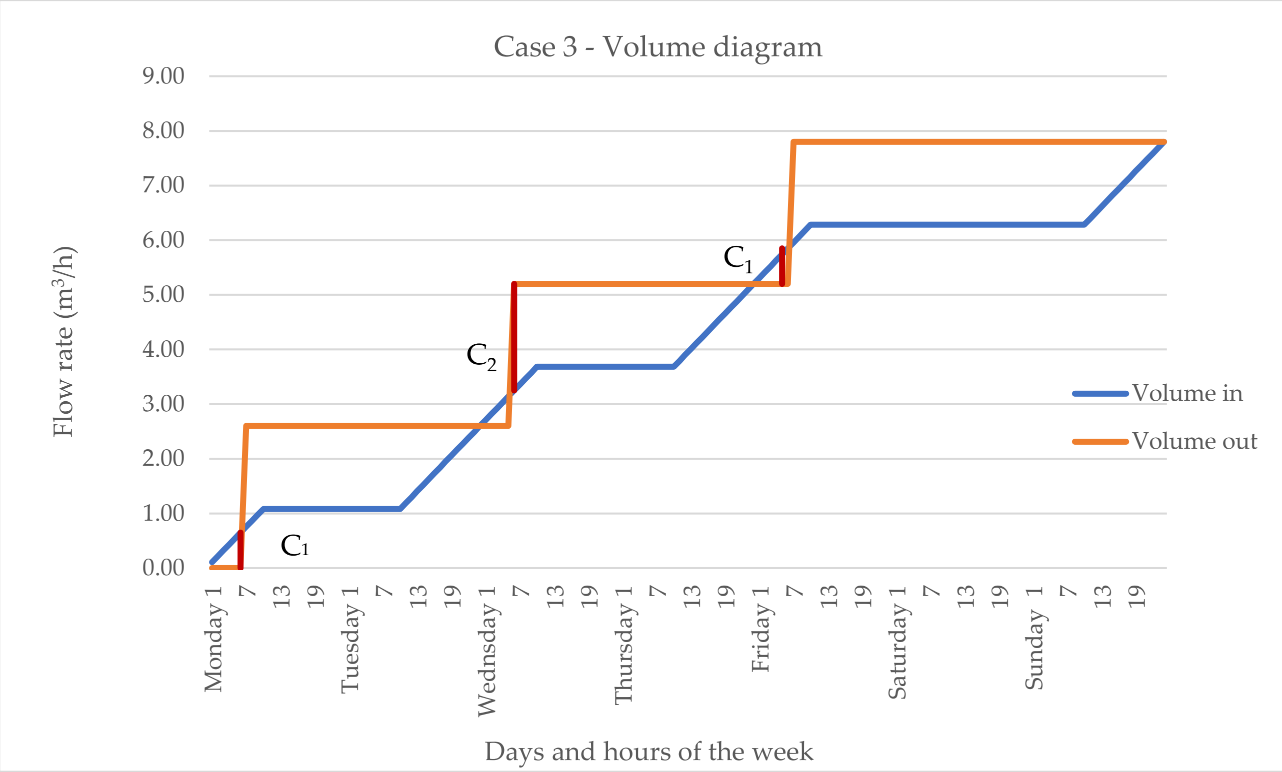


Figure 4.16: Volume diagram and the maximum deviations C_1 and C_2 between the volume out and the volume in.

The minimum volume is calculated as in Formula 4.18.

$$C_{min} = C_1 + |C_2| = 0.65\ m^3 + |-1.95|\ m^3 = 2.60\ m^3 \tag{4.18}$$

The effective volume of water inside the tank is the dashed area in green in Figure 4.17.

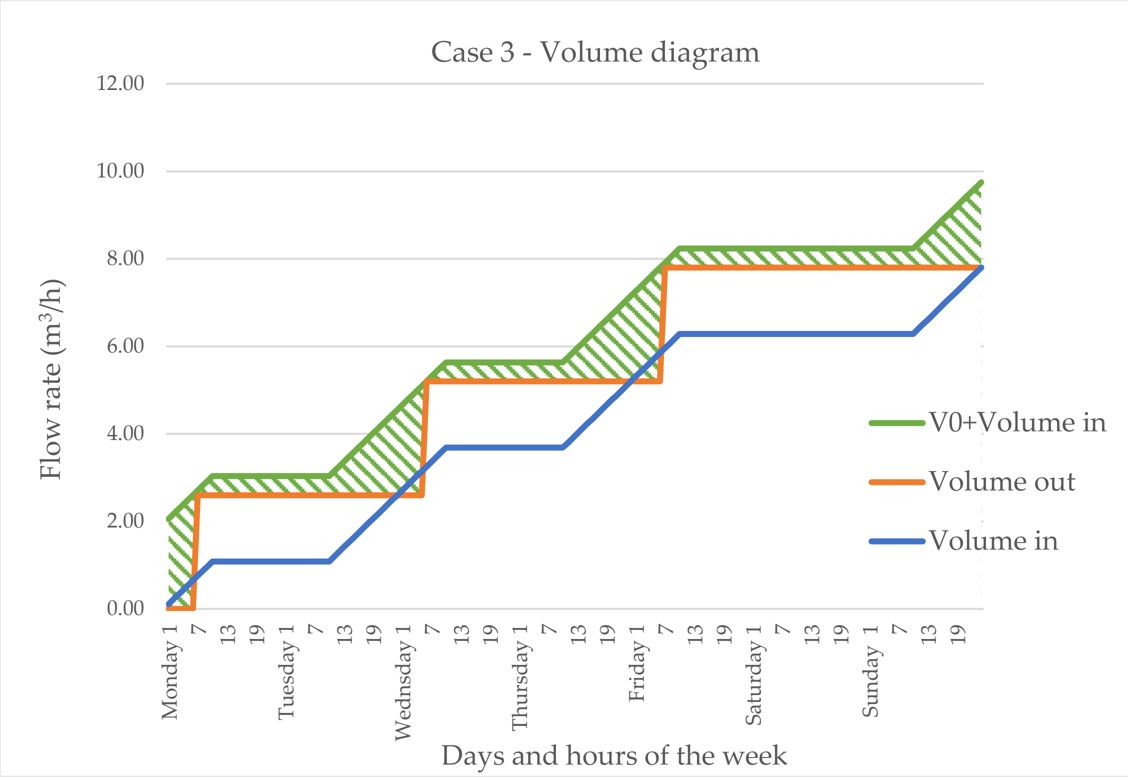


Figure 4.17: Change in volume in the daytime in Case 1. The dashed area in green is the area in the water inside the tank.

The minimum and initial volume for the Case 3 are in Table 4.22.

