

# *Study Of Rainfall Characteristics In The Betafo District In Madagascar*

RAZAFIMITANTSOA Sedera<sup>1</sup>, RAHARINIERANA Hantaniaina<sup>1</sup>, RAMAROSON Jean de Dieu<sup>1,2</sup>

<sup>1</sup>Ecole Doctorale Sciences et Techniques de l'Ingénierie et de l'Innovation, Equipe d'Accueil Doctorale Valorisation des Ressources Propres, Université d'Antananarivo

<sup>2</sup>Centre National de Recherches Industrielle et Technologique

Corresponding author: RAZAFIMITANTSOA Sedera. E-mail: [sedera.raza@gmail.com](mailto:sedera.raza@gmail.com)



**Abstract:** As climate change does not spare any country, we observe a radical modification on the rainfall behavior anywhere on earth. Being an agricultural country, Madagascar needs to be alerted by these changes. This study is intended to provide more details on rainfall behavior in the district of Betafo in the agricultural region of Vakinankaratra, and contains analysis of the quantitative behavior of rainwater in Betafo as well as its quality. Quantitative analysis was based on historical datas and made using linear regression, and rainwaters were collected directly in inert container for the qualitative analysis. The collection of rainwater were done on the very first rain drop, during the second period of rainfall of the rain season, and in the middle of the rain season. In this work, we have noticed a shift in rainfall toward the first quarter of the year. And in the other hand, physical and chemical analysis of the collected rainwater revealed that they are clean yet despite environment degradation, but still not directly drinkable. Considering these results, an implementation of a good rainwater management policy, including a proper treatment strategy, is needed for the district of Betafo in order to compensate the lack of water supply which exists in the area.

**Keywords:** climate, drinkable, analysis, quality, quantity, hydrology, Africa, Vakinankaratra

## 1. Introduction

Despite Madagascar's extremely diverse climate, one thing that all 23 regions of the island have in common is that they are all experiencing a decline in rainfall due to global warming [1]. More specifically, the Central Highlands region is experiencing a decrease in annual rainfall, which must be monitored even though, in its 2023 publication, Madagascar's Meteorological Agency announced a slight increase in annual rainfall for the period 2025-2030 [1].

Our study site, the district of Betafo, is one of the seven districts that form the region of Vakinankaratra which is the south part of the Central Highlands [2]. Betafo is located on the southwest of Vakinankaratra and occupies one of the largest area in the region [2].



Figure 1 : Location of the Vakinankaratra region in Madagascar [2]



Figure 2 : The seven districts of the Vakinankaratra region[3]

Betafo was once the water tower of the Vakinankaratra region, but due to environmental degradation, the district has been unable to retain this title despite the large number of waterways present there[4].

