PLANNING STUDY OF A HYDROELECTRIC POWER PLANT IN LOWER MANDRARE: CASE OF AMBOETSY

Romuald RAMANANTSOAVINA Romuald[1], Clin RAHARIVELO, RAVOLOLONIAINA Annie Zoé[3], Edmond SOLOMANA[4]

[1] *Romuald RAMANANTSOAVINA, PhD Student in Geography with a specialization in Geography with a Specialization in Geosciences from the faculty of Sciences at the University of Toliara, Madagascar*

[2] *Clin RAHARIVELO, Doctor in Physics from the Faculty of Physics at the University of Toliara, Madagascar*

[3] *Annie ZOE, Doctor in French Literature with a specialization in French studies from the Faculty of Arts and Humanities at the University of Toliara, Madagascar*

[4] *Edmond SOLOMANA, PhD Student in Chemistry with a specialization in Chemistry from the Faculty of Sciences at the University of Toliara, Madagascar*

ABSTRACT

The Deep Southern of Madagascar possesses potential natural resources that could be beneficial to the local population. This area is highly rich and has various potentials, making it a zone of excellence for the future. However, the relevance of the vulnerability of the population's livelihood is strongly felt. It is an undeniable strategy that needs to be thoroughly studied for a sound local development project. Nevertheless, the fundamental constraint for socio-economic development in this area is the insufficient water resources. Given the interdependence of various production factors, implementing a single development project does not solve the problems. Therefore, it is essential to establish and implement a multi-component project, including provisions for drinking water supply, agriculture, livestock, hydroelectric power production, etc. Thus, the key factor for the development of the South lies in mastering water resources, regardless of the proposed options. This article focuses on studying an inter-hill type dam at sites with multiple development possibilities, including drinking water supply, irrigation, and hydroelectricity. The development of the Amboetsy hydroelectric power plant in the lower Mandrare was undertaken to harness the hydroelectric energy of the Mandrare River. The construction involved creating a reservoir, a power plant, and related infrastructure. The objective was to provide electricity to the surrounding regions, especially urban areas and industrial installations. However, this has led to environmental and social impacts, such as reduced river flow and population displacement.

Keyword: - *Mandrare, Deep Southern, Amboetsy, Madagascar*

1. Site Location

The Amboetsy site is located in the southwestern part of the Amoron'i Mania region, near the Mandrare River. It covers an area of approximately 10,000 hectares and features rugged terrain, with elevations reaching up to 1000 meters. It is a mountainous and forested region, with numerous watercourses flowing into the Mandrare River. The climate is tropical and humid, with abundant precipitation throughout the year. This situation is favorable for the development of the hydroelectric power plant on the Mandrare River (Randrianjanaharizaka, 2005; JIRAMA, 1993, et al.).

1.1. Watershed Structure of the Mandrare River

The Amboetsy site is located in the southwestern part of the Amoron'i Mania region, near the Mandrare River. It covers an area of approximately 10,000 hectares and features rugged terrain, with elevations reaching up to 1000 meters. It is a mountainous and forested region, with numerous watercourses flowing into the Mandrare River. The climate is tropical and humid, with abundant precipitation throughout the year. This situation is favorable for the development of the hydroelectric power plant on the Mandrare River (Randrianjanaharizaka, 2005; JIRAMA, 1993, et *al*.).

1.2 Hydrogeological and geomorphological context

The extreme southern region of Madagascar has been extensively studied by geographers, notably Battistini René (1964). According to him, this region constitutes almost the entire large parts of the southern Bara country. Consequently, there is a Malagasy western phenomenon, namely the southwestern coastal plain, the limestone and Eocene plateau, the Mahafaly limestone plateau, Isalo, Fiherenana, and peripheral depressions. From a hydrogeological perspective, the South presents three sets of rocks: Precambrian basement rocks are found everywhere inside, forming the Mahafaly peneplains; the Androy interior peneplains and the set of sedimentary rocks from the West, and the large ancient volcanic massif of Androy. Thus, this Androy system is very complex. These are highly varied rocks, such as gneiss, granite, quartzite, and protogine families. These peneplains gently rise northward with an altitude ranging from 100 m to 400 m to the north. (Ratsivalaka, Randriamanga, 1987, and Besairie, 1974 et *al*). Following these formations is a gneiss plateau sloping towards the sea. The Mandrare River also crosses the volcanic formation in its middle course, as well as several tributaries. Alluvial deposits extend around the outlet located in Amboasary-Sud to the sea. The alluvial plain of the Mandrare, upstream and downstream of Amboasary, is conducive to hydro-agricultural development considering the climate and irrigation possibilities (Jean Defos du Rau, 1954; Randriajanaharizaka, 2005 et *al*).

