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Management of Significant Environmental Aspects and Impacts in Accordance with the ISO 14001:2015 Standard during the Operation and Maintenance Phase of Senegal River Basin Development Authority Hydroelectric Works and Facilities: The Case of Manantali Dam

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Abstract

This study aims to determine the environmental aspects and impacts of the phase relating to the operation of Manantali's hydroelectric structures and facilities according to the requirements of the ISO 14001 version 2015 standard. To do this, the mapping of the different work areas made it possible to identify all the activities within the framework of the farm. Based on the mapping, environmental measurements made including noise level, brightness, electric and magnetic fields, total particles, PM_{10}, $PM_{2.5}$, PM_1 showed the work areas with the exposure limit values exceeded. The inventories of the waste produced show eighteen (18) types of waste, 67% of which are special industrial waste (SIW), 28% are ordinary industrial waste (OIW) and 5% are inert industrial waste (IIW). The identification and assessment of environmental aspects and impacts made it possible to determine sixteen (16) positive and negative significant environmental aspects (ESAs). The positive AES must be maintained, and for the negative ones, mitigation and mitigation measures must be put in place in order to manage them effectively. This will ultimately improve environmental management in the operation of hydroelectric structures and facilities.

Keywords

Manantali, Environmental Aspect, Environmental Impact, Waste, Mitigation and Mitigation Measures

1. Introduction

Created in March 1972 in Nouakchott by Mali, Mauritania and Senegal in response to the droughts of the 1970s, the Senegal River Basin Development Authority (OMVS) has launched an ambitious programme of investment in infrastructure to control the waters of the Senegal River. The programme has a threefold objective: 1) to regulate the river's flow and produce energy; 2) to make the river navigable from Kayes in Mali to its mouth at Saint-Louis in Senegal; and 3) to support agricultural development in the three countries (AFD, 2008). The Manantali and Diama dams have been built to regulate the level of the river (flood control and low-water support) and prevent salt water from rising, respectively (Severino & Naudet, 2009). The construction of the Manantali hydroelectric power station in 1998 has also helped to develop the hydroelectric potential of the member states, complemented by the Gouina and Félou hydroelectric schemes built in 2022 and 2013 respectively.

For the Manantali dam, the impact studies for its construction were carried out in accordance with the NEPA (National Environmental Protection Act) following the basic approaches defined in paragraph 1500.8 of the 1973 Guidelines, Preparation of Environmental Impacts Statement (CEQ, 1973). A number of impacts have been identified, including the displacement and rehousing of local people; the deforestation of the 11,000-hectare environmental lake; the prevalence of water-borne diseases; the influx of people, which has led to increased pressure on existing infrastructure and forest resources and a deterioration in the living environment during construction; and an increase in contagious diseases (STI/HIV, tuberculosis, etc.) (Lelek & Tobias, 1982; Ndiaye, 2003; SOFRECO, 2011). For the power station, mainly the high-voltage lines and substations, the main impacts are the loss of vegetation of ecological or agricultural interest, the fragmentation and disruption of habitats due to the presence of a cleared right-of-way, the opening up of new hunting grounds (presence of access tracks), and the collision of avian fauna with the line's conductors; disruption to farming activities (crops, plantations, livestock) linked to the opening up of the line corridor, the erection of the pylons, the running of the conductors and the construction of the traffic and access tracks (ACDI, 1996).

Several projects and programmes have been set up by the OMVS authorities (Environmental Impact Mitigation and Monitoring Programme (EIMMP); Project for Integrated Management of Water Resources and the Environment in the Senegal River Basin (PIMWRE), Manantali Power Project (MPP); Strategic Action Plan for the Management of Priority Environmental Problems in the Senegal River Basin 2017-2037 (SAP)) with a view to mitigating the impacts deemed significant (PASIE, 1999; OMVS, 2017a; OMVS, 2017b). Following the impact studies, environmental monitoring is carried out to ensure that the laws and regulations governing environmental and social impact studies and the commitments made by the developer, including mitigation and/or compensation measures, are respected during the project implementation and operation phases (Official

Journal of Mali, 2018).

It is within this framework that this work, which aims to identify, assess and analyse the significant environmental aspects and impacts in the operation and maintenance phase of the Manantali hydroelectric facilities, has been carried out, enabling all hydroelectric dam operators to anticipate mitigation measures.

2. Materials and Methods

2.1. Materials

2.1.1. Study Area

Located on the Bafing River 90 km south-east of Bafoulabé, in the Kayes region of Mali, the Manantali dam was designed to control flooding while providing a water reserve to ensure the stability of various economic activities, such as water supply, irrigation, flood-recession crops, hydroelectric generation and river navigation. Controlling around 50% of the inflow to the upstream Senegal river basin, the structure has a storage capacity of almost 12 billion cubic meters (BRLI, 2018). The dam is equipped with a hydroelectric power station comprising five units and was commissioned between 2001 and 2002. The dam has a total crest length of 1,495 m and consists of a concrete structure containing the hydraulic structures (spillway, bottom outlet, damping basin and water intakes) and two side dykes. The power station is equipped with five 40 MW generating units, giving an installed capacity of 200 MW, with an expected average annual production of around 807 GWh, corresponding to a load factor of 46%.

The High Voltage (HV) transmission network, known as the "Manantali interconnected Network" (RIMA), links Mali, Mauritania and Senegal. It is supplied by the Manantali, Gouïna and Félou hydroelectric power stations (CIMA, 2017) (**Figure 1**). High-voltage lines totalling 2312 km, broken down as follows: 2055 km 225 kV line; 22 km 150 kV line; 235 km 90 kV line. 18 transformer substations: 6 in Mauritania (Rosso, Nouakchott, Boghé, Kaédi, Sélibaby and Gouraye); 6 in Senegal (Tobène, Sakal, Dagana, Matam, Bakel and Tambacounda); 6 in Mali (Manantali, Kita, Kodialani, Félou, Kayes Médine and Gouina). In addition, there are fibre-optic guard cables (CGFO) and a dispatching centre at Manantali. The RIMA and the electricity networks of the National Electricity Companies of Mali, Mauritania and Senegal make up the OMVS Interconnected Network (RIO).

2.1.2. Measuring Equipments

In order to identify environmental aspects and impacts, measurements of environmental ambiences were carried out using various pieces of equipment to better characterise potential impacts.

The TESTO 816-1 sound level meter is used for noise pollution and environmental acoustics studies and is used to quantify noise and noise pollution.

The TESTO 545 luxmeter, with a measurement range of 0 to 100,000 lux, is used to measure illuminance in the visual spectrum quickly and easily.