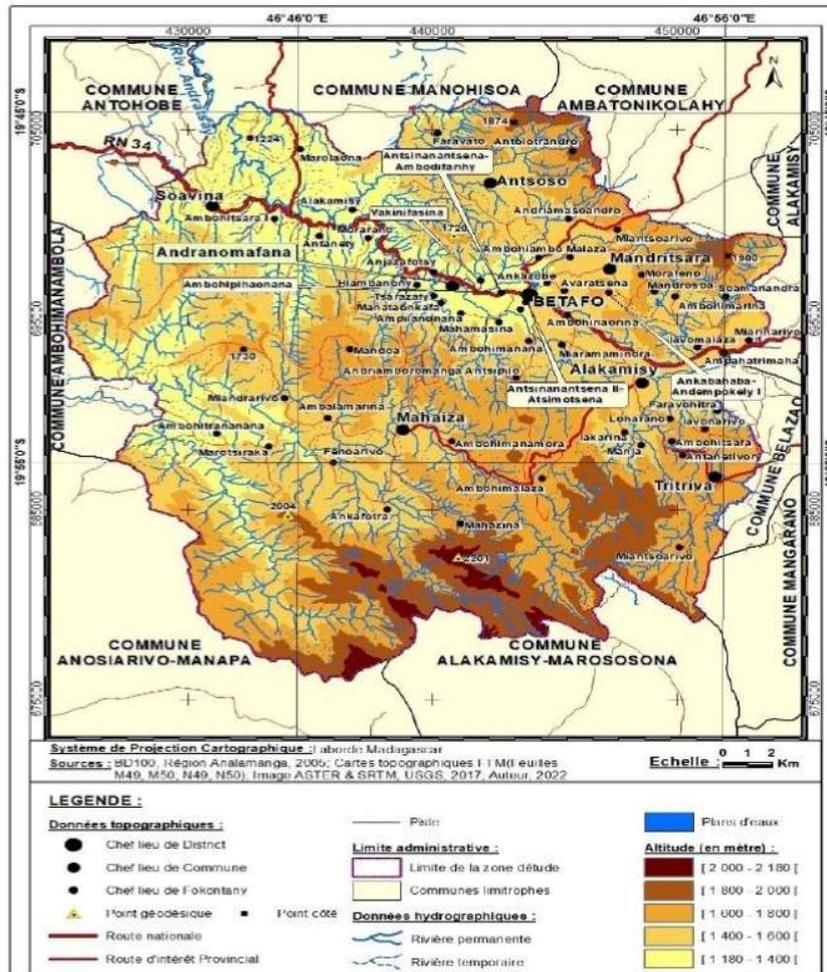


Figure 3 : Hydrography of the Betafo district [4]

In the Betafo district, environmental disruption and degradation are causing changes in the distribution of rainfall over the course of a year, with periods becoming drier but also, symmetrically, periods seeing an increase in cumulative rainfall. This uneven distribution is leading to an increase in the intensity of rainfall, or an increase in the number of days of heavy rain, or both at the same time.

In order to better visualize this change, this study highlights the quantitative and qualitative characteristics of rainfall collected in the Ambohinaorina fokontany in the Betafo district.

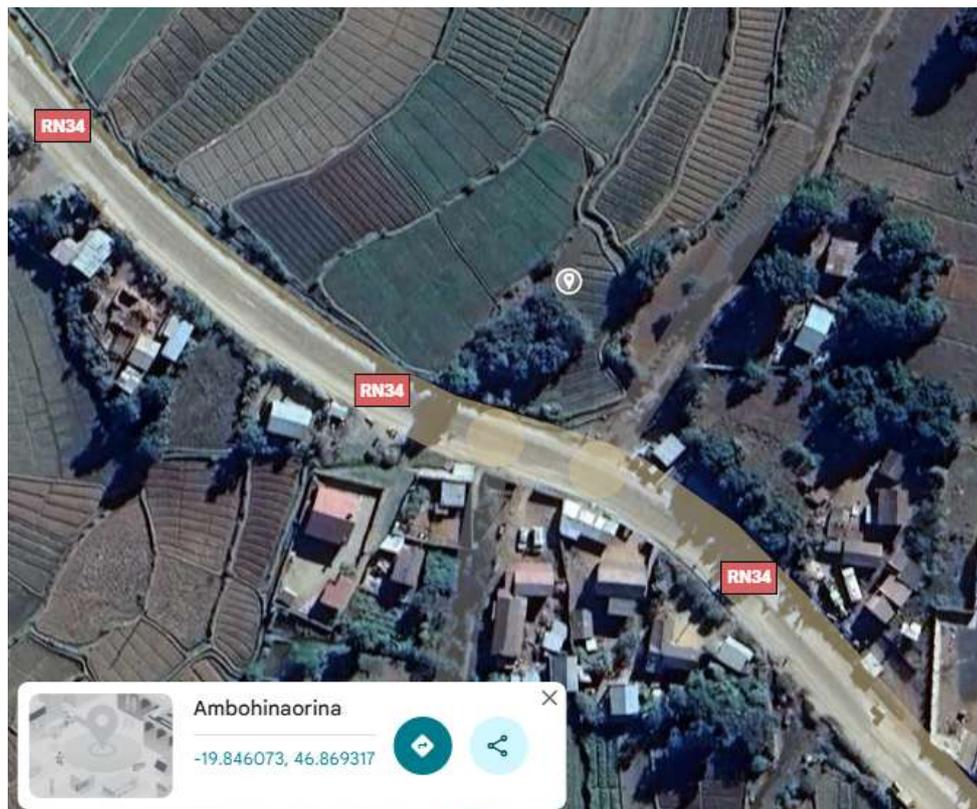


Figure 4 : location of the rainwater collection site

## 2. Materials and methods

From the data collected from Madagascar's Meteorological Agency, we obtain a scatter plot that defines the quantitative nature of rainfall in Betafo. Since it is not practical to perform an analysis directly from a scatter plot, it is necessary to create a model that allows the elements of this set of points to be grouped together, and this is where the linear trend function obtained from the linear regression law comes in. The obtained function will look like  $y = a.x + b$  where  $y$  is the estimated cumulative rainfall,  $x$  is the time elapsed since 2018,  $a$  is the annual growth rate of the estimated cumulative rainfall for the month in question, and  $b$  is the cumulative rainfall for the month in question for the year 2018 according to this estimation method..