2. Climatology

The climate of the Mandrare Valley is subjected to frequent tropical cyclones, which can cause floods and significant damage. Sunshine is abundant throughout the year, with an average of 2500 hours per year. The dry season, from May to September, is characterized by warmer temperatures and lower relative humidity.

2.1. Temperature

In terms of temperature, the Amboetsy site is characterized by a tropical and humid climate, its average annual temperature is around 25°C in January. On the other hand, the lower Mandrare region is also known to be difficult region due to the conditions which characterize its environment: inhospitable natural, intermittent droughts, etc. (Decary, 1930). In the South, according to Donque Gérard, 1975, "the annual average temperatures oscillate between 23°C and 24°C overall. Thus, this situation is verified in the table below: the entire lower Mandrare valley (case in South of Tanandava) is marked by heat and drought, an irregular rainfall pattern, high temperatures, strong thermal amplitudes and a dry climate known as the western facies of the area.

Table-1: The distribution of maxima and minima of monthly temperatures in South Tanandava station, from 2006 to 2011

Years	Month / Temperature(C°)	J	F	M	A	M	J	J	A	S	O	N	D
2006	Minima	29	30	28	25	20	18	17	17	21	24	25	26
	Maxima	34	34	33	29	25	24	25	26	26	35	29	36
2007	Minima	26	23	23	22	17	17	15	15	17	21	24	26
	Maxima	33	25	27	24	25	24	23	25	30	30	32	36
2008	Minima	28	26	24	21	16	16	17	17	22	22	21	28
	Maxima	32	35	29	27	26	23	29	29	32	32	39	40
2009	Minima	29	23	16	13	16	13	13	13	16	18	18	19
	Maxima	40	39	32	35	32	29	27	29	33	36	34	37
	Minima	17	18	20	20	16	13	12	13	13	18	21	23

2010	Maxima	37	39	36	35	32	30	29	31	35	37	40	39
2011	Minima	22	22	24	21	19	14	13	17	16	16	20	20
	Maxima	40	34	36	40	32	29	28	31	35	36	39	37

Source: Communal Development Plan in South Tanandava, 2011

Table-2: The evolution of the minima and the maxima of monthly temperatures in South Tanandava station during the morning and afternoon in one year, 2012

Year	2012			
	Temperature in the morning(°C)		Temperature during the afternoon(°C)	
Month	6h 30mn	10h 00mn	14h 00mn	16h 00mn
January	26	30	32	31
February	24,3	27,1	30,8	30,3
March	24,3	27,1	28,6	8,3
April	22,4	26,3	26,4	25,8
May	19,7	23	22	21
June	16	20	22	21
July	16	20	23	23
August	18	22	26	27
September	19	24	28	25
October	22	28	31	30
November	24	28,5	30,3	30,1
December	23,7	28	29,8	29,4