The ME3030B electromagnetic wave detector is used to detect electromagnetic pollution generated by alternating electric and magnetic fields from high-voltage lines, electrical cables, electrical appliances and electrical transformers. It is designed to provide a simple assessment of a home's exposure to low-frequency electrical and magnetic pollution. The frequency band analyzed extends from 16 Hz to 2 kHz.

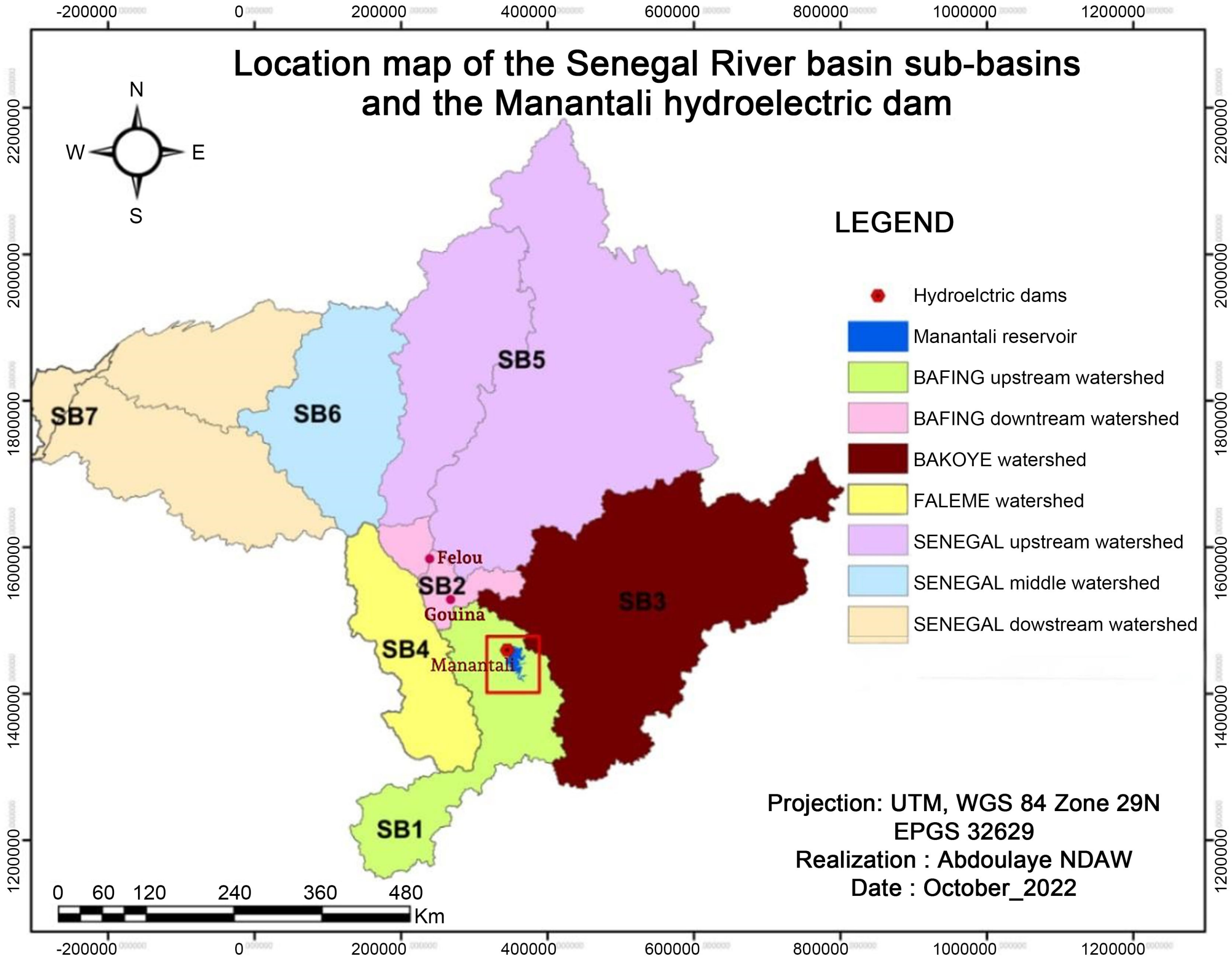

Figure 1. General view of the Senegal River basin. Location of hydroelectric schemes.

The OSIRIS particle analyser can be used to take measurements in environments where the concentration of dust influences ambient conditions and human health. It is particularly used in environments where particles are concentrated in the air. The particle analyser uses a light scattering technique to measure various particle fractions: the total number of particles, particles with a diameter of less than 10 µm (PM_{10}), particles with a diameter of less than 2.5 µm ($PM_{2.5}$), and particles with a diameter of less than 1 µm (PM_1).

2.2. Methods

Articles 5 and 6 of Decree No. 2018-0991/P-RM of 31 December 2018 on the environmental and social impact study and notice in Mali stipulate that projects, whether public or private, consisting of works, developments, constructions or other activities in the industrial, energy, agriculture, mining, handicrafts, trade, transport, telecommunications and hydrocarbons, the implementation of which is likely to harm the environment, are subject to an environmental and social impact study or an environmental and social impact notice (Official Journal of Mali, 2018). According to this decree, category A and B projects are subject to an environmental and social impact assessment (ESIA), and the construction of a hydroelectric facility, being category A, is therefore subject to such an environmental and social impact assessment. As the projects have already been completed, environmental monitoring is required to ensure that the laws and regulations governing ESIAs and the commitments made by the developer, including mitigation and/or compensation measures, are respected during the project implementation and operation phases. It should be noted that one of the key stages of the ESIA is the identification and detailed assessment of environmental impacts.

For the operation phase of the installations and structures, the methodology used consists of 1) identifying the environmental aspects on the basis of the mapping of the various activity zones, 2) identifying the main activities and for each activity, 3) identifying the environmental aspects associated with the operating mode (normal or accidental) and giving its justification and the area concerned (water, air, soil, resources, health), 4) determining the significant environmental impacts (SEIs) for each environmental aspect. It should be noted that aspects with significant environmental impacts are considered to be significant environmental aspects (SEAs).

An environmental aspect may include an activity, a product, a service or an interaction with the environment (e.g. emissions of pollutants/noise/light, human presence, transfer of native or non-native species, direct contact with wildlife/vegetation, leakage or spillage of hazardous substances, etc.) or a withdrawal from the environment (e.g. use of lake water, etc.). Identifying the environmental aspects consists of determining the type of interaction (e.g. emission, discharge, extraction) and the environmental component(s) likely to be involved in interactions with the activity (e.g. discharge of wastewater into surface water, or emission of noise into the air/water) (RCTA, 2016).

