MADAGASCAR
DEFIS+

ANNEX 2.a

CLIMATE CHANGE ALALYSIS

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SUMMARY OF THE STUDY

This Annex 2a of the project **Increase Resilience to Climate Change of Smallholders Receiving the Services of the Inclusive Agricultural Value Chains Programme (DEFIS+)** includes an overview of climate change risk analysis in the six target regions (Figure 1). The purpose of this climate study is to define the climate change adaptation and mitigation activities and justify their relevance in relation to the objectives sought as well as the needs and capacities of the beneficiaries. The rationale for the project and justification for seeking climate financing are provided in this document and more specifically in the climate data, maps and analysis that are included as part of this annex 2a.



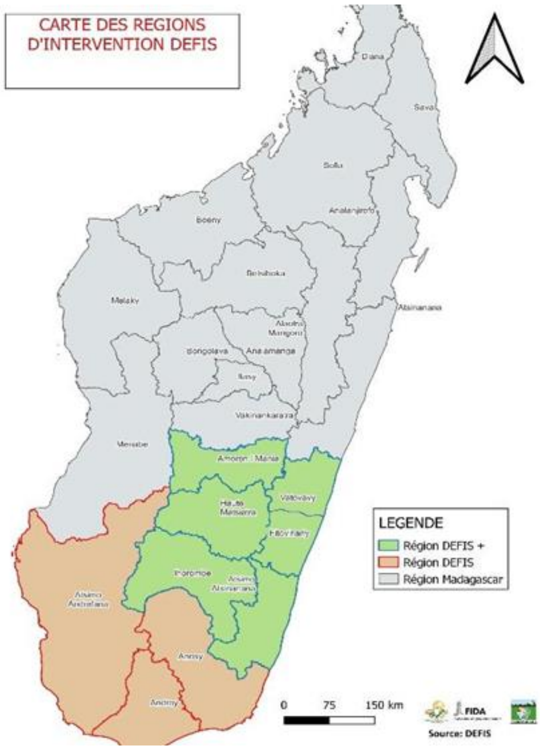


PROGRAMME DEFIS

IFAD
Investing in rural people

MAEP

Figure 1. DEFIS Programme (9 regions, green and orange) and DEFIS+ project (6 regions, green)

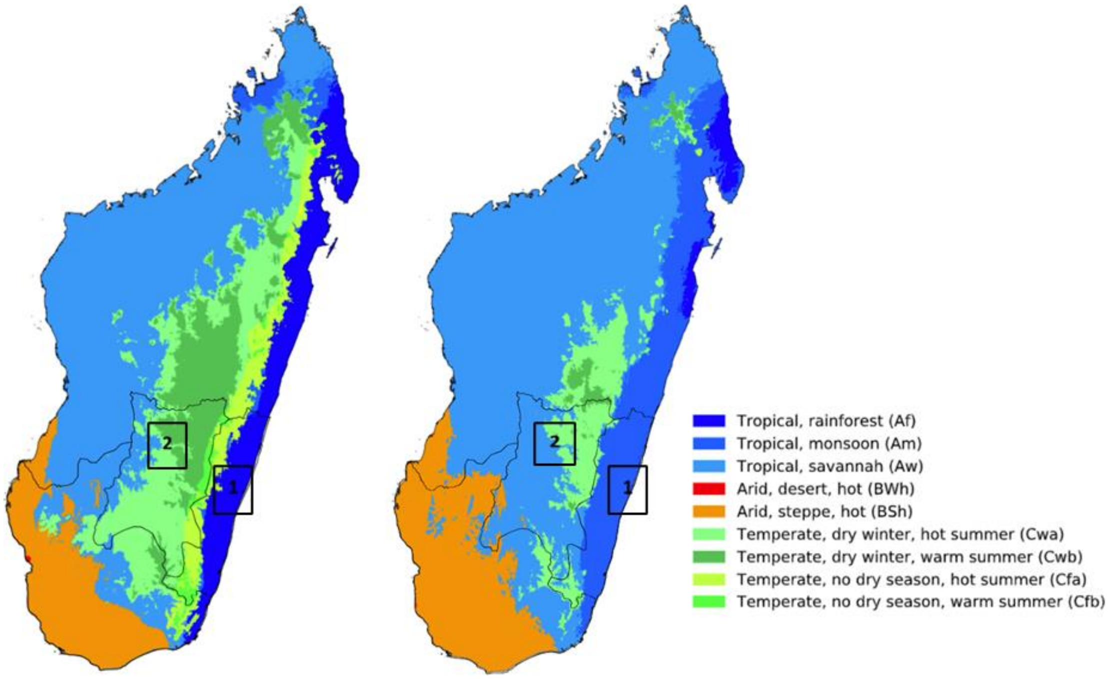


It should be noted that DEFIS+ will complement **"**The Development Programme for Inclusive Agricultural Sectors" or DEFIS. Thus, the programme DEFIS aims to transform agriculture in nine regions of southern Madagascar: Amoron'i Mania, Matsiatra Ambony, Vatovavy, Fitovinany, Atsimo Atsinanana, Ihorombe, Anosy, Androy and Atsimo Andrefana. The overall objective of DEFIS is to sustainably improve the income and food and nutritional security of vulnerable rural people in these nine intervention regions, through the large-scale adoption by family farms of efficient and resilient production systems and their integration into remunerative agricultural value chains, including eight concentration value chains that have been selected by the Programme: rice, corn, cassava, peanuts, onions, coffee, honey, and small ruminants.

Based on the current situation in the six intervention regions in terms of climate change impacts, the purpose of this DEFIS+ study is to define the climate change adaptation and mitigation activities to be proposed to the GCF, and to justify their relevance in relation to the objectives sought as well as the needs and capacities of the beneficiaries. To this end, the DEFIS+ approach adopted includes the collection of bibliographic and field visit data, as well as a SWOT analysis of the strengths, weaknesses, opportunities, and threats in each area concerned in relation to the possible impacts and interventions for climate change adaptation.

Taking into account certain similarities among the different regions, in terms of climatic characteristics, linked to the topographic configuration and the geographical position, and the agricultural activities practised in the area (linked to the climate and the hydrological environment), the six DEFIS+ regions have been grouped into two climatic zones for this study: 1) South East Zone, including the Vatovavy, Fitovinany and Atsimo Atsinanana regions; 2) Central Zone, grouping the Amoron'i Mania, Haute Matsiatra and Ihorombe regions.

Figure 2: DEFIS+ with two climatic zones: South East (1) and Central (2)



Source: Köppen-Geiger climate classification map for Madagascar at 1km. The map outline includes the borders of two zones. Left: (1980-2016). Right: (2071-2100). Beck et al. 2018; Present and future Köppen-Geiger climate classification maps at 1-km resolution.

- *The South-East zone* is characterised by a tropical, per-humid climate with a hot austral summer, high rainfall and an average temperature always above 15° C and which can rise up to 32° C, but varying according to seasons and relief. Tropical cyclones periodically strike this area. Marked climate change is also perceived by farmers with a tendency to drought: rising temperatures and decrease in average annual rainfall, delay in the onset of the rains, shortening of the rainy period, thus resulting in insufficient rainfall in the dry season. In addition, existing studies show a decrease in the frequency of cyclones while their intensity increases, intensifying the risk of flooding during the rainy season. Agricultural production in this area mainly includes rice, cultivated over two seasons, followed by cassava and sweet potato, as well as coffee, spices, fruits and, marginally, vegetable crops. Livestock is poorly developed, zebus are used mainly for working the land. Water resources are abundant with many branched rivers and large flows, favouring the construction of a large number of dams to supply small irrigated areas. However, these parameters are subject to flooding problems caused by the passage of cyclones and silting up due to the degradation of watersheds following bush fires, tavy (slash and burn cultivation) and excessive exploitation of forest resources.

- *The Central zone* benefits from a tropical climate characteristic of the highlands with two contrasting seasons: a hot and humid season, and a winter and dry season. The average annual rainfall varies from 1000 mm in the South to 1400 mm in the North, while the average annual temperature varies from 13° C in mountain areas to 25° C in low areas. In winter, it is not uncommon to find frost and hail at high altitudes. An upward trend in temperatures and a decrease in rainfall with an unpredictable but generally late arrival of rain have also been noted in recent decades, according to public perceptions, and confirmed by meteorological data.

Rice cultivation, cultivated in a single season, occupies a preponderant place in the Central zone, followed by other food crops such as cassava, corn and sweet potatoes. Almost all the valleys are exploited and the slopes with irrigation possibilities are occupied by rice paddies in storey, or otherwise by other food crops. Zebu farming plays an important role, followed by small livestock rearing (pigs and poultry). This area is also characterised by an abundance of exploitable surface water resources, which however tend to decrease. The degradation of watersheds and the depletion of soils also pose significant problems, due to the overexploitation of arable land.

Climate change impacts on rural infrastructure

Madagascar's road networks are among the least developed in the world. The road density is only 5.4 km per 100 km^2, and most of its national and local roads are earth roads and in poor condition. Its rural accessibility index (measured by the share of the rural population that lives within 2 km of an all-weather road) is 11.4%, among the lowest in the world, which means that 17 million rural inhabitants of Madagascar are not connected. Difficulties in accessing villages and markets for the marketing of agricultural products are common to all areas, given **the poor condition of the rural roads**, which are generally subject to water damage and maintenance problems and require strengthening. According to the Ministry of Transport, each year, nearly 300 km of roads are destroyed due to climatic hazards, floods, a lack of maintenance and a lack of financial means.

The impacts of climate change are felt on agriculture and livestock, water resources, hydro-agricultural infrastructure and road infrastructure and are more or less significant in different areas according to their specific characteristics. It should be noted that the components concerned are interdependent, the development of agriculture being conditioned on the availability of water resources as well as the quality of the soil, linked to the degradation of watersheds, and by the state of hydro-agricultural and road infrastructure. The final consequence is the decline in productivity of farms and livestock, as well as problems of access to markets, thus hampering the sustainable improvement of incomes and the food and nutritional security of farmers in the DEFIS+ regions.

Faced with the effects of climate change, farmers are spontaneously trying to adapt to it. The most widespread practice of adaptation to climate change consists of shifting the agricultural calendar, depending on the delay and/or shortening of the rainy season. However, farmers lack reliable agro-meteorological information to enable them to plan effectively at the farm level and make the required shifts. Farmers also change varieties (search for early maturing as a factor in adapting to the drop in rainfall), or even species cultivated to favour more hardy crops. Cultivation practices are also changing both in terms of implementation dates and techniques used, this results in certain cases in the extensification, or diversification of food crops as much as possible, for compensation (for example, an increase in areas cultivated with cassava, sweet potato, and fruit by farmers in the South-East region, after the partial loss of crops following the floods). Another adaptation measure is the development of new agricultural activities in an attempt to spread the risks and/or adapt to new production conditions: introduction of new crops, development of market gardening, small livestock and product processing.

The analysis of the strengths, weaknesses, opportunities and threats in relation to possible climate change adaptation actions makes it possible to highlight the following main points:

- In the South-East and Central zones, the abundant water resources and the existing hydro-agricultural networks are important assets, although they are weakened by floods, silting up, and a lack of maintenance of the networks. The main threats are demographic pressure, severe soil erosion and difficulties in concerted water management.
- For all areas, previous experiences and the presence of numerous organisations and other projects existing locally constitute good opportunities for synergy of actions.

DEFIS+ will also allow the capitalisation of the mitigation potential of agroforestry, reforestation and renewable energy practices. Land-based climate mitigation approaches have significant potential to reduce Madagascar's GHG emissions. The EX-ACT tool shows the DEFIS+'s potential for mitigation which is circa 2.3 tCO2eq per hectare per year, or a yearly average of about 79 936 tCO2eq. Further analysis has highlighted that the climate mitigation potential is considerable. In fact, DEFIS+ can contribute to reducing carbon emissions by 1 598 726 tCO2eq during the project's lifetime (20 years), and it has several climate mitigation co-benefits.
Thus, the envisioned mitigation activities will contribute to the priorities outlined in the country's NDC, including (i) strengthening existing energy systems, promoting renewable and alternative energy sources and distributing improved cooking stoves; (ii) promoting intensive/improved rice farming techniques (SRI/SRA) and implementing Climate Smart Agriculture (CSA); (iii) developing agroforestry and reforestation for sustainable timber production and indigenous species for conservation (LULUCF).

Proposed intervention for climate change adaptation in the DEFIS+ regions

Based on the previous analyses, the activities deemed relevant for climate change adaptation in the DEFIS+ regions were defined as follows, according to four areas of intervention:

1) Improving the availability of water for agriculture and livestock;

2) Development of varieties / crops adapted to extreme climatic conditions, and fighting against pests;

3) Implementation of climate-smart farming techniques and erosion control;

4) Reinforcement of road infrastructure with a view to enhancing its resilience to climatic hazards.

Table 1: Climate change impacts on DEFIS+ interventions and proposed adaptation and mitigation measures

Component	Climate change	Impacts	Interventions
Adaptation Component			
Water / Hydro-agricultural infrastructures	Rainfall decrease Late arrival of rain Cyclones Floods	Insufficient flow / volume Filling problem of reservoirs Water erosion of soils (silting up) Cyclones' damage to structures and networks Bank erosion	Reinforcement of irrigation systems (creation of buffer tanks; reinforcement of desensitisation systems; reinforcement of drainage networks and flood evacuation systems) Capacity building of WUAs (maintenance training; climate change impacts)
Water (Agriculture / Watersheds)	Drought Reduced rainfall Intense cyclones	Decrease in surface water resources / increase in needs Soil erosion Water use conflicts	Concerted management at watershed level (promotion of concertation at inter-municipal structure levels or between upstream watersheds and downstream irrigated areas users)

Agriculture (Water / Watersheds)	Drought Temperature rise Modified rain regime	Declining yields Disruption of the agricultural calendar Insect and pest proliferation	Multiplication and dissemination of seeds / varieties adapted to environmental conditions (with an emphasis on landraces) Support for research for integrated pest management
	Intense cyclones Stronger winds	Water erosion Wind erosion Loss of soil (reduced fertility)	Agro-ecology / Conservation agriculture Terraces / Hedgerows / Lavaka treatment
Livestock	Reduced rainfall Drought Temperature rise	Water problems in the dry season Risks of illness	Construction of drinking troughs (Buried Water Tanks Full of Sand or REEPS)
		Insufficient fodder Grazing issues	Planting improved fodder, more tolerant to drought
Road infrastructure	Cyclones Floods	Water-related Road damage Road Submersion Road cut/down-time Erosion, sedimentation, waterlogging around roads Flooding risk for downstream communities	Reinforcement of sanitation and walkaway networks (scuppers, small bridges) Pavement repair and coating Integration of water management and climate resilience into road rehabilitation work. This will be done by making use of the road infrastructure as it is and adding measures to protect roads and their surroundings and improve water management for the benefit of roadside farmers, such as through farm ponds, sand dams, check dams among others
Mitigation component			
Forestry and land use	GHG emissions	Negative effects on climate change	Reduced or removed/sequestered of GHG by new trees, afforestation, and reforestation
Ecosystems and ecosystem services	Degraded land and environment	Negative impacts on terrestrial and marine ecosystems	Hectares of terrestrial forest, terrestrial non-forest, freshwater and coastal-marine areas brought under restoration and/or improved ecosystems
Ecosystems and	Marginal areas	Negative impact on emissions and climate	Hectares of natural resource areas brought under improved low

ecosystem services			emission and/or climate-resilient management practices

Madagascar is subject to recurrent droughts and the drought phenomenon is cyclical for the southern semi-arid areas (in particular in the Vatovavy and Fitovinany regions), with some areas receiving less than 400 mm of rainfall each year, and is exacerbated by the El-Niño phenomenon.[1] Recently, Madagascar experienced an unprecedented climate induced famine in 2016[2], following a four-year drought, the worst recorded in 40 years[3]. In 2021, four consecutive years of drought reportedly resulted in one of the world's first famines caused by climate change, with people forced to eat locusts and wild leaves to survive in southern Madagascar.[4] Famine is the highest internationally recognised level of food insecurity. Drought effects also led to agricultural losses of up to 60% in the most populated provinces[5].

Madagascar is frequently affected by tropical cyclones. Not only are tropical cyclones more frequent in this ocean basin, but they are also more intense than in other parts of the world. On average, 13 tropical systems with wind speeds exceeding 63 km/h are reported to form each year. Madagascar has one of the highest cyclone risks among African countries, with an average of three to four cyclones affecting the country every year. Climate change is associated with a lower frequency of cyclones, resulting in lower rainfall in the South-Eastern Madagascar. However, the intensity of such cyclones is projected to increase by 46% and, with them, the intensity of associated floods. The eastern and central regions (Amoron'i Mania, Haute Matsiatra, Ihorombe, Atsimo Atsinanana) are expected to experience more intense and frequent cyclones during the wet season and will be subject to more frequent flooding. On the other hand, during the dry season, these same regions are likely to experience periods of increased water deficits. Intense rainfall events caused by strong storms and tropical cyclones, coupled with poor land use practices and increasing deforestation, can lead to significant and damaging floods across the country.

Floods represent the second highest impact disaster, affecting more than 0.3 million people during the 1961-2017 period. Over 30 floods or heavy rainfall events have affected Madagascar in the past 30 years, killing hundreds of people and affecting thousands. In a context marked by deforestation (only 10% of Madagascar's original forest remains)[6] and rapid loss of natural vegetation cover, the vegetation's carbon sequestration capacity is dramatically reduced. Thus, the rapid loss of natural vegetation cover and changes in rainfall patterns resulted in the increased occurrence of floods, which have devastating impacts on the island's rural poor as well as on irrigation and water management networks and warehouses.

1 Unicef. (2021). Wash Technical Paper. Accessed at https://www.unicef.org/madagascar/media/5661/file/Simplified%20Drought%20Monitoring.pdf

2FAO (2021). The impact of disasters and crises on agriculture and food security. Accessed at https://www.fao.org/3/cb3673en/cb3673en.pdf

3 Harding, A. (2021). Madagascar on the brink of climate change induced famine. Accessed at https://www.bbc.com/news/world-africa-58303792

4 https://www.aljazeera.com/news/2021/9/3/madagascar-is-on-brink-of-first-climate-induced-famine-un-warns

5 Ibid

6 Hanski, I., Koivulehto, H., Cameron, A., & Rahagalala, P. (2007). Deforestation and apparent extinctions of endemic forest beetles in Madagascar. Biology Letters.

Floods also intensify the process of soil erosion at the watershed level, as sediments are carried away and silt up irrigated perimeters and lowlands. Such floods also impact road infrastructure. Without any (appropriate) infrastructure to support infiltration, the water runs off and gets 'wasted' which causes soil erosion and increases the risk of flooding in downstream areas. With investments, the water could be harvested not only for agricultural and domestic use, but also to recharge aquifers in the DEFIS+ catchment area – where aquifer productivity is generally low. Thus, according to the data from the Global Forest Watch[7], between 2001 and 2020, Fianarantsoa province lost 664 000 ha of tree cover, equivalent to a 22% decrease in tree cover since 2000 with a negative sequestration balance of 356 Mt of CO_2eq.

In the same period, the province lost 144 000 ha or 18% of the total area of humid primary forest. The justification for the proposed adaptation and mitigation measures is presented in Table 2:

Table 2: Justification for priority climate change adaptation measures

Adaptation measures	**Primary justification**
Irrigation systems	Lower precipitation throughout the rainy season. Irrigation required to compensate decrease. Combined with increasing temperature, evapotranspiration could increase – measures limiting it are required to make irrigation more cost efficient. Irrigation could become especially relevant at the onset of the rainy season as the number of dry days is expected to increase the most in October & November.
Road infrastructure	The Southern regions face flooding risks even though the number of extreme wet days (> 20 mm and > 50mm) is not projected to increase. Road infrastructure could be used for water catchment purposes as a response to decreased precipitation and shorter rainy season.
Evaporation limiting measures	The number of hot days in the rainy season is projected to increase over time, especially at the onset of the rainy season. Measures protecting crops, particularly seedling against heat stress (agroforestry, shading) are essential. Such measures would also reduce crop stress induced by increased evapotranspiration.
Crop shifting & improved seed selection	Lower precipitation throughout the rainy season – crops could fall below optimal levels. The increase in precipitation in Jan-March does not offset reduction in October-November. Need for crop with shorter growing cycles as a response to overall decrease in length of growing season.
Climate information	Potential progressive delay in onset of the rainy season – lower precipitation in October and November. Overall decrease in length of growing season.
Mitigation measures	**Primary justification**
Forestation and reforestation	Large parts of the DEFIS+ area are under severe ecosystem threats. The result is a reduction in vegetation cover, an increase in erosion, and the severity of floods.

[7] Global Forest Watch (n.d) Forest loss in Fianarantsoa, Madagascar

Restoration of degraded land and marginal land	Land not suitable for agriculture due to extreme climate events (droughts, floods, and cyclones) is increasing and represents a risk for food security, access to markets, and human well-being.

Additionally, it is also proposed to carry out transversal activities such as the training of engineers and technicians of the regional departments of the Ministries, and other target audiences, on matters of adaptation and mitigation to climate change and on NIHYCHRI standards, as well as the acquisition and installation of agro-meteorological equipment in strategic locations, in order to be able to have reliable and up-to-date data on climatic parameters.

1. INTRODUCTION

1.1 CONTEXT OF THE STUDY

This feasibility study (Annex 2a) is part of the preparatory study for the project to **Increase Resilience to Climate Change of Smallholders Receiving the Services of the Inclusive Agricultural Value Chains Programme (DEFIS+)**. The project focuses on adaptation to climate change with a mitigation component and financial support from the Green Climate Fund (GCF).

Madagascar's vulnerability to climatic hazards (cyclones, droughts, floods, etc.) and the increased impacts of climate change over the past decades have led to the design of DEFIS+. The DEFIS+ interventions were initially outlined in the DEFIS Programme Design Document. They are developed in more detail in this feasibility study (Annex 2a), so as to justify their relevance in the context of adaptation to climate change and in relation to the objectives of the DEFIS Programme.

As a reminder, the overall objective of DEFIS is to "sustainably improve the incomes and food and nutritional security of vulnerable rural people in the intervention areas", while the development objective of the Programme is "the transformation of family farming through the large-scale adoption of efficient and resilient production systems and the integration of family farming into remunerative sectors".[8,9]

Nine regions were selected for the intervention of the Programme, based on: (i) the incidence of poverty; (ii) the vulnerability to food insecurity; (iii) the complementarity and the scaling up of the positive achievements of previous projects financed by IFAD (AROPA, PROSPERER, FORMAPROD, etc.). The choice of the areas of concentration of DEFIS interventions or "development poles" within these regions was defined according to the following criteria: (i) the level of aggregation of rural populations and family farms; (ii) the level of poverty; (iii) the agricultural potential to be exploited; (iv) the vulnerability to climate change; (v) the processing / marketing / consumption potential.

[8] More information about DEFIS Programme can be fund at: https://www.ifad.org/en/web/operations/-/project/2000001492

[9] https://www.ifad.org/en/-/madagascar-2000001492-defis-supervision-report-february-2022

These nine regions correspond to the Southern part of Madagascar, which is the most affected by poverty, as mentioned above. The main livelihoods of the rural populations targeted in the DEFIS programme is agriculture. Family farms are predominantly subsistence farmers with limited productivity on their land, which results in food and nutrition insecurity in communities. In order to improve the food and nutrition security of the farmers and the income generation from their livelihood activities, eight value chains/ commodities have been selected by the Programme, namely: rice, corn, cassava, peanuts, coffee, onion, honey and small ruminants, with 2 to 3 priority value chains chosen for each region, depending on the existing activities and / or potential for economic development. The current yields for these prioritised commodities are as follows:

Table 3: Average yields of prioritised crops/commodities

Crop/ commodity	Average yield in DEFIS regions	Average yield in other regions
Rice	2.5tons/ha	5.0/6.0 tons/ha
Corn	2.09 tons/ha	4.0 tons/ha
Honey	16.86 liter/hive	N/A
Onions	7.8 tons/ha	N/A
Coffee	250 gr/foot	2.0 tons/ha
Cassava	7 tons/ha	30 tons/ha

These average yields are well below the potential (Table 3). For example, the potential average annual yield for irrigated rice is estimated at up to 5.0/6.0 tons/ha; for maize 4.0 tons/ha; for beans 2.0 tons/ ha; and for cassava 30 tons/ha. This gap can be filled through the use of climate resilient agriculture production techniques including improved inputs such as climate sensitive seeds and cuttings.

The low yields and productivity result in limited incomes for farmers and adversely affect their food and nutrition security at household and community levels. The average incomes for smallholder farmers in the DEFIS+ regions are as follows:

Region	Average income of farmers (Ariary)
Amoron'i Mania	3,017,924
Atsimo Atsinanana	2,424,177
Upper Matsiatra	3,508,226
Ihorombe	3,138,589
Vatovavy and Fitovinany	4,295,280

The southern regions are the poorest and the most affected by chronic food insecurity. Consecutive years of drought impacted the 2020 cropping season, and the situation was exacerbated by travel restrictions to control COVID-19, as a result of which 1.1 million people were critically food insecure in 2021. Food insecurity has particularly worsened in the southern regions of Androy, Anosy and by Atsimo Andrefana. The COVID-19 pandemic notably prevented migration between regions in search of seasonal jobs. As for chronic malnutrition, it also varies according to the regions, ranging from 20.4% in Atsimo Atsinanana to almost 60% in Vakinankaratra according to the 2018 MICS. The regions of Vakinankaratra, Bongolava, Upper Matsiatra and Amoron'i Mania have chronic malnutrition rates exceeding 50%.

Building on the DEFIS Programme**,** the **objective of DEFIS+** is to strengthen the resilience of the agricultural production systems and vulnerable communities to the impacts of climate change while contributing to emission reduction in six regions in Madagascar. Resilience building includes: (i) improving the availability of water for agriculture and animal husbandry, by strengthening irrigation systems and concerted management at the level of watersheds; (ii) developing crop varieties adapted to changing climatic conditions and pest control methods; (iii) implementing climate-smart agriculture techniques, including erosion-control measures; (iv) strengthening road infrastructure against climate risks; (v) improving access to agro-climate data and risks, by using agro-climatic information systems; (vi) managing knowledge on climate change adaptation, especially on food production systems. The planned activities will also allow (vii) capitalisation of the mitigation potential of agroforestry, reforestation and renewable energy practices.

Land-based climate mitigation approaches have significant potential to reduce Madagascar's GHG emissions. As a matter of fact, Madagascar could reach the entirety of its Nationally Determined Contribution (NDC) annual target of a 30 MtCO2eq reduction in emissions in the land sector alone.[10] The EX-ACT tool shows the Project's potential for mitigation that is around 2 tCO2eq per hectare per year or a yearly average of about 83,633.45 tCO2eq[11]. The main activities for mitigation include flooded rice systems with improved water management; mechanical protection (anti-erosion measures implemented that drain into irrigated perimeters) of micro catchments; landscape restoration and reforestation resulting in forests with a moderate level of degradation; annual cropland with improved agronomic practices; climate resilient agriculture practices, afforestation and agroforestry approaches; climate resilient fodder production and; introducing innovative renewable energy-efficient technologies such as solar pumps, dryers, and improved cooking stoves to reduce the use of firewood. The envisioned mitigation activities will contribute to the priorities outlined in the country's NDC, including (i) strengthening existing energy systems, promoting renewable and alternative energy sources; (ii) promoting intensive/improved rice farming techniques (SRI/SRA) and implementing Climate Smart Agriculture (CSA); (iii) developing agroforestry and reforestation for sustainable timber production and indigenous species for conservation (LULUCF).[12]

To achieve the stated objectives, the DEFIS Programme is structured around three components:

1) **Improving the productivity and resilience of agricultural and livestock production systems,** including: 1.1) efficient mobilisation of water; 1.2) local access to agricultural and livestock input networks; 1.3) local agricultural advisory support and nutritional education;
2) **Development of inclusive sectors,** including: 2.1) strengthening producer organisations (PO) for market access and the development of PO - MO (market operators) partnerships; 2.2) access to finance; 2.3) the development of post-harvest infrastructure and market access;

[10] https://www.climatelinks.org/sites/default/files/asset/document/2022-01/Prioritizing%20Investments%20in%20Land-Based%20Climate%20Mitigation%20in%20Madagascar.pdf
[11] See separate Annex with Ex-ACT analysis
[12] Malagasy government: Madagascar's Intended Nationally Determined Contribution

3) **Institutional support, coordination and management of Programmeme's resources:** 3.1) Institutional support and political commitment; 3.2) Coordination, management and monitoring and evaluation of the Programme.

The total estimated cost of the DEFIS Programme is US $ 250 million, of which US $ 53.8 million is expected to be funded by the Green Climate Fund for climate change adaptation activities to meet the specific DEFIS+ objective of building the climate resilience of communities in the target regions.

