WASH Technical Paper TP/15/2021

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Simplified Drought Monitoring: Drawing Lessons from the Installation of a Groundwater Early Warning System in the South of Madagascar

SUMMARY

Madagascar is subject to recurrent droughts. In the semi-arid area of the southern part, the phenomenon is cyclical. To better understand and predict the risks of droughts, UNICEF installed a Groundwater Early Warning System (GEWS) in this area to monitor groundwater and predict droughts. Normalised Difference Vegetation Index (NDVI) and rainfall data were also monitored as part of the survey. The GEWS was installed in 23 piezometers across eight of the most affected districts in the south. Of these sites, ten were equipped with telemetric probes and 13 with manual probes. Data including static water levels, conductivity, and NDVI images were collected, analysed, and reproduced onto a map to show the static water level variations and the impact of drought severity on vegetation, water levels, water quality and price. Monthly drought-focused bulletins, based on the collected data, were produced and shared amongst WASH partners and the communities to provide them with information to better guide planning and implementation of water programmes and the cost of water.

Background

The significant adverse impacts of droughts on people, river basins, water resource systems and ecosystem are indisputable. The world is now contending with ever-increasingly frequent droughts and for longer periods. Africa, India, Australia, the United States, France, Russia have been affected, with almost all regions reported to be suffering from an accelerated global drought (Mishra and Singh., 2010; Haied et al., 2017).

Droughts are characterised by a lack of water over a long period, affecting both the soil and vegetation (Wilhite and al 1985; Wilhite and al 1993). It is not to be confused with aridity, which comes with a lower than the average rainfall (less than 250 mm/year) and intense evapotranspiration (more than 2000 mm) (Mohammed and Scholz.,2016).

Extended drought periods could reduce soil moisture and groundwater levels, diminish streamflow, damage crops and, in some cases, generate general water shortage**.** About 55 million people throughout the world experience droughts every year[1]. Livestock and crops in many parts of the world are also heavily impacted by the phenomenon. Droughts threaten people's lives and livelihoods, increase the risks of diseases and deaths, and potentially

[1] https://www.who.int/health-topics/drought#tab=tab_1

fuel migration. According to studies, 40% of the world's population are impacted by water scarcity[2]. It is feared that, by 2030, up to 700 million people will be at risk of being displaced as a result of droughts[3].

Like most African countries, Madagascar has not been spared from the ravaging phenomenon. Lately, the south has experienced several consecutive natural disasters, including locust invasion in 2013, drought in 2014, and 2015. Extended efforts from the government, supported by partners and donors, is needed to address these risks by implementing immediate and long-term preventive strategies against natural disasters and the development of community resilience to cyclical droughts[4].

Access to a safe drinking water service remains a significant challenge for the local population (UNICEF Madagascar estimates that 11.7 million people in the south do not have access to safe water, and low level of service combined with the scarcity of resources has led to a continuous increase of the cost of water. Such a change directly impacts children's lives considering the exacerbated multi-dimensional poverty in the area. A limited number of water supply options are available in the current context, and boreholes equipped with handpumps are the primary technology used. However, multiple constraints such as the scarcity and poor quality of groundwater (low flow or high mineralisation), low recharge of the aquifer, the complexity of geology, and climate change impacts prevent the implementation of large-scale interventions to increase access to safe water.

In such a context, the monitoring and analysis of groundwater fluctuations are essential as these can predict the risks of declining levels and quality of groundwater (saline intrusion). Such analysis could also be used to mitigate water scarcity and security at the household level by limiting price inflation. Madagascar does not yet have a system to monitor groundwater levels and act as an early warning system at a national level.

In addition to communities, WASH stakeholders and the entire humanitarian sector benefit significantly from such information. Such information can ensure better planning and strategic decision making on water use, its cost and the potential economic impact on poor households. It is then of utmost importance to understand groundwater behaviour in aquifers to develop strategies and partnerships that provide sustainable solutions.

It is in this regard that UNICEF initiated in 2017-2018 the "Aquifer Monitoring in Southern Madagascar" project, funded by ECHO and supported by the European Union Joint Research Centre (EU/JRC), as part of the "Disaster Risk Reduction, Preparedness and Resilience Building in Madagascar" project. The project was implemented in collaboration with the Regional Directorates of Water in the three most drought-impacted regions, namely Androy, Anosy and Atsimo Andrefana, and is still ongoing thanks to UNICEF's own funding.

This Technical Paper aims to share the lessons learned from this experience.

Purpose of the research

Objectives

The project's primary goal is to install a groundwater early warning system (GEWS) to monitor the water availability and quality in eight drought-prone districts in three regions in the south of Madagascar.

More specifically, to:

[2] ibid
[3] ibid
[4] https://www.unocha.org/southern-and-eastern-africa-rosea/madagascar

- Monitor groundwater fluctuations using i) community-based approaches, ii) manual piezometric and iii) telemetric monitoring;
- Train field technicians on the water level and electrical conductivity (EC) measurement protocol (this is applicable only for sites equipped with manual piezometers);
- Process and analyse data collected to produce relevant graphics on groundwater availability and its quality;
- Establish and maintain a database of aquifers
- Link the GEWS to a drought monitoring and alert system to improve drought emergency responses in Madagascar's southern regions.

Hypothesis

Regularly monitoring groundwater (variations in borehole water levels and water price, aquifer recharge levels, extent of saltwater intrusion and seasonal vegetation variation) is critical to forecasting potential and future drought impacts on communities.

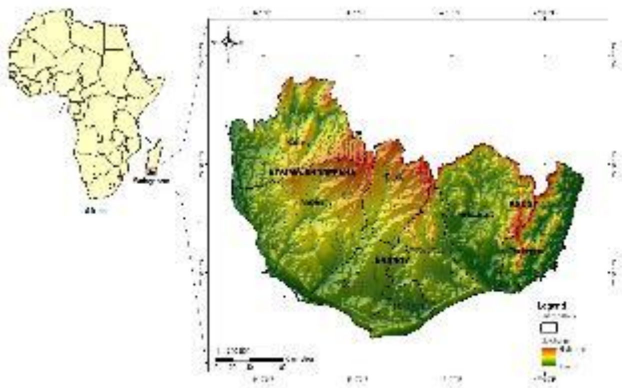
The southern context

Description of the study area

Madagascar is situated south of the equator, between the Indian Ocean and the Mozambique Channel, in the southeast of Africa. It lies between latitude 43 ° and 51° South and longitude 12 ° and 26 ° East and ° covers an area of 587,041 km^2. Administratively, the country is subdivided into 22 regions, with Antananarivo as the capital city.