Table 4.22: Final solution for Case 3.

Times per week	Hours per time	Volume out per hour (m^3)	V_0 (m^3)	C_{min} (m^3)
3	1	2.6	1.95	2.60

4.2.4 Final tank configuration

The three scenarios have produced different solutions. Since the main goal of the tank design is to minimize the minimum volume, Case 2 should not be applied. With the hypothesis to irrigate only one time per day, the minimum tank volumes should be over 10 m^3, with a huge initial volume. Dividing the required volume in two times a day, as in Case 1, the minimum volume is almost divided in half concerning Case 2. In the three scenarios, the smallest minimum compensation volume is in Case 3, because the given water amount is the lowest. As a result of these considerations, the chosen configuration is that in Case 1, assuming that the spring could provide the required water. If the spring should not be able to give the 13 m^3/day, the volume of Case 1 equal to 5.42 m^3, will be sufficient for the implementation of Case 3.

The initial volume of the tank is the value found in Case 1, equal to 2.17 m^3; to accumulate this water amount are necessary 4 hours, considering a constant income flow rate of 0.54 m^3/ day. The results are resumed in Table 4.23.

Table 4.23: Final tank configuration

Final tank configuration					
Times per week	**Hours per time**	**Volume out per hour (m^3)**	**V_0 (m^3)**	**Time to recover V_0 (h)**	**C_{min} (m^3)**
2	2	3.25	2.17	4	2.42

4.3 Water distribution to the gardens

The last design part is the water distribution from the tank to the gardens. The main goal of this part is to verify that the water can arrive at the furthest point of the selected garden area, which is the same for the two tank positions that have been considered (Figure 4.18).

To verify it, as an approximation, that a pipe brings the water from the tank to one of the seven gardens positioned in the furthest point, following a straight line. To calculate the water that the pipe should transport, supposing to use the tank solution in Case 1, the flow rate of 3.25 m^3/h has been divided into seven, to know the water required by each garden at each hour of water distribution. At last, the flow rate has been converted in cubic meters per second equal to $1.29*10^{-4}$ m^3/s. Has also been supposed that the water flows into a tank, with a water level inside of 1 m.

Figure 4.18: the furthest point in the gardens area from the A tank and the B tank position

To do that has been applied the same procedure used for the sizing of the pipe from the water source to the tank. Also in this case, has been considered the two different positions of the tank (on the top side or on the lateral side of the gardens area), and the possible three water levels inside the tank which collect the water before the gardens. The pipes should be at the ground level or bury at 20-30 cm underground, and the pipe material should be PE as for the pipe from the WS02 to the tank. The project data are reported in Table 4.24.

Table 4.24: Project data to verify if the water can arrive to the furthest point from the tank position.

Q (m^3/day)	**Q per one garden (m^3/h)**	**ε (m)**	**υ (m^2/s)**	**g (m/s^2)**	**A tank piezometric height (m)**	**B tank piezometric height (m)**	**Piezometric hight at the gardens (m)**
13	0.46	$0.02 \cdot 10^{-3}$	$1 \cdot 10^{-3}$	9.8	16.47+1	16.50+1	13.58+1
					16.47+1.5	16.50+1.5	
					16.47+2	16.50+2	

The values of the tank heights, the length of pipes *L*, the piezometric levels *h*, the distributed head losses *J*, and the difference of total head ΔH are in tables Table 4.25 and Table 4.26.

Table 4.25: the values of the tank heights, the length of pipes L, the piezometric levels h, the distributed head losses J, and the difference of total head ΔH for the tank on the lateral side of the gardens area.

A Tank					
Water level (m)	**h (m)**	**J (m/m)**	**ΔH (m)**	**Tank altitude(m)**	**L (m)**
1	17.47	0.0143	2.89	16.47	202.23
1.5	17.97	0.0168	3.39		
2	18.47	0.0192	3.89		

Table 4.26: the values of the tank heights, the length of pipes L, the piezometric levels (h), the distributed head losses J, and the difference of total head ΔH for the tank on the top side of the gardens area.

B Tank					
Water level (m)	**h (m)**	**J (m/m)**	**ΔH (m)**	**Tank altitude(m)**	**L (m)**
1	17.50	0.0129	2.92	16.50	226.7
1.5	18.00	0.0151	3.42		
2	18.50	0.0173	3.92		

The results are in Table 4.27 and in Table 4.28 which are reported the theoretical internal diameter D, the velocity v, the Reynolds number Re, the relative roughness ε/D, and the friction factor λ final value.

Table 4.27: results for the tank on the lateral side: the theoretical internal diameter (m), the velocity v(m/s), the Reynolds number Re, the relative roughness ε/D and the friction factor λ.

A Tank						
Water level (m)	**ΔH (m)**	**D (m)**	**v (m/s)**	**Re (-)**	**ε/D (-)**	**λ (-)**
1	2.89	0.0201	0.4070	$8.1755 \cdot 10^3$	$9.9576 \cdot 10^{-4}$	0.0340
1.5	3.39	0.0194	0.4350	$8.4520 \cdot 10^3$	0.0010	0.0337
2	3.89	0.0189	0.4607	$8.6975 \cdot 10^3$	0.0011	0.0335

Table 4.28: results for the tank on the top side: the theoretical internal diameter D(m), the velocity v(m/s), the Reynolds number Re, the relative roughness ε/D and the friction factor λ.

B Tank						
Water level (m)	**ΔH (m)**	**D (m)**	**v (m/s)**	**Re (-)**	**ε/D (-)**	**λ (-)**
1	2.92	0.0205	0.3901	$8.0035 \cdot 10^3$	$9.7480 \cdot 10^{-4}$	0.0341
1.5	3.42	0.0199	0.4167	$8.2716 \cdot 10^3$	0.0010	0.0339
2	3.92	0.0193	0.4410	$8.5101 \cdot 10^3$	0.0010	0.0337

The flow is in a regime of turbulent transition. A commercial diameter has been associated to the theoretical diameter calculated in in Table 4.27 and in Table 4.28 and the relative internal and external diameter, the DN and PN are in Table 4.29 and Table 4.30.

Table 4.29: the theoretical diameter (mm) for the tank on the lateral side and the corresponding commercial pipe identified with its nominal diameter DN (mm), the internal diameter D_i (mm), the pipe thickness (mm), and the nominal pressure PN (bar).