In order to carry out an in-depth environmental analysis, we first carried out an inventory of the different types of waste produced, analysed data from environmental measurements, surveys of camps, hydroelectricity distribution, and activities associated with the operation of the facilities (hospital, water distribution, recruitment, different types of consumption, etc.). This data is used to determine the justification for the environmental aspects.

Next, the different activities and their associated environmental aspects were identified by work zone. The justification for the environmental aspects and the areas of the environment concerned (water, air, soil, resources, etc.) led to the identification of the impacts associated with these aspects. On the basis of a scoring grid, we were able to determine which environmental aspects were significant and which were not in the operating phase of the facilities and structures.

3. Results and Discussions

3.1. Results

The operation phase corresponds to the period following the impoundment of the dam, the construction of the hydroelectric power station and the HV lines and substations, the management of which has been entrusted to Manantali and Félou Operating Company (SEMAF) since July 2014. SEMAF's main mission is to operate and maintain the hydroelectric facilities (dams, power stations, HV lines and substations) with a view to generating hydroelectricity, transmitting the energy via pylons, delivering it to HV substations for distribution on the networks of the Electricity Companies of Mali, Mauritania and Senegal, and regulating the Senegal River.

3.1.1. Identification of Environmental Aspects and Impacts

The operation of these facilities and structures has resulted in the production of various types of waste, which are considered to be potential environmental aspects with significant environmental impacts.

- **Waste**

The inventory of types of waste has made it possible to classify them into 3 main categories: inert industrial waste (IIW), ordinary industrial waste (OIW) and special industrial waste (SIW) (**Table 1**) (CEREMA, 2010).

Table 1. Types of waste during the facility operation phase.

N˚	Waste	Types
1	Used batteries	SIW
2	Used gas cylinders	SIW
3	Cardboard and paper	OIW
4	Used ink cartridges	SIW
5	Soiled rags and used grease	SIW
6	Biomedical waste	SIW
7	Waste electrical and electronic equipment (WEEE)	SIW
8	Household waste	OIW
9	Plastic waste (packaging)	SIW
10	Waste water, sludge	SIW
11	Used oil	SIW
12	Used furniture	OIW
13	Paper and cardboard	OIW
14	Used metal parts	SIW
15	Used tyres	SIW
16	Green waste	OIW
17	Obsolete chemical products	SIW
18	Gravel	IIW

Environmental measurements of noise, light, magnetic and electric fields are carried out at Manantali in all work areas over a monthly period. Measurements of airborne particles, such as total particles, PM_{10}, PM_1 and $PM_{2.5}$, were carried out in the areas most frequented by workers or where they were most exposed, notably in the power plant, the administrative building and the housing estates, over a monthly period. These measurements were essential for characterising the extent of the environmental impact.

- **Noise levels**

Noise levels were analysed to determine minimum and maximum values in all Manantali work areas. Areas, where noise levels exceed 85 dB (WHO standard), are of particular concern. The results show high noise levels in the following areas: in the mechanical workshop (Min: 90.9 dB; Max: 103.3 dB), on level 155 of the power plant (Min: 89.3 dB; Max: 90.3 dB), in the turbine pivots of the power plant (Min: 92.8 dB; Max: 94.3 dB), at the control area of the power station (Min: 86.1 dB; Max: 87.4 dB), at level 149 of the power station (Min: 86.7 dB; Max: 87.3 dB), at the water tower pumps (Min: 91.3 dB; Max: 93.9 dB) (Figure 2).

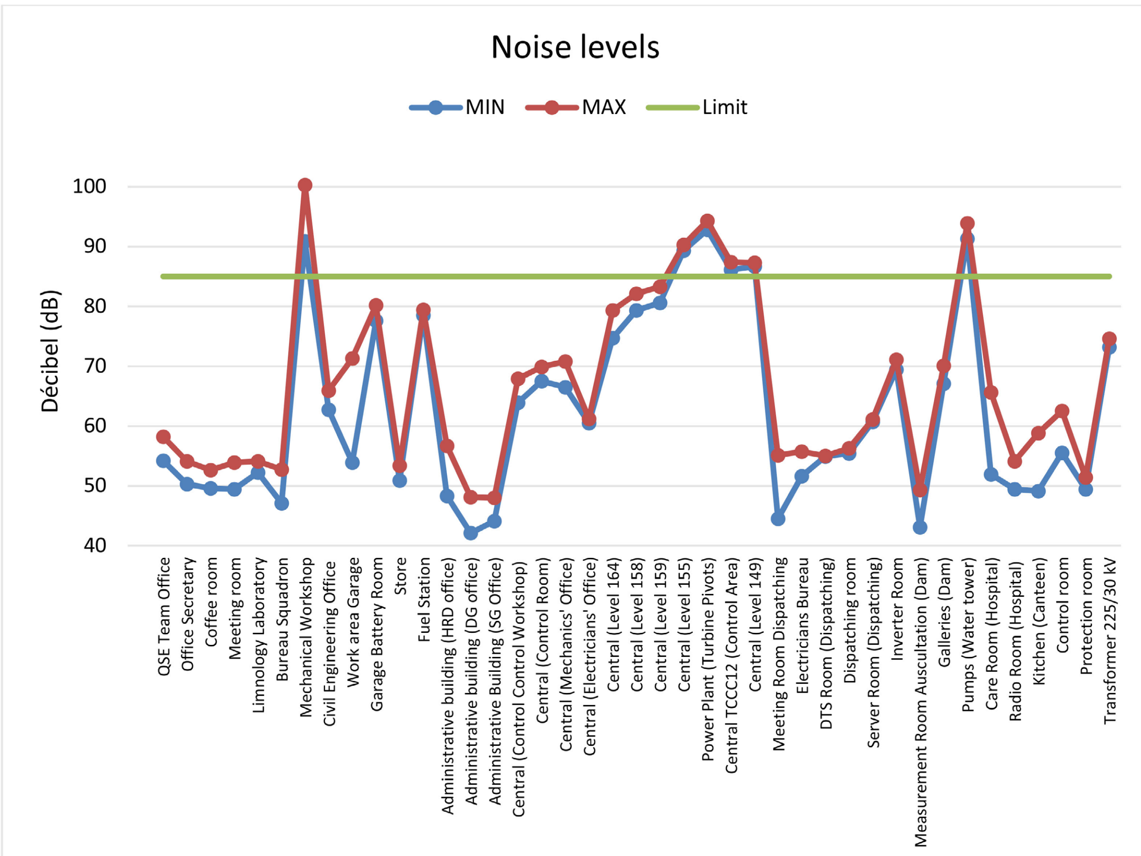

Figure 2. Noise measurements at Manantali facilities and structures.