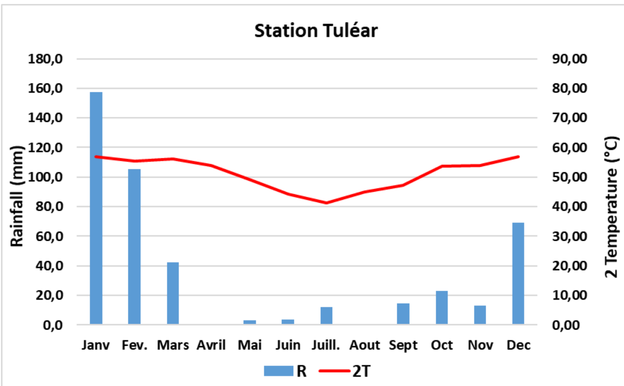
The Great South, which is the subject of this study, extends between the latitudes 23°12' and 25°36' S and the longitudes 43°36' and 47°36' E with a total area of 61,300 km² (Monographie, 2014). It covers three regions and eight districts, namely Betioky and Ampanihy in Atsimo Andrefana; Bekily, Ambovombe, Tsihombe, and Beloha in the region of Androy; and Amboasary and Taolagnaro in the region of Anosy (Figure1).

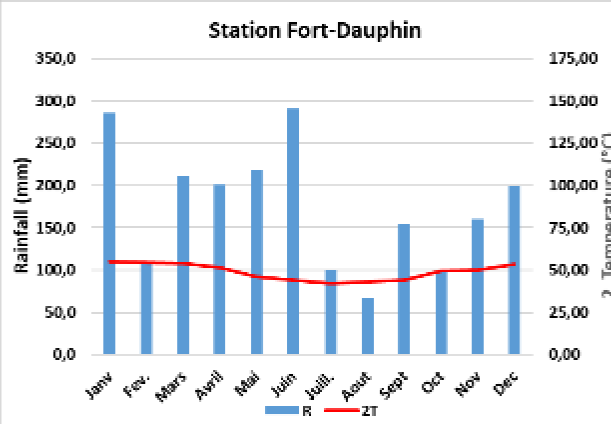
Figure 1. Study area



Two climate types are observed in the south: dry/semi-arid and wet (Ohba et al., 2016). The dry/ semi-arid climate (in the very south) is marked by two alternating seasons: a long dry season (April to October), and a short rainy season (November to March) that is often very irregular and consistently poor in rainfall (less than 400 mm annually), as shown in Figure 2 (a & b). The wet climate is much more common in the southeast area (District of Taolagnaro) with an annual rainfall of up to, and even exceeding, 1200 mm (Monograph, 2009), as shown in Figure 2 (a & b).

Figure 1 (a & b): Ombrothermal diagrams





Source: Direction Général de la Météo-Madagascar 2019)

(R = rainfall; 2T = Tempeaturex2)

The geology in the south of Madagascar is characterised by three distinct lithological units: the Pre-Cambrian basement, the volcanic massif, and the sedimentary formation. The geology of the selected districts is composed of a Pre-Cambrian basement (a mixed complex of metamorphic and igneous intrusive rocks) (Tucker et al., 2014; Boger et al., 2014); sedimentary formation (the Karroo series composed of marine limestone, black shales, coal, conglomerates, clay, sandstones, karstic limestone) (William and John., 1998; Rakotosolofo et al., 1999; Catineanu et al., 2005) and minor volcanic rock forming the four aquifer systems (Aurore, 1959; Rakotondrainibe, 1974).

Methodology

Knowing the situation in Madagascar's southern part, the area is vulnerable to drought and has insufficient drinking water coverage due to the complexity of the geology and the limited rainfall and high evapotranspiration. A study was carried out to monitor the variation in groundwater levels to prevent the overabstraction of the groundwater. Eight districts were chosen to install the monitoring system based on the hydrogeological and climatic information available to ensure a good spread across the study area. The study was mainly based on piezometric monitoring from 2019 to 2020 associated with analysing (monthly) Normalized Difference Vegetation Index (NDVI) images, monthly precipitation data and monthly water prices in the community.

Piezometric monitoring

Boreholes included in this study were equipped with telemetric or manual piezometers that measure the static water level (SWL) and categorised into three levels of monitoring

- Telemetric piezometers - includes data loggers which collect, process, store and transmit in real-time through cell phones via a GSM network. Ten telemetric piezometers[5] were installed primarily in boreholes connected to small/medium-sized water network schemes supplying water to more than 5,000 people.
- Manual piezometers - electric piezometric probes/ EC meters installed in 13 boreholes.
- Measurements of the groundwater levels and quality were manually taken by the water point manager and reported to the Water Directorate via SMS or paper-based reports.
- Community-based observation – the local community's regular monitoring of some operational parameters such as handpump functionality, water quality (smell, taste, salinity), price of the service, etc. Such data could be collected by the water point operator and transferred to the water authorities for analysis.

Site selection

In total, 23 GEWS sites were selected for the installation of piezometric probes (Figure 3).

[5] (GPRS Datalogger Type 255-EB)

Figure 3: GEWS piloted sites

The choice of sites was based on several criteria, including the following:

- the hydrogeology - to interpret the aquifer type and groundwater storage factors
- the watershed limits
- the climate and the land-use to understand the groundwater recharge factors (infiltration, the loss through run-off)
- type of the water source (boreholes, well), and type of system (solar-powered or motorised pumping system)

network coverage and accessibility, especially for the sites with telemetric piezometers.