The qualitative study mainly concerns the physical and chemical analysis of rainwater samples collected on site. The samples were collected during the first rainfall of the rainy season, then during the second rainfall period of the season, and finally in the middle of the rainy season. The samples were collected directly into polyethylene terephthalate containers without passing through any intermediate collection system. These containers were placed on a support approximately 40 centimeters high to prevent splashes from contaminating the samples. The analyses were carried out in the water analysis laboratory of the company Jiro sy Rano MALagasy (JIRAMA). And the parameters we are interested in are Biological Oxygen Demand (BOD5), Total Suspended Solids (TSS) concentration, Chemical Oxygen Demand (COD), pH, Nitrate concentration, Nitrite concentration, Ammonium concentration, Conductivity, and Turbidity.

### 3. Results

#### 3.1. Quantitative analysis

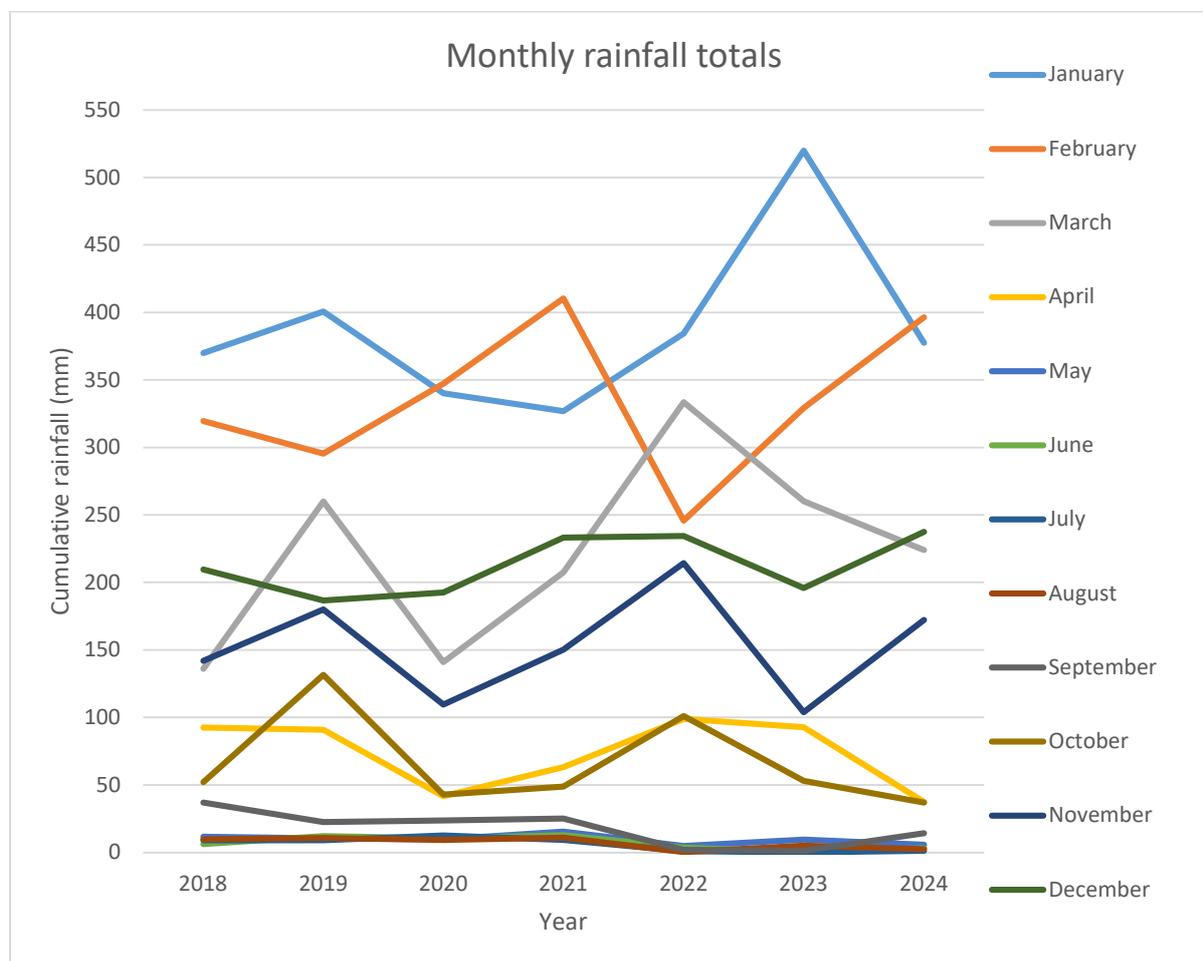


Figure 5 : Monthly rainfall evolution from 2018 to 2024

Analysis of monthly rainfall data collected from Madagascar's Meteorological Agency provides us with a visual representation of monthly rainfall totals and precipitation trends. The curves in the figure above show an increase in monthly rainfall totals during the rainy season and a decrease during the dry season.

#### 3.2. Qualitative analysis

Table 1 : Physical-chemical composition of rainwater

Parameters	Unit	First rain drop	Second rainfall period	Middle of rainy season	Mean value	Reference value
BOD5	mg/L	0	0	10	3,33	5
TSS	mg/L	10	19	8	12,33	
COD	mg/L	0	0	28,8	9,6	50
pH		6,26	6,31	6,28	6,28	6,5 à 9

Nitrates	mg/L	0,44	3,18	0,44	1,35	50
Nitrites	mg/L	0,02	0,18	0,03	0,08	0,1
Ammonium	mg/L	0,04	0	0	0,01	0,5
Conductivity	µs/cm	31,3	23,1	17	23,8	< 3000
Turbidity	NTU	12,1	16	5,23	11,11	< 5

The physical and chemical analysis of water collected in the fokontany of Ambohinaorina reveals that the rainwater is relatively clean. The reference values used are based on drinking water standards, which are very strict contamination thresholds. As the analysis results show values that are not far from the drinking water thresholds, we can conclude that this rainwater is fairly clean.