Source: Communal Development Plan in South Tanandava, 2014

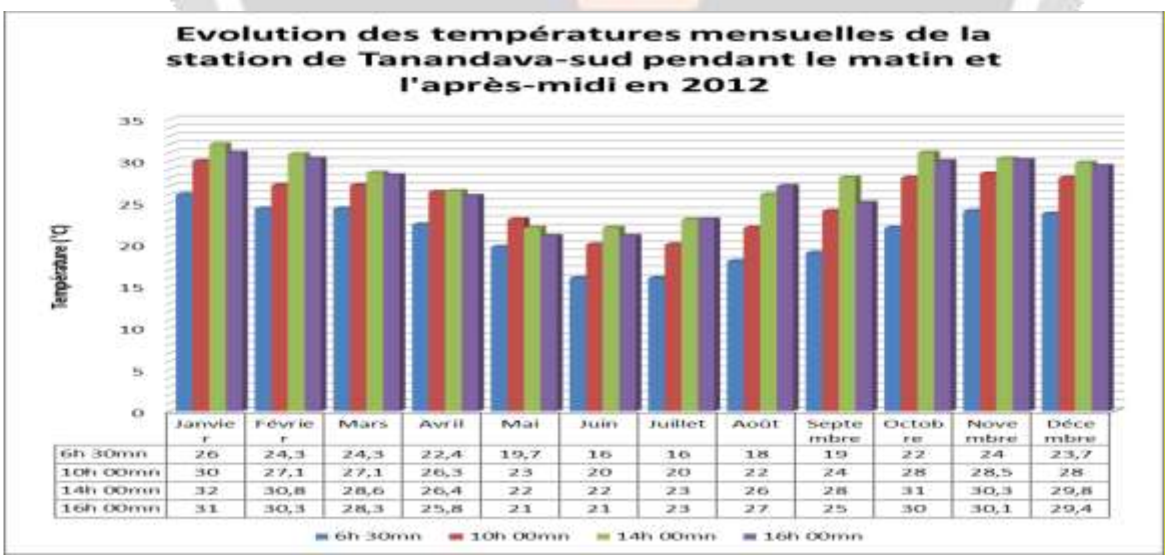

Figure 1: Monthly Temperature Patterns in South Tanandava 2010

The table and the figure depict the distribution of monthly maximum and minimum temperatures in this area. The temperature trends are as follows: from 2006 to 2012, during the austral winter (April to October), temperatures are very low, especially in the morning (6:30 am) and evening. From 10:30 am, the temperature becomes very high, especially in the afternoon (2:00 pm to 4:00 pm), and this is consistent during the dry season.

2.2. Precipitations

According to Battistini René (1986) and Humbert (1955), “average annual precipitation in the South varies between 300 and 400 mm or is less than 500 mm”. This indicates that semi-aridity is present in all its forms, given that precipitation is significantly insufficient. Thus, precipitation does not exceed 600 mm per year because the climate in this zone is arid with a desert-like tendency.

Table-3: Variation in monthly precipitation from 2006 to 2010 in South Tanandava station

Year	Month	J	F	M	A	M	J	J	A	S	O	N	D	Total annual
	Precipitation (mm)													
2006	Rain	16	6	27	58	26	3	0	6	36	0	14	94	286
	Number of days	2	2	5	6	3	2	0	2	2	0	3	4	34
2007	Rain	127	129	16	69	57	7	14	2	3	1	31	17	473
	Number of day	5	14	2	7	6	3	3	1	2	1	8	1	47
2008	Rain	28	64	34	33	26	25	0	18	16	0	3	0	247
	Number of day	4	4	4	4	3	2	0	3	2	0	2	0	28
2009	Rain	87	5	84	40	9	29	5	12	6	10	87	37	411
	Number of day	7	2	6	7	3	3	1	3	1	3	7	5	48
2010	Rain	23	20	95	8	12	49	2	17	14	18	15	48	321
	Number of day	3	3	10	2	6	4	1	3	2	3	1	7	45

Source: South Amboasary Anti-Locust Meteorological Service (CNA), 2010

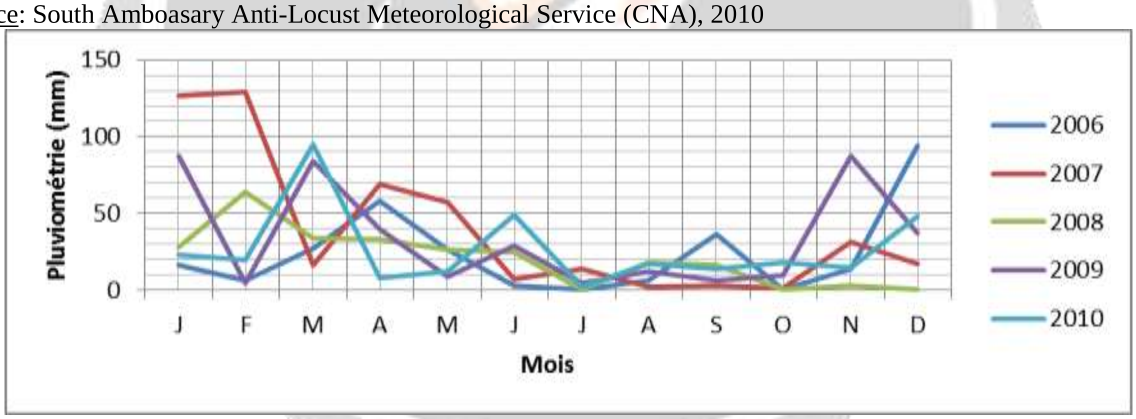

Figure-2: Evolution of Monthly precipitation from 2006 in South Tanandava station, 2006 to 2010

The table and the figure depict the distribution of monthly maximum and minimum temperatures in this area. The temperature trends are as follows: from 2006 to 2012, during the austral winter (April to October), temperatures are very low, especially in the morning (6:30 am) and evening. From 10:30 am, the temperature becomes very high, especially in the afternoon (2:00 pm to 4:00 pm), and this is consistent during the dry season.