Data collection

This paper analyses data on static water level (SWL), temperature, electrical conductivity (EC) which were regularly collected from the 23 piezometers. To ensure accuracy, the following procedures were followed:

Sites with telemetric piezometer

The measurements were recorded every day and taken around midnight (six hours after the end of the pumping). Then the data were transferred automatically to the server http://ht-analytics.com/index.php for download (Figure 4b).

The monthly mean Static Water Level (SWLm) of each site was calculated statistically and compared to the initial Static Water level (SWLi)

to determine the groundwater trends and depletion processes or recharge.

Figure 4 (a & b): Telemetric piezometer probe (datalogger) (a), server (b)

More details https://www.ht-hydrotechnik.com

Sites with manual piezometer

The measurements were taken once a week, at least an hour after the pump was turned off or early in the morning before starting. This helps ensure the technicians measure the static water level or the closest to it. The process is performed by a technician trained on the protocol to measure and record the Electrical Conductivity, pH, and temperature are measured with Combo pH & EC Hanna (Figure 5.a and b).

Figure 5 (a & b): Electrical piezometer probe (manual) (a), Conductimeter (b)

Table 1: Classification of water according to Detay

EC value (µS/cm)	Water class
< 100	Fresh
100 – 200	Soft
200 – 400	Slightly
400 – 600	Moderately
600 – 1000	Important
> 1000	Excessive

The same technique was applied for the measurement of the E.C. The monthly average E.C (E.Cm) was calculated and compared to the initial electrical conductivity (E.Ci) or with the reference unit to identify the risk of salinity. The values were classified according to the table shown in Table 1 and compared to the 2017 WHO drinking water standards and the standard classification applicable in Madagascar (< 3000µsm/cm).

Calculation of drought indices based on NDVI anomaly

A series of Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI), taken between January 2019 to January 2021, were compiled and used to survey the drought conditions in southern Madagascar. The data consisted of a 10-day composite Normalized Difference Vegetation Index (NDVI) of 1 km spatial resolution. The survey applied the processing developed by Klisch and Atzberger, 2016[6] to MOD13A and MYD13A2 V006 16-day global data at 1 km generated by the Institute of Surveying, Remote Sensing and Land Information, BOKU University, Vienna, Austria. This process consists of the analysis and classification of images.

NDVI image allows the observation of the photosynthetic vegetation activity, which is understood to be related to the use of water by the vegetation. (Jiang et al, 2006; Mounia et al., 2014[7]; Nanzad et al, 2019[8], Palchaudhuri and Biswas, 2019[9]). The vegetation dynamics are strongly linked to the rainfall patterns so that the NDVI analysis can indicate the distribution of precipitation or humidity during the month. The EU/JRC provides three pre-processed NDVI satellite images (Dekad 1-2-3) per month. Then, the NDVI values must be correlated which the types of vegetation present on the various sites from the formula below into ArcMap 10.7 via the Spatial Analyst Tool. The seasonal NDVI

Table 2: Proposed classification drought (Groundwater levels and NDVI), Drought severity class by Meroni M., et al. 2019; Klisch and Atzberger, 2016.

Groundwater	SWLi (m) Value	NDVI	NDVI Value	Code colour
Normal	0.5 > SWLi >3.50	Normal	> +0.05	
Vigilance	- 0.5 < SWLi <-1.50	Moderate	-0.05 > NDVI > +0.05	
Alarm	-1.50 < SWLi <-3.50	Severate	-0.125 > NDVI > -0.05	
Urgency	SWLi ≥ -3.50	Extreme	≤ -0.125	

[6] Klisch, A., Atzberger, C., 2016.
NDVI anomaly for drought monitoring and its correlation with climate factors over Mongolia from 2000 to 2016. Journal of Arid Environments, 164, 69 –77.

[7] Mounia, T., Mustapha, H., Anas E., Mohammed, A., Hassan, El H., Abdelfatah, T. 2014. Lithology Data Contribution in Hydrographic Network Distribution Using Remote Sensing and GIS: Case of the Tahaddart Bassin (Rif, Morocco). European Journal of Scientific Research,122-3, 253-274

[8] Nanzad, L., Zhang, J., Tuvdendorj, B., Nabil, M., Zhang, S., Bai, Y., 2019.
NDVI anomaly for drought monitoring and its correlation with climate factors over Mongolia from 2000 to 2016. Journal of Arid Environments, 164, 69 –77.

[9] Palchaudhuri, M and Biswas, S., 2019.
Application of LISS III and MODIS-derived vegetation indices for assessment of micro-level agricultural drought. The Egyptian Journal of Remote Sensing and Space Sciences. https://doi.org/10.1016/j.ejrs.2019.12.004.

anomaly is derived from the formula **NDVI= (DN*0.001) – 0.125**.

Table 2 shows the classification of drought severity adopted to classify NDVI anomaly, including normal, moderate, severe, and extreme drought.

Precipitation data

To better understand the fluctuations in groundwater, analysis of precipitation data is also required. Rainfall is the most dominant influencing factor in groundwater recharge and is the hydrological cycle's primary water source. Due to the limited number of gauge stations, the telemetric stations have been used to determine the area's average monthly rainfall.

Monthly rainfall data are collected from the WFP website https://dataviz.vam.wfp.org/seasonal_explorer/rainfall_vegetation/visualizations#. This site updates ten-day precipitation data from the precipitation estimate of Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS). Indeed, CHIRPS is a set of quasi-global rainfall data for more than 35 years and incorporates 0.05° resolution satellite imagery with in-situ rainfall station data, to create gridded rainfall time series for trend analysis and seasonal drought monitoring.

Water cost data

The data about the cost of water were collected monthly by the field teams (technician and communities). The data was analysed to calculate a monthly average, minimum and maximum price by region.

All data collected was processed into a dynamic database (in Excel format) and transferred to the ArcGIS software.