#### 4. Discussions

##### 4.1. Quantitative analysis

###### 4.1.1. January

The probability distribution calculated for the period 1981-2021 indicates normal rainfall between 250 mm and 450 mm for the month of January[5]. From 2018 to 2022, precipitation levels remain within the normal range, but there is a peak exceeding 500 mm in 2023. The linear trend line follows the direction of the curve of the function  $y = 10.9x + 344.81$ . As the trend has a positive slope, we can expect an increase in cumulative rainfall for the month of January.

###### 4.1.2. February

The normal rainfall for the month of February is between 200 mm and 360 mm. [5]. Rainfall has not been very stable over the last seven years, with a sharp increase between 2019 and 2021, followed by a sudden drop in 2022. The trend in cumulative rainfall for the month of February is increasing and follows the direction of the function  $y = 7.0357x + 306.71$ . As with January, we can expect an increase in precipitation for February, but as the slope is gentler, February is more likely to dry out.

###### 4.1.3. March

For the month of March, the normal cumulative rainfall is between 160 mm and 300 mm. [5]. The cumulative rainfall for March varies much more than that for January and February, but generally remains within the normal range. The trend in cumulative rainfall follows the function  $y = 16.314x + 157.9$ . The slope of 16.314 indicates that we can expect an increase in rainfall in March in the coming years.

###### 4.1.4. April

The normal rainfall for April is between 40 mm and 90 mm. [5]. We also note that there is a sharp drop in rainfall between March and April, which is due to the change of season: from the southern summer, which is the rainy season, to the southern winter, which is the dry season. There is a marked anomaly for the month of April, with only 3 out of 7 years showing cumulative rainfall within the normal range. The trend in cumulative rainfall for April shows a negative slope, indicating a drying trend for April in the coming years. This trend follows the direction of the function  $y = -3.7179x + 88.814$ .

###### 4.1.5. May

The normal cumulative rainfall value is between approximately 10 mm and 25 mm[5]. We can see that the total rainfall has decreased compared to April. This is because May marks the start of the southern hemisphere winter, which is characterized by a pseudo-drought.