- **Luminosity**

The analysis of light levels made it possible to measure the minimum and maximum lighting values in different work areas at Manantali. According to standard

EN 12464-1 on light and lighting in the workplace, the minimum value for average lighting is 100 lux, depending on the work area (AFNOR, 2003). Values below 100 lux were recorded in the Squadron Office (Min: 90.3 lux; Max: 96.5 lux), Civil Engineering Hall (Min: 37.9 lux; Max: 40.1lux), Barrage Galleries (Min: 0.6 lux; Max: 1 lux), Radiography Room (Min: 50.1 lux; Max: 50.7 lux), Kitchen (Min: 61.5 lux; Max: 78.6 lux), VIP Meeting Room (Min: 70.5 lux; Max: 94.8 lux) (**Figure 3**).

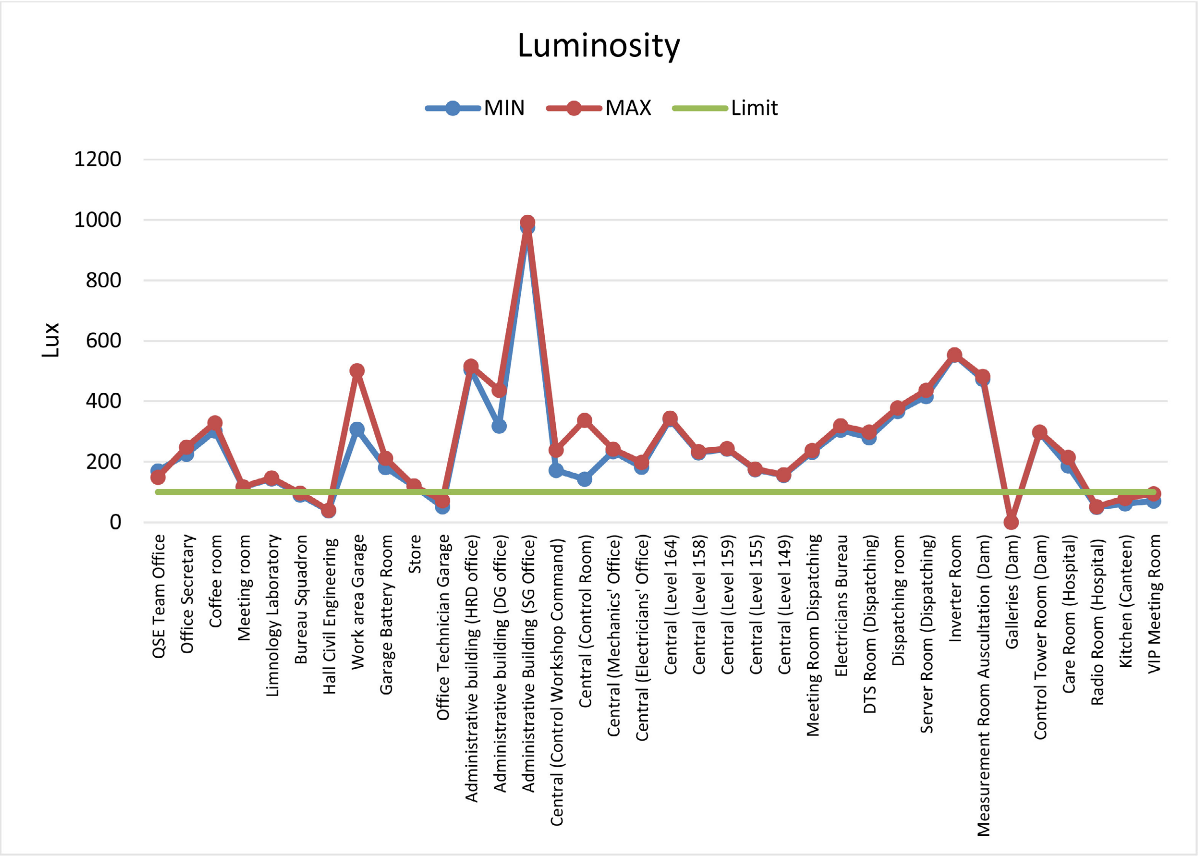

Figure 3. Luminosity measurements at the Manantali facilities and structures.

- **Magnetic field**

The data collected show that several measurements exceed the exposure limit value of 100 µT (ICNIRP, 1998), particularly under the east and west high-voltage lines (1995 and 1998 µT), at the power station, with values ranging from 104 µT (mechanics' office) to 1976 µT (Level 159), at the dispatching centre, with values ranging from 105 µT (server room) to 505 µT (inverter room), and at the entrance to the HV substation, with a value of 163 µT (**Figure 4**).

- **Electric field**

The data collected in the Manantali facilities and structures show that none of the measurements exceed the exposure limit of 5 kV/m (ICNIRP, 1998). However, some areas show particularly high electric field levels, notably under the East and West high-voltage lines (1474 and 1499 V/m) and at the entrance to the HV substation (403 V/m) (**Figure 5**).