Results and discussion

Drought severity map

Vegetation cycles vary according to the precipitation. Vegetation responds better to accumulated precipitation as the moisture available in the soil fuels crop growth (Rundquist and Harrington., 2000; Tateishi and Ebata., 2004; Nanzad et al., 2019). It also depends on the nature of the land cover type (types of vegetation and soil). The vegetation in the southern Madagascar, is dominated by xerophilic to dederaceous and spurge or bush thickets, shrub and palm savannas and a small patch of dense rainforest Fort-Dauphin (Anosy region).

Drought maps based on NDVI anomalies from January 2019 to January 2021 are given in Figure 6a and 6b, respectively, and show the spatial patterns of drought severity, ranging from normal to extreme level as per the drought classification introduced in Table 2.

The green colour on the maps reflect normal NDVI anomalies, indicating normal conditions, representing an intense chlorophyllin activity and wet soil. The red, orange and yellow reflect negative NDVI anomalies, indicating moderate dryness or alertness (yellow), severe or alarm (orange) and very serious or emergency level (red).

Figure 6a: Spatial distribution of drought situation for January – December 2019

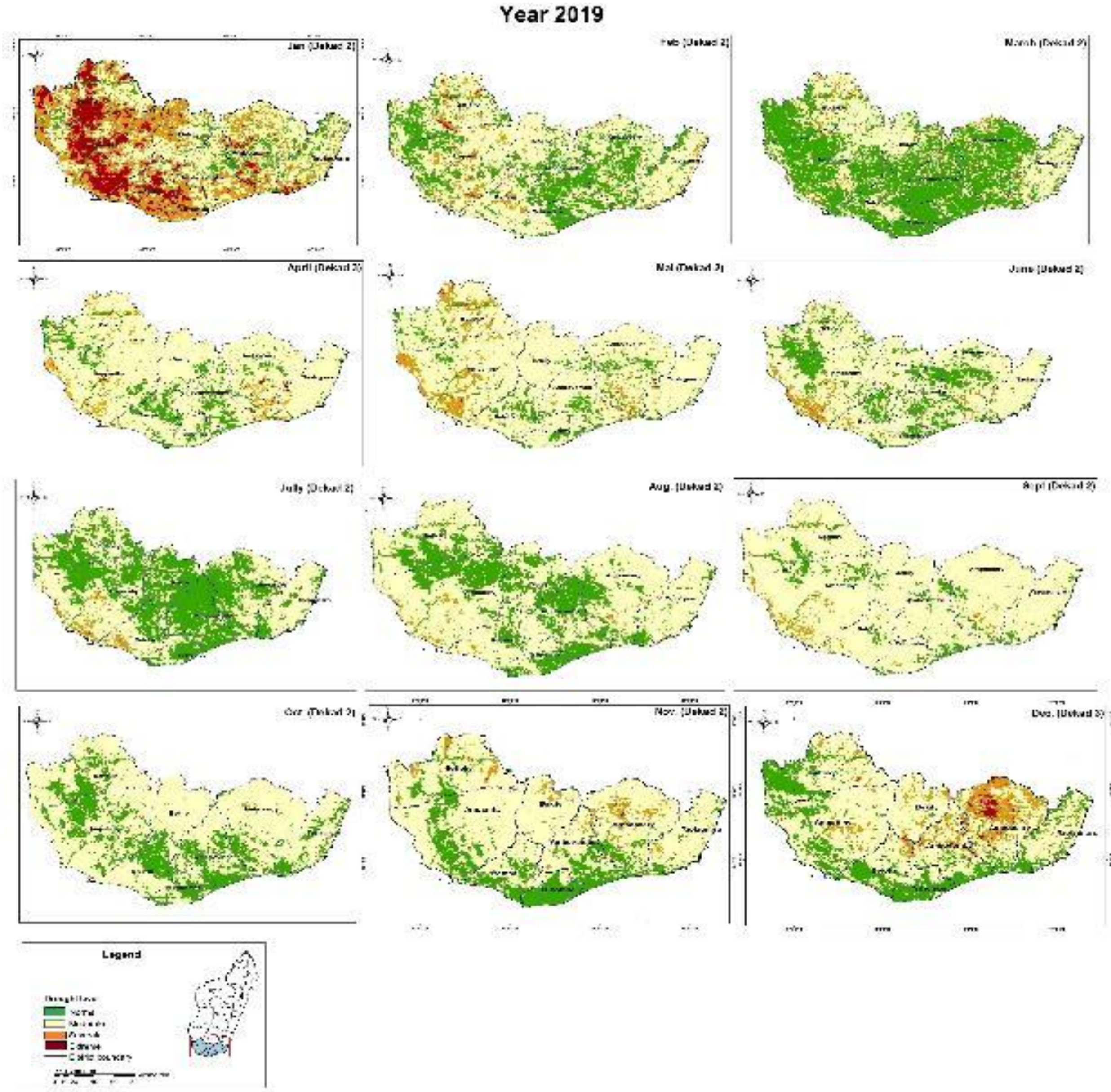
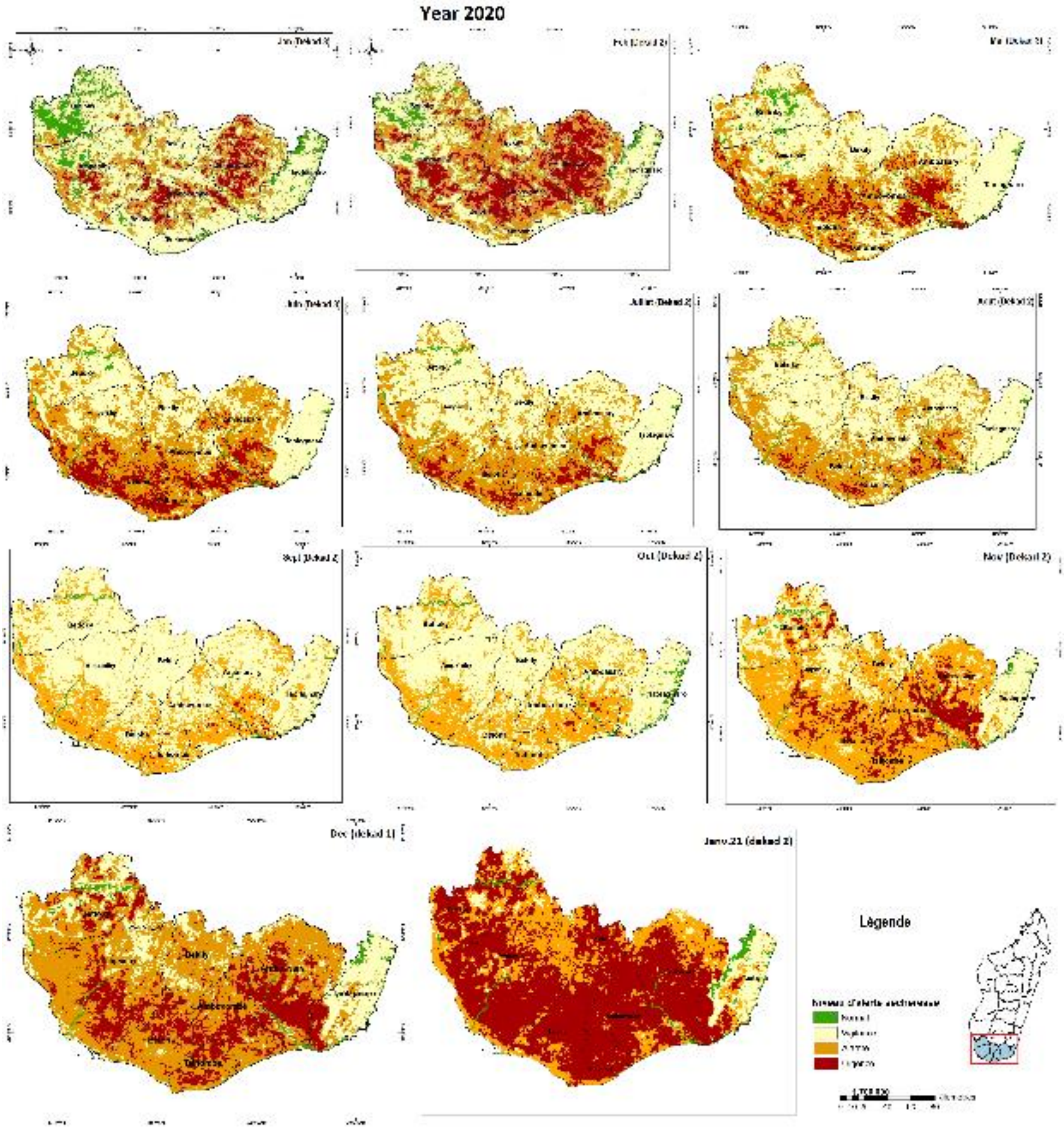