A Tank						
	Theoretical diameter	**Commercial pipe**				
Water level (m)	***D* (mm)**	**DN**	**D_i (mm)**	**D_e (mm)**	**Thickness (mm)**	**PN**
1	20.10	25	20.4	22.7	2.3	16
1.5	19.40	25	20.4	22.7	2.3	16
2	18.90	25	20.4	22.7	2.3	16

Table 4.30: the theoretical diameter (mm) for the tank on the top side and the corresponding commercial pipe identified with its nominal diameter DN(mm), the internal diameter D_i (mm), the external diameter D_e (mm), the pipe thickness (mm), and the nominal pressure PN (bar).

B Tank						
	Theoretical diameter	**Commercial pipe**				
Water level (m)	***D* (mm)**	**DN**	**D_i (mm)**	**D_e (mm)**	**Thickness (mm)**	**PN**
1	20.5	32	23.2	27.6	4.4	25
1.5	19.9	25	20.4	22.7	2.3	16
2	19.3	25	20.4	22.7	2.3	16

At least, has been verified the water amount flown for each commercial pipe. The used formula is Formula 4.9. The velocity, the Reynolds number, and the final value of the frictional factor are calculated with the respective Formula 4.7, 4.3, and 4.2. The final values are reported in Table 4.31 and Table 4.32.

Table 4.31: commercial pipe diameter and the corresponding value of relative roughness, velocity, Reynolds number, flow, and friction factor for the tank on the lateral side.

A Tank						
Water level (m)	**D (m)**	**ε/D (-)**	**v (m/s)**	**Re (-)**	**Q (m³/s)**	**λ (-)**
1	0.0204	$9.8039\cdot10^{-4}$	0.4117	$8.3983\cdot10^{3}$	$1.3456\cdot10^{-4}$	0.0337
1.5	0.0204	$9.8039\cdot10^{-4}$	0.4507	$9.1948\cdot10^{3}$	$1.4732\cdot10^{-4}$	0.0330
2	0.0204	$9.8039\cdot10^{-4}$	0.4873	$9.9400\cdot10^{3}$	$1.5926\cdot10^{-4}$	0.0324

Table 4.32: commercial pipe diameter and the corresponding value of relative roughness, velocity, Reynolds number, flow, and friction factor for the tank on the top side.

B Tank						
Water level (m)	D **(m)**	ε/D **(-)**	v **(m/s)**	Re **(-)**	Q **(m³/s)**	λ **(-)**
1	0.0232	$8.6207\cdot10^{-4}$	0.4265	$9.8952\cdot10^{3}$	$1.8030\cdot10^{-4}$	0.0323
1.5	0.0204	$9.8039\cdot10^{-4}$	0.4250	$8.6702\cdot10^{3}$	$1.9891\cdot10^{-4}$	0.0335
2	0.0204	$9.8039\cdot10^{-4}$	0.4592	$9.3682\cdot10^{3}$	$1.5010\cdot10^{-4}$	0.0328

The flow is in a transient turbulent regime also in this case, and the values of Reynolds number and friction factor are bigger than when the theoretical diameter has been considered.

The final results are Table 4.33 and Table 4.34.

Table 4.33:top side tank: the final values of diameter, velocity, and flow for the different differences of head.

A Tank					
Water level (m)	ΔH **(m)**	**Commercial** D **(m)**	v **(m/s)**	Q **(m³/s)**	Q **(m³/day)**
1	2.89	0.0204	0.4117	$1.3456\cdot10^{-4}$	1.9376
1.5	3.39	0.0204	0.4507	$1.4732\cdot10^{-4}$	2.1214
2	3.89	0.0204	0.4873	$1.5926\cdot10^{-4}$	2.2934

Table 4.34: top top tank: the final value of diameter, velocity, and flow for the different differences of head.

B Tank					
Water level (m)	ΔH **(m)**	**Commercial** D **(m)**	v **(m/s)**	Q **(m³/s)**	Q **(m³/day)**
1	2.92	0.0204	0.4265	$1.8030\cdot10^{-4}$	2.5964
1.5	3.42	0.0204	0.4250	$1.9891\cdot10^{-4}$	2.0004
2	3.92	0.0204	0.4592	$1.5010\cdot10^{-4}$	2.1614

The flow rate has been verified also for the condition of smooth pipes. The Blasius equation has been used as in Formula 4.10 and the distributed head loss J has been expressed as in Formula 4.12. The Formula 4.13 has been used to calculate the flow rate as a function of the commercial diameters in smooth pipes condition. The results are in Table 4.35 and Table 4.36.

Table 4.35: smoothness condition for the lank on the lateral side

A Tank							
Water level (m)	ΔH (m)	Commercial *D* (m)	v (m/s)	λ (-)	*Re* (m)	*Q* (m^3/s)	*Q* (m^3/day)
1	2.89	0.204	0.4167	0.0329	$8.5003 \cdot 10^3$	$1.3619 \cdot 10^{-4}$	1.9612
1.5	3.42	0.204	0.4588	0.0321	$9.3589 \cdot 10^3$	$1.4995 \cdot 10^{-4}$	2.1593
2	3.89	0.204	0.4938	0.0315	$9.3589 \cdot 10^3$	$1.6140 \cdot 10^{-4}$	2.3241

Table 4.36: smoothness condition for the lank on the top side

B Tank							
Water level (m)	ΔH (m)	Commercial *D* (m)	v (m/s)	λ (-)	*Re* (m)	*Q* (m^3/s)	*Q* (m^3/day)
1	2.92	0.232	0.4390	0.0316	$9.9972 \cdot 10^3$	$1.8216 \cdot 10^{-4}$	2.6231
1.5	3.42	0.204	0.4302	0.0326	$8.7770 \cdot 10^3$	$1.4063 \cdot 10^{-4}$	2.0250
2	3.92	0.204	0.4651	0.0320	$9.4888 \cdot 10^3$	$1.503 \cdot 10^{-4}$	2.1892

Also in this case, the water flows with a turbulent transition regime. The Reynolds number is quite bigger than the pipe rough condition, due to the lower friction factor that increases the flow rate and consequently the velocity. The flow rate values in the conditions of smooth and rough pipes are compared in Table 4.37 and Table 4.38.

Table 4.37: comparison between the flow rate transported the pipe smooth and rough condition for the three different commercial diameter and piezometric level at the water tank on the lateral side.

A Tank			
Piezometric level in the tank (m)	Commercial *D* (m)	Q (m^3/day) in Rough pipe condition	Q (m^3/day) in Smooth pipe condition
16.47 +1	0.0204	1.9376	1.9612
16.47+1.5	0.0204	2.1214	2.1593
16.47+2	0.0204	2.2934	2.3241

Table 4.38: comparison between the flow rate transported the pipe smooth and rough condition for the three different commercial diameter and piezometric level at the water tank on the top side.