1.2 CLIMATE CHANGE CONTEXT IN MADAGASCAR AND OTHER ON-GOING PROJECTS

Madagascar is vulnerable to climate change and therefore there is an urgent need to put in place measures to reduce the impacts of climatic events. As in other parts of the world, temperatures have been rising resulting in adverse impacts on the economy with damage to infrastructure and agricultural productivity. The average temperature was 22.48°C between 1901 and 2016, and an increase in temperatures were recorded as 0.2°C in the north and 0.1°C in the south[13]. Out of 21 weather stations, 17 recorded a statistically significant increase in minimum daily temperatures in all seasons (Figures 3 and 4). Several stations have also indicated increasing trends in daily temperatures maximum. There is generally a downward trend over more than 30 years according to the Third National Communication[14]. Over a more recent period (1983-2013), climate trends show a temperature increase of 0.27°C per decade and a decrease in rainfall of 8%[15]. The country experiences extreme climatic events such as cyclones, floods and droughts, the intensity of which can be violent and entail considerable socio-economic costs. Between 1990 and 2015, the country recorded 65 major climate-related disasters, including 50 cyclones and 5 severe droughts[16]. In addition, it was noted the occurrence of 3 to 5 cyclones on average per year, which affect first the eastern slope before crossing the country towards the North-West and the Center-West also concerned.[17] Cyclones account for 65% of disasters registered in Madagascar, with 250,000 people affected on average and 50 million USD in estimated damage[18]. Sea level rise, estimated at 0.6 cm/year between 1994 and 2008, poses a major climatic risk, which can favour salt intrusion and coastal erosion.

Changes in precipitation patterns, increased temperatures and the frequency of extreme climatic events have an impact on the livelihoods of rural populations, farmers, breeders and fishermen are the most exposed (Figures 5 and 6). For agriculture, these impacts result in reduced productivity, some crops being more affected than others. Whatever the scenario, the projections show a negative trend in cassava and maize yields. Thus, an in-depth analysis of climate change and its impacts is provided in section 2 (climate change analysis). The observed trends are summarised in the figures below.

13 World Bank Climate Change Knowledge portal
14 https://unfccc.int/documents/124437
15 USAID. 2018. Profil de risqué climatique Madagascar: Risques climatiques dans les zones urbaines et en voie d' urbanisation. Mars 2018. Available at : https://www.climatelinks.org/sites/default/files/asset/document/180404_USAID-ATLAS_Climate-Risks-in-Urban-and-Urbanizing-Geographies- Madagascar_French.pdf.
16 PPCR. 2017. First Joint Programming Mission Support Madagascar towards developing its Strategic Program for Climate Resilience under the Pilot Program for Climate Resilience (PPCR).
17 RAEM. 2017
18 OIM. 2018

Figure 3: Precipitation and temperatures trends 1961-2017

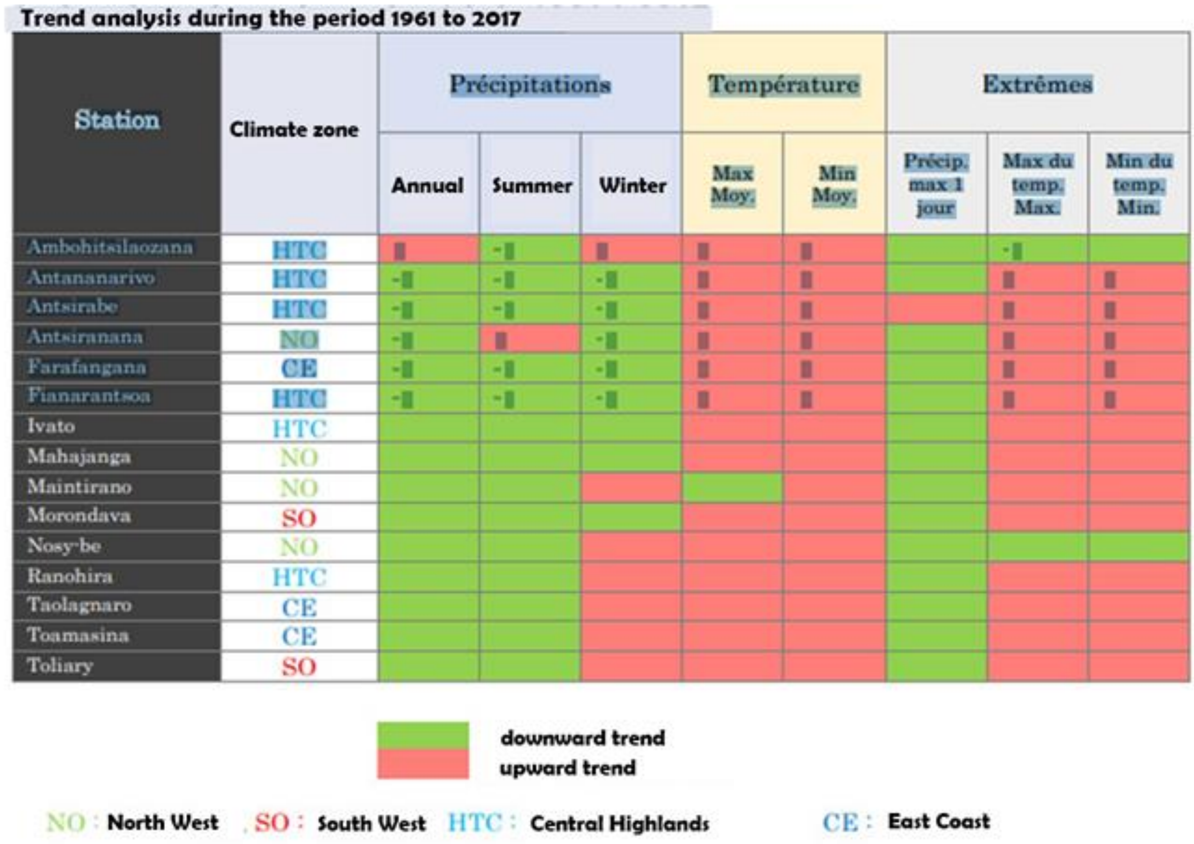


Figure 4: Climate change scenarios by climate zones

Paramètre (Annuelle)	Zones	RCP 4.5 (Modérée)			RCP 8.5 (Elevée)		
		2030s	2050s	2080s	2030s	2050s	2080s
Précipitations (mm)	Côte Est	-1.6	-3.5	-3.1	-4.0	-6.5	-8.6
	Hautes terres centrales	-3.7	-7.8	-7.4	-5.1	-9.0	-11.8
	Nord-Ouest	-3.5	-7.6	-7.1	-4.2	-8.7	-7.9
	Sud-Ouest	0.0	0.0	0.0	-0.1	0.0	0.0
Température maximale (°C)	Côte Est	1.0	1.3	1.8	1.0	1.7	3.0
	Hautes terres centrales	1.1	1.6	2.1	1.2	2.0	3.5
	Nord-Ouest	1.0	1.4	1.9	1.1	1.8	3.2
	Sud-Ouest	1.0	1.6	2.0	1.2	1.9	3.4
Température minimale (°C)	Côte Est	0.9	1.3	1.8	1.0	1.7	3.0
	Hautes terres centrales	1.0	1.5	2.0	1.2	1.9	3.4
	Nord-Ouest	1.0	1.4	1.9	1.1	1.9	3.2
	Sud-Ouest	1.0	1.5	2.0	1.2	1.9	3.4

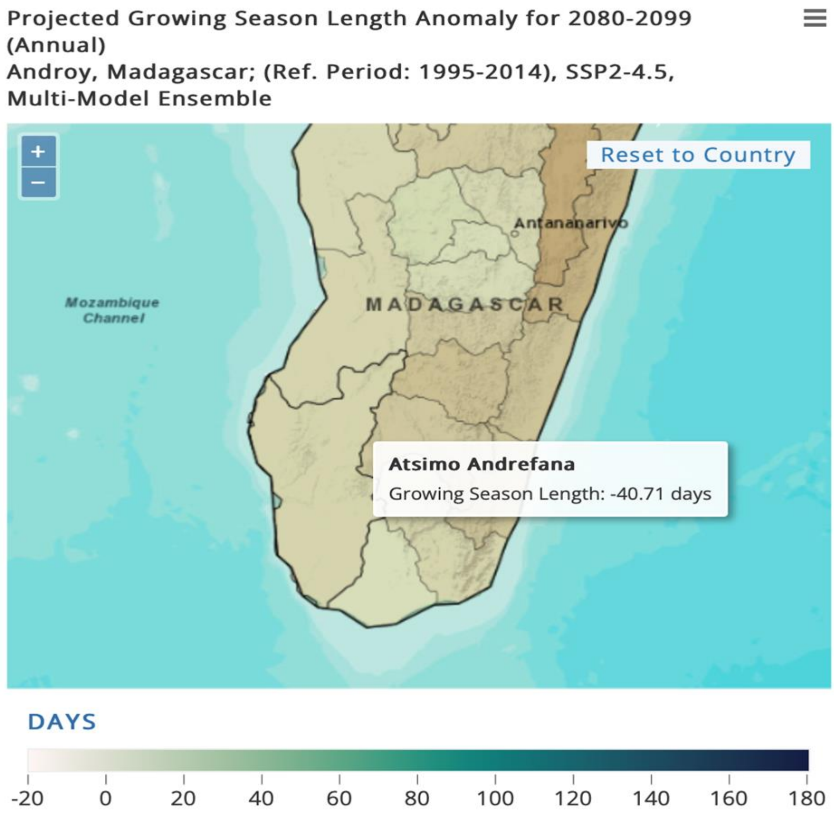
Source des données : NASA NEX

Figure 5: Atlas of natural and climatic risks in Madagascar[19]

Région	Zone	Code	Température Maximale						Température Minimale						Précipitations					
			RCP4.5			RCP8.5			RCP4.5			RCP8.5			RCP4.5			RCP8.5		
			2030	2050	2080	2030	2050	2080	2030	2050	2080	2030	2050	2080	2030	2050	2080	2030	2050	2080
Diana	NO	1	**1.0**	**1.4**	**1.9**	**1.0**	**1.7**	**3.1**	**1.0**	**1.4**	**1.8**	**1.1**	**1.8**	**3.0**	**0.4**	**0.3**	**0.2**	-2.9	-0.7	-1.7
Sofia	NO	2	**1.0**	**1.4**	**1.9**	**1.1**	**1.8**	**3.2**	**1.0**	**1.4**	**1.9**	**1.1**	**1.9**	**3.2**	**0.1**	-0.7	-1.4	-2.8	-0.3	-2.3
Boeny	NO	3	**1.0**	**1.5**	**2.0**	**1.2**	**1.9**	**3.3**	**1.0**	**1.5**	**2.0**	**1.2**	**1.9**	**3.4**	**1.6**	**0.8**	-0.9	**0.5**	**2.9**	**1.8**
Betsiboka	NO	4	**1.0**	**1.5**	**2.0**	**1.2**	**2.0**	**3.5**	**1.0**	**1.5**	**2.0**	**1.2**	**1.9**	**3.4**	-0.8	-1.6	-2.9	-1.7	**0.6**	-0.8
Melaky	NO	5	**1.0**	**1.5**	**2.0**	**1.2**	**1.9**	**3.3**	**1.0**	**1.5**	**2.0**	**1.2**	**2.0**	**3.4**	**1.7**	1.2	**1.1**	1.9	**4.6**	**4.1**
Atsimo-Andrefana	SO	6	**1.1**	**1.6**	**2.1**	**1.3**	**2.0**	**3.5**	**1.0**	**1.6**	**2.0**	**1.2**	**2.0**	**3.5**	-0.2	-1.2	**1.9**	-3.7	-0.1	**2.2**
Menabe	SO	7	**1.1**	**1.6**	**2.1**	**1.3**	**2.0**	**3.6**	**1.1**	**1.6**	**2.1**	**1.3**	**2.1**	**3.6**	**1.3**	1.2	**3.3**	**0.4**	**4.8**	**6.3**
Androy	SO	8	**1.0**	**1.6**	**2.0**	**1.2**	**1.9**	**3.3**	**1.0**	**1.5**	**1.9**	**1.1**	**1.8**	**3.3**	-0.9	-4.1	-2.1	-5.1	-3.6	-4.0
Ihorombe	HTC	9	**1.1**	**1.6**	**2.1**	**1.3**	**2.1**	**3.6**	**1.0**	**1.5**	**2.0**	**1.2**	**1.9**	**3.4**	**0.8**	-1.4	-0.6	-2.4	-0.5	-1.1
Haute Matsiatra	HTC	10	**1.1**	**1.6**	**2.1**	**1.3**	**2.1**	**3.6**	**1.0**	**1.5**	**2.0**	**1.2**	**1.9**	**3.4**	**1.6**	-0.7	-0.3	-2.0	**0.8**	**1.6**
Amoron'i Mania	HTC	11	**1.1**	**1.6**	**2.1**	**1.3**	**2.1**	**3.6**	**1.0**	**1.6**	**2.0**	**1.2**	**2.0**	**3.5**	**1.1**	-0.2	-0.8	-1.6	**2.4**	**2.0**
Vakinankaratra	HTC	12	**1.1**	**1.6**	**2.1**	**1.3**	**2.0**	**3.6**	**1.0**	**1.5**	**2.0**	**1.2**	**2.0**	**3.5**	**0.6**	-0.8	-1.8	-2.0	**3.5**	**1.0**
Itasy	HTC	13	**1.1**	**1.6**	**2.1**	**1.2**	**2.0**	**3.6**	**1.0**	**1.5**	**2.0**	**1.2**	**2.0**	**3.5**	**0.3**	-1.3	-2.5	-2.3	**3.8**	**0.1**
Bongolava	HTC	14	**1.1**	**1.6**	**2.1**	**1.3**	**2.0**	**3.6**	**1.0**	**1.6**	**2.1**	**1.2**	**2.0**	**3.5**	**0.5**	0.0	-0.8	-0.5	**5.1**	**2.0**
Analamanga	HTC	15	**1.0**	**1.5**	**2.0**	**1.2**	**2.0**	**3.5**	**1.0**	**1.5**	**2.0**	**1.2**	**1.9**	**3.4**	-0.9	-2.5	-3.7	-3.5	**0.6**	-2.3
Alaotra-Mangoro	HTC	16	**1.0**	**1.4**	**1.9**	**1.1**	**1.9**	**3.3**	**1.0**	**1.4**	**1.9**	**1.1**	**1.8**	**3.2**	-0.9	-3.0	-4.3	-4.0	-1.8	-4.3
Sava	CE	17	**1.0**	**1.4**	**1.8**	**1.0**	**1.7**	**3.0**	**0.9**	**1.3**	**1.8**	**1.1**	**1.7**	**3.0**	-1.1	-1.4	-0.4	-3.7	-3.5	-3.8
Analanjirofo	CE	18	**1.0**	**1.4**	**1.8**	**1.1**	**1.8**	**3.1**	**0.9**	**1.4**	**1.8**	**1.1**	**1.7**	**3.1**	-0.9	-1.5	-2.6	-3.2	-2.3	-4.7
Atsinanana	CE	19	**1.0**	**1.4**	**1.9**	**1.1**	**1.8**	**3.2**	**1.0**	**1.4**	**1.8**	**1.1**	**1.8**	**3.1**	-0.5	-3.4	-5.0	-4.7	-2.6	-5.9
Vatovavy Fitovinany	CE	20	**1.0**	**1.5**	**2.0**	**1.2**	**1.9**	**3.4**	**1.0**	**1.4**	**1.9**	**1.1**	**1.9**	**3.2**	-0.7	-4.1	-4.6	-4.2	-3.7	-5.9
Atsimo-Atsinanana	CE	21	**1.0**	**1.5**	**1.9**	**1.2**	**1.9**	**3.3**	**1.0**	**1.4**	**1.8**	**1.1**	**1.8**	**3.2**	-1.4	-4.4	-3.3	-4.7	-4.6	-7.7
Anosy	CE	22	**1.1**	**1.6**	**2.0**	**1.2**	**1.9**	**3.4**	**1.0**	**1.5**	**1.9**	**1.1**	**1.9**	**3.3**	-0.7	-3.6	-2.7	-4.6	-3.6	-4.8

NO- Nord-Ouest, SO-Sud-Ouest, HTC-Hautes Terres Centrales, CE-Côte Est
Les chiffres en gras indiquent une tendance à la hausse.

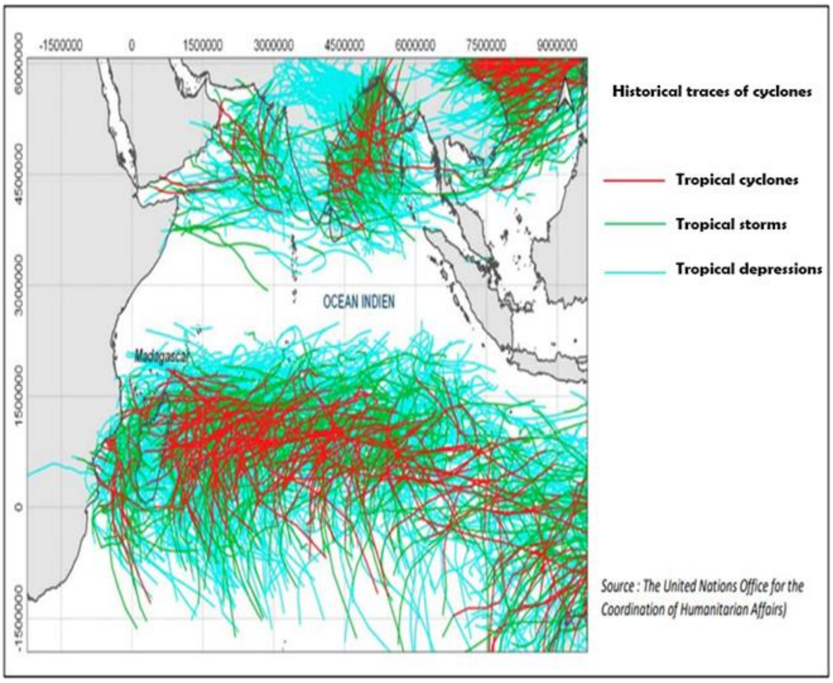
Figure 6: Projected growing season length anomaly 2080-2099



[19] Geosciences for a Sustainable Earth, Emergency Prevention and Management Unit Pilot Program for Climate Resilience, World Bank, 2020

The Indian Ocean Commission (IOC) report[20] stressed that “Madagascar being a tropical country subject to recurrent natural disasters (cyclones, floods and, at times and in some places, increased droughts), issues, such as environmental management in general and adaptation to climate change in particular, are becoming crucial and urgent”. Figure 7 summarises the cyclones' history in Madagascar and in the Indian Ocean.

Figure 7: Historical traces of cyclones



In the Nationally Determined Contributions (NDC) priorities report for Madagascar, the climate adaptation section recommends an ecosystem-based approach for the most vulnerable sectors: agriculture, water resources, forestry/biodiversity, health, coastal zone, and infrastructure. Priority actions defined are grouped into two periods, in particular those to be implemented before 2020 and those concerning the period 2020-2030. Among the actions implemented in the second period (2020-2030) the NDC has included: (i) real-time monitoring of climate information; (ii) the implementation effective implementation of multi-risk early warning systems, integrating at least cyclones, floods, food and nutritional security, droughts/famines, health monitoring and phytosanitary; (iii) the large-scale application of Integrated Models of Resilient Agriculture in the major agricultural hubs, the cultivation areas of rent, extensive farming areas, priority fishing areas, mangroves, and areas susceptible to drought episodes; (iv) strengthening of natural protections and the reduction of the vulnerability of coastal and marine areas and coastal areas affected by coastal erosion and the retreat of the coast; (v) management sustainable and integrated water resources, particularly in sub-arid and those sensitive to periods of drought; (vi) habitat restoration natural resources and (vii) ecosystem-based adaptation to combat advancement of the dunes and other extreme climate events. In addition, the NDC recommends mitigation of GHG emissions with reforestation, afforestation, green technology, and carbon sink tools. The achievement of the objectives in the period 2020- 2030 is subject to the availability of funding estimated at $42 billion to which Madagascar can contribute up to 4%. A number of climate change adaptation projects are also underway or planned in the intervention regions of DEFIS or in other regions of the island, aiming to implement initiatives that are sustainable and resilient to climate change, particularly in the fields of agriculture and the environment.

[20] IOC. Study of vulnerability to climate change - Qualitative assessment, Madagascar, March 2011 https://www.commissionoceanindien.org/?s=

These different projects are briefly presented in Appendix 2a, with their regions of intervention, the components, and the sectors supported where relevant.

1.3 STUDY APPROACH

The purpose of this feasibility study (Annex 2a) is to provide the rationale, the climate change adaptation and mitigation justification, the strategy and the activities proposed under DEFIS+ to strengthen the adaptive capacities of the beneficiaries and their livelihoods.

To this end, the approach adopted for the preparation of the report consists of building on lessons learned from DEFIS programme:

- Present the current situation in the DEFIS intervention regions (nine regions) regarding the impacts of climate in the different regions, six of them part of the DEFIS+ program, and for the sectors supported by the Programme, highlighting the cause-effect links;
- Analyse the strengths, weaknesses, opportunities and threats (SWOT analysis) in each area concerned in relation to the impacts and interventions to be considered for climate change adaptation and mitigation actions;
- Define the areas of intervention for adaptation to climate change in the face of the challenges vis-à-vis the objectives of DEFIS+ and develop the activities proposed to be financed by the GCF taking into account the previous analyses (DEFIS programme), as well as the most recent results.

The present overview is the result of the analysis of primary and secondary data. This includes data collection, through the field visits carried out, and integrated with the available technical and scientific literature. The field visits included stakeholder consultations through interviews with the various local actors working in climate change adaptation, mitigation, and food security (NGOs or project leaders active in the area of intervention), as well as meetings with the villagers, consisting of a collective interview and exchanges in the form of a focus group. The cross checking of information from field visits and bibliographic analysis made it possible to analyse the existing situation and the problems to be resolved, with a view to proposing the appropriate actions for climate change adaptation and mitigation. This overview has been supplemented with an in-depth climate risk analysis including four of the prioritised value chain commodities and an extensive market and social analysis.

2. CLIMATE CHANGE IMPACTS IN DEFIS INTERVENTION AREAS

Here we present the work done in the DEFIS nine regions because it represents the ground for the development of the DEFIS+ project. Before addressing the impacts of climate change at the level of DEFIS intervention areas, it is useful to first present the main characteristics of these different intervention regions. It should be stressed again that the DEFIS programme was developed in nine regions and DEFIS+ is built on six of these regions (Figure 1). The regions are grouped taking into account certain similarities, in terms of:

- ▶ Climatic characteristics, linked to the topographic configuration and the geographic position;
- ▶ Agricultural activities practised in the area, which are themselves generally linked to the climate and the hydrological environment.

Thus, the nine DEFIS regions have been grouped in the following presentation into three zones (see map in Appendix 3 and Figure 1). The South-East and Central zone are included in both DEFIS+ and DEFIS while the South zone includes only DEFIS:

- South zone, including the regions Anosy, Androy, Atsimo-Andrefana;
- South-East zone, including the regions Vatovavy, Fitovinany and Atsimo Atsinanana;
- Central zone, including the regions Amoron'i Mania, Haute Matsiatra and Ihorombe.

A detailed analysis of climatic data trends was provided by the General Direction of Meteorology (Direction of Research and Hydro-meteorological Development) and presented in appendix 4 for each of the nine regions.

2.1 PRESENTATION AND CHARACTERIZATION OF THE THREE DIFFERENT ZONES

2.1.1 South zone (Anosy, Androy and Atsimo andrefana)

The South zone grouping the three regions Anosy, Androy, and Atsimo Andrefana is often commonly called the "Great South of Madagascar" and it belongs only to the DEFIS program. Nevertheless, these three regions present some differences in terms of climate and topography, the Eastern and Northern parts in particular having characteristics fairly similar to the two other zones (Central and South-East zones), and which can be considered as transit zones in relation to these zones, given their geographic location. Thusthe focus will be on the Southern and Southwest parts, corresponding to the most arid zones of the country.

2.1.1.1 Climate characteristics and climate trends of the South zone

This area is generally subject to a semi-arid to arid tropical climate, with two seasons: wet season (summer) and dry season (winter). Aridity increases from the North and Northeast to the South and Southwest of the region and is reflected in the changes in plant landscapes and soils. This aridity is amplified by high temperatures and by strong, persistent and drying winds (Tsiok'Atimo). The drought is aggravated by the El Niño phenomenon, which cyclically affects Madagascar in the southern zone. The average annual rainfall is around 800 mm, with a rainy season that lasts on average 4 to 5 months, while the average annual temperature is around 23 °C to 25 °C.

However, based on field discussions and the results of farmer surveys in other studies, the population has experienced notable changes in the past decade, such as:

- The wet season, which has shortened to three months, with a drop and a delay in precipitation;
- The dry season has increased with an increase of extreme hot days;
- Drought periods have increased significantly;

- The precipitations are more violent but of very short duration and not well distributed in time and space;
- The delay of the first rain in the wet season;
- On average, the temperature has significantly increased.

The analyses and data found in the literature also confirm these trends for climate change in the Great South. Average annual rainfall is currently around 600 mm and temperatures have increased by 1 to 2° C. Additional climate change analyses are also provided indicating that current trends translate into greater inter-annual variability with a statistically significant probability of extreme events. The dry seasons are longer with dry spells becoming more common, while the onset of the rains is more unpredictable. The rains are short but much more intense, sometimes causing severe flooding and significant erosion. Thus, according to the climate trend data provided by the Directorate General of Meteorology (analysis of observed data from 1984 to 2016, see Appendix 4), this trend of temperature increase can be confirmed, while the average annual precipitation tends to decrease, but with much higher point-than-average peaks over the past 10 years.

2.1.1.2 Main socio-economic characteristics: agriculture, livestock and climate

The main food crops grown in the Southern zone are those adapted to a hot and dry climate: corn, cassava, peanuts, cowpeas and sweet potatoes. Rice is also grown in areas where water resources are available. Given the characteristics and the evolution of the climate, agriculture has been oriented for the past decade towards crops that are tolerant to drought and winds, including in particular the revival of the cultivation of sorghum and the promotion of millet and legumes like cowpea. Indeed, for years, corn production has been poor and declining, as shown by statistics from the Ministry of Agriculture. The invasion of red cacti can be noted, which grow naturally and are consumed by the population for survival during the lean season. These fruits have a low nutritional value but in many areas of the South zone is the only food that the population can find to survive.

Finally, cattle breeding, especially sheep and goats, is widely practised in the South zone because these species adapt well to the climatic conditions of the South regions. However, it is worth noting that goats are taboo in certain areas (among the Bara). The possession of a large number of heads of cattle or small ruminants constitutes, on the one hand, an outward sign of wealth and social status, whilst, on the other hand, the breeding of goats and sheep is also used for savings with animals being sold in case of financial difficulties. Currently, the tendency to use livestock as a source of income of family farms is gradually accentuated with the intervention of projects which finance associations of goat breeders in these regions. However, climate extremes such as droughts and high temperatures are reducing the forage and feed availability for the animals and consequently their productivity.

2.1.1.3 Water resources and hydro-agricultural infrastructure

Given the arid climate, the hydrographic networks of the Southern and South-Western part of Madagascar are very unstable. Indeed, with the exception of a few large rivers, flows are very low or even non-existent during dry periods, but they can be violent and destructive during rainy periods. Groundwater resources exist but are difficult to access, their exploitation presents technical constraints (too deep aquifers and low flows) and qualitative constraints (brackish water in the sedimentary aquifers of the south). Thus, the Southern zone, including more particularly the Androy region, is characterised by significant problems of insufficient water resources. On the other hand, the Eastern and North-Eastern parts (Anosy region) have abundant water resources, hence the idea of water transfer to the South which has already been considered many times but which has not yet materialised to date given the very high cost of infrastructure and the high environmental negative impact.

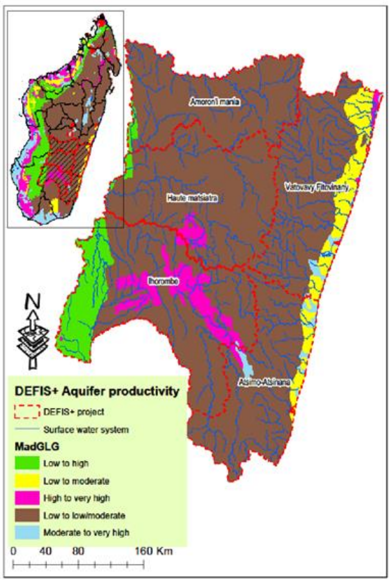
Given this distribution of water resources, hydro-agricultural infrastructures are mainly located in the Eastern and North-Eastern parts of the Anosy region (Tsivory area, in particular). Significant hydro-agricultural infrastructure was also built on major rivers in the years following independence, such as the Mangoky in the Atsimo Andrefana region. However, most of the infrastructure is old, grey technology that has not been well maintained.