Figure 6b: Spatial distribution of drought situation for January 2020 – January 2021



The proportion of the drought-affected areas are in 2019 and 2020 are given as percentages in Table 3:

Table 3: The proportion of the drought-affected areas from January 2019 to September 2020

Month/ Year	Normal		Vigilance		Alarm		Urgency	
	2019	2020	2019	2020	2019	2020	2019	2020
Jan.	8.068	10.437	41.512	54.629	33.948	25.637	16.472	9.295
Feb.	33.57	5.109	58.87	34.402	6.97	38.757	0.58	21.732
March	55.57	-	41	-	3.26	-	0.15	-
April	55.72	-	43.04	-	1.17	-	0.004	-
May	9.57	3.618	81.96	53.562	8.11	32.122	0.34	10.698
June	21.22	1.910	74.26	42.512	4.3	41.948	0.2	13.630
July	46.58	1.872	50.78	54.120	2.56	37.259	0.07	6.750
August	25.11	1.729	72.59	58.969	2.24	36.381	0.035	2.921
Sept	7.68	1.614	89.66	28.968	2.62	68.381	0.03	1.037
Oct.	24.939	2.353	74.502	63.228	0.553	33.725	0.006	0.694
Nov.	20.116	1.630	74.92	28.520	4.831	55.500	0.133	14.35
Dec.	22.118	2.320	64.455	55.50	12.015	55.540	1.412	23.34

Precipitation variation

The analysis of the monthly rainfall amounts in the three regions of the study (Figures 7 a & b) shows that the year 2020 was very low compared to the seasonal normal and the previous year. All the eight districts of the great south are arid except for Taolagnaro (east cost of Anosy). The months identified with the driest conditions are January, February, May, and January 2021. The hardest-hit area includes Amboasary (in the Anosy region), Ambovombe, Tsihombe, Beloha (Androy, region) and Ampanihy South-West region, an area with deficient rainfall

This lack of water can be explained by a long period of no rain (November to March are supposed to be the rainy season in normal years), high temperatures over this period, and as a result, there was more evapotranspiration, reduced soil moisture or groundwater, causing malnutrition, drought and water scarcity

Regarding evapotranspiration, in the western sedimentary basin, potential evapotranspiration (ETP) values were between 1700 mm and 2000 mm. In the extreme south, the ETP is 1200 mm mm to 1300 mm, and the actual evapotranspiration (ETR) is 350 mm to 500 mm.