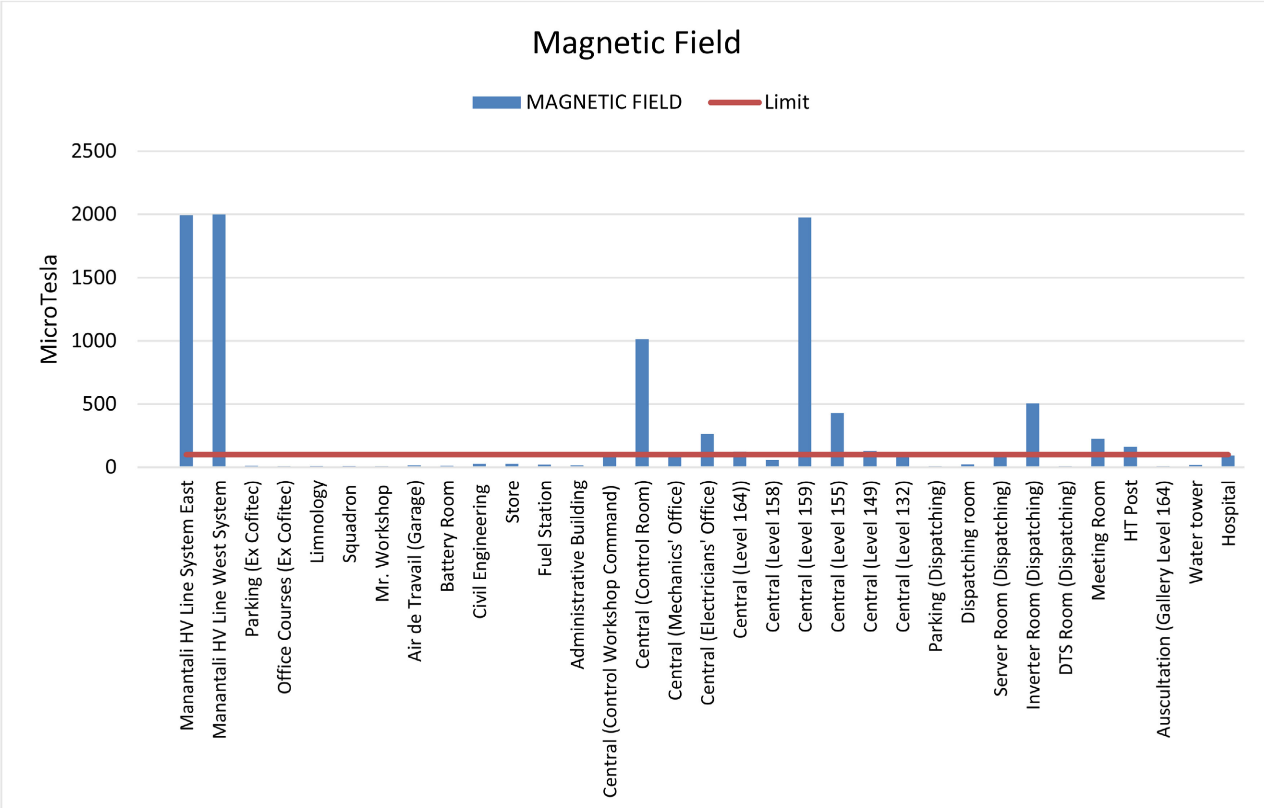

Figure 4. Magnetic field intensity.

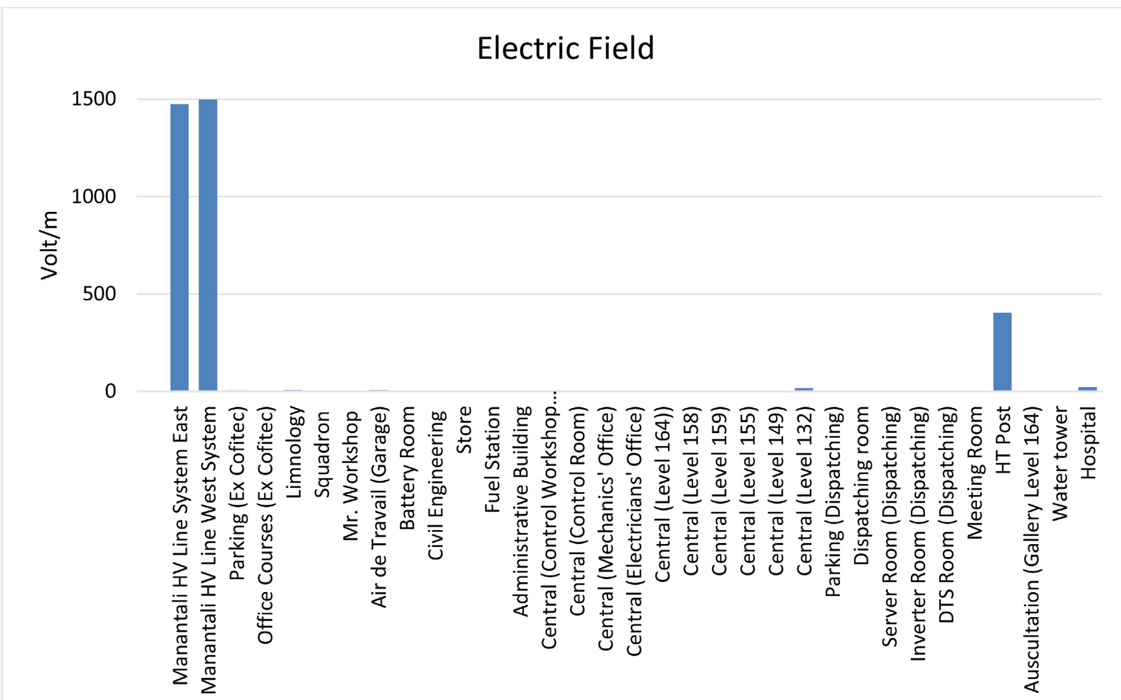

Figure 5. Electric field intensity.

Measurements of airborne particles are taken in the most frequented areas, notably the power plant, the administration building and the housing estates.

The data collected enabled us to determine the concentrations of total particles (all particles in the air), particles with a diameter of less than 10 micrometers (PM_{10}), particles with a diameter of less than 2.5 micrometers ($PM_{2.5}$) and particles with a diameter of less than 1 micrometer (PM_1).

- **Total particles (μg/m³)**

Measurements of total particles matter show a notable concentration of particles in certain specific areas of the Manantali site, with average concentrations of 2529.04 μg/m³ at level 154 m IGN (power plant turbine area) and 1761.96 μg/m³ at level 165 m IGN (power plant entrance hall). At the level of the administration building (the area closest to the hydroelectric works), the concentration of total particles is 230 μg/m³ at the level of the housing estates (approx. 7 km from the hydroelectric works). All values are within the Senegalese air pollution standard of 50 to 100 mg/m³ (**Figure 6**) (Senegalese Association of Standardization, 2003).