Lack of infrastructure, dilapidation of resources and the lack of regular maintenance of existing hydro-agricultural networks characterise the situation in terms of available infrastructure. Sometimes, some municipalities have large hydro-agricultural dams but their lack of maintenance, coupled with the problems of environmental degradation, leads to the silting up of structures and networks, and the reduction of available water resources.

The map (Figure 8, left) shows the productivity of aquifers and the elevation in the DEFIS+ catchment area (Figure 8, right). Even with a more developed seasonal surface water system, the productivity of the aquifer system is still low. There are two hydrological regimes within the DEFIS+ catchment area: the regime of the eastern slopes (RES) and the south-central regime (SOCER). The catchment area is largely a basement where groundwater availability is generally sparser, except where fractures are developed in the crystalline bedrock, principally at shallow levels, and where the weathered overburden is best developed.[21] In RES the low water discharge is very high, about 15 to 30 $l/s/km^2$, with the lowest discharge observed during November or December. SOCER, which characterises the largest portion of DEFIS+ catchment area, represents a transition regime between those of the east, the high plateaux and the west coast. Low water is always very insignificant, possibly only 1 $l/s/km^2$ or even less – observed in October-November, and sometimes the lowest discharge is observed in July-August.[22]

Aquifers recharge is related to the groundwater potential (GWP), which increases with: (1) increasing recharge of groundwater (rate of precipitation is able to infiltrate), (2) higher soils and rocks permeability (geology and lithological units), (3) higher density of lineaments (geological structures), and (4) flat slopes.

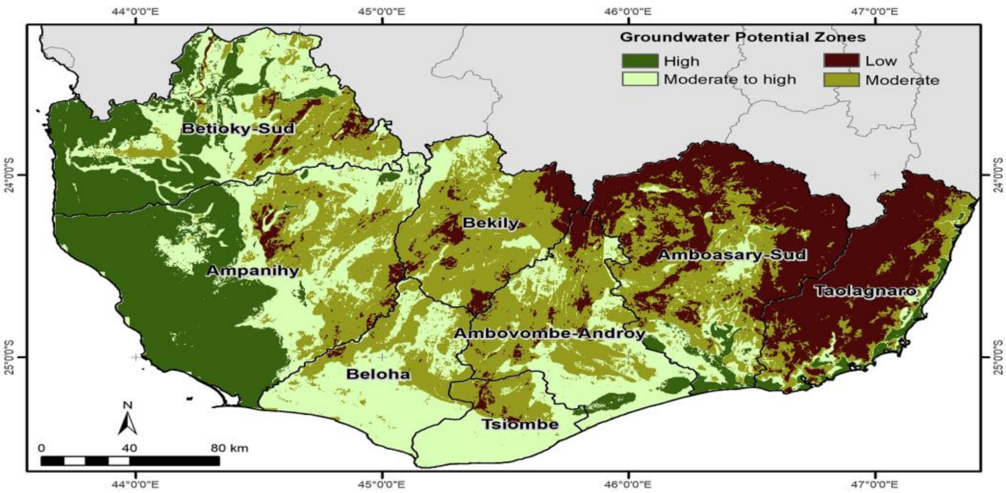
Figure 8: Map of aquifers in DEFIS+



[21] British Geological Survey (2002) Groundwater Quality: Madagascar
[22] Aldegheri, M (n.d). Rivers and streams on Madagascar

In southern Madagascar, groundwater potential is ranging from very low to medium, occupying an area of 18.1% and 39.1%, respectively (Figure 9), while the area under high and very high together occupy 42.7% of the area.[23] The region of Andrefana falls within the high and moderate-high groundwater potential areas. This is mainly due to the geological nature of this region characterised by high permeable karstified limestone and sandy formations. Additionally, around 600 mm/yr rainfalls feed the east side and naturally flow towards the centre and western areas of the region. The region of Androy is dominated by a moderate potential of groundwater accumulation which follows the pattern of the crystalline basement. Potential areas for groundwater occurrence are linked to the presence of fractured and altered aquifers mainly fed by low rainfalls and underflows from temporary rivers. The GWP map of the region of Anosy is dominated by low groundwater potential. This is due to the geological nature of this mountainous region with two-third of its surface covered by a crystalline basement.

Figure 9: Groundwater potential categories in South of Madagascar



Source: Based on data from Earthwise[24] and Diva-GiS[25] (left) and Stalenberg et al[26]

Action to be taken: Efficient water management systems and greening of roads will be critical in improving the water retention in the catchment area, contributing thereby to recharging aquifers. The construction of Green Roads for Water involves environmentally friendly, simple and low-cost techniques to systematically manage the run-off across the entire catchment. Most of the run-off in the catchment can be retained by implementing several water conservation techniques – such as eyebrows, terraces, soak pits etc. – throughout the entire catchment. At the road level and in the downstream areas, there are additional opportunities for increased infiltration by capturing and guiding the road run-off to level land and spreading it.[27] Some of these green techniques are further detailed below:

- Ponds: Based on factors such as land topography, soil type, texture, permeability, water holding capacity, land-use pattern, the project will support recharge pits or ponds, borrow pits, infiltration trenches, etc**.,** as storage structures collecting and storing runoff water and for aquifer recharge – that can be used for livestock drinking water as well as irrigation purposes.

23 Serele et al. (2020) Mapping of groundwater potential zones in the drought-prone areas of south Madagascar using geospatial techniques, available at: https://www.sciencedirect.com/science/article/pii/S1674987119302324
24 Earthwise (n.d) Hydrology of Madagascar
25 https://www.diva-gis.org/gdata
26 Stalenberg E. et al (2018) Using historical normals to improve modern monthly climate normal surfaces for Madagascar
27 Van Steenbergen, F., Arroyo-Arroyo, F., Rao, K., Hulluka, T. A., Woldearegay, K., & Deligianni, A. (2021). Green Roads for Water. Washington, DC: World Bank.

- Check dams: These decrease the slope and velocity of runoff water to control erosion, retain excess water flow while replenishing nearby groundwater reserves and wells.
- Monitoring of groundwater recharge and soil moisture: To monitor the groundwater recharge percentage, DEFIS will employ borehole dippers, or Water Level Dip Meters as they are also known. Water Level Dip Meters are used to determine the water level within a borehole, piezometer pipe or sump. They consist of a stainless steel probe which is specially designed to minimise displacement errors providing unparalleled accuracy.[28] It should be noted that the potential impacts concomitant such as extension of flood duration and reduction of peak discharge with the proposed structures for underground water systems are well captured in the construction of water tanks, including mitigation measures and indicators of achievement/sources of verification. To evaluate the effects of the interventions on soil moisture, measurements will be carried out during the periods in which crop failures in the region, due to shortage of moisture at crop maturation, are most frequent, and will be compared with previous records. The in-situ soil moisture measurement will also involve soil sampling and laboratory analysis.[29] However, it should be noted that **DEFIS+ will use only surface water**, and underground water will not be utilized by the project.

The proposed structures are part of the overall Green Roads for Water (GR4W) concept. The core idea of GR4W is that the negative impacts of roads on the surrounding landscape can be inverted, and roads can simultaneously become instruments of beneficial water management and climate resilience. The proposed structures apart from protecting the road infrastructure from climate-related hazards also control soil erosion and harvest runoff water for various purposes including farming and aquifer recharge that would otherwise go to waste. This will be principally an upstream benefit. Downstream, improved underground water resources will be of great benefit to communities for their domestic but also pastoral activities. Where they have been used, for example, evidence shows that check dams and ponds increase bofedal vegetation, in situ soil moisture, groundwater levels and standing water at a local scale, and lead to increased greenness at a basin scale.[30,31]

Transport infrastructure: Accessibility inside the Southern zone is difficult, especially during the rainy season, because the access roads are unpaved and / or in a state of advanced deterioration. Madagascar's road networks are among the least developed in the world. The road density is only 5.4 km per 100 km2, and most of its national and local roads are earth roads and in poor condition. In the CIRAD-BM report which dates from 2011, the rural accessibility index (measured by the share of the rural population that lives within 2 km of an all-weather road) in Madagascar was 22%.[32] Today, 12 years later, this index has decreased to 11.4%, which means that 17 million rural inhabitants of Madagascar are not connected, and it can be said that this is heavily linked to the impacts of climate change. However, the municipalities and the country have not been able to provide the maintenance of secondary and tertiary roads, as maintenance is prioritized only for primary roads. The already poor connectivity is further worsened by the damage that occurs to the rural roads as a result of frequent extreme climatic events such as cyclones and floods. The poor connectivity undermines the adaptive capacity of the rural communities as they are not linked to basic services and markets that can improve their incomes from their agricultural productivity.

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28 Geotechnical Centre. (2019). Water Level (dip) Meter

29 Woldearegay et al. (2019). Practices and Hydrological Effects of Road Water Harvesting in Northern Ethiopia: Towards Design of Multi-Functional Infrastructures, Momona Ethiopian Journal of Science. Available at: https://roadsforwater.org/wp-content/uploads/2019/12/latest-paper-ptractices-and-hydrological-effects-of-roads.pdf

30 HARTMAN, D.B ET AL (2016). THE EFFECTS OF CHECK DAMS AND OTHER EROSION CONTROL STRUCTURES ON THE RESTORATION OF ANDEAN BOFEDAL ECOSYSTEMS. JOURNAL OF RESTORATION ECOLOGY

31 Woldearegay et al. (2019). Ibid.

32 https://agritrop.cirad.fr/570482/1/document_570482.pdf

2.1.1.4 Environmental constraints related to climate and human activity

From an environmental point of view, the rainfall irregularity in the South zone, combined with the variations and the importance of the thermal amplitudes, often promotes soil degradation. Thus, the passages of tropical depressions are not considered an evil and are even sometimes desired by the population as they bring a lot of rain. However, they are often accompanied by very strong gusts of wind, followed by even higher precipitation which accentuates the irregularity of the climatic conditions. This large amount of water leads to flooding in the plains and low areas, and the deposit of materials torn from the soil in the watersheds (water and wind erosion).

Primary forest loss in Fianarantsoa. According to the data from the Global Forest Watch[33], between 2001 and 2020, Fianarantsoa lost 664,000 ha of tree cover, equivalent to a 22% decrease in tree cover since 2000, and an increase of 356 $MtCO_2eq$ of emissions. The region lost 144,000 ha of humid primary forest, making up 22% of its total tree cover loss in the same time period. Total area of humid primary forest in Fianarantsoa decreased by 18% in this time period. Table 4 shows the level of forest loss in several regions of Madagascar.

Table 4: Forest lost due to human activity and extreme climatic condition

Sub-region	Level of forest loss (000 ha)
Vatovavy Fitovinany	415.0
Atsimo-Atsinana	150.0
Amoron'i mania	36.1
Haute matsiatra	34.8
Ihorombe	27.6

2.1.2 South-East zone (Vatovavy, Fitovinany and Atsimo Atsinanana)

2.1.2.1 Climate characteristics and climate trends of the South-East zone

The South East zone, which is also commonly referred to as "Great South East", is located in the climatic zone of the eastern slope of Madagascar where the annual rainfall is quite high, ranging from 1,500 mm to 2,500 mm. The tropical per-humid climate is characterised by a warm southern summer, high rainfall distributed unevenly between November and April and less rain in winter. The temperature in this area varies between 15 ° C and 32 ° C, depending on the season and on the terrain. It is warmer on the coastal zone, but cooler, even very cool during the austral winter (May to September) on the cliff zone and the mountainous areas on the western part of the two regions.The whole area is vulnerable to natural disasters. Indeed, tropical cyclones crossing the Indian Ocean periodically hit these regions, with the cyclone risk decreasing from north to south. Interviews conducted with farmers and local stakeholders during field visits carried out as part of the study revealed a perception of fairly marked climate change, with a tendency of a delay in the arrival of the rains, a shortening of the rainy period, as well as a decrease in overall rainfall and the increase of frequency of cyclones in recent years, thus causing insufficient rainfall over several months of the year, with prolonged pockets of drought between the months of August and December.

[33] Global Forest Watch (n.d) Forest loss in Fianarantsoa, Madagascar

In a report by the National Bureau for Risk and Disaster Management BNGRC (Report on the State of the Environment in Madagascar 2012), it is stated that: “Since 2010, the regions most affected by drought events are mainly the South and South-East part of the island, including the Atsimo Atsinanana, Vatovavy and Fitovinany regions.” The consequences of drought were most felt in these regions, due to the significant vulnerability of the population.

Referring to the climate trend data provided by the Directorate General of Meteorology (analysis of the data from 1984 to 2016, see Appendix 4), there is a marked trend towards an increase in temperature, while the average precipitations have tended to decrease since 2010.

In short, the South-East zone therefore appears to be subject to two distinct trends:

- Increase in temperatures and decrease in average annual rainfall (and a marked tendency to drought);
- Increase in the intensity of floods, concentrated over short periods. Table 5 shows the recent flood incidences and the impacts on the land:

Table 5: Area flooded in 2017 and 2018

Year	Regions	Devastated areas (ha)
2017	Atsimo Atsinanana	4790,28
	Haute Matsiatra	2037
	Amoron'i Mania	580,8
	Vatovavy Fitovinany	4283
	Ihorombe	90
2018	Amoron'i Mania	7818
	Vatovavy Fitovinany	55477
	Atsimo Atsinanana	2811

2.1.2.2 Main socio-economic characteristics: agriculture, livestock and climate

Three main types of agricultural production systems can be observed in the South-East zone: (i) food crops: seasonal and off-season rice, cassava, sweet potato; (ii) agroforestry crops: coffee, spices, wild fruits; (iii) fruit and vegetable crops: brèdes, and vegetables (which are quite marginal).

The climate of the South-East zone is particularly favourable for the cultivation of rice because the temperatures are warm all year round (above 15 °C even in winter) and allow the cultivation of two seasons of rice, unlike the Hautes lands. The main season, "vatomandry" rice, runs from January to May (from transplanting to harvest). The counter season, "vary hosy" rice, runs from June to November. The two seasons are generally cultivated successively on the same plots. Intended mainly for local consumption, any loss of rice production immediately leads to food insecurity in rural households.

The second type of food crop in the South-East, in order of importance, is the cultivation of tubers: cassava and sweet potato. Cassava is grown on "tanety" (land in watersheds). It is an undemanding plant in terms of soil quality. The work invested in this crop is minimal, so that the Madagascans cultivate this plant a lot, despite its low social value: cassava is considered "the food of the poor". The sweet potato is more demanding in terms of soil. It is particularly suitable for light soils, without excess water. It is more easily sold than cassava and can become a cash crop for smallholders and family farms.

The humid tropical climate also particularly favours the cultivation of coffee, spices, and fruits for export (lychees). The cultivation of coffee flourished during the colonial period, and is practised today by all farmers in the agro-forest system. However, planted several decades ago, these agro-forest systems are ageing and the performance of farms in this field in the Southeast has gradually decreased. The coffee produced has little value for export. In addition, the Vatovavy and Fitovinany regions, due to the specific nature of its honey resources, offers favourable conditions for the production of exotic honey such as niaouli, eucalyptus and lychee honey.

Livestock activities are restricted in the South-East. Cattle farming is mainly aimed at helping with working the land. Zebus are used for mudding rice fields, for pulling plows or harrows or by the traditional system of trampling plots.

2.1.2.3 Water resources and hydro-agricultural infrastructure

The rivers in the South-East are fairly dense and branched, but the length of many rivers is quite short. In general, the rivers in these regions are distinguished by steep slopes in the upper reaches and very weak in the lower reaches. The region is well watered with significant river flows. These different rivers, of a fairly slow course in the central part, offer fertile rims, but their control for hydro-agricultural developments is quite limited given their capricious flow and their depth upstream and downstream. On the other hand, they are spread out either on important low-bottoms with temporary or permanent waterlogging of difficult drainage or on large marshes unfit for agricultural development.

The development or rehabilitation of a large number of hydro-agricultural networks on small perimeters was generally carried out around 1990s in the South-East zone within the framework of Micro Hydraulic projects, Small Irrigated Perimeters and other projects, with the establishment of Water User Associations (WUAs). Many development or rehabilitation projects have also been carried out in this area over the last decade (BVPI South-East funded by AFD, ASARA funded by the European Union, PUPIRV funded by the World Bank, etc.). Thus, the irrigation infrastructures are relatively numerous: dams of containment or diversion, with a gravity network comprising a main channel, secondary canals and the minimum of basic infrastructure: the canals, the crossing works (tarpaulin, siphon, scuppers), control structures, water intakes, outlets, etc. However, the problems of flooding and degradation of watersheds leading to silting up in the perimeters hamper, in some cases, the proper functioning of these networks.

2.1.2.4 Transport infrastructure

The South-East is characterised by poor transport infrastructure. Most of the municipal roads made up of unpaved roads are practically impassable during the rainy season. The tracks leading to the villages are often in poor condition, especially since they are subject to deterioration due to the passage of cyclones and intense rain. There are many crossing structures given the large hydrographic network in the area, but their condition sometimes handicaps the accessibility of villages and the outlet for production. There is not much harness traction in the South-East area, in particular because of the steep slopes characteristic of the region and the absence of carriage roads leading to the farms. All transport is generally done on foot, or by canoe if possible. This makes it difficult to get production to market. Farmers sometimes need a full day to reach buyers, which can deter them. The transport of large quantities of production is only possible through the employment of hired labour; however, most households pay workers when they are really needed, that is, for field work. Thus, certain products, such as vegetables, fruits, and processed food products are perishable and are easily spoiled if they cannot be sold on time. The farmers are dependent on the arrival of collectors.

The main impacts of climate change on road infrastructure are linked to the increase in the intensity of cyclones and floods. It is well known that the negative effects of water are one of the main causes of degradation of road infrastructure. Many parts of Madagascar including Vatovavy and Fitovinany regions will face more intense precipitation, which can increase flooding frequencies. These floods can overrun and erode roads, particularly unpaved roads. Also conventional roads are designed in a way to only protect the road infrastructure from water-related damage but not the environment around the roads. Therefore, there are many problems caused by conventional roads on the surrounding landscape such as erosion, flooding, drainage congestion and sedimentation.

The site specific feasibility studies are being conducted on a rolling basis. Below are summaries of two targeted rural roads/tracks in the South-East zone illustrating the status of the infrastructure and the envisaged works.

Lokomby-Marofarihy rural road

The objective of the sub-project is to repair the hot spots of the Lokomby-Marofarihy track (Vatovavy and Fitovinany regions) and rehabilitate the remaining sections.

The track with hot spots measures a total of 10,830 km and is divided between 27 sections which are located from the beginning and towards the end of the axis. As a result, the statement of the points is made from the Lokomby-Bekatra axis (the start pt is in Lokomby) and from the Marofarihy-Amboanjo axis (the start pt is in Marofarihy). Which divides the axis into 2 parts: axis 1 and axis 2.

The damage observed on the roadway is characterized by longitudinal rutting, quagmires, longitudinal and transverse gullies, potholes and the absence of bulging due to spontaneous wear of the surface of the platform.

The lack of drainage works is one of the causes of the difficulty of access to the track. The structures no longer play their role in cleaning up and/or protecting the track because the latter is strongly affected by degradation; the water is no longer evacuated towards the earthen ditches, which increasingly promotes deterioration of the roadway.

Facilities offered: Given the state of the hot spots, it is proposed to reinforce the flood-prone parts with concrete and gravel for the deteriorations of gravity 3 and materials selected for the deteriorations of gravity 2. The overall amounts of the works are summarized in Table 6.

Table 6: Cost of facilities

N°	Name of tracks	Length (km)	Amount including tax (Ariary)	
			Amount	Price per km
1	LOKOMBY-BETRAKA	5.48	1 268 965 485.000	231 394 144.00
2	MAROFARIHY-AMBOANJO	5.35	1 075 803 284.051	201 159 925.00
TOTAL		**10,83**	**2 344 768 769 051**	

2.1.2.5 Environmental constraints related to climate

The South-East zone is subject to environmental degradation due to bushfires, tavy and the excessive exploitation of forest resources. The soils on tanety, already not very fertile, are impoverished by the succession of cultures, the stripping on the slopes and the rambling of zebus. They are subject to a high erosive risk on the slopes of the hills. Coffee, cloves, lychees and bananas are the main cash crops. The very high rainfall during cyclones causes flooding at the same time as the deposition of materials torn from the soil in the watersheds (water erosion), which silt up the land downstream.

2.1.3 Central zone (Amoron'i Mania, Haute Matsiatra and Ihorombe)

2.1.3.1 Climate characteristics and climate trends

These three DEFIS+ intervention regions have been grouped together because of their geographical location in the Central Highlands, but their climatic characteristics show variations that increase from North (Amoron'i Mania) to South (Ihorombe). The Amoron'i Mania region and the Haute Matsiatra region (Central Highlands) benefit from a tropical climate of altitude on the highlands: the seasons are well contrasted and the altitude tempers the climate. In winter, it is not uncommon to find frost and hail. In summer, the heat is important and thunderstorms are frequent at the end of the day.

The Ihorombe region is a transition zone between the semi-arid climate of the southern zone and the tropical climate of altitude characteristic of the highlands. The dry season can last up to nine months against seven months in the two previous regions and the weather is generally less rainy (average annual rainfall of around 800 mm, while the average annual rainfall in the two regions Amoron ' i Mania and Haute Matsiatra is between 1200 mm and 1500 mm). The average altitude in these three Highland regions is around 1000 m, but it varies between 300 m in the plains, and more than 2000 m in mountain areas. The average temperature also varies accordingly, ranging from 13 °C in the high areas to 25 °C in the low areas.

An upward trend in temperatures and a decrease in rainfall have been noted, according to surveys of population perceptions of climate change in the Fianarantsoa region (USAID, 2008). In addition, according to those surveyed, the rain patterns have changed, with an unpredictable but generally late arrival of the rains and a shorter duration, which has led to a decrease in the amount of annual rainfall. However, some more intense rain events may occur during the year. The data transmitted by the General Directorate of Meteorology confirms this marked upward trend in temperatures, due to climate change in the Center area. Conversely, it appears that average precipitation tends to decrease over the last ten years as mentioned above (cf. data in appendix 4, for the 3 regions concerned). Thus, for the Central zone in general, climate change is reflected in higher temperatures and reduced precipitation, as well as increased unpredictability of the onset of the rains and more intense episodes.

2.1.3.2 Main socio-economic characteristics: agriculture, livestock and climate

In general, irrigated rice cultivation occupies a preponderant place among the cultures practised in the Central zone, followed by other food crops such as cassava, corn, and sweet potatoes, which are mainly intended for self-consumption. Generally, on the highlands, almost all of the valleys are exploited, and the slopes with irrigation possibilities are occupied by the rice fields in stages. Even the rocky, wooded, and sloping grounds are exploited for food crops in the Amoron'i Mania region and are arranged in bleachers. The plots are exploited at least twice a year.

For information, the existence in the region Ihorombe of various industrial cultures, which are implemented by the private company of Italian origin "TOZZI GREEN" can be noted. These crops include: growing and producing essential oils of Jatropha and geranium, planting of corn, sunflower and Bambara peas. These productions use the pumping of groundwater to meet the water needs of crops, and to compensate for rainfall irregularities.

Zebu farming plays an important role, followed by small farming (pigs and poultry). Cattle farming is multi-functional in Betsileo communities: i) agro-technical (manure, work); ii) economic (milk, meat, savings on foot); and iii) socio-cultural (funerals, famadihana, other ceremonies). The importance given to each of these functions varies according to the sub-region.

2.1.3.3 Water resources and hydro-agricultural infrastructure

The Central zone is characterised by an abundance of exploitable surface water resources: they are used as a source of supply both for drinking water and for agriculture. Two main rivers of East-West direction, Mania and Matsiatra, respectively form the North and South limits of the Region of Amoron'i Mania: in the North, the Mania river and its tributaries form the "upstream part" of the watershed Tsiribihina; in the south, that of the Matsiatra and its tributaries extend over the Mangoky watershed into which the entire western part of the Upper Matsiatra also converges. In the east, the Maintinandry basin and its tributaries cover the eastern part of the district of Ambositra.

The site specific feasibility studies are being produced on a rolling basis. Below is a summary of two irrigation sites in the central zone that provide an illustration of the state of the infrastructure to be rehabilitated and the works envisaged.

Tsiefa-Andriana irrigation network[34]

This sub-project aims to restore and remain functional the irrigation network of the Tsiefa-Andriana cluster to sustainably improve incomes and security food and nutrition of the beneficiaries. The detailed preliminary project file includes: the diagnostic results of the parameters that are related to its current network operation, the appropriate solutions to the

[34] The full feasibility study in the French language can be provided as an annex.

problems so that it is fully functional; and estimating budgets in order to make a decision on the follow-up to be given to the sub-project.

The site of this sub-project is located at the Dam site: Andranobe; - Name of the perimeter: Tsiefa; Fokontany: Tsiefa; - Rural Commune: Ambondromisotra; District: Ambatofinandrahana; Region: Amoron'i Mania. Andriana Natural Drain Catchment - Catchment site: Andriana.

The dam site is located in the Rural Commune of Ambondromisotra. This municipality located 90 km from Ambositra by taking the National Road RN7 to PK 15 towards Fianarantsoa, there is a fork to the right following the National Road RN 35 until PK 45, there is also another fork to the right taking the Route d'Interêt Pronviciale RIP 144T over a distance of 30 km. These roads are accessible by car and passable all year long.

Regarding access to the dam site, take the municipal road for a distance of 7 km from the capital of the Commune and this road is accessible by 4x4 car and motorbike throughout the year. The entire perimeter of Tsiefa belongs to the Fokontany of Tsiefa, Rural Commune of Ambondromisotra.

During the field investigation in consultation with the beneficiaries of the hydro network farm of Tsiefa, we identified two axes of track inside the perimeter and hot spots such as:
- Ambalafeno-Andranotsokina axis;
- Crossing axis towards Andriana;
- The Andranotsokina apron.

The perimeter of Tsiefa is located in the Fokontany of Tsiefa, Rural Commune Ambondromisotra, Ambotofinandrahana District, Amoron'i Mania Region, the total irrigable area is 80 ha. The area is no longer well irrigated due to massive silting at the level of the Andranobe dam and the silting up of the front canal.

Following this situation, the WUA Farimbona was created in 2020, whose attributions main objectives are to ensure the routine maintenance of these existing networks and make them functional. Given the relatively large size of the perimeter, the average rice yield is 2 tonnes/ha which is quite low. This sub-project could bring tangible positive results in terms of socio-economic development in the Commune after the rehabilitation of the present perimeter.

From the socio-economic and technical point of view, this present sub-project for the rehabilitation of the irrigated perimeter of Tsiefa is relevant to the objectives of the Program as well as to the local context. It is therefore feasible on socio-economic and environmental conditions.

In general, the sub-project is profitable, with a higher internal rate of return of 20% for each variant offered. It is also viable, even if some weaknesses have been observed in the viability of the sub-project both on the socio-organizational level and on the technical level.

But it is useful to sensitize and supervise the beneficiaries on the popularization of more productive agricultural techniques since in the area covered by this sub-project, the majority of the working population insists on the traditional cultivation method. The endowment of tools, materials and agricultural inputs is among the priorities to ensure the compatibility of the sub-project with the objectives of the DEFIS+ project and in order to achieve the targeted objectives and to obtain the expected results.

It is also a priority to revitalize the WUA Farimbona in order to ensure the realization of its beneficiary contributions for the implementation of the sub-project and to establish good management rehabilitated infrastructure. On the other hand, the fight against the degradation of the ecology of the Tsiefa watershed, which threatens the sustainability of this sub-project in terms of environment must be involved with the beneficiaries and the entire population of the Commune; because it is therefore very urgent to take mitigation or preservation measures adequate to stop the evolution of the predominant lavakization phenomenon at the level of the catchment area and avoid silting up of the hydro-agricultural network.

Besadia irrigation network

The program site (Ambalamarina Bekily village, Fokontany Ambodivohitra) is located 12 km from the city of Ikalamavony (Upper Matsiatra region), its capital of the Commune and District, facing north. The main activities of the population are generally devoted to agriculture and livestock. The infrastructure to rehabilitate is the existing hydro-agricultural network on the site, which is made up of a direct frontal type river water intake, protected by a covered embankment / clods of earth with vegetation and fascines for the irrigation of the perimeter of Besadia, and a main channel that circulates in it, dominating the entire area that it must irrigate, and from this branch off the secondary channels that supply the tertiary canals themselves, and which have not been properly functional since 2008.