Figure 7a: Comparison between precipitation 2019 – 2020 for Androy

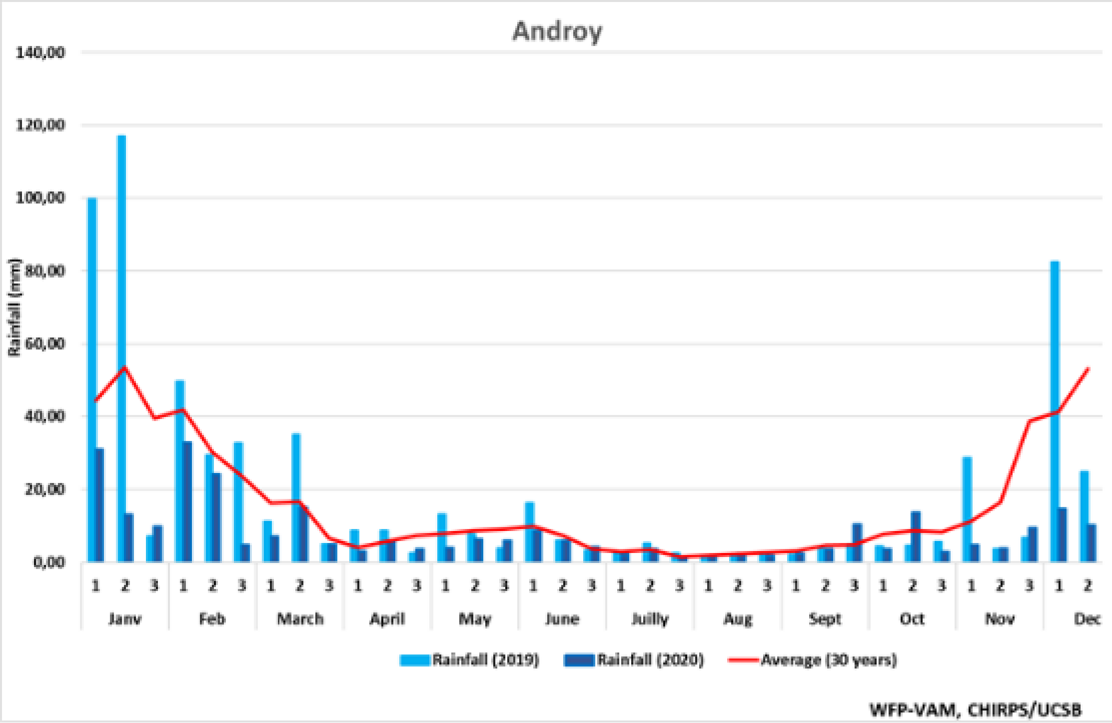
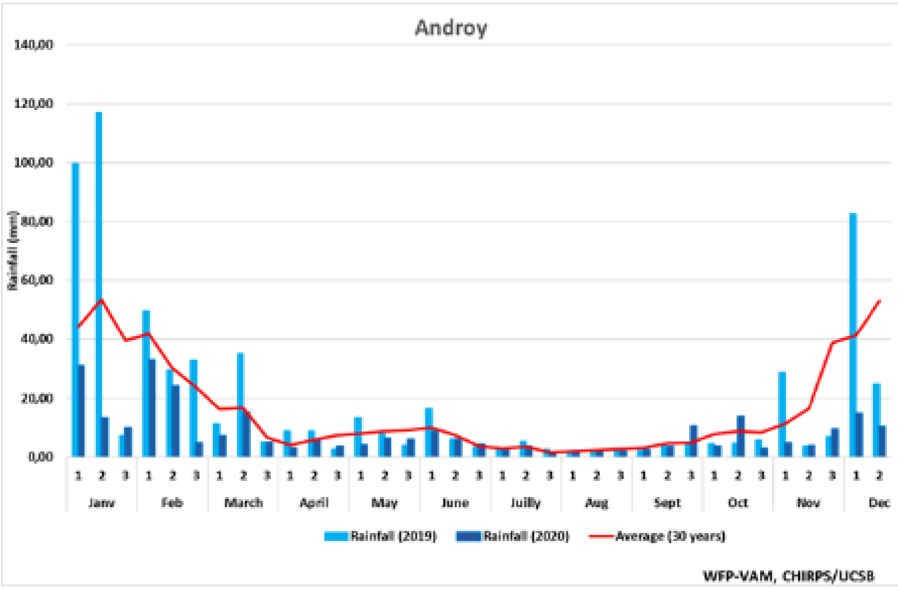


Figure 7b: Comparison between precipitation 2019 – 2020 for Ambosary (Anosy)



Water level fluctuation

Data on water levels are also mapped monthly (Figure 8a and b) to monitor the fluctuation in water tables in the three regions. From this analysis, it is evident that 2019 is considered as a year of groundwater recharge.

Figure 8a. Fluctuation in water level in South in 2019

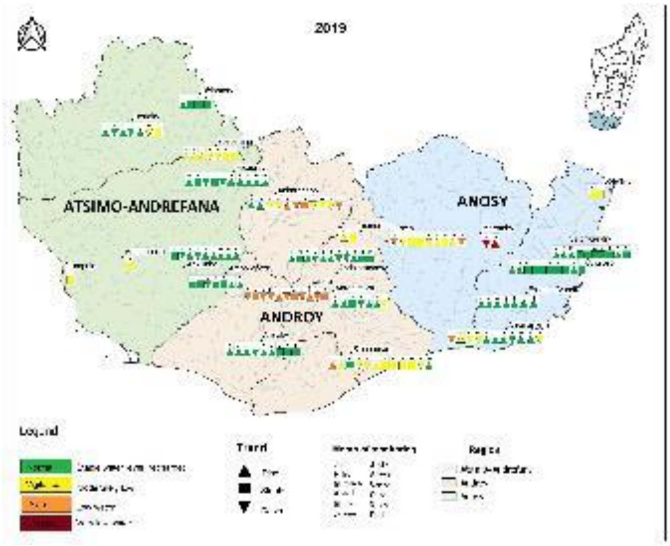
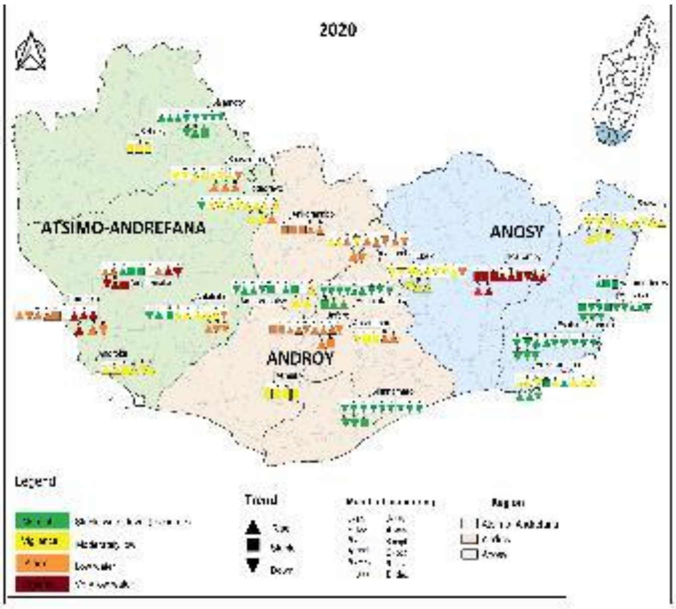


Figure 8b. Fluctuation in water level in South in 2020



According to the analysis of the maps, seven of the 23 sites monitored were stable throughout the 2019/2020 monitoring period with normal water levels (recharge) with generally stable recharge rates. These seven sites were abstracting from all three aquifer types, and have good recharge during the rainy seasons (recharge period) and are resistant to droughts.