B Tank			
Piezometric level in the tank (m)	Commercial *D* (m)	*Q* (m^3/day) in Rough pipe condition	*Q* (m^3/day) in Smooth pipe Condition
16.47 +1	0.0232	2.5964	2.6231
16.47+1.5	0.0205	2.0004	2.0250
16.47+2	0.0205	2.1614	2.1892

The calculus has demonstrated that in every case taken into consideration the water can be transported to the furthest point of the garden area. The flow rate transported with the commercial diameter is bigger than the initial required flow rate in both rough and smooth pipe conditions. This could be resolved using a valve to regulate the flow. The valve could be positioned at the start of the pipe which outcome from the tank to the single garden.

4.4 Final considerations

The system design could provide the required water with all the possible solutions. The flow rate which could be transported by the pipe from the water source to the tank, in used pipe condition, ranges from 13.05 m^3/day to 17.32 m^3/day. The pipe from the tank to the gardens could transport a flow from 1.94 m^3/day to 2.60 m^3/day. The flow rate transported by both pipes is bigger than the initial required water amount (13 m^3/day) but the flow in excess could be regulated by a valve installed at the start of the pipe. The tank has been sizing for an income and outcome flow rate of 13 m^3/day, but if the flow rate will be higher than that, the tank could be re-sizing following the same procedure explicated in Paragraph 4.2. The selected volume for the tank is 5.42 m^3; since it is the minimum volume, the final tank volume should be bigger than it, because the headspace and the dead space must be considered. The headspace is the free space above the water level inside the tank. This space guarantees that the water does not pour out of the tank. As a first approximation, the headspace is assumed equal to 0.5 m above the water level. This additional height will be over the water level and will be summed to the minimum tank height. The dead space, instead, is the water volume that remains inside the tank because it is under the outcome flow pipe entrance. Also in this case, as a first approximation, the high of the dead space is assumed equal to 0.5 m. The dead space is supposed to be below the ground level since the pipe should be at the ground level or below it of 20 – 30 cm. The tank position and the different water levels inside the tank provide different pipe diameter solutions. Aspects to take into account are the economical aspect and how the water is supposed to be used in the future. The economic aspect will condition the choice of pipe diameter and the flow rate transported and consequently the final size of the water tank. The water could be used for purposes different from agriculture, for example for hygienic purposes as providing water for some public showers. This could require a bigger flow rate and consequently a bigger pipe diameter and a second water tank or a unique tank with bigger dimensions.

If the tank is positioned along the lateral side of the garden area (A tank), the most economical solution is that with a water level inside the tank equal to 1 m. This is the cheapest solution because it requires the smallest pipe diameters. The flow rate transported is not too far from the required water amount, 14.34 m^3/day for the main pipe and 1.94 m^3/day for the pipe in the gardens. For this last pipe, with the A tank position, the commercial internal diameter is still the same for the three water level options. This kind of solution required a tank with a minimum height of 1 m, and the other sides with a minimum dimension of 2.33 m, assuming that the length and width of the tank have the same dimension and that the flow rate will be modulated to be 13 m^3/day. The result is a tank short and large. Instead, if the system would be expanded in the future, for example providing water for hygienic purposes, the system should be oversized. The solution that gives the biggest water flow rate from the water source to the tank (15.40 m^3/day) , is the second solution, with a water level equal to 1.5 m and an internal pipe diameter equal to 32.6 mm for the main pipe. For the secondary pipe, the flow rate transported is 2.12 m^3/day with a diameter of 20.4 mm. The minimum height for the water tank is 1.5 m, and the other dimension should be 1.91 m for the two sides (if the flow rate will be modulated with a valve to be 13 m^3/day); with this configuration, the tank will be well-proportioned. From an economical point of view, this solution is not the most expensive: the pipe from the tank to the gardens has the same diameter for the three solutions, and the diameter of the main pipe is not the biggest diameter found, which is the diameter for the last solution (36.2 mm for 13.05 m3/day).

The tank can be also arranged along the top side of the garden area (B tank). Also in this case, different observations can be done. The less expensive solution should be that with a minor pipe diameter, which is provided by the first solution, with a water level inside the tank of 1 meter. This is the solution that provides the biggest water flow to the gardens: the main pipe could bring 17.32 m^3/day and the secondary pipe 2.60 m^3/day. In this case, if the water flow will be modulated with a valve, the minimum tank dimensions will be 1(h)x2.33x2.33 m. But if the income flow rate will be 17.32 m^3/day the tank must have a larger length and width and the tank could result not well-proportioned. If the flow rate transported in this way is too big, but it is supposed that the water could be used for other purposes, the third solution could be applied. This solution provides for a minimum tank height of 2 meters; if the water flow will be modulated to be 13 m^3/day the minimum tank dimension will be 2(h)x1.65x1.65 m. For the last solution the income volume inside the tank is 15.41 m^3/day with a pipe diameter of 40.8 mm and a flow rate transported to the gardens of 2.16 m^3/day. This is the solution with the biggest pipe diameter, so from an economical point of view is not the most advantageous.

The solution which includes the economical aspect, the possibility to use the water for purposes different to the irrigation, and a well-proportioned tank, is the tank in the A position (on the lateral side) with a minimum height of 1.5 meters, the main pipe diameter of 40 DN (internal diameter of 32.6 mm) and the secondary pipe of 25 DN (internal diameter of 20.4 mm) which can transport 15.40 m^3/day from the water source to the tank and 2.12 m^3/day from the tank to the distant point in the gardens area.. If the water flow will be modulated to be 13 m^3/day the minimum volume of compensation of the tank will be 5.42 m^3 and a minimum tank dimension of 1.5(h)x1.91x1.91 m, at which will be added the headspace volume and the dead space volume. Instead, if the transported water flow will be 15.40 m^3/day the tank will be sizing with the new income flow rate or can be added a second water tank.