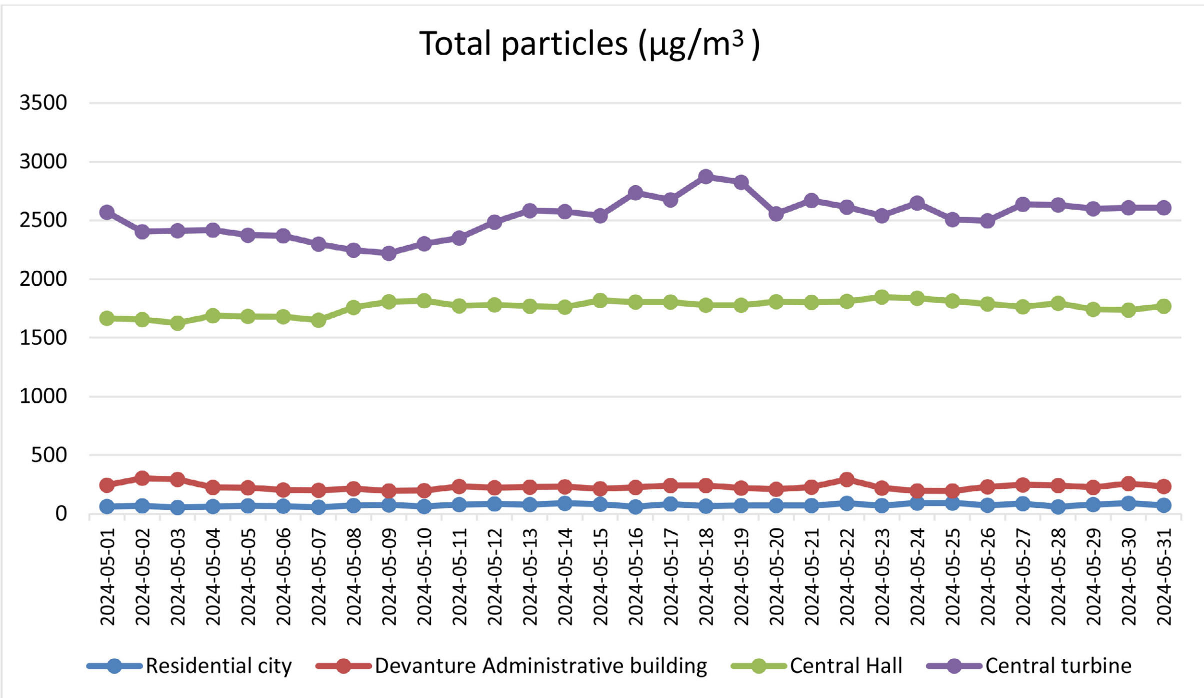

Figure 6. Total particle concentration.

- **PM_{10}**

Measurements of PM_{10} particles revealed high concentrations, particularly in the Manantali power station, with average monthly concentrations of 1495.88 μg/m³ and 1077.38 μg/m³ at levels 154 and 165 m IGN respectively. These values far exceed the Senegalese air pollution standard of 260 μg/m³. Average PM_{10} concentrations are lower at the administrative building and housing estates, with values of 96.57 μg/m³ and 35.58 μg/m³ respectively, which comply with the Senegalese standard (**Figure 7**) (Senegalese Association of Standardization, 2003).

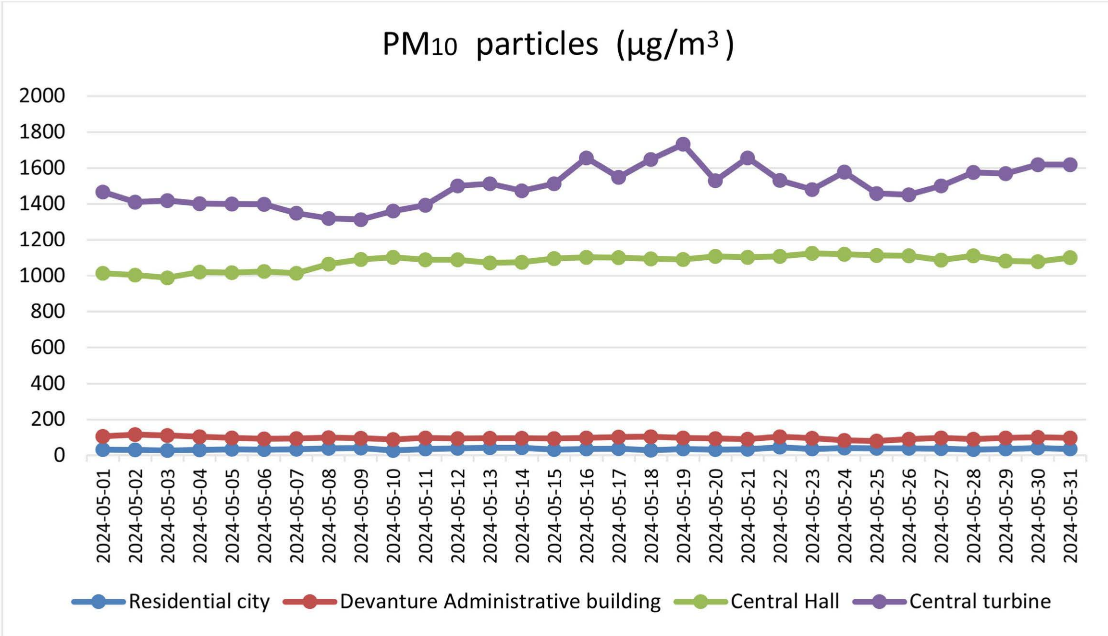

Figure 7. PM_{10} concentration.

- **$PM_{2.5}$**

Measurements of $PM_{2.5}$ particles show high concentrations at the power plant, with respectively 268.87 µg/m³ at the 154 m IGN level and 217 µg/m³ at the 165 m IGN level. These values far exceed WHO recommendations (15 µg/m³). Concentrations are lower at the administration building and housing estates, at 6.57 µg/m³ and 2.98 µg/m³ respectively, and are within WHO guidelines (Figure 8) (WHO, 2021).

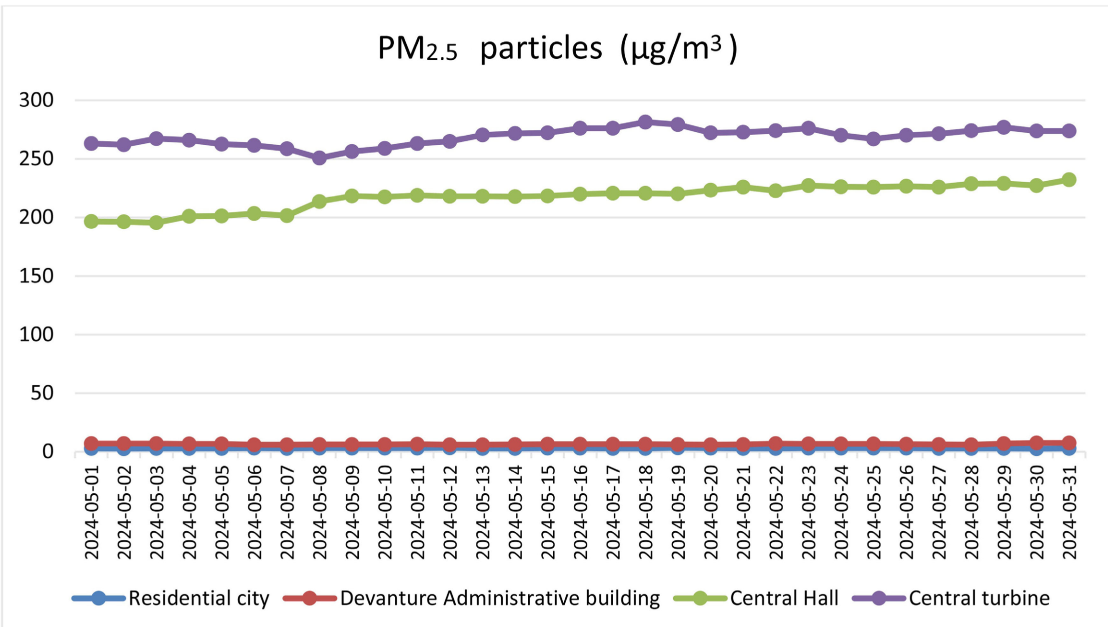

Figure 8. $PM_{2.5}$ concentration.