Issues

The existing problems in the scope can be summarized in five main points:

- The current hydro-agricultural network since 2008 does not allow the population of the site to irrigate the perimeter properly because of the water intakes, considered illegal in the vicinity of the Besadia water intake, carried out by users upstream; and also by the existence of multiple leaks/losses of water in certain places along the route of the canal which are the origin of the water shortages/lacks downstream of the perimeter.
- Adequate hydro-agricultural infrastructure lacking, and poorly maintained networks (devoid of hard works, canal main in earth of irregular section with slightly accentuated slope, invaded by brushwood in some points, and silted up/laden with solid deposits or sediments at certain points).
- Degraded watershed; low water flows of the Ionarivo River; strong river floods to be feared; existence/presence of rice paddies/crop fields upstream and around the location of the Besadia water intake over the weather that causes significant and threatening water loss; lack of water control by users.
- The protection/rehabilitation of the network requires means that are no longer within the reach of users.
- Circulation inside the project area is difficult for the movement of products, for the operation and maintenance of canals and for linking the villages affected by the project.

Rural populations are therefore exposed to problems of irrigation of their perimeters. Yet they have a strong agricultural potential, with the availability of vast rice fields (irrigated perimeters), and this is the reason why the DEFIS+ project is important for the Central zone.

Work Envisaged

The hydro-agricultural network and intra-perimeter tracks to be rehabilitated, subject of the project, were visited with the beneficiaries, and direct consultation with them was carried out to take into consideration their wishes and their knowledge of the field. The degradations or disorders and the existing realities were noted point by point. In order to achieve the objectives set, two scenarios have been proposed in the *Summary Preliminary Project* (APS) file, the principles of the studies presented of which are for the improvements to be made in order to restore the network - installation of protective coatings (in masonry, in concrete) on delicate places (at the level of the Besadia, dead head, and primary canal); installation, in particular at the Besadia intake, of a structure longitudinal bottom of a level below the average water level for the creation of lateral cells gradually clogging, and also in order to avoid illegal actions by users upstream; - development of the main canal No. 01 (cleaning and resurfacing of 2295 ml of the existing one; reinforcement of the bank by 67 ml backfill; installation of a new channel of 4220 ml on soft ground and 1573 ml on rocky ground; rock breaking of 08ml); and the main canal No. 02 (cleaning and resurfacing of 352 ml of the existing); - installation of new ancillary works on the main canal N°1 (06 sections of concreted canal of 1,443 ml of total length having respectively length 336.50, 987.5, 25, 08, 35, 37ml, and 14 ml; 05 scuppers; 01 drinker; 02 pass superior; 09 zebu crossings; 14 pedestrian crossings; 76 secondary sockets; 04 tarpaulins; low wall 20 ml in length); on the main channel N°2 (06 secondary sockets); - repairs to intra-perimeter tracks; - the participation of the Beneficiaries of the network with respect for their contribution to be made within the framework of the project (approximately 5% of the development cost, the consistency of the work being limited by manual work on the secondary canals with a length of 350 m and a track with a length of 5720 m with biological protection), and also awareness for the maintenance of infrastructure in the future, and close collaboration with decentralized communities (communes and district).

2.1.3.4 Environmental constraints related to climate and human activity

Environmental degradation is starting to be felt by the population in the Amron'i Mania region: floods during rainy periods become extremely dangerous, as well as silting up of basins and gullying of tanety due to the reduction in plant and forest cover. In dry periods, the flow decreases sharply. Some sources dry up temporarily or permanently due to the lack of measures to protect the sources and surrounding forest cover. One of the causes of the decrease in water resources is the regression of forest cover due to human pressure: cultivation of tavy (slash and burn cultivation) in the forest corridor, deforestation in favour of crops (central areas bordering the corridor), and excessive timber extraction. Not only does the western area of Fandriana and the northern area of Ambositra have originally poor soil formations, but soil degradation and depletion are also more significant. The phenomenon is partly due to the overexploitation of cultivable land which results in soil exhaustion. The fertilisation of the soil is becoming more and more essential, as the agricultural exploitation of the originally non-cultivable lands, such as steep slopes and rocky soils, are at the origin of soil erosion and degradation.

To summarise, these changes relate overall to: i) the decrease in the amount of precipitation annually, with more marked and / or more frequent periods of drought; ii) a delay in the arrival of the rains, which requires adaptation (lag) in the agricultural calendars; iii) the increased intensity of extreme climatic phenomena (cyclones, drought, floods, storms and strong winds); iv) finally, a very high temporal and spatial variability in rainfall, which is unpredictable.

In conclusion, climate change in the 2 zones grouping the six regions of DEFIS+, results in extreme climate events which have a negative impact on production, animal, and human health and well-being.

2.2 CLIMATE CHANGE IMPACTS IN THE DIFFERENT AREAS

This paragraph aims to highlight the cause-and-effect links between the impacts of climate change in the different intervention areas of DEFIS+. Furthermore, these impacts are also linked to the characteristics of these zones, which have been presented above.

2.2.1 Impacts on agriculture and livestock

Agriculture is highly dependent on climatic conditions, including temperature and rainfall. It is extremely sensitive to climate change which generally has negative impacts on agriculture (in the broad sense, including livestock) and, by extension, on food security. According to discussions and exchanges with farmers during field visits and analyses made in previous and current studies, the main impacts of climate change mentioned above can be summarised as follows:

- The delay in the arrival of the rains results in a delay or even failure of sowing and the obligation to sow again; the resulting shift in the crop cycle can have negative chain consequences.
- The lack of rainfall leads to an increase in the need for water for irrigation. However, water resources are themselves in decline.
- A water deficit during the cycle, due to an irregular distribution or insufficient precipitation at critical periods, such as the flowering of corn or the initiation of rice panicles, is strongly detrimental to the good development of crops and decreases yield or may result in crop losses. In addition, this deficit is associated with abnormally high temperatures, which also have negative consequences on certain crops.
- The shortening of the rainy season leads to time constraints for agricultural work. Farmers are forced to adopt improved rice cultivation techniques, which are time consuming or labour intensive, such as transplanting in line or weeding to remove weeds. This obviously results in lower yields.
- Rising temperatures favour the development of pests (armyworms and other pests). On the other hand, excessive water favours moulds (Aspergillus spp, Penicillium spp, Alternaria spp and other moulds).
- Water stress in animals leads to illness, death and reduction of productivity. The decrease in rainfall also leads to a quantitative and qualitative decrease in the available fodder. Fertility declines, compromising the growth of new born and in the worst scenario even abortion of the foetus.
- Intense cyclones, accompanied by strong winds, cause flooding and partial or total crop losses. These accidents can occur at any time during the crop cycle, but the most damaging are the later ones. When a flood lasting several days overwhelms a rice field ready to be harvested, or a storm destroys a fruit plantation in production, the farmer loses the fruit of his labour, sometimes for several years, and finds himself without resources and often without seeds for the following season. The lean period then lasts many months, forcing to look for emergency solutions (migration among others).
- In addition, significant runoff promotes soil erosion (water erosion), while strong winds tear particles from the topsoil (wind erosion).

The general consequence of the modification of climatic conditions is the fall in agricultural productivity for all crops, which may be due either to the decrease in yields (poor development of the plant), or to a partial or total loss of crops.
In the southern regions, rain-fed crops (maize, peanuts, and cassava) are particularly affected by

drought, irregular distribution, the unpredictability of the rains, low rainfall, and strong winds. Livestock also suffers from the consequences of these climatic changes, as indicated above. In the South East and Central zones, it is mainly irrigated rice cultivation that is affected, given the lack of water resulting from the decrease in rainfall or silting up, the shift in the cropping calendar and the intensification of cyclones and floods. In addition, the yield of agroforestry crops and food crops on tanety is also impacted by the lack of rainfall and drought, as well as by the decline in soil fertility due to erosion.

Farmers in the DEFIS+ regions adopt adaptation measures in an ad-hoc manner in the absence of reliable agro-met information. The lack of reliable agro-met information compromises the farmers' adaptive capacity as they make uninformed or short-term decisions to cope with climate variability, forgoing good agricultural and climate resilient practices. The availability of agro-met information would help farmers better plan at the farm level with a medium- to long term perspective on maintaining and improving their productivity in the face of climate change.

The relevance of agro-met information differs depending on the decision-making situation of farmers. Several factors play an important role in farmer's agricultural decision-making. The usefulness of the agro-met information depends on the access, salience and credibility of the information[35]. Meteo Madagascar is the natural provider of climate and agro-met services but generally demand outpaces their capability to respond in terms of spatial and temporal accuracy - unclear climate/weather information therefore they respond to requests rather than needs. In addition, decision-makers such as farmers at the farm level are not prepared to use climate and agro-met information efficiently. Therefore, for DEFIS+ farmers improved access to agro-met information should be accompanied by the relevant capacity building in the effective use of the information for decision making at the farm level. Informed decision making will build the adaptive capacity of farmers and their reliance on climate change.

2.2.2 Impacts on water resources and hydro-agricultural infrastructure

In addition to the direct effects on agriculture and livestock, climate change also has effects on water resources, which indirectly influence agricultural productivity, to the extent that the links between water, soil and agriculture are inseparable.

The impact of climate change on water resources is mainly reflected in the reduction of resources available for agriculture (and other uses). In addition, the state of hydro-agricultural infrastructure is deteriorating following erosion in the watersheds, leading to the silting up of land and downstream networks. The impacts of climate change on water resources and water-related aspects are presented in more detail in Table 7.

Table 7: Impact of climate change on water resources and hydro-agricultural infrastructure

Climatic parameters	Impacts on water and hydro-agricultural infrastructure
Drought/ Decrease in annual precipitation	Reduced flow / drying of rivers and water points Drying up of springs, lakes or ponds Lower water table Reduction in the quantities of water available for agriculture and other uses Conflicts over the use of water Increased cultivation in upstream watersheds, erosion of soils Reduction of water availability for animal and human consumption

[35] C. Ofoegbu & M. New, Agriculture (2022) Evaluating the Effectiveness and Efficiency of Climate Information Communication in the African Agricultural Sector: A Systematic Analysis of Climate Services

Temperature rise	Increased evapotranspiration Degradation of water quality Increased risk of water-related illnesses Increased drought
Increased rainfall intensity in the rainy season	Pollution Floods
Late arrival of the rains	Delay in filling the reservoirs Insufficient water table recharge Decrease in the quantities of water available Delay/disruption in the cropping calendar, drop in yields
Intense cyclones	Heavy floods Increase in runoff water Water erosion of soils
Strong winds	Wind erosion and silting up of reservoirs and riverbeds

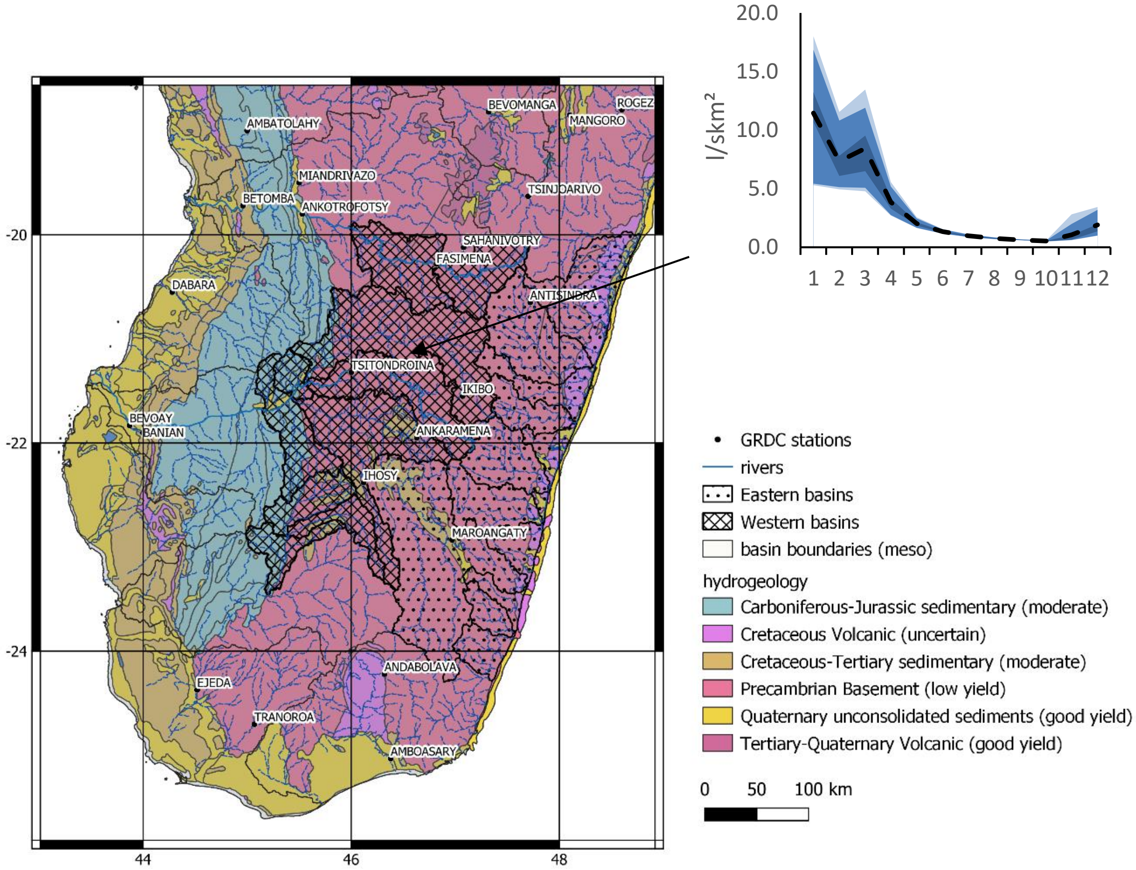
Thus, the impacts of climate change on hydro-agricultural infrastructures to be addressed by the Project can be summarised as follows:

- Insufficiency of available water resources compared to needs, due to the increase in evapotranspiration (linked to the increase in temperature) or the decrease of precipitation.
- Cyclones and floods, which can cause significant damage to irrigation networks and structures as well as crop destruction.
- Erosion from watersheds, which can be linked to poor exploitation of upstream watersheds (more cultivation on watershed because of the decrease of water resources for irrigated agriculture) or also due to an increase in runoff.

Moreover, these issues are often exacerbated by poor management and maintenance of the networks by the WUAs and the competent authorities. To address the hydrological changes in the catchment areas, it is necessary to quantify these impacts, by carrying out a comprehensive water resources assessment over the area using a state-of-the-art integrated hydrological model. The project will follow an integrated water resources management approach (IWRM) and will start with the delineation and definition of hydrological basins (a) and groundwater bodies (b). Hydrological basins for the project region have been delineated and calculated at 9 different levels of precision from first order basins draining to the western and eastern (Indian) oceans. In the centre of the project area, the islands water divide separates westward and eastward draining basins. In addition, the groundwater bodies and aquifers have been determined. The eastern part of the project area is dominated by Precambrian rocks. These rocks form a fractured basement aquifer with a very limited storage of only 0.1 to about 5 % of the aquifer volume. Directly at the coast there are quaternary sediments that can be used for water supply. Also, the Cretaceous-Tertiary sediments (e.g. between Ihosy and Maroangaty) can act as storage for harvested water. Eastward drainage basins are steeper and receive an increasing amount of rainfall approaching the coast.

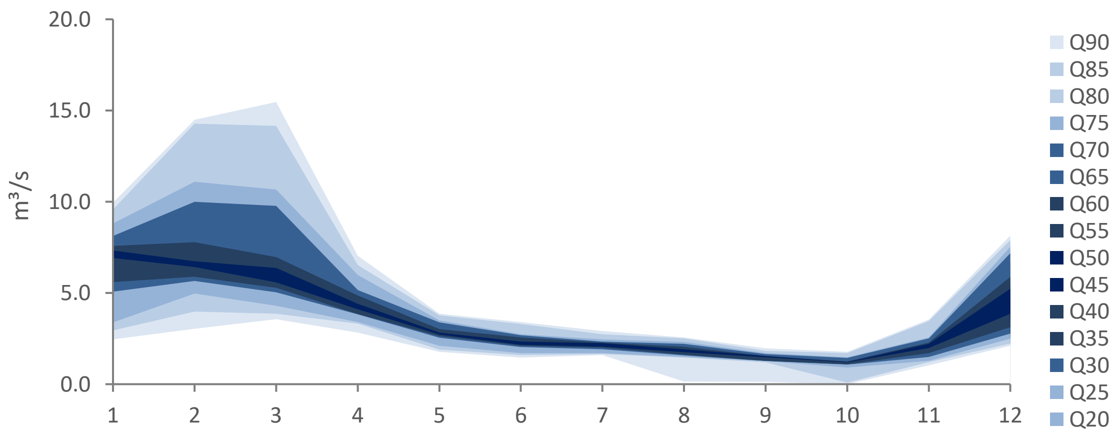
The westward draining basins discharge into the Carboniferous-Jurassic sedimentary aquifer that also has moderate to good storage capacity. Hydrological data on rivers has been retrieved from the Global Runoff Data Centre and will be integrated into an Observatory and Data Platform for IWRM in the basins. The data show the high variability of discharge and the decline of baseflow and runoff during the dry season, highlighting the need for improved water retention and groundwater storage. Westward draining basins receive less rainfall and are more vulnerable to droughts when moving south and west.

Figure 10: Surface basins (black) with westward (hatched) and eastward drainage (points) and groundwater bodies



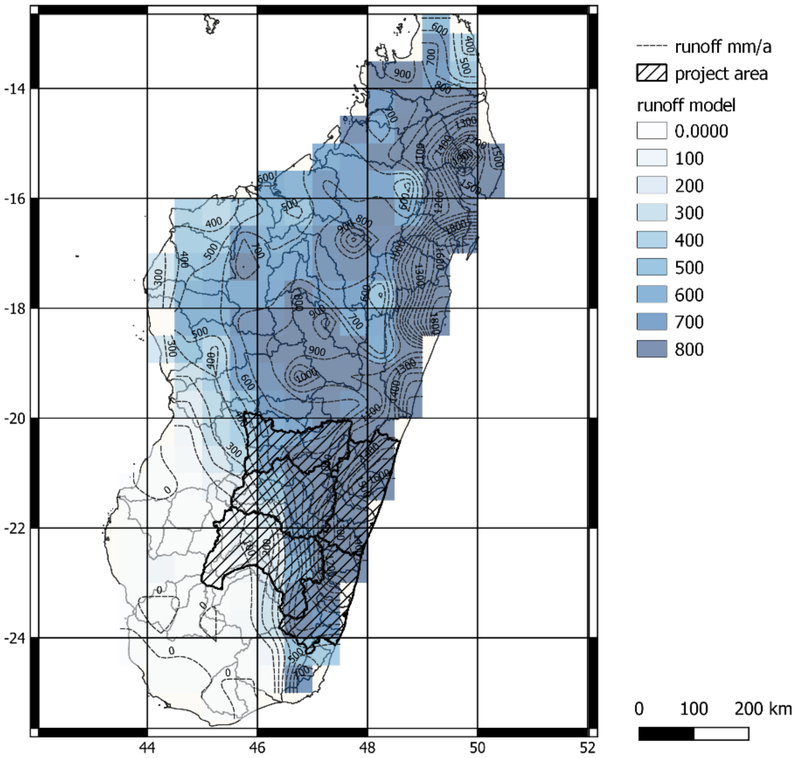
The runoff from different basins decreases strongly towards the south-west and reaches values close to zero. In the project area, runoff ranges from 100 to 1000 mm per year, increasing eastwards. This runoff represents an important resource that can be managed and storage in decentral water harvesting structures. Due to the high evapotranspiration, underground storage should be enhanced. The available data from 9 hydrometric stations in the study area show a very high degree of variability in discharge. Time series shown in quantiles indicate that especially during the rain season a coefficient of variation of 4 to 5 can be observed, introducing a high degree of uncertainty into the water management.

Figure 11: Hydrological regime at a GRDC hydrometric station in the project area



The runoff production in the project area of 100 to 1000 mm per year is concentrated in 2 or three months of the year (Fig. 11). Groundwater storage needs to retain the water for the summer months minimizing exposure to evapotranspiration.

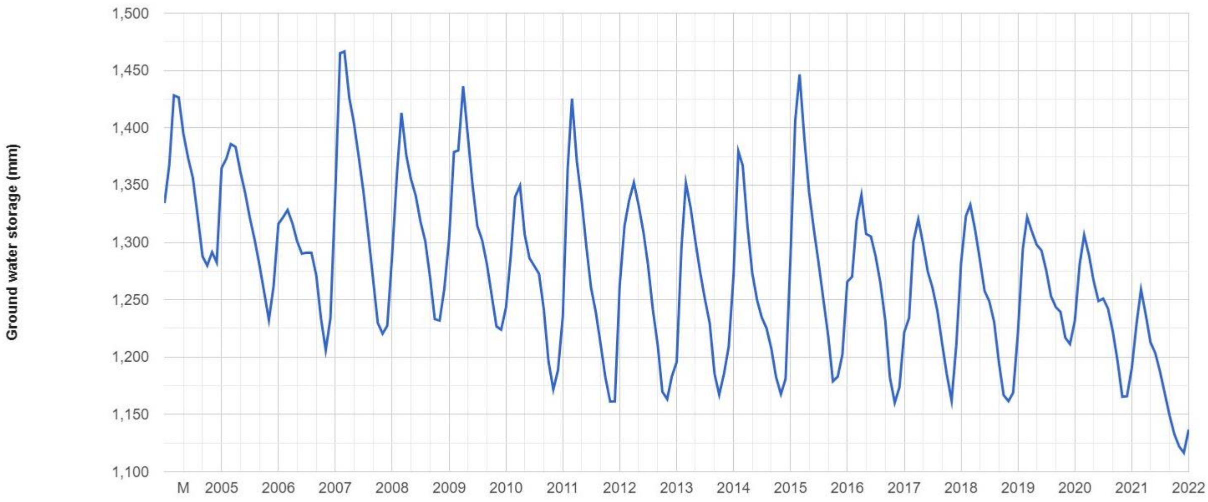
Figure 12: Runoff production derived from GRDC stations and hydrological modelling in Madagascar



The MODFLOW model simulates groundwater recharge changes due to change in precipitation patterns with precipitation data from the Multi-Source Weighted-Ensemble Precipitation (MSWEP) dataset. The assessment will involve running the model over the last decades using various parameterizations, where each parameterization represents a different scenario. Possible scenarios include low-efficiency irrigation, high-efficiency irrigation, improved water harvesting, reforestation, improved drainage systems, etc. The comparison of different scenarios allows to quantify the impact of different activities, policies, or measures on groundwater recharge, soil moisture, and river flow. The impacts of climate change can be assessed as well, by running the model using future climate change projections. The reliability of the hydrological model can be evaluated with measurements of river flow, soil moisture, as well as groundwater levels, where available.

The groundwater storage in the study area decreases without intervention as a consequence of increasing temperature, increased evaporation and soil degradation limiting infiltration, percolation and recharge. The runoff potential estimated using the hydrological model with MSWEP data shows that the potential for managed aquifer recharge in the project area is above 20 million m³ per year. The potential can be derived from a groundwater model of the study area for the main water bodies if the runoff in the river network can infiltrate with a regional transmission loss rate. This would not only attenuate the decrease in groundwater storage but could improve the groundwater balance by 10 to 20 mm/year and m² and hence about 10-20 percent of current recharge.

Figure 13: Groundwater Model without measures of water harvesting and managed aquifer recharge



2.2.3 Impacts on road infrastructure

The deterioration of road infrastructure and the difficulty of access to production areas and to markets, linked to the climate, are recognized as one of the main constraints for the development of agriculture in Madagascar. Thus, within the framework of the DEFIS+ project, the improvement of access roads in the various intervention areas is planned in this annex and summarized in the project proposal. DEFIS + interventions will aim more particularly at ensuring the resilience of the access roads that are most exposed to the impacts of climatic hazards.

The main impacts of climate change on road infrastructure are linked to the increase in the intensity of cyclones and floods. It is well known that the negative effects of water are one of the main causes of degradation of road infrastructure. Thus, taking sanitation into account in the study of a road project is essential to capture and evacuate runoff water and prevent it from damaging road structures. In addition, the recovery of excess water can be considered with a view to using it for other important needs.

Climate proofing unpaved rural roads means that roads are taken up as an opportunity to create a ‘resilience corridor’. The roads and the landscape together are made stronger through efforts of water harvesting, buffering provision, bioengineering/nature-based-solutions, recharge of groundwater and water supply for productive use.

These efforts are valid for ‘spot’ rehabilitation of parts of road infrastructure, as well as for larger landscape approaches. All of this improves the vitality of the ecosystem and makes it possible for the roads to fulfil their function as part of it. The road is, then, no longer a disruptive asset, but rather a productive and supportive market and services access asset. With keen and smart adaptations, this new road ecology can withstand climate shocks without being toppled over.

Climate-proofed and green roads are completely geared towards protection of the vital source of water, through protection of ecosystem services, such as vegetation cover and landscape restoration. Actually, the road itself becomes a supportive function to its environment. This is what the road ultimately should be, not just a connectivity link, but part of the catchment and contributing positively to the water management in that catchment. Measures that have the double purpose of reducing damage and promoting beneficial water use will contribute to the longevity of vital rural road connections.

2.3 SWOT ANALYSIS (STRENGTHS, WEAKNESSES, OPPORTUNITIES, THREATS)

In addition to the literature review, the analysis of the climate impacts, the SWOT analysis can help in the identification of the most appropriate solutions for each zone.

2.3.1 SWOT analysis of the regions of the South zone

South zone (Anosy, Androy, Atsimo Andrefana)	
Strengths • Local presence of the Southern Agro-Ecological Technological Center (CTAS) already experienced in supporting farmers for the fight against climate change, erosion and the promotion of improved seeds • Local existence of the Agnarafaly Seed Production Center (CPSA) • Existence of innovative technology for storing water for use as needed (REEPS) • Population aware of the impacts of climate change and motivated for adaptation actions	**Weaknesses** • Quite scarce and difficult to exploit water resources • Market for cereals like millet and sorghum and legumes like cowpea still non-existent (family consumption) • Difficulties in accessing the area due to the state of road degradation • Poor infrastructure network
Opportunities • Experience of previous projects that can be capitalised and improved taking into account the lessons learned (sorghum recovery projects and millet promotion, agro-ecological blocks) • Existence of numerous organisations and other projects working in climate adaptation, mitigation and food security in the area, which can create positive synergies • Collaboration with research and support organisations FOFIFA, CTAS, FAO, CIRAD, IITA which can be exploited for adaptation to climate change	**Threats** • Increased risk of attack by pests if problems are not addressed appropriately • Natural conditions increasing the risk of erosion and soil degradation (loss of soil fertility, silting up) • Risks of food insecurity which can aggravate insecurity and the phenomenon of immigration • Increase risks of extreme weather events (cyclones and floods)

2.3.2 SWOT of the South-East zone

South-East zone (Vatovavy, Fitovinany, Atsimo Atsinanana)	
Strengths • Abundance of water resources in river basins • Hydro-agricultural networks and associations of water users existing on many small areas • Population aware of the impacts of climate change and motivated for adaptation actions	**Weaknesses** • Problems of flooding and insufficient water resources in difficult times aggravated by siltation and lack of network maintenance • Difficulties in accessing the area due to the state of road degradation • Insufficient road and water infrastructure • Limited climate resilience of local communities

Opportunities	Threats
• Experience of previous projects that can be capitalised and improved taking into account the lessons learned (agro-ecological projects by GSDM, BVPI South East, etc.) • Existence of organisations and other projects working in climate adaptation and agricultural development in the area, which can create synergies (INTERAIDE, PAPAM, PROSPERER, PrADA, AFAFI South, etc.)	• Agricultural land pressures accentuated by demographic pressure • Natural conditions and human activities increase the risk of erosion and create serious problems downstream (silting up, floods, landslides, etc.) • Integrated Water Resource Management (IWRM) not yet operational, making concerted action between users of watersheds more difficult • Extreme events such cyclones and floods

2.3.3 SWOT of the Central zone

Central zone (Amoron'i Mania, Haute Matsiatra, Ihorombe)	
Strengths • Abundance of water resources • Hydro-agricultural networks and associations of water users existing on many small areas • Good crop diversification • Presence of dynamic small-scale producers leaders promoting innovation and the evolution of practices • Population aware of the impacts of climate change and motivated for adaptation actions	**Weaknesses** • Problems of floods and insufficient water resources aggravated by siltation and lack of network maintenance • Difficulties in accessing the area due to the state of road degradation • Poor infrastructure • Limited training on climate change • Lack of capacity building • Limited meteorological information
Opportunities • Experience of previous projects that can be capitalised and improved taking into account the lessons learned (agro-ecological projects by GSDM, PURSAPS) • Existence of organisations and other projects working in agricultural development within the area, which can create synergies (FERT, AIM, SAHA, ADRA)	**Threats** • Agricultural land pressures accentuated by demographic pressure • Increased risk of attack by pests if problems are not addressed appropriately • Integrated Water Resource Management (IWRM) not yet operational, making concerted action between users of watersheds more difficult • Exacerbation of extreme climate events

3. PROPOSALS FOR INTERVENTIONS RELEVANT TO CLIMATE CHANGE ADAPTATION

The analyses carried out above make it possible to propose solutions and orient appropriate interventions for climate adaptation and strengthening the resilience of beneficiaries and stakeholders. It is also interesting to understand how farmers have adapted to climate change so far. There are many possible solutions, however the actions proposed will be all more easily adopted by farmers if they correspond to their logic and their perceptions of risk, their capacities and their expectations. Water resources and their availability whether as water stress (drought events) or as excess water (floods including those resulting from cyclones) are central to the climate change impacts in the DEFIS+ regions therefore integrated water resources management is a key climate change adaptation strategy in the Southern regions of Madagascar. The principles of IWRM will therefore be applied in DEFIS+ to strengthen the resilience of the target communities and their livelihoods. According to recent reviews of UN and recent scientific papers, IWRM in Madagascar is still at a low to medium level (38 out of 100 points). The necessary work to ensure the application of IWRM includes, delineation of basin areas, compilation of water balance component data especially for runoff (baseline, extremes), drought statistics and water recharge. This will be done as part of the DEFIS+ investments building on the pole development plans that have initial delineation of watersheds (see separate annexes on development poles under DEFIS).