5 Conclusions

Different results have been found for the investigated topics. From a social and economic point of view, the necessity to establish stable vegetable gardens with a permanent supply system to meet the food demand of the island inhabitant has emerged. With the found configuration of pipe diameters and tank dimensions, the required water for the vegetable gardens can be satisfied. Of course, the found configuration cannot be the solution that will be built in the Ampanitsoha village, because different variables affect the final dimensions. The final solution depends on how much the system will be expanded in the future, if the transported water will be used also for different purposes, or if the area for the gardens will change. Concerning all these variables, the calculus in Chapter 4 can be applied to different cases and they are proposed to size the system when the final gardens configuration will be defined. The presence of permanent vegetable gardens will allow the population to have a diversified diet and defeat malnutrition. The crops should provide the different macronutrients: legumes for protein, rice, corn, potatoes, and vegetables for carbohydrates and fibers. Even though the gardens cannot provide all the required daily caloric intake, which must be integrated with meat or fish and fruits, they represent the starting point to improve the local diet and depend less on the sources of food from outside the island. The local population is in favour of the creation of the vegetable gardens and participated actively in the data and samples collections during the expedition on Nosy Mitsio. The 21 selected families for the gardens, will be followed by H4O and Kukula in the management of the gardens and will be taught to them how to handle the gardens in the perspective of the *Smart Cooperation*. Given the remote location of the site, little or no data literature existed prior to the present work. The rainfall and temperature trends have been studied, looking also at the variation in trends in different decades. The rainfall data analysis, has brought to suppose that the average water amount in a year ranges between 1000 and 1500 mm. The soil and the bedrock characteristics were searched, and the found data were compared with the local knowledge. Also, thanks to the water and soil samples, laboratory data analysis demonstrated that water on the island is suitable for irrigation and made it possible to know the soil granulometric composition and its behaviour in dry and wet condition. The literature created about the island could be the support for future projects, such as taking advantage of the heavy rains and collecting water to use it as a secondary water source. On the other hand, it could be expanded with more specific data or other laboratory analysis.Working on a site in another continent, and without the possibility to go on the site in first person due to the Covid-19 pandemic, has defined a new way of working. Communication between the project partners has become essential, increasing the collaboration between the different parties. This new approach to international cooperation project could be used when the sanitary emergency will be over, to involve more the local population and make every project more resilient.

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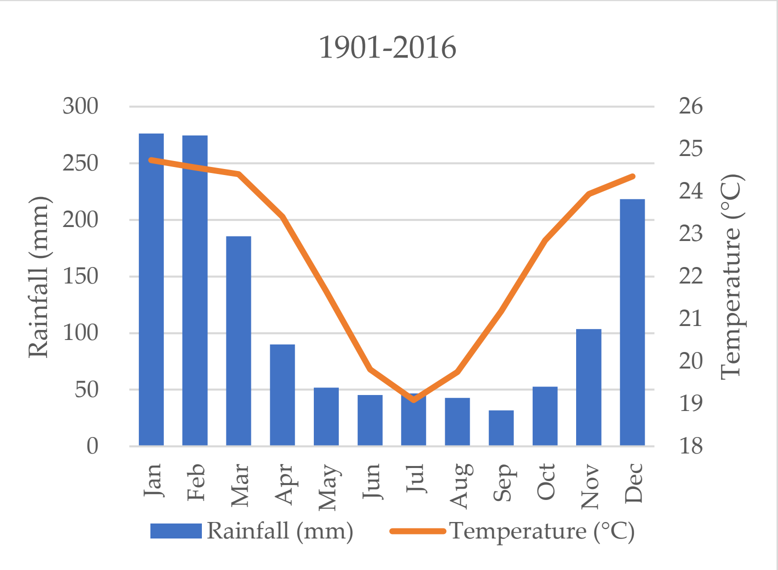
6 Appendix

6.1 Appendix 1

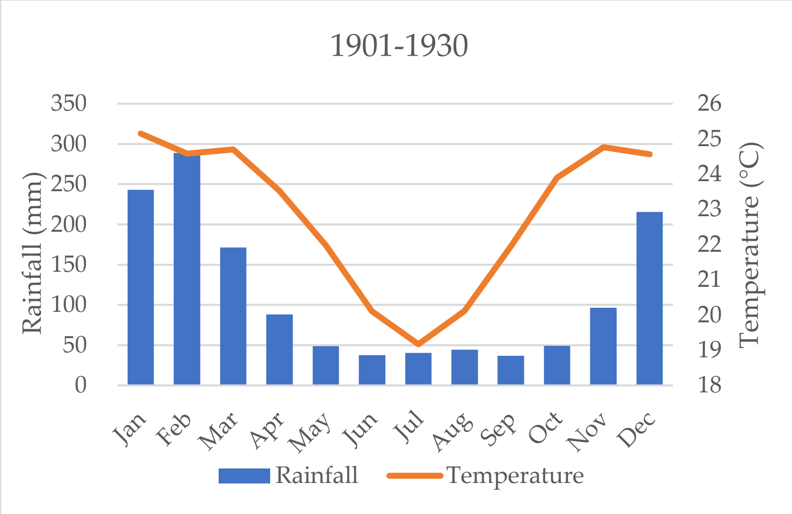
Average monthly temperature and rainfall in Madagascar in form of table and graph and for different time.

Figure and Table 6.1: Rainfall and temperature data and trend in Madagascar from 1901 to 2016



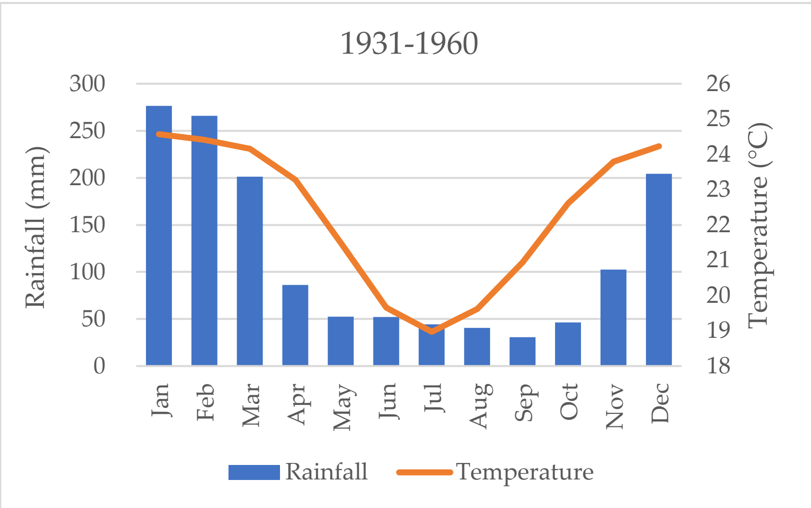
1901-2016		
Month	Rainfall (mm)	Temperature (°C)
Jan	276.18	24.74
Feb	274.61	24.57
Mar	185.66	24.41
Apr	90.01	23.41
May	51.77	21.65
Jun	45.33	19.81
Jul	46.82	19.09
Aug	42.76	19.75
Sep	31.76	21.18
Oct	52.69	22.85
Nov	103.69	23.94
Dec	218.21	24.36
	Total rainfall (mm)	**Average temperature (°C)**
	1419.49	22.48

Figure and Table 6.2: : Rainfall and temperature data and trend in Madagascar from 1901 to 1930