In contrast to these, 16 other sites show a decline (discharge) with some at moderate to extreme levels.

Anosy region:

- Taolagnaro (in the southeast) has crystalline aquifers and high rainfall, and water levels were normal and stable with a slight declining.

- In the district of Amboasary (Maromby, Ebelo), the groundwater levels decline, and the situation is deteriorating to low and even very low levels (severe - extreme). Both sites are characterized by crystalline aquifer and volcanic aquifer with low rainfall.

Androy region:

- The sites of Imanombo, Ankaranabo and Jafaro show an unfavorable situation with low to very low water (alert alarm and urgency). These sites are all characterized by a crystalline aquifer with low rainfall. During the rainy season from November 2019 to March 2020, the rainfall was very low compared to normal, and the aquifers were depleted.

Atsimo-andrefana region (in the west coast):

- The site of Fotadrevo, Ankiliabo (both in the crystalline aquifer) goes from stable water to moderately low and low water.
- Itampolo and Ampitanaka (in the sedimentary aquifer) goes from low water to shallow water and Soaseranana to moderately low- to low water.

All the monitoring sites show a consistent decline in water levels in 2020.
The difference in the aquifer recharge across the sites can be partially explained by the local climate and geological proprieties (the difference in the coefficient of permeability of the ground, degree of weathering etc) and the hydrodynamic properties of the aquifer (confined or unconfined), so groundwater is unevenly distributed in both quantity and quality (Ngouh et al., 2020).

Rain of high intensity over short periods allows for less infiltration and more surface run-off, whereas low intensity rain of long duration facilitates higher infiltration and recharge rates. When rain falls, some of the water evaporates, plants transpire some, some flows overland and collects in streams, and some infiltrates into the pores or cracks of the soil and rocks. The first water that enters the soil replaces that evaporated or used by plants during a preceding dry period.

On another note, pumping can also lower water levels if a borehole/well is pumped at a higher rate than the aquifer is recharged by precipitation or by other underground flows, resulting in a decline in the level of water in the boreholes /wells.

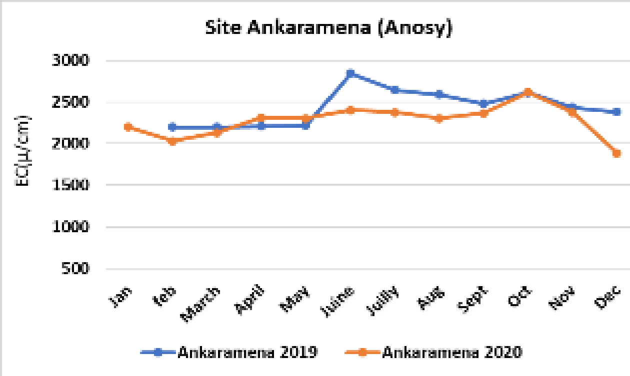
For most of the boreholes in the south, the depths are between 10-50m below ground level, and the water level is around 3.15m to 21.80m. On the basis of these relatively shallow depths, the boreholes and wells are more sensitive to changes in recharge rates.

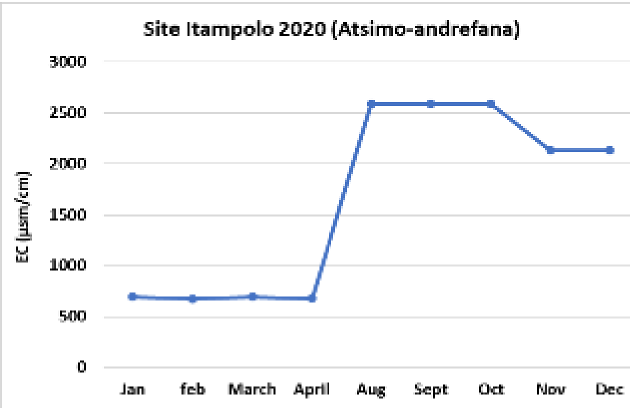
Variation of Electrical conductivity (EC)

The groundwater E.C in the aquifers of the south ranges between 80 to 2656 µS/cm. According to Detay (1993), from very low to excessive. The value indicates the geochemical evolution of freshwater to saline water (Fareze et al., 2016; Rabemanana., 2005).

The highest E.C, above 1000 µS/cm, is recorded in the coastal areas, including Sihanamaro, Atreaky (Androy), and Ankaramena (Anosy), where saline areas are observed, and in Belamonty (Atsimo-Andrefana).
Groundwater with very low E.C is recorded on the side of Fort Dauphin (Vatomorindry, Antsoso). In general, groundwater has normal salinity[10], below 3000µS/cm; however, there was some slight increase in EC during the dry period of 2020, specifically in the coast of Itampolo, Ankaramena. These places are close to the coast and so when water levels are lowered, it can induce the pumping of saline water.

Figures 9 (a & b). The trend shows the EC variation for some sites





Water cost analysis

In landlocked areas with no water point, water can be purchased by vendors who sell water from water carts. As there are few alternatives, these carts profit on the price of water and increase the price regularly during the dry season. Sometimes during the dry season, the production capacity of the boreholes and wells decreases, and the price of water naturally increases.

As the price of water is an indicator of the limited availability of water, monitoring of the fluctuation in water prices was also carried out in the three regions concerned by the study, particularly in the Anosy and Androy regions more affected by the drought. The price of a 20- litre container is higher in rural areas compared to urban areas.