Looking at the trend curve, we can see that from 2018 to 2020, the cumulative rainfall curve for May is very steady, then becomes very unstable from 2020 onwards and even tends to remain outside the normal rainfall range. The rainfall trend for May is decreasing and follows the function  $y = -0.8857x + 13.229$ . The slope of the trend is negative, but relatively weak, suggesting that rainfall in May is decreasing slowly.

#### 4.1.6. June

The normal cumulative rainfall value between 2 mm and 7 mm for the month of June [5]. For the Betafo district, the driest month of the year is June.

The behavior of the cumulative rainfall for the month of June is highly unstable, with a sharp increase from 2018 to 2019 then a sudden drop from 2021 onwards. The rainfall trend is characterized by a decrease in cumulative rainfall. This trend follows the direction of the function  $y = -1.3786x + 12.543$ . The month of June is therefore becoming drier, despite a few instances of rainfall exceeding the upper limit of the normal range.

#### 4.1.7. July

The normal cumulative rainfall is between 2 mm and 9 mm [5]. As the upper value of the normal is slightly higher than that of June, July is therefore slightly wetter.

In July, two periods can be distinguished based on rainfall intensity. The first period is before 2021, which is characterized by relatively high cumulative rainfall, followed by the period after 2021, which is marked by a sudden drying up.

Rainfall in July tends to decrease and follows the function  $y = -1.8929x + 13.643$ .

#### 4.1.8. August

Although August is still in the middle of the dry season, it sees a slight increase in rainfall, with normal cumulative rainfall between 3 mm and 9 mm.[5].

Similar to July, August is relatively wet until 2021, followed by a dry period. The rainfall trend is moving towards drier conditions and follows the function  $y = -1.4929x + 12.929$ , where the slope remains negative but is less steep than in July.

#### 4.1.9. September

The normal rainfall for September is between 15 mm and 35 mm [5]. There has been a marked increase in cumulative rainfall compared to the previous three months. This is because September marks the end of the dry season.

Although September is the month when rainfall begins to increase, the evolution of cumulative rainfall does not follow suit. The trend in cumulative rainfall shows a downward slope and follows the function  $y = -4.7357x + 36.943$ . The slope of the trend line is  $-4.7357$ , indicating a very rapid drying out in September.

#### 4.1.10. October

In October, there is a marked increase in the normal cumulative rainfall compared to September. Its value is between 70 mm and 150 mm. [5]. This sudden increase is justified by the fact that October marks the end of the dry season.

Rainfall accumulation in October is highly unstable, with several instances falling below the minimum normal value, reaching a total of only 37 mm in 2024. The trend is downward, following the function  $y = -5.15x + 87.229$ . The slope of  $-5.15$  indicates a high rate of drying.

#### 4.1.11. November

November marks the beginning of the rainy season. This explains why the normal rainfall total is between 120 mm and 220 mm [5].

The cumulative rainfall for November remains largely within the normal range despite a marked irregularity. The rainfall trend is increasing and follows the function  $y = 1.55x + 146.93$ .

#### 4.1.12. December

December marks the end of a very wet year for the Betafo district. Normal rainfall is between 180 mm and 280 mm [5].

December is fairly stable compared to other months of the year, and cumulative rainfall values do not exceed the normal range.

The cumulative rainfall trend follows the direction of the function  $y = 5.15x + 192.23$ . The slope of 5.15 suggests that December tends to see an increase in rainfall.

#### 4.1.13. General trend of the monthly cumulative rainfall

The slopes of the cumulative rainfall trend for each month allow us to observe the distribution of rainfall over a year. We can see that the dry season (April to October) is becoming drier, while during the rainy season, monthly rainfall tends to increase, peaking in March. This suggests that rainfall is shifting towards the first quarter of the year (January-February-March).

When we look at the overall changes in monthly rainfall, we see that the fluctuations in total rainfall do not offset each other, resulting in a positive average for the slope of the trend curve. As a result, there is an upward trend in total rainfall over the course of a year. This situation converges with the result announced by the Meteorological Agency of Madagascar in 2023, in which all of its climate projections show an increase in rainfall between 2025 and 2030, despite the general trend showing a decrease in rainfall compared to the 1980s. [1].

### 4.2. Qualitative analysis

#### 4.2.1. First rain drop

When the rain first falls, fairly high levels of contamination are observed. This phenomenon is completely normal, as the dry season has just ended and all the pollutants accumulated in the air are washed away by the rain, making the atmosphere a little cleaner. This first rainfall is usually followed by a short dry period lasting a few weeks.