Modelling of artificial recharge requires aquifer properties, determination of techniques, mudflow modelling to simulate possible recharge and produce quantifiable outcomes. A compilation of aquifer storage data can be done and technical measures to strongly improve water storage and water use efficiency can be developed. In general aquifer storage in the DEFIS+ area is low (see BGR Whymap) but recharge potential is good. Most of the DEFIS+ area is composed of fractured rocks with very low storage. However, in some places good storage capacity is available. A concept can be developed to collect runoff water, transfer it to good storage locations, store and then redistribute it. The additional water stored as an outcome would then need to be integrated with agricultural activities and other engineering activities and the related outcomes. This is an integration work that needs to be done jointly during implementation of the DEFIS+ activities.

- The modelling of artificial groundwater recharge with mudflow would take into account the geological context with mapping of seasonal groundwater fluctuations during flood and drought seasons for future and historical scenarios.

3.1 ADAPTATION OF FARMERS TO CLIMATE CHANGE

Faced with the effects of climate change, farmers spontaneously try to adapt to it. The most common practice of adapting to climate change involves shifting the agricultural calendar, depending on the delay and / or shortening of the rainy season. Otherwise, they change varieties (search for precocity as a factor to adapt to the drop in rainfall), or even cultivated species to favour more hardy crops. Cultivation practices are also evolving both in terms of the dates of production and the techniques used (abandoning tillage in certain cases and planting on the residuals of previous crop). The use of the means of production (work, inputs) is reasoned to take into account the risks: this translates in certain cases in the extensification, or in the diversification of the food crops as much as possible, for compensation (for example: increase in areas cultivated with cassava, sweet potato, and fruit by farmers in the Southeast region, after the partial loss of crops following the floods).

Another way of adaptation, which is also adopted in certain cases by producers, is the development of new agricultural activities in an attempt to spread the risks and / or adapt to new production conditions: introduction of new crops, development of market gardening, small farming, and improved processing of local products.

Among livestock breeders, the survey has highlighted the change in herd structure, in particular the distribution between species (goats, sheep, and cattle), and the modification of fodder calendars with an increase in mobility herds and changing grazing areas. Due to limited access to markers, herders are forced to sell their products only to neighbours. Road availability is important to access local and national markets where their products (e.g., live animals, meat, milk, cheese, etc.) can guarantee a better income for the family.

In summary, small-scale producers are trying to find relevant solutions to problems and are gradually adapting in their own way. The search for appropriate solutions will consist in improving the current adaptation of the systems to the evolution of their environment, but also in increasing their climate resilience and developing the capacities of future adaptation of family farms.

3.2 DEFINITION AND JUSTIFICATION OF THE PROPOSED LINES OF INTERVENTION AND CORRESPONDING ACTIVITIES WITHIN THE FRAMEWORK OF DEFIS +

On the basis of the above, the solutions proposed to ensure resilience to climate change can be classified around five main axes:

1) Improving the availability of water for agriculture and animal husbandry, by strengthening irrigation systems and concerted management at the level of watersheds applying IWRM principles, as well as the construction of animal watering infrastructure;
2) Strengthening of road infrastructures with a view to improve their resilience to climate risks;
3) The implementation of climate-smart farming techniques and the fight against erosion;
4) The development of varieties or crops adapted to changing climatic conditions, and of pest control methods;
5) Improving the climate information through the agro-meteorological networks.

These five axes are not independent and, on the contrary, appear to be closely linked in order to achieve the objective of resilience of smallholders and farms. The justification for the axes is provided in Table 8 with further details on the climate change risk provided in the in-depth climate change analysis sections:

Table 8: Climate adaptation and mitigation measures

Adaptation measures	Justification
Irrigation systems and integrated water resources management	Lower precipitation throughout the rainy season. Integrated water resources management including irrigation required to compensate for decrease in water availability. Combined with increasing temperature, evapotranspiration could increase – measures limiting it are required to make irrigation more cost efficient and improve agricultural productivity. Irrigation could become especially relevant at the onset of the rainy season as the number of dry days is expected to increase the most in October & November. Integrated water resources management will enhance the provision of ecosystem services in the watersheds and micro-catchment of the irrigation schemes.

Road infrastructure	The Southern regions face high flooding risks even though the number of extreme wet days (> 20 mm and > 50 mm) is not projected to increase. Therefore, measures are required to enhance the robustness of the infrastructure including improved drainage of the irrigation schemes. Road infrastructure could be used for water catchment management purposes as a response to decreased precipitations and shorter rainy season.
Evaporation limiting measures	The number of hot days in the rainy season is projected to increase over time, especially at the onset of the rainy season. Measures protecting crops, particularly seedlings against heat stress (agroforestry, shading) are essential. Such measures would also reduce crop stress induced by increased evapotranspiration (analysis shows slight decrease in annual SPEI) and forestry trees act as a carbon sink.
Crop shifting & improved seed selection	Lower precipitation throughout the rainy season – crops could fall below optimal levels. The increase in precipitation in Jan-March does not offset reduction in October-November. Need for crops with shorter growing cycles as a response to overall decrease in length of growing season.
Climate information	Potential progressive delay in onset of the rainy season – lower precipitation in October and November. Overall decrease in length of growing season. The agro-meteorological network improvements will inform the advisory services provided to the smallholder farmers for them to make informed investment decisions at the farm level regarding the crops and varieties planted and timing of the planting.
GHG mitigation	Forestation, reforestation, and protection of vegetation and soil can reduce GHG emissions. Plants and natural soil rich in humus can provide ecosystem services and sink CO2. Carbon sink is extremely important because it helps the country meet the NDC's international agreements about GHG reduction.

3.2.1 Improving the availability of water for agriculture and livestock

Studies aimed at identifying irrigation infrastructure to be rehabilitated or new construction have already been carried out within the framework of DEFIS. These studies made it possible to select the perimeters to be retained on the basis of criteria predefined by the firm in charge of the studies, jointly with the DEFIS+ project team, such as the existence of a strong agriculture production potential, existence of a WUA to ensure the management and maintenance. Indeed, WUAs are widely recognized to be a key factor in the levels of service provision on irrigation schemes, and to ensure sustainable operations, management and maintenance, after the project closure.

This multi-criteria analysis was carried out in parallel with a participatory approach to confirm the interest and acceptance of the project by the beneficiaries. It allowed making a first pre-selection, from which a final selection will be made during the technical study according to the irrigation potential, problems to solve and budget availability.

3.2.1.1 Strengthening of irrigation systems

Problem:	1) Insufficient water resources; 2) Sanding of canals and upstream of head works; 3) Floods.
Causes:	Decrease in water resources / increase in needs; 2) Supply of sediments from watersheds; 3) Passage of cyclones or intense rain.
Objectives:	Improve the availability of water resources, quickly evacuate flood water, reduce maintenance costs, and perpetuate facilities.
Proposal:	1) Creation of a buffer tank in the upstream part of the watersheds; 2) Strengthening of the modernization of the irrigation networks; 3) Strengthening of the drainage networks and the flood evacuation system.
Expected results:	**Water availability for larger irrigated areas; Water availability for humans and animals; Resilient and sustainable infrastructure; Rapid increase in crop productivity**

The intervention in the DEFIS+ zones aims at restoring the networks, increasing agricultural productivity, and strengthening irrigation infrastructure related to climate change, as presented above.

However, it should be noted that some of the perimeters selected by DEFIS programme are already being studied, or even the works are already completed and accepted, mostly for the Atsimo Atsinanana, Vatovavy and Fitovinany regions. Thus, these perimeters will no longer be concerned by DEFIS+ for the irrigation investments but only for interventions on watersheds. A new selection of existing perimeters that only require reinforcement work to ensure climate resilience may therefore be realised if necessary for the intervention of DEFIS+.

The list of perimeters planned to be rehabilitated or built jointly by DEFIS and DEFIS+[36] is giving below.

N°	Région	District	Commune	Irrigated Perimeter/Location	Type of development	Area (ha)		
						Irrigated area (before the works) (ha)	Irrigable area (after works) (ha)	Additional area
25	Amoron'i Mania	Ambatofinandrahana	Ambondromisotra	Tsiefa	New development	60	80	20
26	Amoron'i Mania	Ambatofinandrahana	Ambondromisotra	Sahafohy	New development	77	200	123

[36] Without the perimeters which already were in works by DEFIS (24 irrigation schemes in the Center area are already studied or in works).

27	Amoron'i Mania	Ambositra	Sahatsiho Ambohimanjaka	Ankatsaoka	New development	108	230	122
28	Haute Matsiatra	Ambalavao	Iarintsena	ANDRAIKIRO	New development	450	950	500
29	Haute Matsiatra	Ikalamavony	Ikalamavony	LAZARIVO	New development	50	490	440
30	Haute Matsiatra	Ikalamavony	Ikalamavony	BESADIA	New development	36	256	220
31	Haute Matsiatra	Ikalamavony	Ikalamavony	BEKOFAFA	New development	25	270	245
32	Haute Matsiatra	Ikalamavony	Ikalamavony	MATSIATRA	New development	30	480	450
33	Ihorombe	IHOSY	Mahasoa	Mikaiky	New development		150	150
34	Ihorombe	Ihosy	Sakalalina	Angodogondo	New development		200	200
35	Ihorombe	Ihosy	Ambatolahy	Andranotakatra	Réhabilitation	10	333	323
36	Ihorombe	Ihosy	Ilakakabe	Ilakakabe	Réhabilitation	0	980	980
37	Ihorombe	Ihosy	Ranohira	Andreatomily/Andremanero	New development		400	400
38	Ihorombe	Iakora	Ranotsara Nord	Antampon'Ivory/Mandabe	New development		630	630
39	Amoron'i Mania	Ambatofinandrahana	Soavina	Ambatomita	New development		630	630
40	Amoron'i Mania	Ambositra	Ihadilanana	Ampitsinjovamborona	New development		630	630
41	Amoron'i Mania	Ambatofinandrahana	Soavina	Tsaramandroso-Ambatomainty	Réhabilitation		500	500
42	Ihorombe	Iakora	Volambita	Vatovihy	New development		400	400
43	Haute Matsiatra	Ambalavao	Vohitsaoka	Ikipy	New development	130	630	500
44	Haute Matsiatra	Ambalavao	Volamena	Andreanavo-Vinany	Réhabilitation	10	260	250
45	Haute Matsiatra	Ikalamavony	Ambatomainty	Maintsobato Ambony-Amboasary	Réhabilitation	10	510	500

46	Haute Matsiatra	Vohibato	Mahasoabe	Ranomainty-Ambohibarihena	New development	130	200	70
47	Haute Matsiatra	Vohibato	Ihazoara	Antanifotsy	New development	600	630	30
48	Haute Matsiatra	Ambalavao	Besoa	Angodongodona Ambony	Réhabilitation	200	350	150
49	Amoron'i Mania	Manandrina	Andakatanikely	Ankona-Tsiandrarafana	Réhabilitation		630	630
50	Amoron'i Mania	Ambositra	Andina	Kianjanamalona-Antanifotsy	New development		350	350
51	Amoron'i Mania	Fandriana	Sahamadio F.	Antetezambato	New development		630	630
52	Amoron'i Mania	Fandriana	Fiadanana	Ampitana	New development	220	520	300
53	Amoron'i Mania	Ambositra	Ambohimitombo I	Masiaka-Antanifotsy	New development		620	620
54	Amoron'i Mania	Ambositra	Kianjandrakefona	Ikitra-Soanierana	Réhabilitation		346	346
55	Amoron'i Mania	Ambatofinandrahana	Ambatomifanongoa	Tsipolombeta	Réhabilitation	300	600	300
56	Haute Matsiatra	Isandra	Mahazoarivo	Ankoretsoka	Réhabilitation	50	150	100
57	Haute Matsiatra	Ambohimahasoa	Ampitana	Ankona-Vatositry	Réhabilitation	250	330	80
58	Ihorombe	Vohibe	Maropaiky	Vatoy	Réhabilitation	100	610	510
59	Ihorombe	Vohibe	Vohibe	Andreabe-Ankazovinelo	Réhabilitation	100	247	147
60	Ihorombe	Iakora	Andranombao	Antondabe	New development	100	350	250
						3046	**15772**	**12726**

In order to deal with the reduction / insufficiency of water resources for irrigation or to ensure the protection of structures against floods resulting from climate change in the DEFIS+ regions, the design of the work will take into account the Standards for the construction of hydro-agricultural structures against floods or NIHYCHRI, which aim to ensure the durability of these structures and their resilience to floods. Activities for rehabilitation and development of irrigation schemes will include (i) recalibrating, reshaping and compacting canals, drains and intakes supplying irrigated areas; (ii) rehabilitation of small dams (walls, gates, diversion canals, etc.); (iii) installing or rehabilitating sand trap and flood evacuation systems; (iv) installing or rehabilitating pumping stations using solar technology; and (v) improving water-use efficiency, including land-levelling and piloting drip irrigation systems where appropriate. Drip irrigation is quite new in these regions, except in the Ihorombe region with Tozzi Green investments (private company). Lessons from successful projects in water-saving irrigation would have to be capitalised in this activity. In addition, water mobilisation will be carried out using an Integrated Water Resources Management (IWRM) approach taking into account water management at basin level.

Capacity building for Water User Associations: The capacity building action of WUAs complements the activities provided in 3.2.1.1. This will ensure the long-term sustainability of the infrastructure. It aims to enable managers of WUAs to fully understand the problems of climate change and their impact on infrastructure, as well as the importance of their role in relation to the sustainability of hydro-agricultural networks. This activity can take the form of an exchange visit with other WUAs on areas subject to similar climate change problems, but which are well managed and can serve as a model of resilience.

3.2.1.2 Concerted management at watershed level

This action also supplements those proposed in 3.2.1.1. Indeed, strengthening hydro-agricultural infrastructure in downstream areas only makes sense if, in parallel, actions are taken to resolve possible water conflicts and reduce the risk of erosion / silting up by concerted management of water and watersheds.

Problem:	Lack of consultation for the management of water resources and land in the watershed; Conflicts among end-users for water: Insufficient water resources downstream; Erosion and silting up.
Causes:	Individualised management of water resources and watersheds and / or resolution of potential conflicts.
Objectives:	Ensure the availability and good management of water resources; Reduce the risk of erosion; Reduce the risk of conflicts among users.
Proposal:	Promotion of consultation at the level of inter-municipal structures (OPCI) or between users of downstream areas and upstream watersheds for the implementation of actions to protect watersheds.
Expected results:	**Land use and development plan / zoning / reforestation and agreement for the management and preservation of water resources; Improved water availability for irrigated areas downstream; Reduced erosion; Peaceful resolution of conflicts.**

3.2.1.3 Construction of animal watering infrastructure in arid areas

Small ruminants, especially goats, are animals well adapted to the climatic conditions of southern Madagascar. However, during the dry season and especially in the context of increased drought by climate change, the problem of water for their watering becomes a priority, as the fodder availability. Solutions must therefore be found so that they can drink and eat and guarantee sufficient productions.

REEPS corresponds to an innovative technology in Madagascar for the storage and mobilisation of water in areas where supply is difficult. Some structures have already been built for multiple use of water in southern Madagascar (notably for the Antanandava Basic Health Center, in the Androy region). The operating principle of REEPS is quite simple: it is a storage and reuse system of good quality water at a lower cost and respectful of the environment, which fills automatically when there is water available in the collection system. It requires little maintenance and does not cause loss of water by evaporation.

Problem:	Problem of watering small ruminants during drought periods.
Causes:	Decrease in available water resources.
Objectives:	Have water reserves for dry periods.
Proposal:	Construction of 50 REEPS of 100 m3 each.
Expected results:	**Ensure the water needs of small ruminants and test this innovative technology with a significant number of structures and volumes.**

3.2.2 Development of varieties or crops adapted to changing climatic conditions

3.2.2.1 Multiplication and dissemination of seeds resilient to climate change

Problem:	Need for large quantities of seeds resilient to climate change.
Causes:	Older varieties are no longer adapted to the climate.
Objectives:	Have seed varieties better suited to drought periods.
Proposal:	Support for multiplication and dissemination in collaboration with CTAS / CPSA and PMS.
Expected results:	**Production of basic seeds at CPSA, multiplication with PMS (seed multiplier farmers) and dissemination of seed varieties adapted to the climate among farmers via local shops.**

This activity also requires the strengthening of the irrigation network of the Agnarafaly Seed Production Center, to ensure the production of the quantities of basic seeds necessary for large-scale dissemination among multiplier farmers. The multiplied and disseminated seeds will include in particular the varieties of sorghum and millet, which have been developed by the CTAS Ambovombe and which are better adapted to the drought compared to maize and other cereals, as well as to the attack of birds compared to varieties used previously. However, the attack by pests (caterpillars) remains one of the problems raised by multiplier farmers and to which effective solutions must be found to allow the adoption of these new varieties by farmers.

3.2.2.2 Support to research for integrated pest management

This activity is fully justified in the context of adaptation to climate change, which tends to encourage the control of dangerous insects and harmful organisms. In the absence of financial means to be able to use insecticides, Malagasy farmers often practise natural control which is also more respectful for the environment, but which must be improved within the framework of research to be fully effective.

Problem:	Attack of crops by harmful organisms and insects.
Causes:	Proliferation of these pests which cause the loss of production.
Objectives:	Find integrated pest management methods adapted to crop conditions (armyworm, millet & sorghum caterpillar, rice) and respectful of the environment.
Proposal:	Support for research by FOFIFA (research organisation for agricultural development attached to the Ministry responsible for scientific research) and test in a small-scale producer environment before dissemination among farmers.
Expected results:	**Have effective integrated pest management methods tested and disseminated.**

3.2.3 Implementation of climate-smart farming techniques and erosion control

Climate Smart Agriculture (CSA) techniques as well as conservation agriculture (CA), which is part of the CSA, are currently recognized, both internationally and nationally, as models of sustainable agriculture that respond well to the current challenges and issues of rural development, food security, adaptation and mitigation to climate change, protection of natural resources and the environment.

3.2.3.1 Implementation of climate-smart farming techniques

For climate change adaptation and adaptation activities in the DEFIS+ intervention areas, particular attention will be paid to agro-ecological techniques, which protect the soil against erosion and restore its fertility. These activities could be based on the experience of agro-ecological blocks which have already been disseminated by the CTAS in the Androy region over the past years. These systems include the installation of hedges of cajanus (pigeon pea) or acacias which make it possible to fight effectively against wind erosion and the ground cover by leguminous plants adapted to the local climate such as konoke, mucuna and creeping cowpeas, while providing products to ensure food security for farmers. For the South-East and Central zones, the experiences of the BVPI South-East project in the implementation of conservation agriculture or crops under cover may also be capitalised. Agroforestry crops may also be used for the same purpose.

Problem:	Significant soil erosion in the DEFIS+ and loss of fertility and water erosion.
Causes:	Strong winds tearing the topsoil or intense precipitation that cause soil erosion.
Objectives:	Avoid soil degradation, promote infiltration of runoff water and provide livelihoods for farmers.
Proposal:	Protection by hedges (in the South) and establishment of cover plants adapted to the climate and proven in previous experiments.

Expected results:	**Protection against soil erosion while providing adequate income or livelihoods for farmers and improving water availability by infiltration of runoff water. Mitigation potential due to the GHG reduction component.**

3.2.3.2 Watershed protection works (which can be combined with agriculture)

Several techniques can be considered depending on the case:

- Establishment of blocking hedges or sediment trap via agroforestry zones set up at the foot of the tanety and in the shallows to trap the sand and reduce silting downstream;
- Implementation of terracing (terrace cultivation), according to the innovative methods tested by the PURSAPS project in the Amoron'i Mania region;
- Lavaka treatment (type of gully erosion), if applicable.

Problem:	Soil erosion.
Causes:	Heavy precipitation that leads to soil erosion.
Objectives:	Avoid soil degradation, while providing livelihoods to farmers as appropriate.
Proposal:	See above techniques (hedgerows, terraces, lavaka treatment)
Expected results:	**Protection against soil erosion and downstream silting up. Mitigation component due to agroforest activities.**

3.2.3.3 Plantation of fodder

In addition to measures for livestock resilience, the planting of more climate-resistant fodder for feeding small ruminants (Cactus, Bracharia, Penissetum) is also proposed within the framework of DEFIS and DEFIS+. The unarmed cactus, easy to grow in dry lands, can be used in particular as fodder for animals.

Problem:	Feeding problem of small ruminants during drought.
Causes:	Reduction in quality fodder available.
Objectives:	Have resilient fodder for dry periods.
Proposal:	Planting of plants to serve as fodder between crops (Cactus, Bracharia, Penissetum, etc)
Expected results:	**Ensure the forage needs of small ruminants and test / improve this practice for wider distribution later.**

3.2.4 Strengthening of road infrastructure with a view to their resilience to climate risks

The deterioration of road infrastructure and the difficulty of access to production areas and to markets, linked to the climate, are recognized as one of the main constraints for the development of agriculture in Madagascar where the national network of secondary and tertiary roads is characterised by its poor condition. DEFIS + interventions will aim more particularly at ensuring the resilience of the access roads that are most exposed to the impacts of climatic hazards.

The main impacts of climate change on road infrastructure are linked to the increase in the intensity of cyclones and floods. It is well known that the negative effects of water are one of the main causes of degradation of road infrastructure. It has been predicted that some regions (ex: Vatovavy and Fitovinany) will face more intense precipitation, which can increase flooding frequencies. These floods can overrun and erode roads, particularly unpaved roads. Also, conventional roads are designed in a way to only protect the road infrastructure from water-related damage but not the environment around the roads. Therefore, there are many problems caused by conventional roads on the surrounding landscape such as erosion, flooding, drainage congestion and sedimentation.

To solve this complex problem, in the context of DEFIS+, the Green Roads for Water approach (www.roadsforwater.org) will be adopted. The main benefits of the Green Roads for Water approach are: (1) protect the road infrastructure from flood induced damage making the roads open and usable year round and decreasing their rehabilitation and maintenance costs; (2) minimise or even adverse impacts of roads on the surrounding landscape, such as flooding, waterlogging and land degradation; (3) increase access to water and enables farmers to use water from roads that previously could cause flood damage by intercepting the water and guiding it to recharge areas, surface storage places or distributing it over farmland; and (4) promote green and long term sustainable technology in the infrastructure sector

The problem for road damage is due in particular to cyclones or floods, which lead to the deterioration of the conditions of the runways and the destruction of structures, and which is aggravated by climate change. Indeed, the lack of water control is one of the main factors in the degradation of road infrastructure. The damage caused by the passage of four successive cyclones in the Southeast, Vatovavy, and Fitovinany regions and in the South of Madagascar illustrates in a concrete way the impacts of climate change in Madagascar and in particular in the zones of intervention of DEFIS+.[37]

The road damage and market access problems induced by the passage of these cyclones can be found in the WFP rapid assessment report on the impacts of Batsirai on market access in these areas (see link 2 below): e.g. in Fitovinany: Accessibility: Reduced accessibility: flooding, road cut (tree trunks, landslides) on the RN12 and RN25, Infrastructure: 25% damage, flooding in Vohipeno etc.[38]

Indeed, this district - in the path of cyclone Batsirai - has seen many roads cut off and the destruction of market infrastructures due to heavy winds and extensive floods.[39]

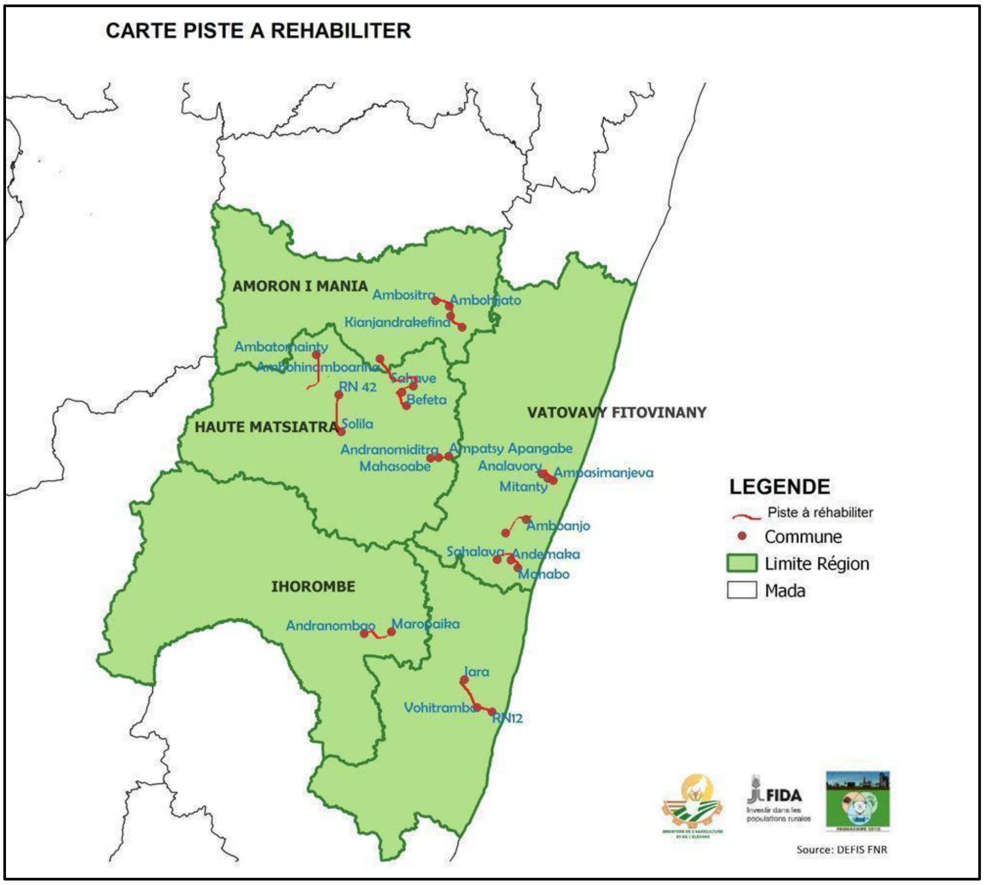
[37] https://www.aa.com.tr/fr/afrique/changement-climatique-madagascar-dans-l-%C5%93il-du-cyclone-/2524805
[38] https://fscluster.org/sites/default/files/documents/madagascar_batsirai_rapid_market_assessment_vf18022022_final.pdf
[39] https://fscluster.org/sites/default/files/documents/madagascar_batsirai_rapid_market_assessment_vf18022022_final.pdf

Problem:	Impassable use of trails in the rainy season.
Causes:	Cyclones and intense precipitation which lead to the deterioration of the runway condition.
Objectives:	Strengthen the resilience of tracks to climate hazards and allow their accessibility.
Proposal:	Application of innovative technology: Green Roads for Water. In addition, consideration should be given, if possible, to recovering excess water for its use in areas that lack water (e.g. for REEPS).
Expected results:	**Easier access to markets, mitigate the negative effects of extreme climate events, improve production, and the health and well-being of the local population.**

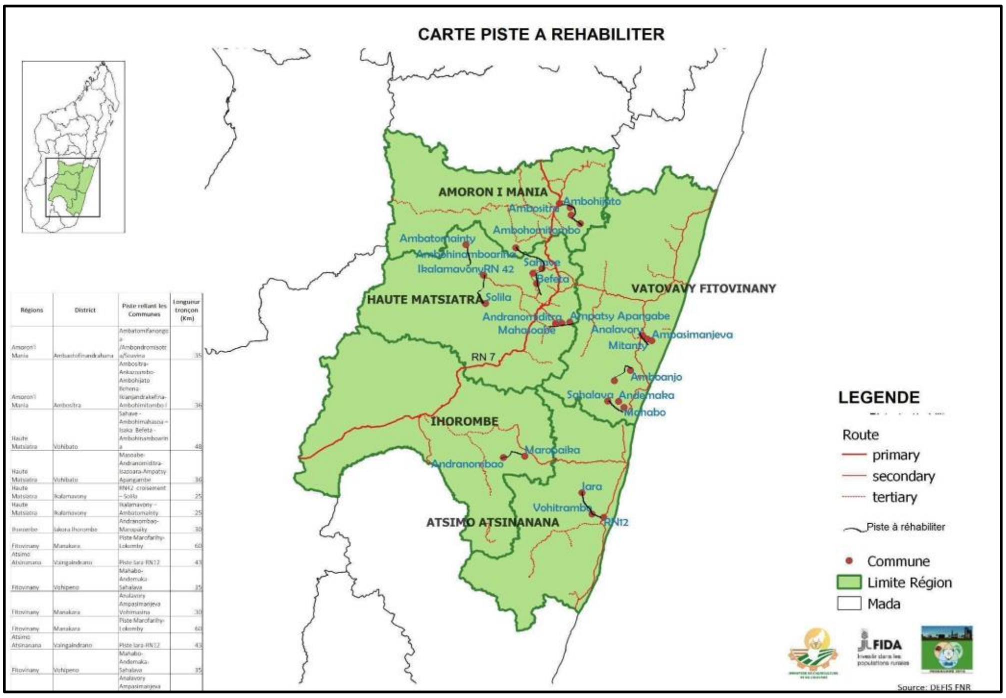
3.2.5 List of Roads to rehabilitate with DEFIS+

As for irrigation schemes, studies aimed at identifying roads to be rehabilitated have already been carried out within another IFAD project (DEFIS). The criteria for selecting these roads are mainly based on the location (where to intervene) and the type of interventions necessary depending on the road conditions (how to intervene). Site selection will be linked with the difficulties of access to markets and economic impacts of road rehabilitation. This diagnosis was also confirmed by surveys and consultation of local communities on their needs. The list of roads planned to be rehabilitated is given below:

Region	District	Road selected for rehabilitation	Length (Km)
Amoron'i Mania	Ambatofinandrahana	Ambatomifanongoa-/Ambondromisotra/Soavina	35
Amoron'i Mania	Ambositra	Ambositra-Ankazoambo-Ambohijato Behena-Ikianjandrakefina-	36
Haute Matsiatra	Vohibato	Sahave -Ambohimahasoa – Isaka Befeta - Ambohinamboarina	48
Haute Matsiatra	Vohibato	Masoabe- Andranomiditra-Isazoara-Ampatsy Apangambe	36
Haute Matsiatra	Ikalamavony	RN42 croisement – Solila	25
Haute Matsiatra	Ikalamavony	Ikalamavony – Ambatomainty	25
Ihorombe	Iakora Ihorombe	Andranombao- Maropaiky	30
Fitovinany	Manakara	Piste Marofarihy-Lokomby	60
Atsimo Atsinanana	Vaingaindrano	Piste Iara-RN12	43
Fitovinany	Vohipeno	Mahabo-Andemaka-Sahalava	35
Fitovinany	Manakara	Analavory Ampasimanjeva Vohimasina	30
		Total	**403**



The proposed roads to be taken into account in DEFIS+, will be prioritised by selecting the tracks which are most exposed to climate risks.