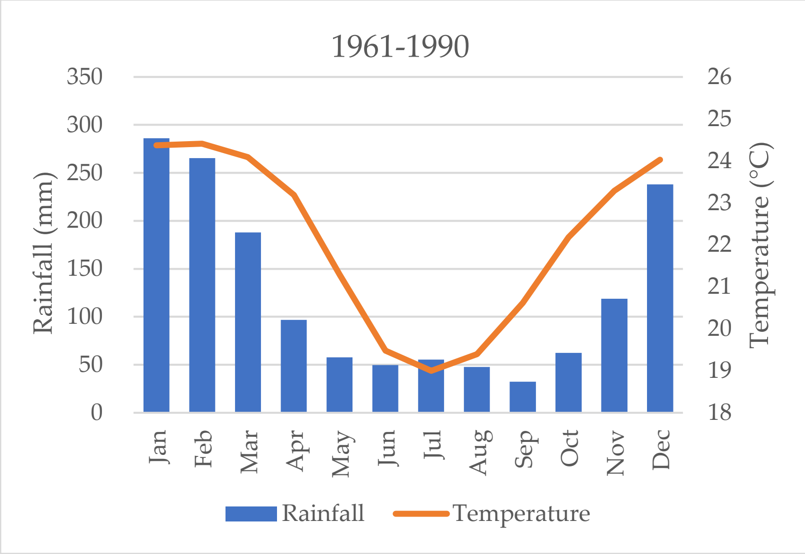
1901-1930		
Month	**Rainfall (mm)**	**Temperature (°C)**
Jan	243.03	25.15
Feb	288.67	24.58
Mar	171.3	24.7
Apr	88.37	23.53
May	48.7	21.98
Jun	37.72	20.11
Jul	40.33	19.17
Aug	44.45	20.12
Sep	36.66	21.95
Oct	49.09	23.9
Nov	96.34	24.76
Dec	215.64	24.56
	Total rainfall (mm)	**Average temperature (°C)**
	1360.3	22.88

Figure and Table 6.3 Rainfall and temperature data and trend in Madagascar from 1931 to 1960



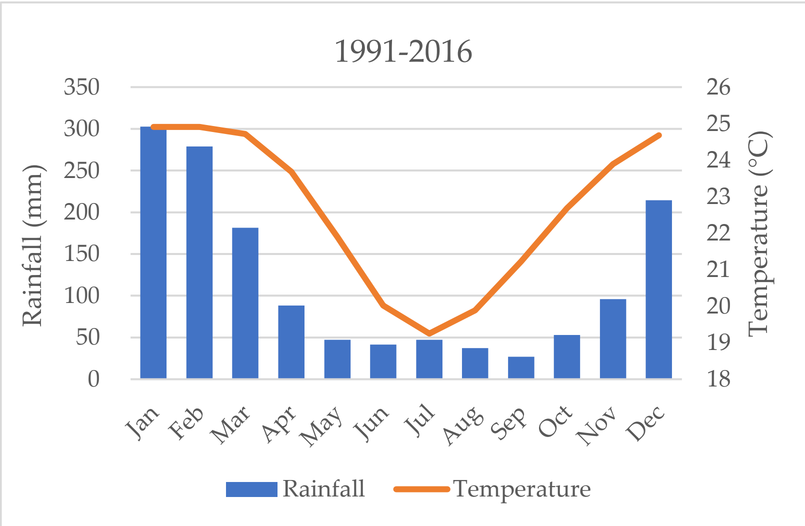
1931-1960		
Month	**Rainfall (mm)**	**Temperature (°C)**
Jan	276.58	24.74
Feb	266.07	24.57
Mar	201.16	24.41
Apr	86.24	23.41
May	52.62	21.65
Jun	52.04	19.81
Jul	44.18	19.09
Aug	40.61	19.75
Sep	30.59	21.18
Oct	46.24	22.85
Nov	102.61	23.94
Dec	204.15	24.36
	Total rainfall (mm)	**Average temperature (°C)**
	1403.09	22.31

Figure and Table 6.4: Rainfall and temperature data and trend in Madagascar from 1961 to 1990



1961-1990		
Month	**Rainfall (mm)**	**Temperature (°C)**
Jan	286.13	24.37
Feb	265.42	24.41
Mar	188.1	24.09
Apr	96.94	23.19
May	57.73	21.29
Jun	49.67	19.48
Jul	55.51	19
Aug	47.79	19.4
Sep	32.34	20.62
Oct	62.46	22.18
Nov	118.79	23.29
Dec	238	24.03
	Total rainfall (mm)	**Average temperature (°C)**
	1498.88	22.11

Figure and Table 6.5: Rainfall and temperature data and trend in Madagascar from 1991 to 2016



1991-2016		
Month	**Rainfall (mm)**	**Temperature (°C)**
Jan	302.48	24.91
Feb	278.82	24.91
Mar	181.53	24.72
Apr	88.26	23.68
May	47.46	21.89
Jun	41.36	20.02
Jul	47.33	19.25
Aug	37.47	19.89
Sep	26.79	21.23
Oct	53.02	22.68
Nov	96	23.89
Dec	214.57	24.68
	Total rainfall (mm)	**Average temperature (°C)**
	1415.09	22.65

6.2 Appendix 2

TDS, pH and the relative temperature measured in the well of interest and at the taps in Ampanitsoha. The mean and the standard deviation have been calculated for the three parameters.

Table 6.6: pH, TDS and temperature at well VMM

No potable well (VMM)			
Hour and date: 9.29 03/12/20			
Ph1	8.41	T1 (°C)	31
Ph2	8.22	T2 (°C)	33
Ph3	8.28	T3 (°C)	33.7
Mean	8.30	Mean	32.57
St. Dev.	0.10	Dev.st.	1.40
TDS1 (ppm)	241	T1 (°C)	33
TDS2 (ppm)	256	T2 (°C)	33.5
TDS3 (ppm)	219	T3 (°C)	33.5
Mean (ppm)	238.67	Mean (°C)	33.33
St. Dev.	18.61	Dev.st.	0.29

Table 6.7: pH, TDS and temperature at well WS02

Water Source 2 (WS02)			
Hour and date: 8.23 04/12/20			
Ph1	9.23	T1 (°C)	30.1
Ph2	9.19	T2 (°C)	30.6
Ph3	9.2	T3 (°C)	30.2
Mean	9.21	Mean	30.30
St. Dev.	0.02	Dev.st.	0.26
TDS1 (ppm)	76.8	T1 (°C)	30.4
TDS2 (ppm)	78.4	T2 (°C)	29.7
TDS3 (ppm)	92.6	T3 (°C)	30
Mean (ppm)	82.60	Mean (°C)	30.03
St. Dev.	8.70	Dev.st.	0.35