#### 4.2.2. Beginning of second rainfall period

After the short dry period at the beginning of the rainy season, there is a short period of successive rainfall, which is the second rainfall period. The results of the analyses indicate an increase in water pollution. This is a direct consequence of the fact that between the first two periods of rainfall of the rainy season, local residents rush to cultivate the land, and agricultural practices generate pollutants in addition to the usual emissions (greenhouse gases, vehicle exhaust, etc.).

#### 4.2.3. Middle of rainy season

The results of the analysis of rainwater collected in the middle of the rainy season indicate that the rain was fairly clean. This is due to the fact that the series of rains that occurred before the samples were collected significantly cleaned the atmosphere. Furthermore, BOD and COD values increased in this study. This anomaly was caused by a sudden gust of wind that occurred during rainwater collection, which slightly contaminated some samples.

#### 4.2.4. General quality of rainwater

Compared to the Malagasy drinking water standard [6], The results of the physical and chemical analyses indicate that rainwater in the Betafo district does not fully meet the criteria for drinking water. However, it is undeniable that it is relatively clean, given that the deviations from normal values are not excessive. These deviations are mainly caused by greenhouse gas emissions, vehicle exhaust fumes from traffic on National Highway 34, and pollutant emissions from agricultural practices.

### 4.3. Limits of the study

Even though the results obtained from this analysis coincide with those of the General Directorate of Meteorology, they are only applicable over a short period of time, as the analyses are based solely on the trend calculated over a short interval (2018 to 2024). Furthermore, other environmental parameters have not been taken into account, which means we are unable to make long-term projections.

## Conclusion

By analyzing rainfall patterns and their physical and chemical composition, this study highlighted the kinetics of rainfall distribution over a year and its cleanliness rate. Analysis of rainfall trends for each month confirmed that rainfall is likely to increase in the coming years. However, we also observed that rainfall is shifting towards the first quarter of the year, causing the dry season to see a decrease in cumulative rainfall. Above all, rainwater in the Betafo district is not directly drinkable despite its cleanliness. It has been polluted by gases and particles present in the atmosphere. Although this study is based solely on historical rainfall data and does not take environmental factors into account, it does allow us to make projections over a short period of time. However, it also highlights the need to treat rainwater slightly before using it in the home.

## References

- [1] S. F. Kotomangazafy, R. Nirivololona, Z. A. Rakotomavo, Leroux, et F. Bonnardot, « Tendances Climatiques Observées et Futurs Changements Climatiques à Madagascar 2023. », Direction Générale de la Météorologie de Madagascar & Direction Interrégionales de la Météo-France pour l’Océan Indien, La Réunion., 2023.
- [2] « Monographie region Vakinankaratra », CENTRE DE RECHERCHES, D’ETUDES ET D’APPUI A L’ANALYSE ECONOMIQUE À MADAGASCAR, février 2013.
- [3] « Vakinankaratra Une Région à forte vocation agro-pastorale », Ministère des Affaires Étrangères, Ministère de l’Intérieur et de la Décentralisation, Région Vakinankaratra, PNUD, sept. 2022.
- [4] H. S. RAVERONIRINA, R. HERITAHINA, D. F. RAZANADRANAIVO, et R. RANDRIANJA, « ESSAI DE DIAGNOSTIC HYDROGRAPHIQUE VIA SIG : CAS DU DISTRICT DE BETAFO », MadaRevue, vol. 1, no ISSN 2220-0681, 2024.
- [5] « MAPROOM », Météo Madagascar. Consulté le: 2 janvier 2026. [En ligne]. Disponible sur: <https://www.meteomadagascar.mg/maproom/>
- [6] MINISTERE DE L’ENERGIE ET DES MINES, « DECRET N° 2004-635 PORTANT MODIFICATION DU DECRET N°2003-941 DU 09 SEPTEMBRE 2003 RELATIF A LA SURVEILLANCE DE L’EAU, AU CONTROLE DES EAUX DESTINEES A LA CONSOMMATION HUMAINE ET AUX PRIORITES D’ACCES A LA RESSOURCE EN EAU ». MINISTERE DE L’ENERGIE ET DES MINES, 15 juin 2024.