3. Hydroelectric and Agricultural Power Plant Development Project

This project is divided as follows:

3.1 Hydroelectric Power Plant

For the establishment of the final balance and the need for hydroelectric development, we proposed that the useful agricultural surface be 40,000 [ha] for wet season cultivation and 4,500 [ha] for dry season cultivation. Madagascar has significant hydraulic potential, with less than 5% of the potential being exploited. The Mandrare Basin could be a possibility for the installation of multiple hydroelectric power plants. The difference in level between the installed dams and the altitude of the downstream plain allows the installation of these hydroelectric plants. These facilities will depend on the gross power offered by the available water height after subtracting all needs other than electricity (needs for irrigation, livestock, water supply, etc.). The power produced by a hydroelectric power plant depends on the head and the flow arranged for that plant. The development of a hydroelectric power plant can take two forms: mountain development and plain development. The production obtained can be used to meet the power needs of the urban areas of South Amboasary, Ambovombe Androy, even Fort-Dauphin, and industrial and mining operations in the South, through small agglomerations targeted in a rural electrification project. For this, the forecast for peak electricity demand in the South Amboasary, Ambovombe, and Fort-Dauphin regions is estimated at 1,600 kW in 2005, 2,300 kW in 2010, and 3,087 kW in 2020. For example, the needs of the Qit Mineral Madagascar (QMM) Company are estimated at around 15 MW (Randrianjanaharizaka, 2005, Anosy Monograph, 2009, et al.). This power plant has an installed capacity of 12 MW and was built by the French company Sogea-Satom in 1993. The main structure of the plant is an embankment dam 30 meters high and 160 meters long, which retains the waters of the Mandrare River to generate electricity. The plant is managed by the state-owned company JIRAMA, which provides electricity to a large part of the country. Certainly, the total daily consumption is obtained by the formula:

Ct Np bp

With Ct: total daily consumption in (m3 / day)

Np: number of beneficiary population

bp: daily need for drinking water per inhabitant expressed in l /head/day

3.2. Hydro-Agricultural Plant

To enhance the hydro-agricultural development project in the Mandrare Basin, it is essential to raise awareness among farmers to cultivate rice in December for the wet season and August for the dry season. The water requirement in a dry decade is estimated at 16,389 [m3/ha] per cultivation cycle. Meanwhile, the water requirement in a dry quinquennium is 15,829 [m3/ha] per cycle. For estimating water needs in rice cultivation, unfavorable cases are considered, so the requirement will be 16,389 [m3/ha] per cycle with a hypothetical discharge of 1.47 [l/s/ha]. Thus, the largest area in the Mandrare Basin is in the Behara plain, Andronobory, in South Tanandava, Sampona, Ifotaka, South Amboasary, and Tranomaro, with an agricultural area of 50,000 [ha]. The recognition of the Mandrare development in 1964 would allow irrigating 37,000 ha in the two sub-prefectures of Amboasary and Ambovombe, divided into 15,000 [ha] of rice fields and 22,000 [ha] of dry farming. The construction of the retention dam at Andabolava, where Amboetsy appears to be a topographically favorable site, would irrigate over 50,000 [ha]. For the case of our Amboetsy site, the choice of turbine type has already been made during preliminary studies.

It is about Francis turbines. Indeed, their average head of 30 meters makes them perfectly suitable because the Francis turbine is classified among forced or reaction turbines. The energy of the water, at the outlet of the distributor, is partly in the form of kinetic energy and partly in the form of pressure energy.