- **PM_1**

Measurements of PM_1 particles show high concentrations at the power station, with mean values of 40.30 µg/m³ and 32.84 µg/m³ respectively. PM_1 concentrations are lower at the administration building (0.97 µg/m³) and at the housing estates (0.40 µg/m³). No limit values for PM_1 were found in this study (**Figure 9**).

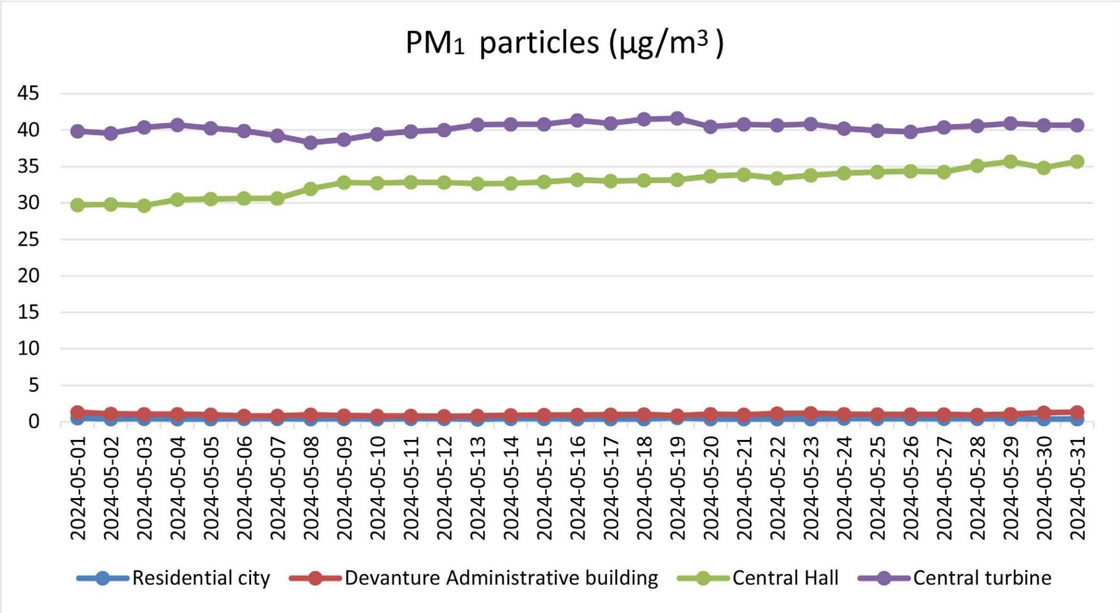

Figure 9. PM_1 concentration.

- **Results of fishing camp surveys**

The presence of the reservoir has encouraged the development of fishing camps around the lake. In August 2023, a survey carried out by SEMAF's limnology laboratory team identified 28 fishing camps around the reservoir, classified into three categories according to the duration of existence and the lifestyle of the fishermen: itinerant from the outset and inhabited by transhumant fishermen, temporary from one year of existence and permanent from five years of existence. Among these 28, there is one itinerant and one temporary camp. The camps are made up of 253 families comprising 2316 people, including 562 boys, 616 girls, 485 women and 653 adult fishermen who live exclusively from fishing. Fishing is done with motorized (334) and non-motorized (27) pirogues, using nets (3382), creels (3802), baited and non-baited longlines (258) (SEMAF, 2023).

- **Hydropower presence**

In addition to the electricity distributed to Sociétés d'Électricité (SdE) in Mali (EdM), Mauritania (SOMELEC) and Senegal (Senelec), the presence of hydroelectricity has enabled the electrification of the town of Manantali (the dam's headquarters), the 34 villages displaced when the dam was built, the towns of Mahina and Bafoulabé, villages in the Felou complex area in Mali, and the electrification of Bakel and Matam in Senegal and Gouraye, Sélibaby and Diaguili in Mauritania (SOGEM, 2017).

- **Water supply**

SEMAF supplies drinking water from four water towers, 2 of which are located in the village of Manantali. These towers supply drinking water to the entire village of Manantali and the surrounding area, and are fed by two drainage pumps, each with a capacity of 160 m^3/h. Every day, around 800 m^3 of water is treated and distributed.

- **Recruitment**

SEMAF currently employs around 400 people to operate the RIMA facilities. In addition, some 300 local service providers are hired for tasks such as security, maintenance, cleaning, carpentry, plumbing, etc.

- **Medical corps**

The medical corps provides health care for workers and the surrounding population, in particular almost all the villages in the 3 Bafing communes of Bamafélé, Diokéli and Koundian, which surround the facilities. As a result, the medical service has handled 10,242 consultations for 2023 and 9383 for 2022 (RGPH, 2013).

- **Different types of consumption**

In order to carry out the activities involved in the operation of structures and facilities, a number of items of equipment, materials, products, etc. are used and/or consumed. After use/consumption (end-of-life), most of them become waste, which has been inventoried. Depending on the quantities used and their hazardousness, they have a significant impact on the environment. They include oils, petrol, diesel, paper, ink cartridges, electrical and electronic equipment, water bottles, plastic bags, etc.

3.1.2. Identification of Significant Environmental Aspects (SEAs)

The types of waste, environmental measures, inventories, analyses and consumption are presented in the justification of environmental aspects, which summarizes the SEAs according to the impacts assessed as significant on the basis of the scoring grid.

The environmental analysis highlighted 16 significant positive and negative environmental aspects of the operation phase of the Manantali hydroelectric facilities and structures (Table 2).

Table 2. Significant environmental aspects of the operating phase.

N°	Significant environmental aspects
1	Water distribution and consumption
2	Fuel consumption
3	Brushing and weeding
4	Heat release, smoke from incinerator use
5	Spillage/spreading of fuels and oils
6	Noise emissions
7	Emission of fine particles, greenhouse gases and pollutants (VOCs, NOx, etc.) into the atmosphere

Continued

8	Fire and explosion
9	Presence of fishing camps
10	Presence of magnetic fields
11	Presence of medical corps
12	Waste production (DIS, DIB, DIN)
13	Hydroelectric power generation
14	Recruitment
15	Dam failure
16	Water release from the dam

3.2. Discussions

The operation of hydropower schemes has effects on the local and regional environment that raise important ecological, social and economic issues. These issues are reflected in both positive and negative impacts (Treabaol & Chabal, 2003).