The actions to be carried out within the framework of DEFIS+ will consist of rehabilitating rural roads by incorporating water management in the design and construction phases of road development according to the GR4W concept. The objective of GR4W is to (1) protect roads, increase their resilience to climate impacts and safeguard their transport functions, (2) reduce soil erosion and protect the surrounding of the roads' landscape and (3) increase water availability for drinking purposes, livestock and farming. There is a wide variety of techniques available depending on the geography, bio-physical conditions of the area, and needs and priorities of key stakeholders and communities.

Because GR4W is a cross-sectoral approach, implementation of Green Roads requires changes in road sector governance to encourage openness to cooperation and recognition of a multidimensional approach to sustainability, and to promote trust and transparency among a larger group of collaborating stakeholders. Getting the process started may entail several steps, including fact-finding, encouraging diverse agencies to talk, identifying champions, focusing on early implementation, working on different fronts, capacity building, and consolidation of experiences from various working methods. Community engagement is at the heart of GR4W and it helps reveal how the road affects the landscape and environmental quality for the community and how the road can support community goals such as livelihoods and resilience to climate change.

a. Designing GR4W interventions to build resilience

According to the global guideline on Green Roads for Water, there are different approaches to resilience when looking at road construction and maintenance. The first level of resilience (basic resilience) is called "protective approach" and its key objective is to protect the road infrastructure from water-related damage. Under the protective approach to resilience, road infrastructure specifications are adjusted to account for specific climate risks, such as higher flood peaks. This approach treats stresses as exogenous and follows traditional methods for engineering roads to withstand environmental stresses. The first downside of the protective resilience approach is that it often improves the resilience of the road at the expense of the resilience of the natural or human-made environment. Although protecting the road is essential for connectivity and accessing services and markets, larger cross drainage immediately passes the impact of extreme weather events onto the surrounding area, causing more severe floods, more inundation, and heavier erosion. The second downside is that the protective approach does not use the road's potential to improve water management and the climate resilience of the surrounding area.

GR4W advocates alternatives to protective approaches that could be called "resilience plus". The "plus" involves integrating water management into road development. This approach adapts or designs roads to fit within the landscape in various ways that allow them to support improved management of water and the local environment, including managing water for the benefit of nearby communities. In most cases, the resilience plus approach will reduce road damage from water just as well as the protective approach and will also reduce maintenance and sometimes even construction costs. The resilience plus approach is a preferable option compared with the protective or basic approach to climate resilience and it is used for rehabilitating existing roads. The second level is resilience plus 2 or "proactive approach". The proactive approach calls for designing roads that optimally contribute to better land and water management, in addition to allowing for better communication and coordination among stakeholders involved in road design. This approach is mainly used when designing new roads or redesigning road infrastructure to optimise the water management in the areas and the climate resilience of livelihoods. In the context of DEFIS+, a high density of unpaved rural roads is already in existence and, therefore, most of the focus will be put on the "proactive approach".

Level of Road Resilience	**0**	**1**	**2**
Type of resilience	**Basic Resilience: Protective**	**Resilience Plus 1: Adaptive**	**Resilience Plus 2: Proactive**
Key objective	Protect road infrastructure	Make the best use of and adapt to hydrological changes introduced by the road	Redesign road infrastructure to optimise area's water management and climate resilience, often to the benefit of livelihoods
Paved roads	Increase cross drainage and protect road surface with additional layers of aggregate	Manage catchments to retain water and control erosive runoff to reduce risk to infrastructure	Include drainage for water harvesting as part of road development; take measures to manage subsurface flows; protect catchments
Roadside slopes	Adjust critical slopes	Implement bioengineering and vetiver planting for productive uses	Implement bioengineering and vetiver planting for productive uses
Drainage structures	Increase dimensions to accommodate larger flood peaks	Implement gated control and water spreading from culverts and drains	Place culverts to optimise drainage patterns for water harvesting

The following sets of measures help preserve the affected roads or road sections:

- Using basic road-surface drainage: a series of rolling dips (small depressions with a small bump) or water bars (small, slanted humps) to divert water from the road surface to the land for productive use. These structures have two purposes: 1. prevent water from flowing on the road surface by diverting it from the road; 2. Through these diversions, water is conveyed to an area where it can beneficially be deployed, i.e. recharge of groundwater, feeding a spring, or directly flowing into an on-farm pond to be used for irrigation.

- Using infiltration bunds to slow down the side erosion from the roads and promote recharge. This is a typical issue on many unpaved roads where road runoff builds up, causing erosion and sedimentation. It is best combined with vegetative protection to reduce the erosive effect of runoff from the road template, in particular if no side drain is provided and the road template is out sloped or crowned. However, in arid areas it is more appropriate to put stone bunds in place because of the difficulty of vegetation to take root. Infiltration bunds can be placed on the downhill side of the road or at any other location in the catchment where they intercept sheet flow. The stone bunds disperse water and slow runoff. They ensure more infiltration, contributing to improved soil moisture and recharge of groundwater.

- Implementing a range of bio-engineering methods to revitalise vegetation in the road adjacency. Bioengineering is the use of plants for slope stabilisation and runoff control. It involves using plant parts such as roots, cuttings and stems as a cost-effective and locally adaptable means of erosion control. It ranges from planting deep-rooted species to a combination of vegetation with civil engineering structures. It helps not only to preserve the slopes, but it also buffers the water through higher infiltration capacity.

- A lot of the road water harvesting takes place in the 'road catchment' rather than on the road surface itself. The most vital aspect of preserving unpaved roads is to minimise the amount of water that flows on its surface or directly next to it. Therefore, its integration in the landscape is of utmost importance.

b. Implementation modalities for rural infrastructure

- Regional/local governments invest in rural road infrastructure. When they do this in-house, they generally seek expertise from road engineers and construction companies to lead the actual implementation. The government determines the framework and the design criteria. The executing agency Madagascar Road Agency (ARM) has the role of managing the national road network and has the status of delegated contracting authority, which implements the programs adopted and which are entrusted by the Ministry in charge of public works (MTP). As such, the ARM is mandated to implement the work of construction, maintenance / upkeep and operation of the network of National Roads, including ferries and related road structures. The role of communities differs: at times they are involved in multiple steps, i.e. planning, construction works and maintenance. What is needed is also carefully planned and delivered public information and social mobilisation campaigns.

- Communities may take up the entire package themselves and start to adjust the road without interference from government or road engineers. They put in place 'simple' and low-cost measures, such as infiltration bunds, rolling dips and cut-off diversions. With this they protect the roads, and they harvest water to their farms.

- When water engineering or other agricultural projects are being developed in the vicinity of the road (as is the case of DEFIS or other IFAD projects), this raises the question on how to harvest the road runoff water. Road engineers are invited, and efforts are made to include the road as an instrument for harvesting water for agricultural purposes.

- Through mass mobilisation campaigns, i.e. as in Ethiopia, communities actively contribute to the construction of low-cost road water harvesting structures, such as trenches.

- Road engineers who have the task to upgrade roads may include new designs, such as those for 'sand-dam crossings' (REEP).

Example Box: Creating youth employment with sand harvesting in Ethiopia

In Ethiopia, organised groups of youth (with equal numbers of males and females) are given permits by the government to mine sand for a period of time. This activity is very successful and may be considered for more countries. For one year, the group is expected to retain the profit from sand harvesting as seed capital for business activities. For this business graduation, the government contribution is 80 percent provided as a loan on top of the US$850/year that the group member may have saved. In total, each member may establish his/her own business with about US$4,250. This employment opportunity has resulted in better regulation of sand and gravel mining through the local government. Controlled sand mining from road hydraulic structures can enhance the safety of the road and provide livelihood opportunities for nearby communities.

The measures taken for road rehabilitation are usually low-cost and will help to preserve the integrity of the road and ensure robustness over the years with low maintenance needs. The highest damage to unpaved roads is caused by water. Therefore, this needs to be cushioned through the landscape, road placement, road alignment, drainage facilities and additional features to guide the water for beneficial use. This also means that once the road furniture and supportive systems are in place, the maintenance costs are projected to be lower compared to the average rural road without these provisions. The below table shows the costs and benefits of implementing Green Roads for Water under (1) Mechanised method, (2) Hybrid method (mechanised and HIMO) and (3) HIMO method. These figures refer to a large-scale GR4W's implementation in Ethiopia through the national watershed campaigns.

	NO CLIMATE RESILIENCE INTERVENTIONS	GREEN ROADS FOR WATER (ETHIOPIA)[a]	PROTECTIVE RESILIENCE[b]
Costs per kilometer			
Intervention costs:			
Paved roads	US$0.00	US$1,800	US$45,000
Unpaved roads	US$0.00	US$1,800	US$31,200
Benefits per kilometer			
1. Resilience dividend			
Routine maintenance	Costs increase substantially across the network because of climate change impacts that damage the road over the years	Cost savings per year: Paved: US$1,100 Unpaved: US$2,200	Cost savings are generally comparable to those from the roads-for-water technique
Periodic maintenance	Costs increase substantially across the network	Cost savings: Paved: US$3,400 Unpaved: US$1,870	Cost savings are generally comparable to those from the roads-for-water technique
Reduced damage from erosion	Erosion from peak weather events is not mitigated	US$2,675	Erosion often worsens down-stream from protected roads, sometimes severely
Reduced damage from flooding	Flood impacts typically not mitigated upstream or downstream of roads	US$1,762	Road is protected; Flood damage often worsens downstream of improved roads
Reduced damage from sedimentation	Higher levels of sedimentation	US$180	Higher levels of sedimentation, sometimes severe
2. Unlocking economic potential			
Reduced impact from climate change	Climate impacts not mitigated	US$550	Climate impacts are not mitigated and may be exacerbated
Duration of road closures or downtime	More road closures and downtime	US$3,800	Generally comparable to those from the roads-for-water technique
3. Co-benefits			
Beneficial use of water harvested by the road	No opportunities to harvest water beneficially	US$4,500	Opportunities to use water beneficially are forgone

Source: MetaMeta, (www.roadsforwater.org).
a. Benefits from the roads-for-water program in Ethiopia (Demenge et al. 2015). The benefits in this column are on annual basis and are expected to be delivered every year (after the rainy season).
b. Cost of protective resilience for paved roads is based on the estimated prices for new planned investments of 796 kilometers of multicountry roads under the Program for Infrastructure and Development in Africa (Cervigni et al. 2016).

c. Maintenance arrangement

Since the institutional reforms initiated by the State in 2005, the Madagascar Road Agency (ARM) and the Road Fund, formerly Road Maintenance Funds (FER), are responsible for road maintenance. (i) The executing agency ARM has the role of managing the national road network and has the status of delegated contracting authority, which implements the programs adopted and which are entrusted by the Ministry in charge of public works (MTP). (ii) FER, has the main mission of receiving and to administer the funds intended for the maintenance of all the roads on the national territory including ferries, road structures and other related infrastructure.

The contracting authority is the "owner" of the road network to be maintained and the beneficiary of the services or works carried out on the roads of this network. Within the framework of an effective decentralisation of the powers of the State, the departments and the communes would become owners of works of the infrastructures of which they would receive the management.

The departments are responsible for road maintenance management and for budgetary envelopes and technical objectives. The mayor is required to enact the measures necessary for the proper maintenance of communal roads, knowing that the maintenance expenses of communal roads are part of the compulsory expenses borne by the communes. While the Grassroots Community Organizations are associations of local residents created for a wide variety of purposes, which can take on, for a fee, routine road maintenance tasks (manual labour-intensive work).

On the other hand, the Road Protection Guide Against Flooding in Madagascar is mandatory throughout the national territory and will be taken into account during the various phases: project (APS, APD, Execution Project), Works, Maintenance and monitoring; whether new construction of roads and road works or rehabilitation of road infrastructure in the national network. Responsibilities concern all stakeholders and road network managers, contracting authorities, project managers, design offices, companies, etc. For unpaved roads, local communities are heavily involved in the maintenance of roads. Hence, it is important that they are trained very well on the right techniques. Regular maintenance remains a very important issue for unpaved roads, so it is very important that this is done regularly and not only after a major rainfall event or shock event where part of the road is already inaccessible. It is about maintaining the road and ensuring it stays in good conditions.

3.2.6 Green Roads for Water (GR4W)

Two sets of criteria need to be considered when planning Green Roads for Water (GR4W) interventions that increase resilience to climate change: (a) site/road selection criteria, and (b) selection criteria for water harvesting measures.

a. Site Selection Criteria: where to intervene

Ranking and prioritization of roads to determine where is most urgent to intervene: Different sites and roads are visited and observed. Each site or road is then given a score based on three main criteria (more criteria may be added, as appropriate). This allows for a comparison of all the potential sites to assess where the interventions would be most effective and most valued (see figure below). More information can be found in the Guided Learning on Roads Water Harvesting.[40]

[40] MetaMeta, Guided Learning on Roads Water Harvesting, 2016: http://roadsforwater.org/wp-content/uploads/2017/11/20161206_Guided-Learning-on-Roads-Water-Management-LQ.pdf (p. 86)

Road name	Start/end	Importance for the community (0=low; 5 = High)	Water related problems with the road (0= low; 5 = High)	Roadwater problems in nearby land (0= low; 5 = High)	Totals
Gaiuls road	From Antani to Gaiuls	3	4	3	**10**
Matapi road	From Kircha to Antani	5	3	3	**11**
Boiadeh road	From Boiadeh to Antani	4	5	4	**14**

b. Intervention selection criteria: How to intervene

Road Inventory – Map out hot spots: Through a field visit (or virtually through drone mapping), roads are visited and observed. Through this inventory, the conditions of road infrastructure and drainage along roads as well as points of vulnerability are mapped, which is the first step in developing an effective and preventative road management plan. GPS recorders are used to map and catalogue the hot spots for intervention, which is a cheap and easy method. Also, tracking roads on google earth (pro) allows the slope and terrain classification to be quickly calculated. More information can be found in the Guided Learning on Roads Water Harvesting.[41]

<table>
<tr><td colspan="2">Woreda name</td><td></td><td>Kebele name</td><td></td><td colspan="2" rowspan="3">Sketch box</td></tr>
<tr><td colspan="2">Community catchment name</td><td></td><td>Road name</td><td></td></tr>
<tr><td colspan="2">Road length</td><td></td><td>Change in elevation (metres)</td><td></td></tr>
<tr><td>No</td><td>coordinates</td><td colspan="3">Observed feature</td><td>Intervention to protect road</td><td>Productive use of water</td></tr>
<tr><td>1</td><td>N
E</td><td colspan="3">(Photo number)</td><td></td><td>Yes/No
How:</td></tr>
<tr><td>2</td><td>N
E</td><td colspan="3">(Photo number)</td><td></td><td>Yes/No
How:</td></tr>
<tr><td>3</td><td>N
E</td><td colspan="3">(Photo number)</td><td></td><td>Yes/No
How:</td></tr>
</table>

After the hot spots have been identified, the optimum technique will be selected according to:

- Communities' needs (through communities needs assessments);
- Water harvesting potential (more information can be found here);
- Municipal priorities;
- Budget availability;
- Other criteria linked with local communities.

[41] Ibid, p. 89

Example Box: How roads are selected for either construction or maintenance by the government of Nepal

The government of Nepal prepares a District Transportation master plan (DTMP), where they do an inventory of all the roads (strategic, urban, rural roads) in a district. After inventory, the District Transport Perspective Plan (DTPP) is prepared by listing all the identified interventions necessary to bring the roads to a maintainable all-weather standard as well as the construction of any new roads to complete the District Road Core Network (DRCN). The cost estimation of all the interventions made in DTPP is prepared. Once the cost of intervention is made, the roads are ranked according to priority. Prioritisation is according to the cost per capita. Separate ranking is carried out for conservation, improvement and new construction. The final part of the DTMP process is to determine which interventions can be carried out in the 5-year DTMP period. This DTMP is presented to the District Transport Infrastructure Coordination Committee (DTICC), District Development Committee (DDC) and District council for approval. The DTMP is presented and explained to the target audience. DTMP is prepared every 5 years. Thus, selection of the road that needs to be constructed or that needs improvement is made according to DTMP.

3.3 COMPLEMENTARY ACTIVITIES PROPOSED TO BE FINANCED WITHIN THE CONTEXT OF INSTITUTIONAL STRENGTHENING

To complement the actions planned in the main areas of intervention above, capacity building of the various actors in the field of adaptation to climate change is to be expected. Training of managers,technicians, and engineers at the level of regional departments of ministries, farmers and roadside communities or other target audiences on climate change adaptation issues, to enable them to better understand the issues and make the appropriate decisions in their respective roles and increase their technical know-how on various climate adaptation practices. The training will cover the road infrastructure construction standards (GPRCIM or Guide to Road Protection Against Floods in Madagascar) and hydro-agricultural standards (NIHYCHRI or Standards of Construction of Hydro-agricultural Infrastructures Against Floods) to deal with floods will be also offered.

There is quite a long list of training material that can be used to train local level technicians on how to implement “Green Roads for Water” (GR4W) and support the climate proofing of roads. There are also manuals, guided learning packages, presentations, brochures and videos that are most relevant to Madagascar. These are provided during training activities to all participants (half males and half females). Apart from this type of classroom trainings, field visits and exchange visits to neighbouring countries where GR4W has been implemented in a large scale are proposed to showcase GR4W techniques to trainees and engineers, also highlighting the associated issues and opportunities, for them to get the practical know how of GR4W’s implementation.

Example Box: Capacity building on GR4W for local level technicians (experience from Nepal)

In Nepal, MetaMeta (MM) has an ongoing project (TMT) to train the Department of Local Infrastructure (DoLI) on GR4W. The journey to Tailor made Training (TMT) starts with the number of discussions made with the Department of Local Infrastructure (DoLI) before actually applying for TMT. DoLI exists in all the districts in Nepal with a responsibility to support district level staff in planning, designing, and implementation of local roads, drinking water supply systems and small scale irrigation infrastructure, which is a perfect start for MM to collaborate on GR4W activities.

- TMT Budget: MM has received a total budget of around EUR 74000 plus around EUR 10000 co-funding.
- Number of people trained: 24 people will be trained (16 from DoLI and eight technical people from different municipalities in Province 6).
- TMT Context: four modules were proposed:
  Module 1. Road water management and environmental practice for Nepal. Module 2 Technical know-how and skills on low-cost, high impact solutions. Module 3: Capacity building and knowledge management. Module 4: Gender inclusion through governance.
- Method: MM has proposed both trainers from MM and Nepalese trainers in road and bioengineering sectors. This will ease the blending of the GR4W approach in the Nepalese context. Training will mix classroom sessions with practical sessions on the field i.e. scanning existing practices and feasibility of GR4W technologies/techniques for the actual roads.
- TMT outcomes: Nepalese trainers and training participants will prepare a feasibility and assessment report during the training period. MM also plans to ask them to perform a feasibility study for the roads in their respective municipalities as a post-training activity. MM will support them with all the necessary materials and formats (also in local languages) for the field assessment and for GR4W's implementation. MM will also ensure that the participants will be able to provide training to other technical personnel in other municipalities by providing certificates to the trainees.

Finally, the acquisition and installation of easy-to-use and -maintain agro-meteorological equipment in strategic locations, in addition to those already existing in other areas, will provide reliable and up-to-date data on climatic parameters. Technician training in the use of these devices will also be required, in addition to installation. This activity will be done in collaboration with the General Directorate of Meteorology.

3.4 RELEVANT ACTIVITIES ACCORDING TO THE INTERVENTION AREAS

The activities proposed above may vary due to different intervention zones, since it depends on the problems at the level of each zone, in relation to the impact of climate change.

Table 9 summarises the activities planned within the framework of DEFIS+ and their relevance according to the two zones South East and Central. However, given the limited amount of total funding planned for these activities, which will lead to the objectives being limited in the results framework, it is obvious that prioritisation will remain necessary for the activities to be carried out in each zone. This choice will be made during implementation, after more detailed technical and economic studies. The South zone is included as a comparison but it is not part of the DEFIS+ budget.

Table 9: Relevant activities for each zone

Climate change adaptation activities (DEFIS+)	Zone		
	South not DEFIS+	South-East DEFIS+	Central DEFIS+
Rehabilitation or upgrading of resilient hydro-agricultural networks	X	X	X
Consultation for the management of watersheds and water resources, including aquifer recharging infrastructure	X	X	X
Construction of Underground Water Reservoirs Full of Sand (REEPS)	X	X	
Multiplication and dissemination of climate resilient seeds	X		X
Support for research for integrated pest control	X	X	X
Climate smart agriculture (Agroecology)	X	X	X
Watershed protection works (hedges, terraces, line, lavaka)	X	X	X
Planting improved forages	X		X
Development of resilient tracks	X	X	X

In this context, the interventions defined in this overview must be continued in the downstream part (marketing, market research, etc.). The overview is followed by the detailed climate risk analysis including considerations of the prioritised value chains as well as market analyses for some of the value chains that will also inform the investment. The DEFIS+ financed activities respond to the priorities of adaptation to climate change and mitigation described in Madagascar's Nationally Determined Contributions (INDC, 2015). The activities envisaged will also complement those implemented within the framework of other climate change adaptation projects in the intervention zones or in other regions in Madagascar to help reduce the country's vulnerability to climate change.

3.5 ECONOMIC AND FINANCIAL ANALYSIS OF INTERVENTIONS

The economic viability of ten investments (IT) in water and road management has been assessed via the creation of an integrated Cost-Benefit Analysis (CBA). CBA includes two components, a financial and an economic one. The *financial part* shows whether the investment generates a financial net gain over its lifetime, or an assumed period of time. The *economic part* is an extension of the financial part and it is performed to estimate whether the investment generates net economic benefits over its lifetime, or the same assumed period of the financial part. The economic analysis includes costs and benefits accrued by the economy and society as a whole, hence the society as the whole. Further details can be found in the Annex on Economic and Financial Analysis.

The *economic indicators* are named E-NPV, E-IRR, E-BCR, and E-payback period. The social discount rate is set at 6.0% (this value has been retrieved from the World Bank,2019). The *financial indicators* are named F-NPV, F-IRR, F-BCR, and F-payback period. The financial discount rate of all investments is assumed to be 8.5%.

The ten investments analysed are: (IT1) improved drainage networks, (IT2) irrigation schemes, (IT3) de-silting systems, (IT4) landscape restoration, (IT5) water tanks, (IT6) irrigation parameters, (IT7) ridge ditches, (IT8) runoff collection, (IT9) road improved drainage and reinforcement during the rehabilitation, (IT10) road storage infrastructure.

While the economic analysis was performed for all investments, the financial analysis was performed for six investments only. This is because four investments (IT7, IT8, IT9 and IT10) do not generate revenues for the investor.

Concerning GHG co-benefits, IT2 considers avoided emissions from motor pumps, while investments IT3, IT4, IT5, and IT6 consider carbon sequestration. The economic valuation of GHG emissions was performed using a shadow price retrieved from the World Bank. The main text of the Economic and Financial Analysis presents results that use the low estimate and also presents the economic results when using the higher shadow price.

The economic and financial analysis uses the following assumptions:

- The Income tax amounts to 13.5% and the discount rate is 8.5% for the financial analysis, and 6% for the economic analysis.
- The annual budget of the project was calculated as follow:
  - The project document indicates that the total available budget for “Reduction of impacts of climate hazards on unpaved rural access roads” amounts to 16,078,000 USD.
  - 10% is assigned the total available budget to each of the ten ITs, adding up to the total budget available.
  - An equal implementation of the investment over time is assumed, throughout the six years of duration of the project.
- The proposed project covers the capital cost of the investments analysed, for the 6 years of implementation. Additional investment is required for operation and maintenance, and for the years of lifetime of the investment, past the 6-year duration of the project.
- The implementation time of the investment is 6 years, but the lifetime of the investment stretches beyond the implementation time of the project.
- The results of the economic and financial analyses consider the following mix of crops: Vanilla (20%), Maize (20%), Rice (20%), Onion (20%), and Cassava (20%). This mix has been considered in all ITs from IT1 to IT10 except for IT9 (paving or encroachment).

Overall, the results show that the investments are economically viable, when considering both the economic and financial performance of the investment. It is also worth noting that the size of the positive externalities generated (and included in the economic assessment) is at times larger than the revenues generated by the project. This highlights the importance of considering the societal outcomes of the investment in addition to the direct economic benefits it generates (i.e. comparing the economic and financial performance of the investment).

Specifically, the total investment considered is USD 55.9 million (including the investment made available by the project and the cumulative O&M costs occurring throughout the lifetime of the investments considered) and generates a total F-NPV of USD 33.9 million with an average F-IRR of 62.7%. When considering investments in agriculture (directly aiming at increasing land productivity), the total investment, total F-NPV, and average F-IRR of the proposed project correspond to USD 77.5 million, USD 127.7 million, and 52.4% respectively.

Concerning specific investments, when considering a mix of commodities, the economic analysis shows an E-IRR of 63.1% and F-IRR of 62.7% and benefit to cost ratio in the range of 3.8 (E-BCR) and 3.2 (F-BCR); IT2 (irrigation schemes) and IT5 (water tanks) show the smallest return (14% and 15%) but are nevertheless economically viable.

The assessment of two different investment portfolios shows positive economic and financial outcomes. Investing in IT1, IT2 and IT4 results in an E-NPV and a F-NPV of close to USD 4 million and USD 2 million respectively. Investing in IT2, IT5 and IT6, as an alternative focused on similar development outcomes, results instead in an E-NPV and a F-NPV of close to USD 1.67 million and USD 0.65 million respectively.