Furthermore, the fundamental objective of this article is also to provide the southern part of Madagascar with hydraulic infrastructure with sufficient capacity for needs. However, this requires the establishment of an efficient management structure to ensure the sustainability of the service. The type of project implemented in the Mandrare is similar to the functionality of reservoir dam developments existing on our island. It would also be necessary to conduct additional studies, such as the environmental impact study of this project, considering all its aspects in the event of the realization of the grand project.

Finally, the Amboetsy hydroelectric power plant on the lower Mandrare is also used for agricultural irrigation. The water stored in the reservoir created by the dam is directed to agricultural fields through a network of canals and ditches. This combined use of hydraulic energy and water for agricultural needs is a common practice in many developing countries.

Map-1**:** location of the Amboetsy watershed

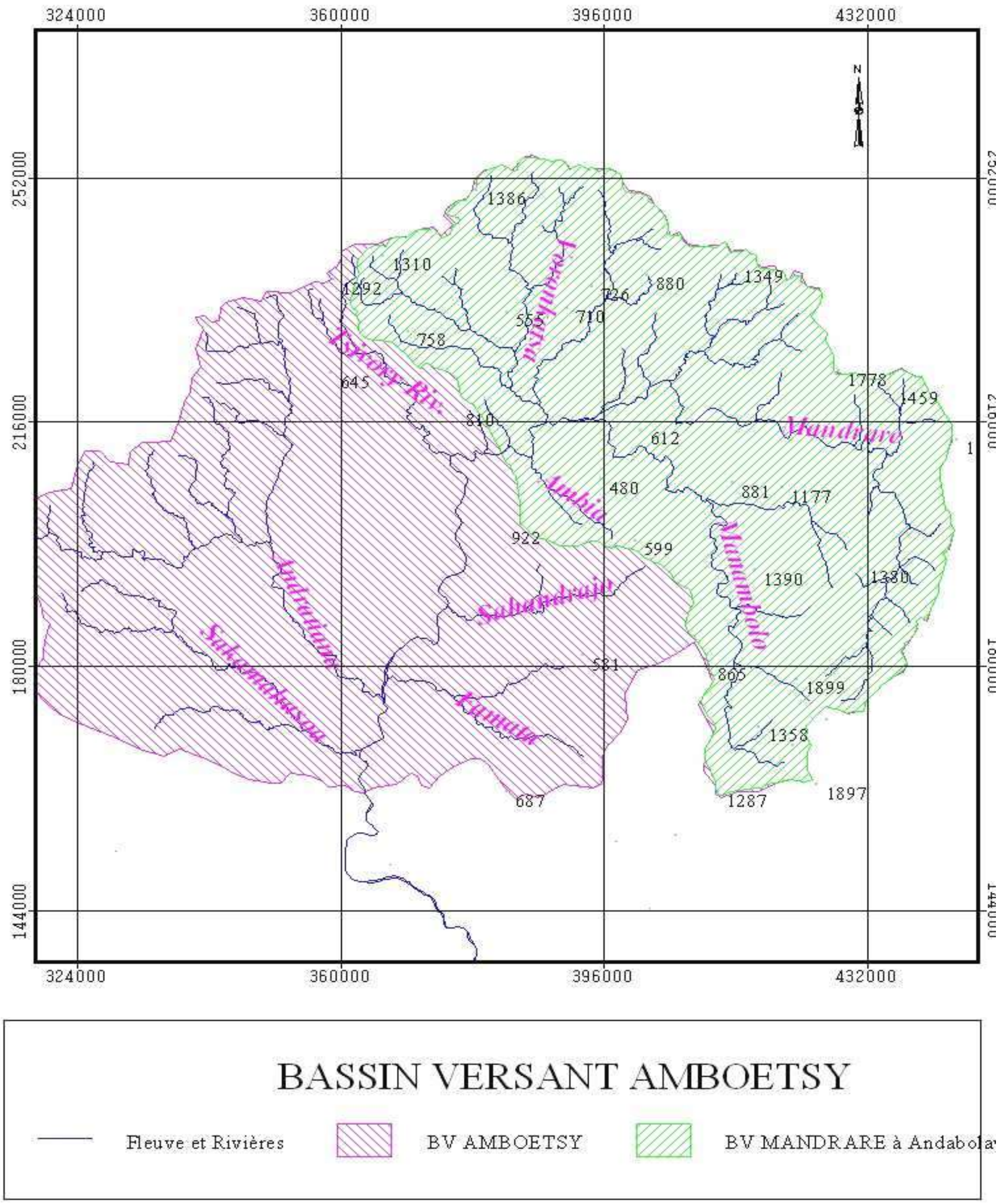

Table- 4: Surface area and volume of the water body

Sites	Height = 20m		Height = 25m		Height = 50m	
	Long (m)	V (m^3)	Long (m)	V (m^3)	Long (m)	V (m^3)
Ambero	156	7 300 000	200	12 500 000	700	190 000 000
Andetsy	240	4 210 000	300	7 500 000	600	135 000 000
Mahaly	219	15 700 000	350	32 500 000	3 600	1 222 000 000
Andabolava	476	28 400 000	600	45 500 000	1 900	625 000 000
Amboetsy	335	503 000 000	350	669 000 000	450	2 750 000 000

Source: JIRAMA, Study of the Amboetsy site on the Mandrare, 1993.

The surface $S = 6\ 712\ H^{2,4}$ and the volume $V = 1\ 607\ 943\ H^{1,9}$

The analysis of Amboetsy sites has allowed for tracing the contour lines of the level at the dam site, which have allowed for establishing the height/volume and height/surface curves of each reservoir. The calculation will be presented below:

Table-5: Surface area and volume of the water body at the Amboetsy site

COASTS	H(height)	S(surface)		V(volume)	
		m^2	Ha	m^3	$10^6\ m^3$
90	0	0	0	0	0
95	5	319 433	32	34 222 660	34
100	10	1 685 978	169	127 723 483	128
105	15	4 461 398	446	275 958 736	276
110	20	8 898 646	890	476 680 895	477
115	25	15 202 253	1 520	728 377 918	728
120	30	23 547 400	2 355	1 029 914 420	1 030
125	35	34 089 078	3 409	1 380 384 388	1 380
126	36	36 473 543	3 647	1 456 282 083	1 456
127	37	38 952 567	3 895	1 534 101 273	1 534
128	38	41 527 193	4 153	1 613 836 703	1 614
129	39	44 198 446	4 420	1 695 483 267	1 695
130	40	46 967 336	4 697	1 779 036 007	1 779

Source: JIRAMA, Study of the Amboetsy site on the Mandrare, 1993