Table 6.8: pH, TDS and temperature at well WS01

Water Source 1 (WS01)			
Hour and date: 9.29 03/12/20			
Ph1	8.81	T1 (°C)	32.5
Ph2	8.87	T2 (°C)	32.3
Ph3	8.9	T3 (°C)	32.3
Mean	8.86	Mean	32.37
St. Dev.	0.05	Dev.st.	0.12
TDS1 (ppm)	61.48	T1 (°C)	32.1
TDS2 (ppm)	88.2	T2 (°C)	31.9
TDS3 (ppm)	107.2	T3 (°C)	31.6
Mean (ppm)	85.63	Mean (°C)	31.87
St. Dev.	22.97	Dev.st.	0.25

Table 6.9: pH, TDS and temperature at well Tap 1

Tap 1			
Hour and date: 08.01 03/12/20			
Ph1	8.56	T1 (°C)	34.6
Ph2	8.77	T2 (°C)	35.1
Ph3	8.79	T3 (°C)	34.5
Mean	8.77	Mean	34.73
St. Dev.	0.13	Dev.st.	0.32
TDS1 (ppm)	83.5	T1 (°C)	35.4
TDS2 (ppm)	77.8	T2 (°C)	33.8
TDS3 (ppm)	63	T3 (°C)	34.5
Mean (ppm)	74.77	Mean (°C)	34.57
St. Dev.	10.58	Dev.st.	0.80

Table 6.10: pH, TDS and temperature at well Tap 2

Tap 2			
Hour and date: 07.46 03/12/20			
Ph1	8.56	T1 (°C)	34
Ph2	8.66	T2 (°C)	34.4
Ph3	8.6	T3 (°C)	33.5
Mean	8.61	Mean	33.97
St. Dev.	0.05	Dev.st.	0.45
TDS1 (ppm)	48.2	T1 (°C)	33.9
TDS2 (ppm)	62.2	T2 (°C)	33.5
TDS3 (ppm)	58.8	T3 (°C)	33.3
Mean (ppm)	56.40	Mean (°C)	33.57
St. Dev.	7.30	Dev.st.	0.31

Table 6.11: pH, TDS and temperature at well Tap 3

Tap 3 (School tap)			
Hour and date: 07.26 03/12/20			
Ph1	8.49	T1 (°C)	33.1
Ph2	8.61	T2 (°C)	31.8
Ph3	8.57	T3 (°C)	32.2
Mean	8.56	Mean	32.37
St. Dev.	0.06	Dev.st.	0.67
TDS1 (ppm)	50.6	T1 (°C)	33
TDS2 (ppm)	43.1	T2 (°C)	32
TDS3 (ppm)	48.5	T3 (°C)	32.6
Mean (ppm)	47.40	Mean (°C)	32.53
St. Dev.	3.87	Dev.st.	0.50

6.3 Appendix 3

The data for the Case 3 in Paragraph 4.2 are reported in Table 6.1. The flow rate in and out of the tank has been divided into the seven days of the week. The highlighted values are the exit volume from the tank and the maximum difference in positive and negative between the cumulative volume in and out.

Table 6.1 : Case 3: the volume in and out of the tank during the week, the cumulative volume in and out and the difference between the cumulative volume in and the cumulative volume out.

Hours in a day	**Vin**	**Cum Vin**	**Vout**	**Cum Vout**	**CumVin - CumVout**	**Hours in a day**	**Vin**	**Cum Vin**	**Vout**	**Cum Vout**	**CumVin - CumVout**
h	**m3**	**m3**	**m3**	**m3**	**m3**	**h**	**m3**	**m3**	**m3**	**m3**	**m3**
Monday 1	0.11	0.11	0.00	0.00	0.11	**Tuesday** 1	0.00	1.08	0.00	2.60	-1.52
2	0.11	0.22	0.00	0.00	0.22	2	0.00	1.08	0.00	2.60	-1.52
3	0.11	0.33	0.00	0.00	0.33	3	0.00	1.08	0.00	2.60	-1.52
4	0.11	0.43	0.00	0.00	0.43	4	0.00	1.08	0.00	2.60	-1.52
5	0.11	0.54	0.00	0.00	0.54	5	0.00	1.08	0.00	2.60	-1.52
6	0.11	0.65	0.00	0.00	**0.65**	6	0.00	1.08	0.00	2.60	-1.52
7	0.11	0.76	**2.60**	2.60	-1.84	7	0.00	1.08	0.00	2.60	-1.52
8	0.11	0.87	0.00	2.60	-1.73	8	0.00	1.08	0.00	2.60	-1.52
9	0.11	0.98	0.00	2.60	-1.63	9	0.00	1.08	0.00	2.60	-1.52
10	0.11	1.08	0.00	2.60	-1.52	10	0.00	1.08	0.00	2.60	-1.52
11	0.00	1.08	0.00	2.60	-1.52	11	0.11	1.19	0.00	2.60	-1.41
12	0.00	1.08	0.00	2.60	-1.52	12	0.11	1.30	0.00	2.60	-1.30
13	0.00	1.08	0.00	2.60	-1.52	13	0.11	1.41	0.00	2.60	-1.19
14	0.00	1.08	0.00	2.60	-1.52	14	0.11	1.52	0.00	2.60	-1.08
15	0.00	1.08	0.00	2.60	-1.52	15	0.11	1.63	0.00	2.60	-0.98
16	0.00	1.08	0.00	2.60	-1.52	16	0.11	1.73	0.00	2.60	-0.87
17	0.00	1.08	0.00	2.60	-1.52	17	0.11	1.84	0.00	2.60	-0.76
18	0.00	1.08	0.00	2.60	-1.52	18	0.11	1.95	0.00	2.60	-0.65
19	0.00	1.08	0.00	2.60	-1.52	19	0.11	2.06	0.00	2.60	-0.54
20	0.00	1.08	0.00	2.60	-1.52	20	0.11	2.17	0.00	2.60	-0.43
21	0.00	1.08	0.00	2.60	-1.52	21	0.11	2.28	0.00	2.60	-0.33
22	0.00	1.08	0.00	2.60	-1.52	22	0.11	2.38	0.00	2.60	-0.22
23	0.00	1.08	0.00	2.60	-1.52	23	0.11	2.49	0.00	2.60	-0.11
24	0.00	1.08	0.00	2.60	-1.52	24	0.11	2.60	0.00	2.60	0.00
Wednsday 1	0.11	2.71	0.00	2.60	0.11	**Thursday** 1	0.00	3.68	0.00	5.20	-1.52
2	0.11	2.82	0.00	2.60	0.22	2	0.00	3.68	0.00	5.20	-1.52
3	0.11	2.93	0.00	2.60	0.33	3	0.00	3.68	0.00	5.20	-1.52
4	0.11	3.03	0.00	2.60	0.43	4	0.00	3.68	0.00	5.20	-1.52