Overall, the analysis shows positive economic and financial outcomes from investments in water and road management with the goal to improve climate resilience. It is worth noting that the only investments for which financial indicators are not calculated are IT7, IT8, IT9 and IT10 (road-related investments), since they do not generate direct cash inflows. However, these investments generate considerable economic value (i.e., externalities). Specifically, these are investments in improved climate resilience for existing roads. As a result, such investments do not increase the value of existing assets (e.g., real estate) and do not open up agricultural land for increased agricultural production. Instead, they improve access to markets for farmers. On the other hand, since these are not toll roads, there is no direct benefit generated for the investor, hence the focus on the economic and on climate resilience rather than on the financial analysis.

4. ACHIEVEMENTS UNDER THE INITIAL INVESTMENTS THROUGH DEFIS

In the baseline study conducted for the DEFIS Programme the main climate change impacts were related to water i.e., excess water linked to intense rains or deficiencies linked to droughts depending on the different regions and the climate risks faced. Smallholder farmers confirmed the effects of limited access to water is the reduction in their productivity.

In Isorana in the district of Isandra, the members of the Producer Organisation Ndao Mba Hivoatra observed a decrease in production: 500 kg of paddy in 2017 against only 100 kg, on the same plot and with the same techniques and inputs for 2021. If previously, rice farmers managed to cultivate with two different seasons in the year, the shortening of the rainy period no longer ensures enough production during the main agricultural season. In other cases, the data confirms a decline in cultivated area, especially for agriculture over the past three years. The high and least productive plots are abandoned, and priority is given to those closest to the springs. Moreover, in regions with high rice-growing potential and where the availability of water made it possible to carry out several harvests, the situation has changed, and producers only invest in high-season for rice growing.

This disruption of agricultural water supply also affects the ability of farms to cultivate off-season crops, other than rice. The shortening of the rainy season makes the soils less humid. The risk of loss of investment in terms of inputs and mobilized labor is too high such that most producers abandon off-season crops. “We already use Sustainable Rice Intensification (SRI) and SRA techniques, but production is low due to lack of water. The local collective agreement should be strengthened in the management of infrastructure, especially against those who destroy infrastructure”. Reforestation activities are already also undertaken to preserve the environment, but the monitoring is insufficient.

The resurgence of diseases and pests occurs after the drought and represents a major constraint to agriculture. In the absence of financial means for the purchase of phytosanitary products and because the producers consider that the integrated phytosanitary control "ady gasy" is not very effective, the producers have no choice but to abandon certain cultivation fields. In the southern part (Anosy, Androy and Atsimo Andrefana), for lack of means and in relation to this perception of efficiency but also in terms of investment risk assessment, producers reduced the area exploited. By way of illustration, the usual area for growing cassava from 2 hectares fell to only 2 acres, following these climatic constraints and the reduction in productive capacity. For livestock, the depletion of natural pastures due to drought marked the years 2020 and 2021. Cactus leaves, which are used as an alternative fodder during this phase of decreasing availability, are even affected by the lack of water. Herders travel dozens of kilometres or are forced to buy fodder from other herders in the surrounding villages in order to be able to feed their livestock, justifying the intensity of the drought in recent years.

Contrary to the water shortage, the south-eastern part (Vatovavy and Fitovinany, Atsimo-Atsinanana and Anosy regions) is facing an intensification of the cyclone period and flooding. The risks of destruction of cash crops, including coffee, during the hurricane season, are enormous in this eastern part. In flood-prone areas and lowlands, producers have recorded a decrease in agricultural yield due to their inability to control rising water.

In terms of adaptation, smallholder farmers first opt for short-cycle seed varieties that are more tolerant to drought. However, access to these seeds is still very difficult for most smallholder farmers. The second strategy is to gradually migrate to rainfed rice growing on tanety, but the availability of seeds and the low technical level compared to speculation also remains a major constraint.

Area of land under climate resilient management

The sustainable land management practices include the control and rational use of water resources for the development of rice fields at the level of the lower slopes and plains. In addition, hydro-agricultural dams are rehabilitated and/or newly built and irrigation canals are dug. In the Anosy region, 447 ha of agroecological blocks have been installed from combinations of multiple activities in a process of collective development of community spaces. Through the agroecological blocks, DEFIS is bringing innovative actions to limit the process of impoverishment of the environment and the means of production of the smallholder farmers in the long term.

DEFIS investments should lead to an increase in the productivity of agricultural land and the protection of slopes and watersheds against their possible degradation, which would threaten the security of crops downstream. In this regard, this approach for sustainable land management in the face of climate change and the frequency of delayed rainfall at the start of the agricultural season would solve the difficulties of the timing of planting and the efficiency of water use. The popularization and application of agroecological techniques should improve the rational management of the productive agricultural landscape and the feeding of livestock by local communities. In 2021 the area of land under climate resilient management in the DEFIS regions was 6,950 ha.

Hydro-agricultural and pastoral infrastructure

The area of agricultural land with access to water-related infrastructure including dams and ditches, infrastructure for irrigation, drainage, rainwater harvesting field level, wells and other water points, etc., constructed or rehabilitated with DEFIS support is being monitored. The mini projects for the construction of production infrastructures at the level of the irrigated perimeters are based on the APS and APD studies covering nearly 25,008 ha. 40.5% of this estimated area has been effectively developed so far thanks to the construction and/or rehabilitation of 53 hydro-agricultural dams. The FDA financing mechanism contributed to the achievement of 53% of these 10,129 ha of developed PPI.

In all, these achievements have directly benefited 27,815 smallholder farmers in all areas of intervention. Nearly 46% of them have been trained so far for the development of irrigated rice fields with SRI/SRA techniques. Sixteen (16) out of the 53 newly inaugurated dams, i.e., only one third, have Water User Association (WUA) management structures, either newly created or revitalized. Training packages on the socio-organizational side and on the maintenance of infrastructures were provided to the WUAs.
The initial benefits of these achievements include the strengthening of the technical knowledge of the smallholder farmers in the field of irrigated rice cultivation, water control and management of their assets. In addition, the programme technicians were able to improve their knowledge of socio-organisation, management and site monitoring over time through the training sessions organized.

Having experienced for the most part, two major rice-growing campaigns at most, the impacts of these very recent infrastructures in terms of productivity and household food self-sufficiency still remain partial. The priority for the Program now is to determine to what extent the completion of the construction of the dams at the level of the communes would effectively contribute to the improvement of the living environment, at least of the direct members of the WUAs. The most important thing is to be able to provide continuous support and monitoring of the use of the acquired knowledge by the beneficiary smallholder farmers who are members of the WUAs: this primarily concerns the development of water by exploiting the plots as much as possible irrigable by mobilizing time, family and salaried labor according to the available means and the necessary factors of production; and secondly the application of the knowledge retained during the exchanges and training at the level of the PIUs, such as the gradual putting into practice of innovative techniques in rice cultivation, respect for technical itineraries and increased investment in weeding to minimize or even avoid losses on the yield. The area of agricultural land with hydraulic infrastructure built/rehabilitated as of November 2021 is 6,513 ha.

The DEFIS Program also builds or rehabilitates pastoral hydraulic infrastructures, only in the semi-arid zones of the South. Indeed, surface water disappears during the dry season and the watering of animals can in some cases only depend on the mobilization of groundwater by wells or mechanized boreholes. To this end, the DEFIS Program has been able to build 57 multi-purpose wells with watering troughs for animals and 11 water tanks buried in the sand (REEPS), built for the most part in 2021. At the same time, 37 Farmer Field Schools have been promoted, which give hope to smallholders, especially those who are landless.

The training and exchanges were able to demonstrate to the participating stockbreeders that despite the scale and the limited means at their disposal, it is still possible to make a decent living from stockbreeding as a main or complementary activity in this arid zone thanks to the improvement of management, health and quality of the animal in connection with watering, livestock management techniques employed through the use of local materials, and control of sales schedules. The number of stockbreeders who have benefited from pastoral hydraulic infrastructure as of November 2021 was 2,083.

Initial benefits of the installation of these watering infrastructures by the DEFIS Program, include the stability of life of smallholders and thus of their personal safety and their habitat with personal assets. Indeed, the factors that lead herders to migrate are mainly linked to the availability of water sources and their seasonality, not to mention the choice of prioritization between water for household needs and water for feeding their families animals. This water factor is often more important than pasture because of the very relative and diversified availability of the latter. In the Communes of the district of Amboasary Sud, for example, it has been observed that individuals mark out to protect and privatize small ponds, already infested with parasites that can be harmful to the health of small ruminants. The development of REEPs-type drinkers or the installation of multiple-use wells remedy the problems of pathology and have an impact on the quality of the meat.

Production and natural resources

The main production factors of households in the regions of intervention of the Program, their production, their yields as well as, in a general way, production practices include the land resources devoted to agriculture and livestock, the techniques implemented, the inputs and materials used and finally access to water for productive purposes. Production and performance are also part of the DEFIS Programme indicators.

Area, production and yield

The transformation of family farming through the large-scale adoption of efficient production systems adapted to the current climatic context is one of the development objectives of the Program. Production depends on yield but also on the scale of production systems.

Available area

Producers generally have several plots that can be used for a single crop, several crops alternately, in association or in parallel. The areas of land devoted to agricultural value chains vary widely. It should be noted that the average areas are higher among beneficiaries compared to non-beneficiaries, with the exception of coffee plantations. The average areas are slightly lower for mainly irrigated crops, namely rice and onion. The average surface area for rice is 57 acres for the DEFIS intervention regions. The average area on a national scale was 87 acres according to the last agricultural census to date (2004 – 2005).

Given the importance of rice in Malagasy culture and the predominance of irrigated rice cultivation in rice production, producers generally dedicate the best land to this crop. Producers generally own several plots devoted to rice cultivation, the combined area of which is on average 48 acres. The beneficiaries of the Program have a significantly larger surface area, i.e. 56 acres against 39 acres for the non-beneficiaries.

Notable differences exist according to the regions: overall, the average surface areas available in the southern regions, namely Anosy, Androy, Atsimo Andrefana and Ihorombe are larger compared to those of the other regions. Significant disparities are also to be noted if the gender and age category of the smallholders is considered whether among beneficiaries or non-beneficiaries: men on the one hand, and the category of those over 35, on the other hand, have larger surface areas. These figures illustrate the problems of access to land resources that disadvantage women, generally due to the persistence of rules that seek to maintain land heritage within the patriarchal lineage, and the younger generations who suffer above all the consequences of fragmentation and who often have less financial capacity, and therefore fewer opportunities to buy agricultural land.

While the figures put forward by producers on the areas of agricultural land available to them must always be considered with caution, the differences observed between regions and different groups have logical and plausible explanations. In terms of crop plot area, the following salient points emerge:

- The average areas are generally larger in the southern regions, compared to those of the highlands and the eastern coast
- Men operate larger agricultural plots than women
- The population of the age category under 35 years exploits smaller plots than the older category

Cultivated area

Some smallholder farmers are able to cultivate all of the available area, while others are able to cultivate only a portion. The cultivated area depends on many factors, including the financial capacities of the producers, the availability of labour, but also the climatic conditions including the delays in the rain, which often cause the destruction of the seedlings sown and transplanted, as well as the various negative impacts on the crops.

In the DEFIS areas, most producers are able to cultivate the available land, except for the case of maize producers, who are only able to cultivate 89% of the available area. For the cultivation of maize, the attacks of the armyworm, which are added to the climatic disturbances, can explain, among other things, this lower proportion. Faced with the recurrence of the rainfall deficit in most regions, rainfed rice cultivation is of growing interest to producers. The best placed rice fields in terms of accessibility to water have been preserved, but the extensions on the tanety are more and more frequent.

Production

The average production during the campaign considered (2020 – 2021) during the reference study varies strongly depending on the sectors. For the rice sector, there may be more than one harvest on the same plot in a campaign. There are significant differences in production particularly for the most demanding crops, namely rice and onion. These cultures in most cases require good water control and their technical itineraries involve crucial additional steps compared to other crops in the concentration sectors. It can therefore be hypothesized that beneficiaries have been able to improve their productivity thanks to DEFIS Program support. Production is naturally correlated with cultivated area:

- Average production is generally higher in the southern regions where the plots exploited are larger and despite less favourable climatic conditions

• Different categories of smallholder farmers cultivate different land areas based on their holdings
• Men produce much more than women
• Producers in the over 35 age categories produce more than younger ones because they have larger plots

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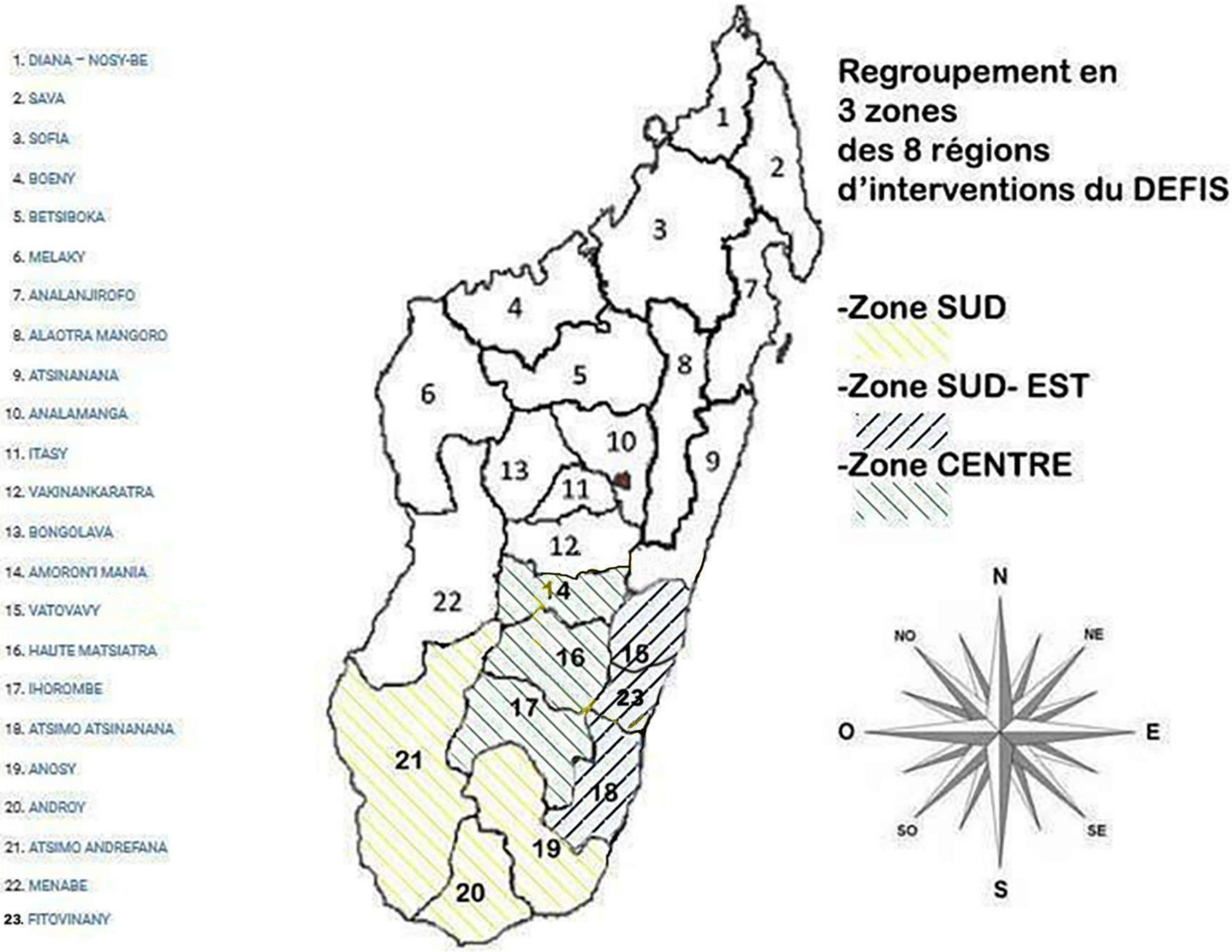
APPENDIX 2: LIST OF PROJECTS WORKING ON CLIMATE CHANGE ADAPTATION AND MITIGATION IN THE INTERVENTION AREAS

Organization / Project	**Regions / Value Chains / Components**
GIZ **PrAda (Adaptation of agricultural value chains to climate change)** **(2017 - 2020)**	Intervention regions: Anosy, Androy and Atsimo Atsinanana Value chains: ● Anosy: Onion, small ruminants, vanilla, honey ● Androy: Castor, millet / sorghum, small ruminants ● Atsimo Atsinanana: pepper, coffee, vanilla 3 Components: ● Component 1: Agro-meteorological and climatic information ● Component 2: Agricultural value chains adapted to climate change ● Component 3: Climate risk insurance
European Union **AFAFI Sud (Support for the financing of agriculture and inclusive sectors - South of Mcar)** **(2019 - 2023)**	Intervention regions: Anosy, Androy and Atsimo Atsinanana (with defined districts and municipalities: 4 agro-ecological zones) Value chains: to be defined but approaching the sectors of interest in these regions. Millet will be the subject of Programme activities, as well as the promotion of agro-ecological blocks. Two main axes: i) Support for strengthening nutrition and food security ii) Support for the development of inclusive value chains Component 1: Inclusive, equitable and sustainable agricultural development is supported Component 2: Food security and nutritional status of rural households are improved Component 3: Inclusive value chains in selected sectors are developed
PNUD - FEM/FPMA **PACARC (Improvement of Adaptation and Resilience Capacity of Rural Communities)** **(2017-2021)**	Regions: Analamanga, Atsinanana, Anosy, Androyandt Atsimo Andrefana Components: ● C1: Strengthening the adaptive capacities of communities and rural development institutions (agriculture, livestock, environment, forestry, fishing, water, meteorology) ● C2: Production and dissemination of agro-meteorological and hydrological information for appropriate decision-making in the field of rural development ● C3: Introduction of adaptation options at the level of the 11 municipalities Project in preparation on "increasing resilience and improving the livelihoods of the most vulnerable people and communities with extreme climatic phenomena in the 3 Regions: Anosy, Atsimo Andrefana and Androy" with Green Climate Fund funding.

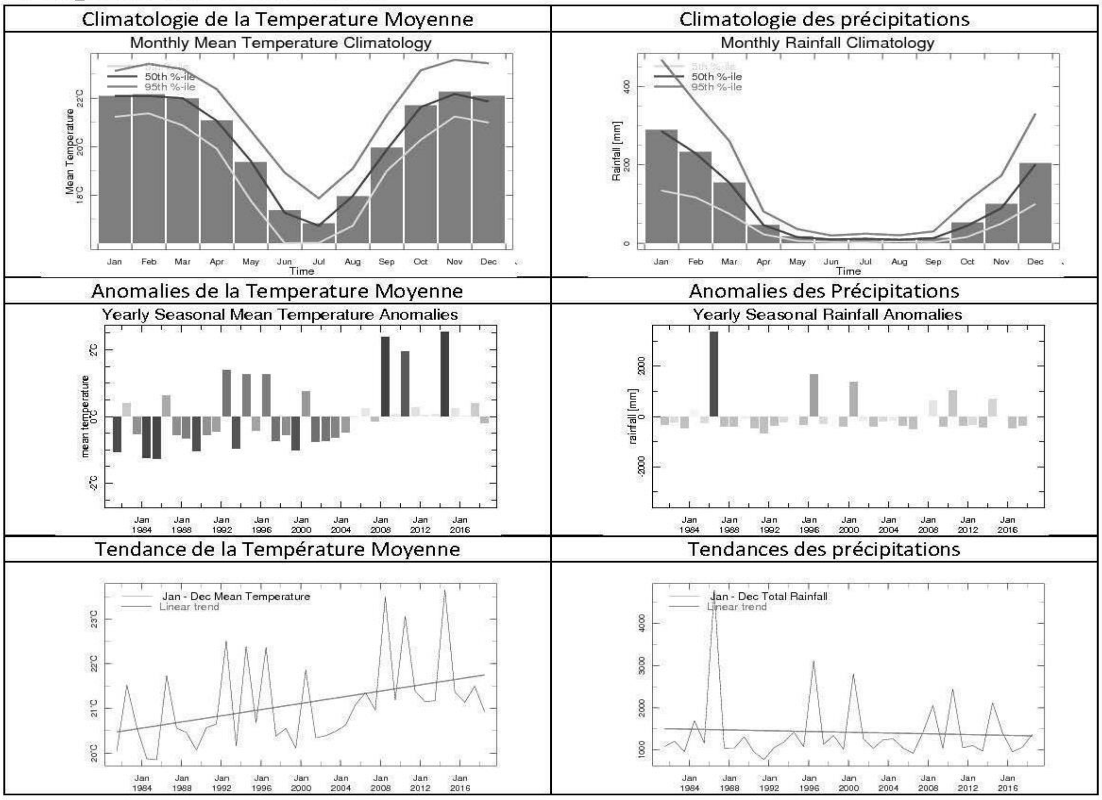
Organization / Project	Regions / Value Chains / Components
BM - BAD **PPCR (Pilot Programme for Climate Resilience in Madagascar)** **(2016 – 2027)**	2 phases: - Phase 1: 2 years (soft) - Phase 2: 10 years (investments) ● Component 1: Improve understanding of climate risks and their gender implications ● Component 2: Strengthening of institutional and political frameworks for resilience to climate change ● Component 3: Knowledge management and gathering of evidence ● Component 4: Support for the implementation, coordination and monitoring and evaluation of the SPCR
AFD **PAPAM** **(2016 – 2027)**	2 phases : - Phase 1: 2 years (soft) - Phase 2: 10 years (investments) ● Component 1: Improve understanding of climate risks and their gender implications ● Component 2: Strengthening of institutional and political frameworks for resilience to climate change ● Component 3: Knowledge management and gathering of evidence ● Component 4: Support for the implementation, coordination and monitoring and evaluation of the SPCR
UE **PACZ** **(2016 – 2020)**	2 phases : - Phase 1: 2 years (soft) - Phase 2: 10 years (investments) ● Component 1: Improve understanding of climate risks and their gender implications ● Component 2: Strengthening of institutional and political frameworks for resilience to climate change ● Component 3: Knowledge management and gathering of evidence ● Component 4: Support for the implementation, coordination and monitoring and evaluation of the SPCR

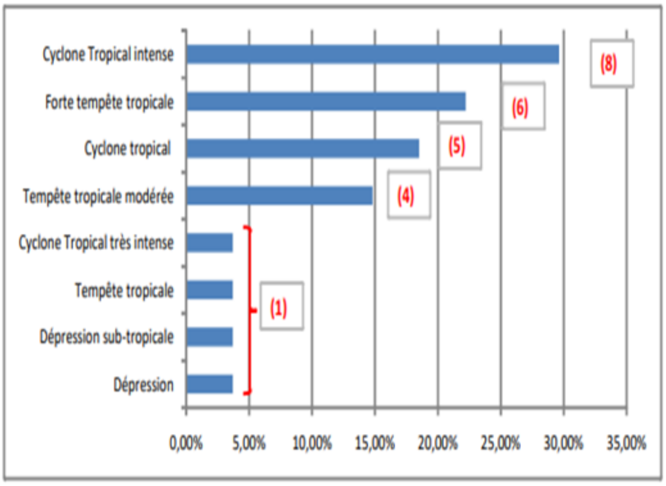
APPENDIX 3: LOCATION MAP OF THE 3 ZONES GROUPING THE INTERVENTION REGIONS OF DEFIS



APPENDIX 4: CLIMATE TREND DATA CYCLONES

8-Région HAUTE MATSIATRA



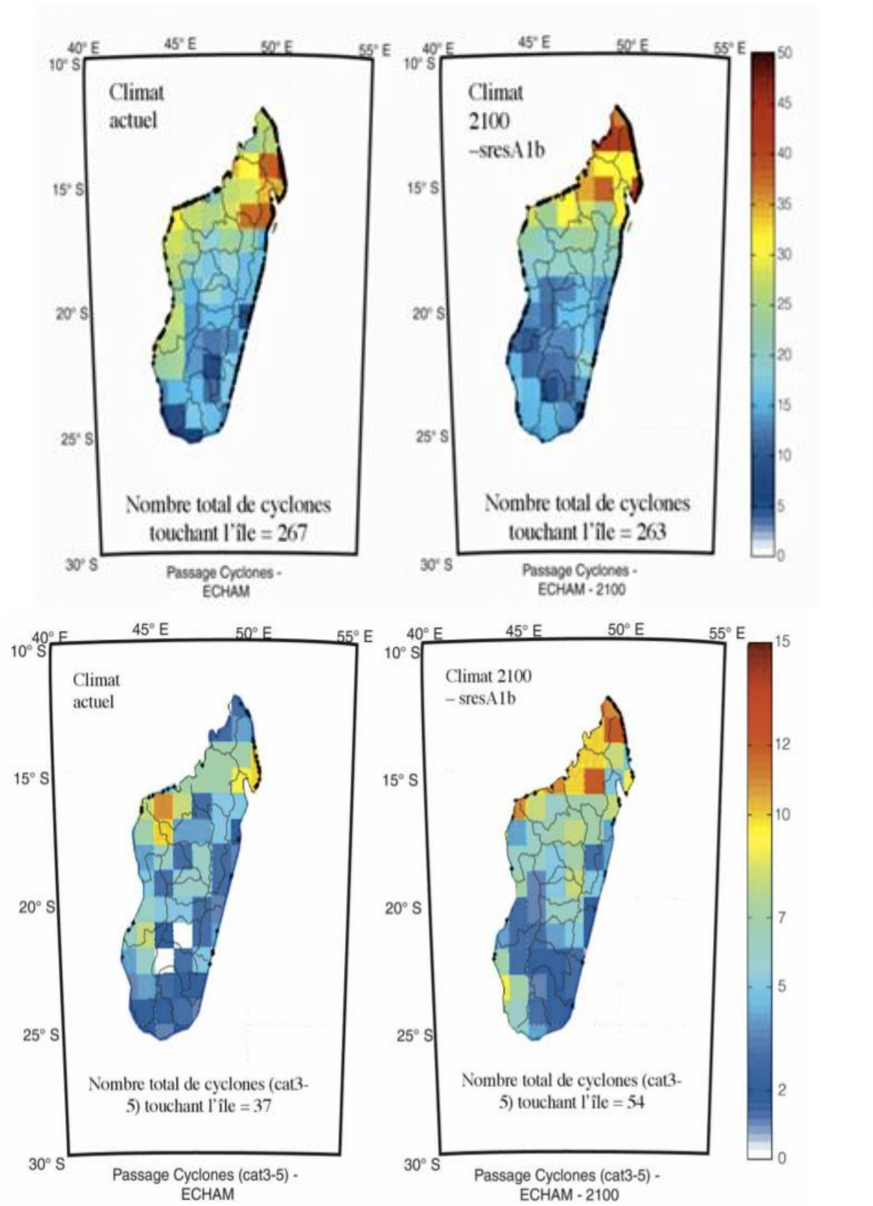


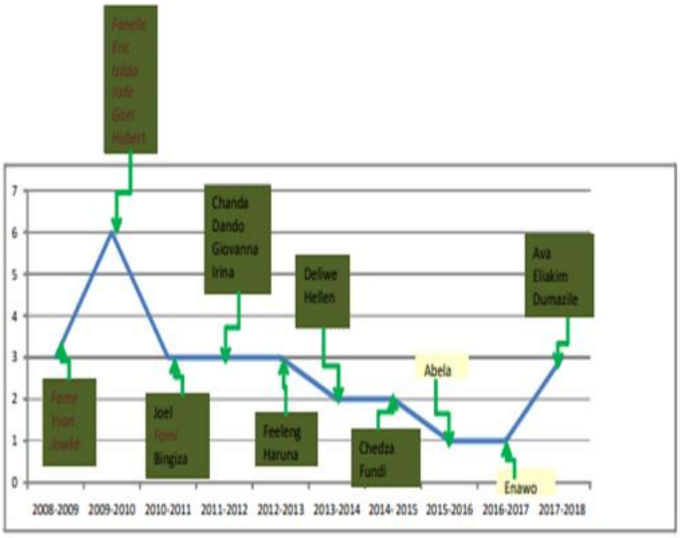
Source : Desinventar - 2019

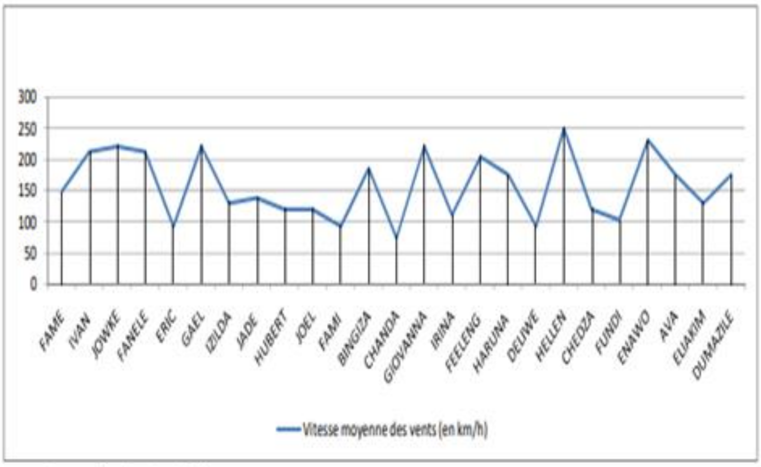
Tableau 1 : Cyclones tropicaux ayant frappé le pays à chaque saison cyclonique depuis 2008