4. CONCLUSIONS

This article draws attention to the challenges faced by the Extreme South due to insufficient water resources and uneven rainfall distribution in the southern region. The main objective of this article is to study different forms of utilizing hydrological resources in the Upper Mandrare Basin at the Amboetsy site, involving the construction of a water retention dam based on the water balance. Therefore, the positioning of a 46-meter high dam with a crest length of 650 meters and a spillway width of 400 meters at the topographical narrowing of Amboetsy would allow the storage of approximately 1.534 billion cubic meters of water. This stored water could be used to support various development plans downstream, including the irrigation of a 44,450-hectare area in the middle and lower Mandrare, as well as the areas north of the Ambovombe Androy district. It would also contribute to meeting the water supply needs of the population in the two districts of Amboasary and Ambovombe Androy, in line with the Poverty Reduction Strategy Paper (DSRP) goal of achieving 100% coverage in urban areas and 80% in rural areas by 2015. Additionally, the construction of a hydroelectric power plant with a capacity of approximately 3,488 kW is proposed to supply power to urban centers, various small settlements in the rural electrification project, and pumping stations. This would strengthen the energy utilization capacity for mining operations and support water supply for livestock and other development projects in the region.

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7. BIOGRAPHY

	PhD Student in Geography with a specialization in Geography with a Specialization in Geosciences from the faculty of Sciences at the University of Toliara, Madagascar. Pedagogical trainer at the CRINFP Toliara I, Madagascar.
	Doctor in Physics from the Faculty of Physics at the University of Toliara, Madagascar. Volunteer at the University of Toliara (E.N.S.), Madagascar. Pedagogical trainer at the CRINFP Toliara I, Madagascar

	Doctor in French Literature with a specialization in French studies from the Faculty of Arts and Humanities at the University of Toliara, Madagascar. Volunteer at the University of Toliara, Madagascar. Coordinator at the Alliance Française of Toliara, Madagascar. Pedagogical trainer at CRINFP Toliara-I, Madagascar
	PhD Student in Chemistry with a specialization in Chemistry from the Faculty of Sciences at the University of Toliara, Madagascar. Principal at Tsianisiha of High School, Toliara, Madagascar.