5	0.11	3.14	0.00	2.60	0.54	5	0.00	3.68	0.00	5.20	-1.52
6	0.11	3.25	**2.60**	5.20	**-1.95**	6	0.00	3.68	0.00	5.20	-1.52
7	0.11	3.36	0.00	5.20	-1.84	7	0.00	3.68	0.00	5.20	-1.52
8	0.11	3.47	0.00	5.20	-1.73	8	0.00	3.68	0.00	5.20	-1.52
9	0.11	3.58	0.00	5.20	-1.63	9	0.00	3.68	0.00	5.20	-1.52
10	0.11	3.68	0.00	5.20	-1.52	10	0.00	3.68	0.00	5.20	-1.52
11	0.00	3.68	0.00	5.20	-1.52	11	0.11	3.79	0.00	5.20	-1.41
12	0.00	3.68	0.00	5.20	-1.52	12	0.11	3.90	0.00	5.20	-1.30
13	0.00	3.68	0.00	5.20	-1.52	13	0.11	4.01	0.00	5.20	-1.19
14	0.00	3.68	0.00	5.20	-1.52	14	0.11	4.12	0.00	5.20	-1.08
15	0.00	3.68	0.00	5.20	-1.52	15	0.11	4.23	0.00	5.20	-0.97
16	0.00	3.68	0.00	5.20	-1.52	16	0.11	4.33	0.00	5.20	-0.87
17	0.00	3.68	0.00	5.20	-1.52	17	0.11	4.44	0.00	5.20	-0.76
18	0.00	3.68	0.00	5.20	-1.52	18	0.11	4.55	0.00	5.20	-0.65
19	0.00	3.68	0.00	5.20	-1.52	19	0.11	4.66	0.00	5.20	-0.54
20	0.00	3.68	0.00	5.20	-1.52	20	0.11	4.77	0.00	5.20	-0.43
21	0.00	3.68	0.00	5.20	-1.52	21	0.11	4.88	0.00	5.20	-0.32
22	0.00	3.68	0.00	5.20	-1.52	22	0.11	4.98	0.00	5.20	-0.22
23	0.00	3.68	0.00	5.20	-1.52	23	0.11	5.09	0.00	5.20	-0.11
24	0.00	3.68	0.00	5.20	-1.52	24	0.11	5.20	0.00	5.20	0.00
Friday 1	0.11	5.31	0.00	5.20	0.11	**Saturday** 1	0.00	6.28	0.00	7.80	-1.52
2	0.11	5.42	0.00	5.20	0.22	2	0.00	6.28	0.00	7.80	-1.52
3	0.11	5.53	0.00	5.20	0.33	3	0.00	6.28	0.00	7.80	-1.52
4	0.11	5.63	0.00	5.20	0.43	4	0.00	6.28	0.00	7.80	-1.52
5	0.11	5.74	0.00	5.20	0.54	5	0.00	6.28	0.00	7.80	-1.52
6	0.11	5.85	0.00	5.20	**0.65**	6	0.00	6.28	0.00	7.80	-1.52
7	0.11	5.96	**2.60**	7.80	-1.84	7	0.00	6.28	0.00	7.80	-1.52
8	0.11	6.07	0.00	7.80	-1.73	8	0.00	6.28	0.00	7.80	-1.52
9	0.11	6.18	0.00	7.80	-1.63	9	0.00	6.28	0.00	7.80	-1.52
10	0.11	6.28	0.00	7.80	-1.52	10	0.00	6.28	0.00	7.80	-1.52
11	0.00	6.28	0.00	7.80	-1.52	11	0.00	6.28	0.00	7.80	-1.52
12	0.00	6.28	0.00	7.80	-1.52	12	0.00	6.28	0.00	7.80	-1.52
13	0.00	6.28	0.00	7.80	-1.52	13	0.00	6.28	0.00	7.80	-1.52
14	0.00	6.28	0.00	7.80	-1.52	14	0.00	6.28	0.00	7.80	-1.52
15	0.00	6.28	0.00	7.80	-1.52	15	0.00	6.28	0.00	7.80	-1.52
16	0.00	6.28	0.00	7.80	-1.52	16	0.00	6.28	0.00	7.80	-1.52
17	0.00	6.28	0.00	7.80	-1.52	17	0.00	6.28	0.00	7.80	-1.52
18	0.00	6.28	0.00	7.80	-1.52	18	0.00	6.28	0.00	7.80	-1.52
19	0.00	6.28	0.00	7.80	-1.52	19	0.00	6.28	0.00	7.80	-1.52
20	0.00	6.28	0.00	7.80	-1.52	20	0.00	6.28	0.00	7.80	-1.52
21	0.00	6.28	0.00	7.80	-1.52	21	0.00	6.28	0.00	7.80	-1.52
22	0.00	6.28	0.00	7.80	-1.52	22	0.00	6.28	0.00	7.80	-1.52
23	0.00	6.28	0.00	7.80	-1.52	23	0.00	6.28	0.00	7.80	-1.52

24	0.00	6.28	0.00	7.80	-1.52	24	0.00	6.28	0.00	7.80	-1.52
Sunday 1	0.00	6.28	0.00	7.80	-1.52						
2	0.00	6.28	0.00	7.80	-1.52						
3	0.00	6.28	0.00	7.80	-1.52						
4	0.00	6.28	0.00	7.80	-1.52						
5	0.00	6.28	0.00	7.80	-1.52						
6	0.00	6.28	0.00	7.80	-1.52						
7	0.00	6.28	0.00	7.80	-1.52						
8	0.00	6.28	0.00	7.80	-1.52						
9	0.00	6.28	0.00	7.80	-1.52						
10	0.00	6.28	0.00	7.80	-1.52						
11	0.11	6.39	0.00	7.80	-1.41						
12	0.11	6.50	0.00	7.80	-1.30						
13	0.11	6.61	0.00	7.80	-1.19						
14	0.11	6.72	0.00	7.80	-1.08						
15	0.11	6.83	0.00	7.80	-0.97						
16	0.11	6.93	0.00	7.80	-0.87						
17	0.11	7.04	0.00	7.80	-0.76						
18	0.11	7.15	0.00	7.80	-0.65						
19	0.11	7.26	0.00	7.80	-0.54						
20	0.11	7.37	0.00	7.80	-0.43						
21	0.11	7.48	0.00	7.80	-0.32						
22	0.11	7.58	0.00	7.80	-0.22						
23	0.11	7.69	0.00	7.80	-0.11						
24	0.11	7.80	0.00	7.80	0.00						