Saison cyclonique	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014- 2015	2016-2017	2017-2018
Cyclone tropical	3	1	1	2	2	1	1	1	2
	Fame	Fanele	Jade	Bingiza	Feeleng	Hellen	Chedza	Enawo	Ava
	Jowke			Giovana	Haruna				Dumazile
	Ivan								

Source : Desinventar - 2019


Climat actuel
Nombre total de cyclones touchant l'île = 267
Passage Cyclones - ECHAM
Climat 2100 –sresA1b
Nombre total de cyclones touchant l'île = 263
Passage Cyclones - ECHAM - 2100
Climat actuel
Nombre total de cyclones (cat3-5) touchant l'île = 37
Passage Cyclones (cat3-5) - ECHAM
Climat 2100 – sresA1b
Nombre total de cyclones (cat3-5) touchant l'île = 54
Passage Cyclones (cat3-5) - ECHAM - 2100





Source : Desinventar - 2019

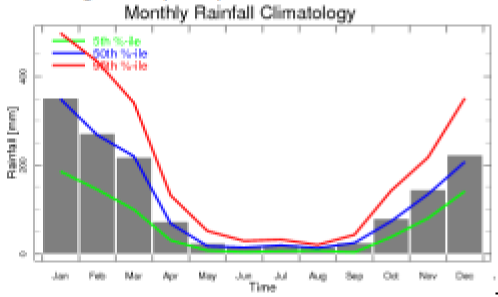
APPENDIX 5: CLIMATE TRENDS

DIRECTION GENERALE DE LA METEOROLOGIE

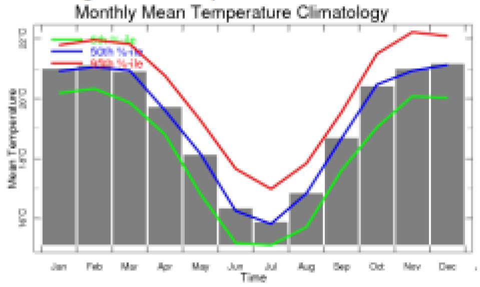
SOURCE DES DONNEES WWW.METEOMADAGASCAR.MG/MAPROOM

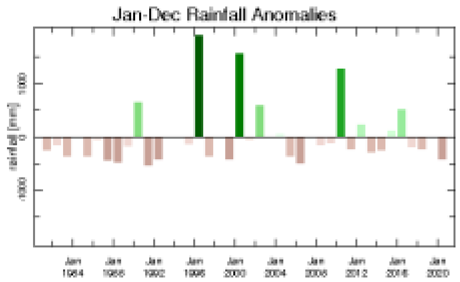
A-1. AMORON'I MANIA

Climatologie des précipitations

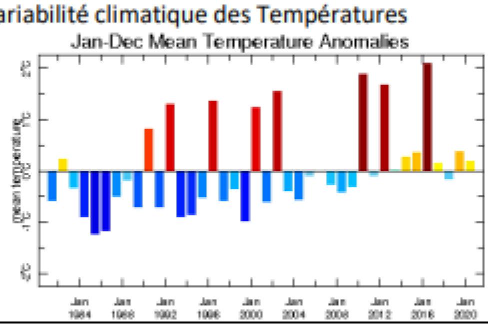


Climatologie des Températures

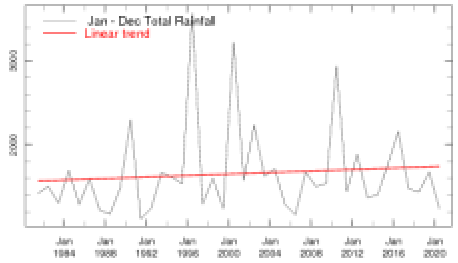




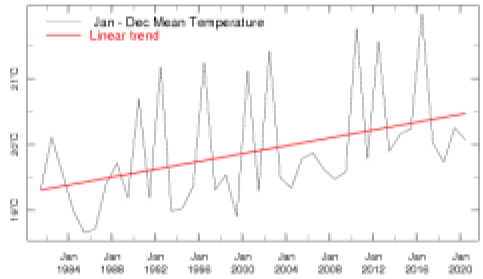
Variabilité climatique des Températures



Tendance des précipitations

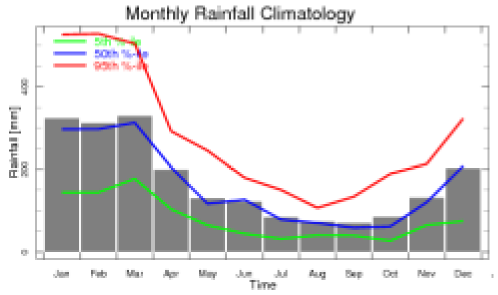


Tendances des températures

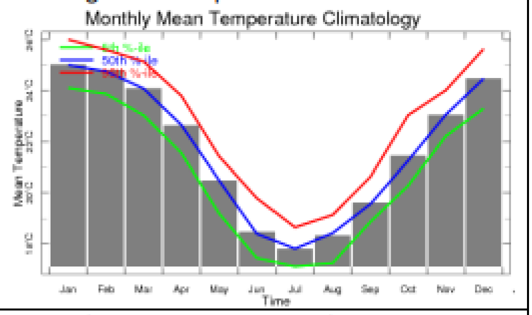


A-2. ATSIMO ATSINANANA

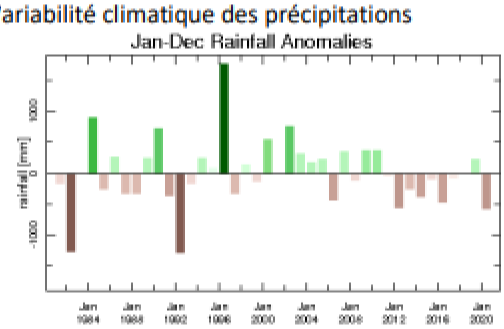
Climatologie des précipitations



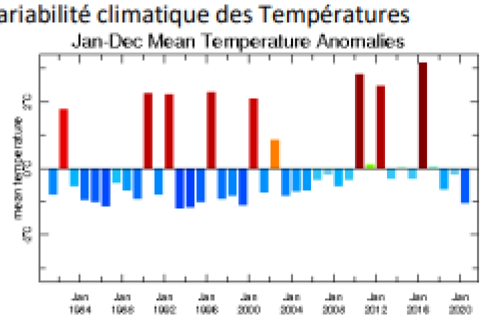
Climatologie des Températures



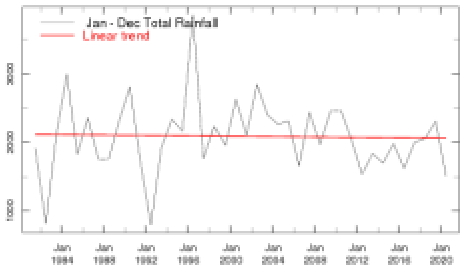
Variabilité climatique des précipitations



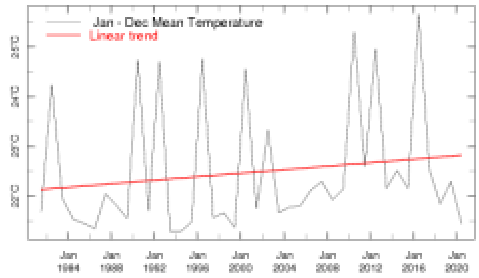
Variabilité climatique des Températures



Tendance des précipitations

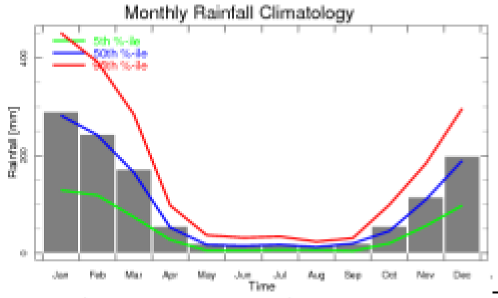


Tendances des températures

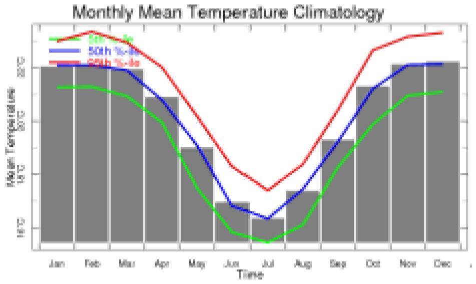


A-3. HAUTE MATSIATRA

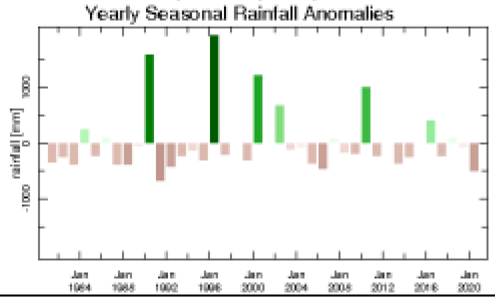
Climatologie des précipitations



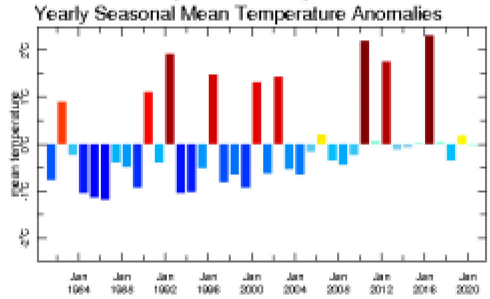
Climatologie des Températures



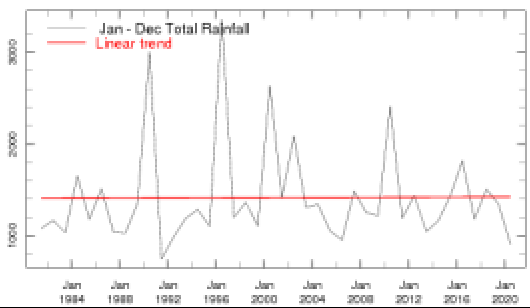
Variabilité climatique des précipitations



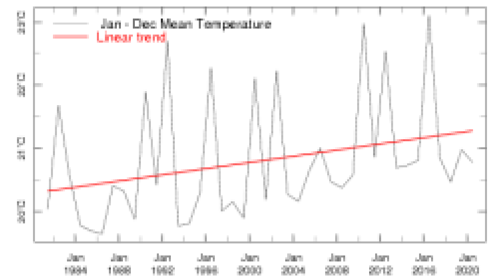
Variabilité climatique des Températures



Tendance des précipitations

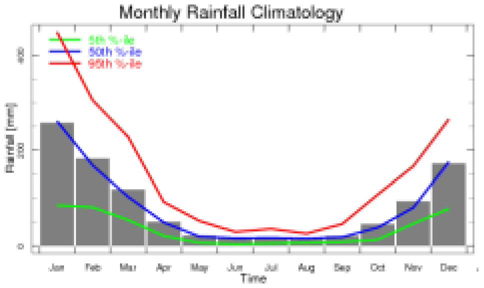


Tendances des températures

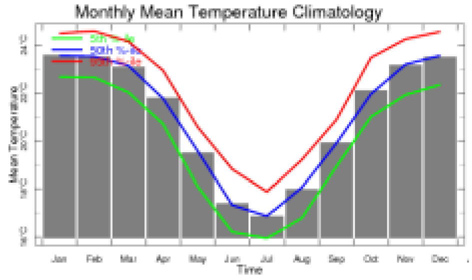


A-4. IHOROMBE

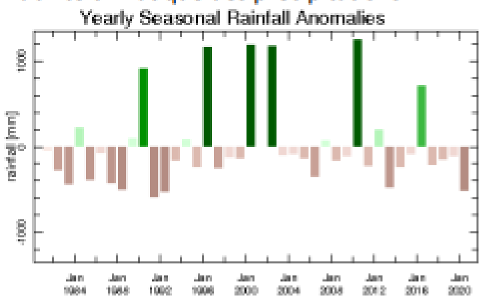
Climatologie des précipitations



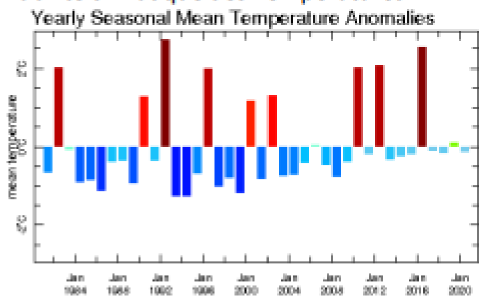
Climatologie des Températures



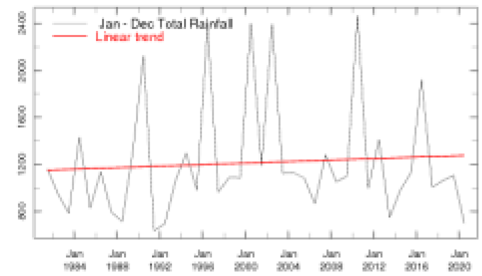
Variabilité climatique des précipitations



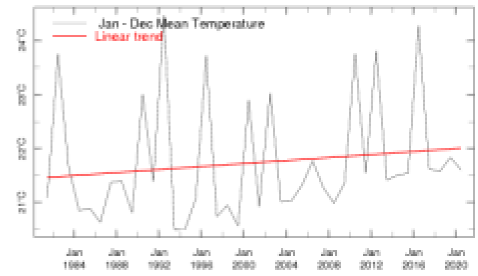
Variabilité climatique des Températures



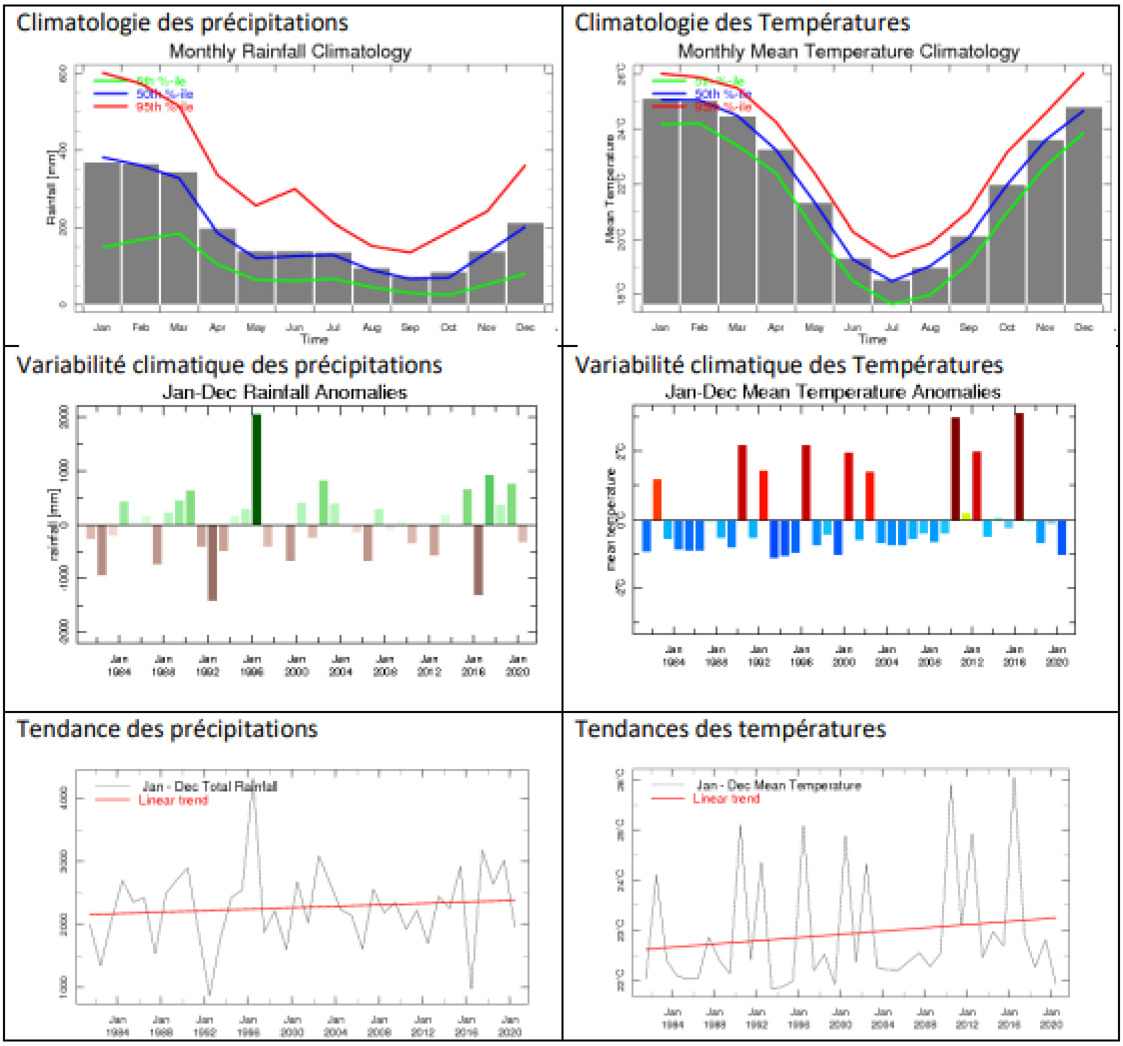
Tendance des précipitations



Tendances des températures



A-5. VATOVAVY FITO VINANY



Interpretation: The climatic variability of precipitation/temperature indicates the inter-annual or year-to-year climatic variation of precipitation/temperatures. The horizontal axis zero (0) represents the normal value which is the average for thirty years, here from 1981 to 2010.

Positive values are above 0 (above the horizontal axis) and negative values are below 0 (below the horizontal axis).

Abnormalities are used, which represent the difference between the observed value and the normal value (proper value for a year and for a specific place).

Example in Amoron'i Mania: Precipitations were normal to slightly below normal during nine consecutive years (from 1981 to 1989), followed by normal to slightly above normal levels in 1990, in turn followed by five successive years of normal to slightly low rainfall patterns from 1991 to 1995. Year 1996 was marked by abundant rains.

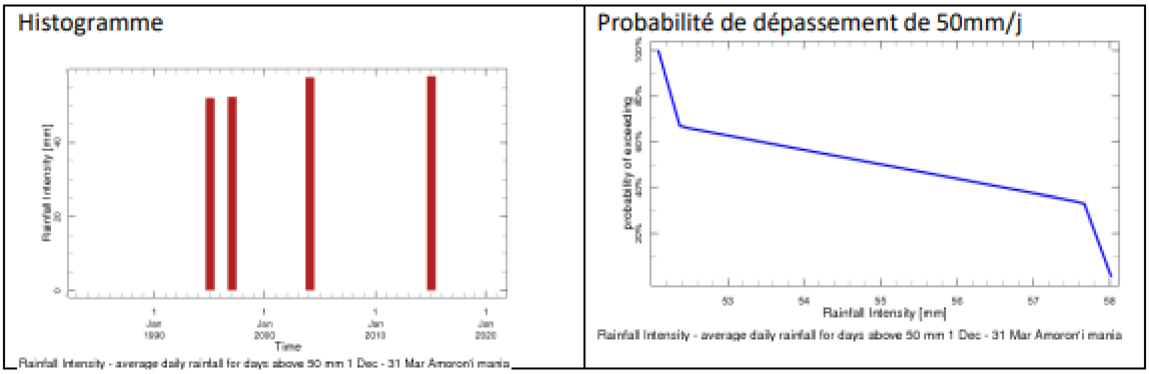
APPENDIX 6: PRECIPITATION PATTERNS

DIRECTION GENERALE DE LA METEOROLOGIE

SOURCE DES DONNÉES WWW.METEOMADAGASCAR.MG/MAPROOM

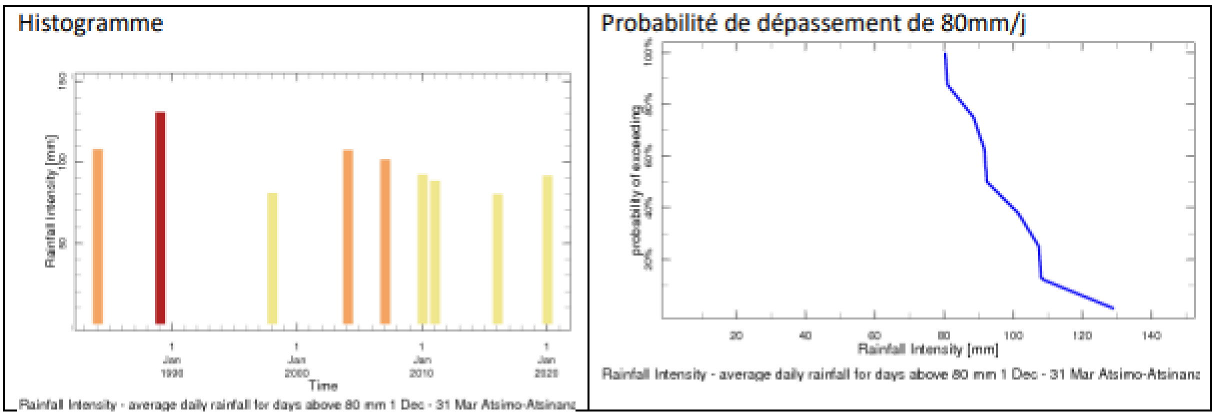
The analysis of heavy rains is done on a daily scale. It is identified by the number of days of consecutive rainfall events and the daily average rainfall intensity.

AMORON'I MANIA
Number of consecutive rainy days: 7
Average daily rainfall: 50mm/d
Chosen period: December 1981 to March 2021



- In 40 years, from 1981 until 2021, heavy rains (7 consecutive rainy days, with an average of 50mm/day) are observed in 4 years: 1995, 1997, 2004 and 2015.
- In this period the probability of exceeding 50mm/day is 99%, while for 58mm/day this probability is 5%.

ATSIMO ATSINANANA
Number of consecutive rainy days: 7
Average daily rainfall: 80mm/d
Chosen period: December 1981 to March 2021

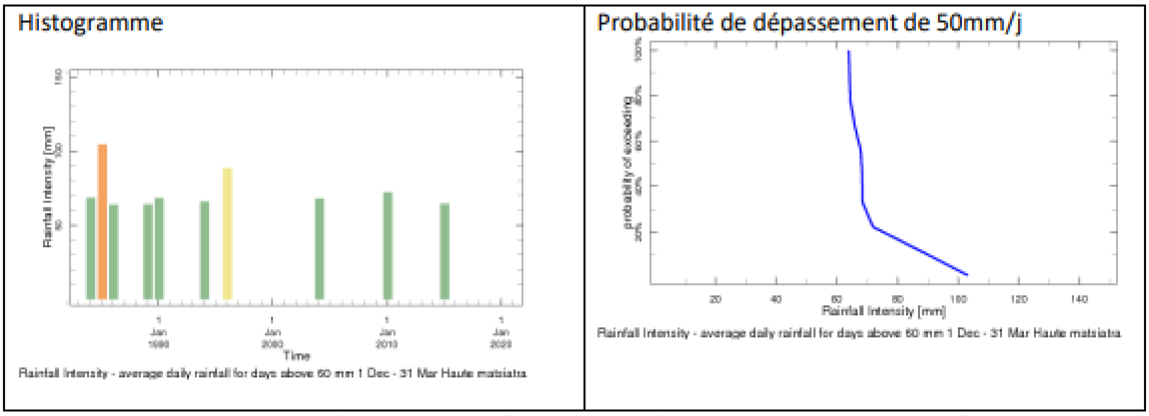


- In 40 years, from 1981 until 2021, heavy rains (7 consecutive rainy days, with an average of 80mm/day) are observed in the following years: 1989, 1998, 2004, 2007, 2010, 2011, 2016 and 2020.

- In this period, the probability of exceeding 80mm/day is 99%, while for 120mm/day this probability is 5%.

HAUTE MATSIATRA

Number of consecutive rainy days: 7
Average daily rainfall: 60mm/d
Chosen period: December 1981 to March 2021



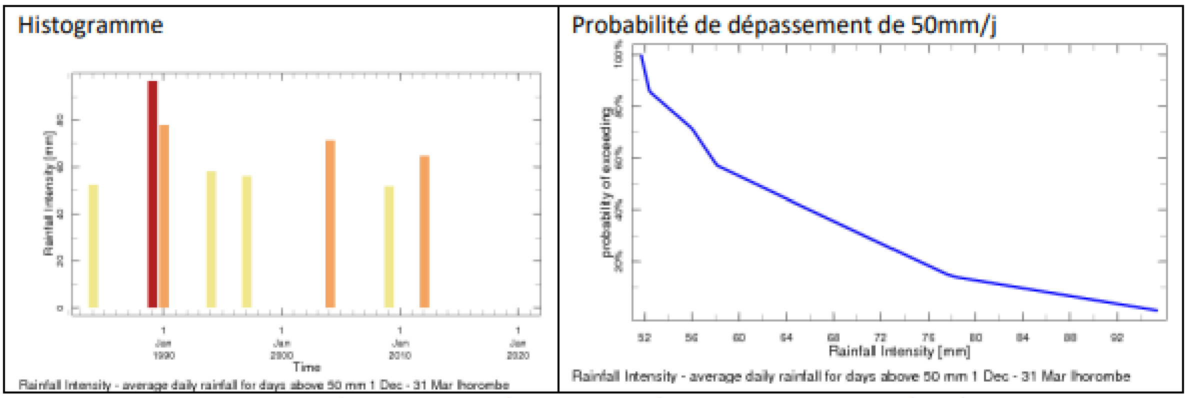
- In 40 years, from 1981 until 2021, heavy rains (7 consecutive rainy days, with an average of 60mm/day), 10 cases are observed: 1982, 1983, 1984, 1989, 1990, 2000, 2004, 2010 and 2015.
- In this period, the probability of exceeding 60mm/day is 99%, while for 100mm/day this probability is 5%.

IHOROMBE

Number of consecutive rainy days: 7

Average daily rainfall: 50mm/d

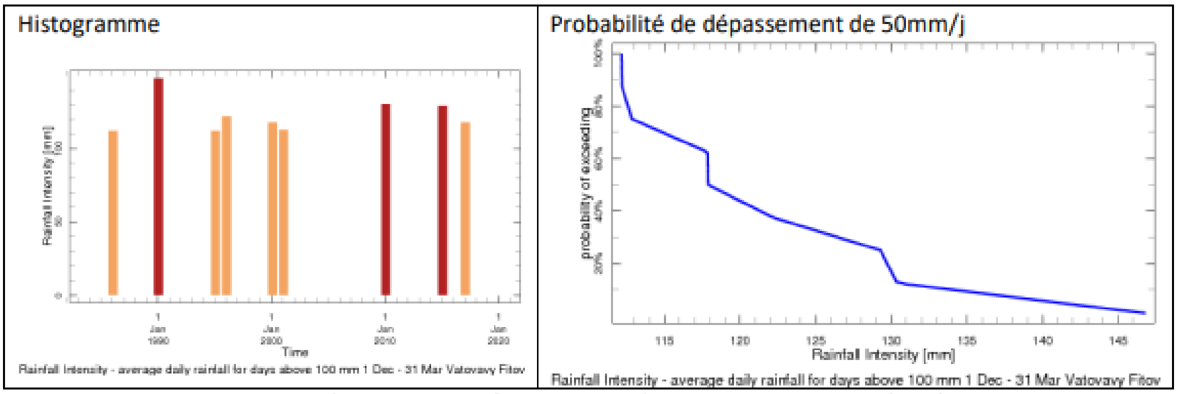
Chosen period: December 1981 to March 2021



- In 40 years, from 1981 until 2021, heavy rains (7 consecutive rainy days, with an average of 50mm/day) are observed in 8 cases: 1982, 1989, 1990, 1994, 1997; 2004, 2009, 2012.
- In this period, the probability of exceeding 50mm/day is 90%, while for 92mm/day this probability is 5%.

VATOVAVY FITOVINANY

Number of consecutive rainy days: 7
Average daily rainfall: 100mm/d
Chosen period: December 1981 to March 2021



- In 40 years from 1981 until 2021, heavy rains (7 consecutive rainy days, with an average of 100mm/day) are observed in 9 cases: 1986, 1990, 1995, 1996, 2010, 2015, 2017.
- In this period, the probability of exceeding 100mm/day is 99%, while for 145mm/day this probability of exceeding is 5%.