Between 2019 and 2020, the price of a 20-litre container in the Anosy region cost between \$0.079 and \$0.185 in urban areas. This same quantity of water costs between \$0.185 and \$0.476 in rural areas (near Amboasary), almost double in rural areas.

In the Androy region, the price of a 20-litre container varied between \$0.079 to \$0,132 in the urban area (Ambovombe); this cost fluctuated between \$0.066 and 0.211 in rural areas. For the municipalities served by the pipeline (a long pipe transports a water from a borehole to an over village in the South), the 20-litre container is \$0.031.

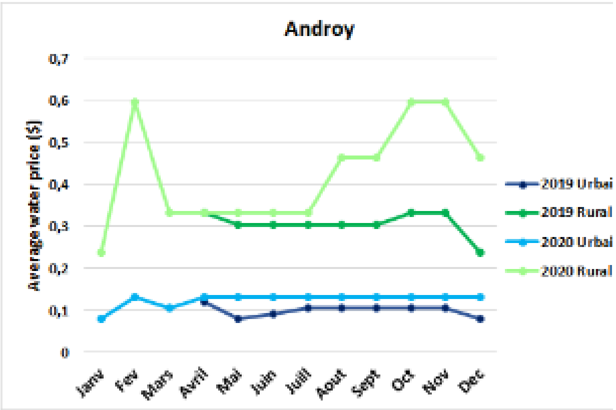
The graph presented in Figure 10 shows the fluctuation of water prices between 2019-2020 (expressed as monthly average water prices).

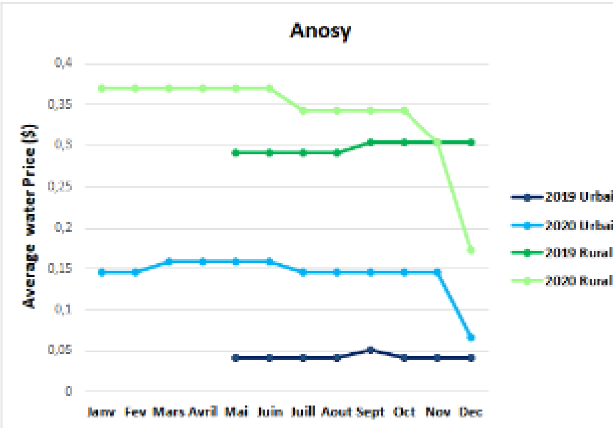
An increase in water price was observed in 2020, particularly in rural areas from January and February 2020 and August - November 2020 in the region of Androy - Anosy (months

[10] The levels of 'normal' for salinity have been adapted to the context of Madagascar

declared dry and windy season). In December there was a slight decrease.

Figure 10. Water cost fluctuation





Drought bulletin

To help disseminate information on the water levels and to activate corrective action, a bulletin containing relevant information on groundwater fluctuations and water quality has been produced every month from the data collected on static water levels, precipitation, NDVI images and water cost.

The bulletin is shared with all partners and can be downloaded from the UNICEF website https://www.unicef.org/Madagascar/rapports/bulletin-dalerte-sécheresse.

In May 2020, a survey was undertaken concerning how sector partners use the bulletin. The survey indicated that the bulletin is used to:

- Orient the drought emergency intervention strategy (BNGRC)[11]
- Understand the risks that could arise for drinking water infrastructure in the south
- anticipate actions or measures to be taken in case of groundwater depletion (dry period)
- in the field of agriculture, the state of vegetation and water resources is very helpful, and helps inform decisions, for example, on the choice of a water supply system (borehole or well).

In case of significant drops in water levels, "Alarm" and "Emergency" alert levels, corrective actions e.g. undertaking water trucking were initiated.

Lessons learned from the Installation of the Groundwater Early Warning System

- The Groundwater Early Warning System has proven to be a critical tool to understand the south of Madagascar's vulnerability to recurrent droughts.
- Analysing a Normalised Difference Vegetation Index (NDVI) satellite image by GIS tools constitute an important component worthy of considering in the drought survey.
- It is essential to understand the impact of drought on water costs for households.

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- The importance of information on groundwater fluctuations helps decision-makers and actors assess and timely implement associated programmes to alleviate suffering related to water scarcity in households.

Conclusions

The present study aimed at highlighting the lessons learned from the installation of the Groundwater Early Warning System in the south of Madagascar. Though this has only been a preliminary study, it marks an essential step in groundwater monitoring evolution in Madagascar. It constitutes a critical approach for drought survey and warning, and a path to understanding water cost variations and their implications for households.

Remote sensing drought assessment and monitoring have yielded very positive results by combining NDVI time series with precipitation (P). NDVI produced negative values, thus indicating a reduction of vegetation greenness that also decreased water in the soil as a relevant limiting factor for vegetation growth.

Correlations between NDVI, precipitation and groundwater levels were not very strong, probably because the aquifer recharge depends on several things, such as the soil types (weathering rock), the type (confined or unconfined) of the aquifer and the depth of the well. The unconfined aquifers are more directly influenced by the lack of rain and evapotranspiration than those screened in deeper confined aquifers. Most of the boreholes/wells in this study area have a depth that varies between 10-50m.

Nevertheless, analysis of NDVI images already allows us to identify the drought risks.

In the long term, data collected from the groundwater monitoring and NDVI survey will enable a better understanding of aquifer properties under static and pumping conditions, determining aquifer recharge and level status of drinking water, seasonal variations, and also allow adaptation to climate change.

Next steps and future perspectives

As an outlook and next steps to the study, it would be advantageous to:

- Transfer the monitoring system to the government (Water Ministry),
- Set up a long-term monitoring network across the country, with an expansion of the GEWS through more monitoring sites in other regions)
- Enhance work on accessibility of the information to the farmers and people living in the areas affected by the drought alerts - translate the Drought alert bulletin into Malagasy and make it more accessible and user-friendly for farmers
- Establish a partnership with other stakeholders (working in the area of environment and agriculture)
- Ensure unification and interconnection with other relevant data (such as geospatial technologies),
- Develop a specialised website for GEWS.

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