The waste inventory shows 17 types of waste, of which 65% is SIW, 29% is OIW and 6% is IIW. All of this waste, with the exception of incinerated biomedical waste, is stored, whereas the main risk associated with storage activity is the contamination of soil, groundwater and surface water through the migration of leachates out of the storage area (Ding et al., 2001). The majority of these wastes constitute significant environmental aspects, and mitigation measures need to be put in place. All OIW can be used in composting, which represents a solution for enriching agricultural soils that are poor in organic matter (Tabet-Aoul, 2001). Waste production is more critical in developing countries, which do not always have the means to manage it properly. At the same time, the composition of this waste has shifted from an organic profile (food waste) to complex materials (end-of-life products, plastics and packaging) that present major risks for health and the environment (Holenu Mangenda et al., 2024).

WHO standards recommend a maximum permissible noise level of 70 dB in mixed residential areas, and 55 dB in public gardens and squares. In Senegal, Decree No. 2006-1252 of November 15, 2006, laying down minimum requirements for the prevention of certain physical environmental factors, stipulates in Article 14 that the level of daily noise exposure received by a worker throughout the working day must not exceed eighty-five (85) decibels (Senegal Official Journal, 2006). In the mechanical workshop, at the various levels of the hydroelectric power station and at the water tower pumps, the 85dB threshold is exceeded. It should be noted that, beyond its effects on comfort and quality of life, noise can also entail serious and multiple risks to human health, which can be classified into two categories: auditory and non-auditory effects (Van Oyen, 2010). On biodiversity, noise has a harmful impact on insects, birds, fish and mammals, especially those that use sound signals to communicate, find their bearings and move around. These changes in the characteristics of sound signals disrupt communication between these living beings, affecting their presence in urban space as well as their reproduction (Reijnen et al., 1996). In all work areas where noise levels are higher than normal, preventive and protective measures must be put in place.

Several reference values are given in the EN 12464-1 standard on light and lighting in the workplace, although we note that the minimum value, depending on exposure time, is 100 lux (AFNOR, 2003). A well-lit workstation avoids situations that can lead to various consequences: risk of accident, errors in task execution, visual fatigue linked in particular to deficient lighting, leading to a continuous effort of attention which is passed on to the eye muscles (accommodation and adaptation), central nervous fatigue resulting in a loss of vigilance efficiency (aggravating the risk of accidents at work and on the way to work) (CARSAT, 2022). In the context of this study, areas with low levels of illumination are seldom used, so the aspect relating to brightness is not considered an AES, but it is necessary to increase the level of brightness.

In many work areas, magnetic field values exceed the 100 µT limit. In the case of electric fields, no measurements reach the 5 kV/m standard. For almost 40 years, a succession of scientific studies have failed to show a direct link between electric and magnetic fields and an effect on health (Ledent et al., 2015). However, in view of the very high field strengths and the precautionary principle, the presence of magnetic fields is considered an SEA, and measures must be put in place.

The WHO's first recommendations focused on total suspended particulate matter in 1987, and in 2000 the WHO emphasized knowledge of the dose-response relationship for PM_{10} and $PM_{2.5}$ in order to assess the health risk according to the type of exposure (short- or long-term exposure). In 2005, the values proposed by the WHO were revised to take account of new studies on the health effects of air pollution published in the scientific literature (WHO, 2006). The global burden of disease associated with exposure to air pollution is taking a heavy toll on human life worldwide: according to estimates, exposure to air pollution is the cause of millions of deaths every year. Estimates show that the burden of disease attributable to air pollution is now comparable to other major global health risks, such as unbalanced diets and smoking; air pollution is currently recognized as the most significant environmental threat to human health (WHO, 2021).

PM_{10} and $PM_{2.5}$ come from a multitude of emission sources and physico-chemical transformation processes in the atmosphere. Emissions result from natural phenomena (desert sand, sea salts, volcanic eruptions, forest fires, etc.) and human activities (industry, transport, agriculture, heating, etc.). Secondary emission particles are formed in the atmosphere from precursor gases such as sulfur dioxide, nitrogen oxides and nitrates, volatile organic compounds and ammonia (ANSES, 2019). In the context of this study, the presence of particulate matter is considered to be an AES, requiring the implementation of mitigation and attenuation measures.

The presence of fishing camps in the vicinity of the Manantali reservoir has led to the development of fishing activities and the presence of water-borne diseases (bilharzia, malaria, etc.). Fishing in Mali is far from being a marginal activity, even though the country has no outlet to the sea. Like Manantali, with the construction of the Sélingué hydroelectric dam, completed in 1980, many nomadic fishermen left their fishing grounds in the central Niger Delta to settle around the reservoir (Togola, 2009). Dam sites and their perimeters are subject to hydrological, geodynamic and ecosystem changes, favoring the transmission of water-related diseases and the proliferation of certain disease vectors (Ripert et al., 1979; Atangana et al., 1980; Philippon & Mouchet, 1976). Another negative consequence of the creation of vast bodies of water in tropical environments has been the multiplication of habitats eminently favourable to numerous anopheles insects, simulium, tsetse flies and other vectors of endemic diseases (Charest, 1992).

Hydropower production has, as one of its IES, the contribution to reducing the country's electricity deficit and improving living standards both upstream and downstream of the dam. Hydropower is one of the solutions that can help African countries make a success of their energy transition. It helps achieve at least two of the seventeen Sustainable Development Goals endorsed by the United Nations General Assembly in September 2015: "Ensure access to reliable, sustainable and modern energy services for all at affordable cost" (Goal 7) and "Take urgent action to combat climate change and its impacts" (Goal 13) (Fondja Wandji & Kamdem, 2020). Hydropower generation on the RIMA has played a crucial role in improving the quality and continuity of electricity supply in Mali, Mauritania and Senegal. This network provides a significant share of the electricity supply in these countries, covering 40% - 50% of Mali's needs, 10% - 12% of Senegal's and 20% - 30% of Mauritania's. Hydropower has considerably reduced dependence on diesel thermal generation, which is not only costly but also highly damaging to the environment. Savings estimated at around €1440 million over the period from 2002 to 2016 for the three countries as a whole are as follows: €859 million in Mali, €393 million in Senegal and €188 million in Mauritania. (SOGEM, 2017).

The presence of the medical corps has as its IES, the improvement of the population's state of health. For health monitoring purposes, a Company Medical Service has been set up at Manantali, whose main mission is to monitor the state of health of workers according to their age, health risks and the arduousness of their work, as well as their dependents. The department comprises a hospital and a dispensary. It carries out occupational health actions to safeguard workers' health throughout their career, and also provides free medical care to the surrounding population (Barel & Frémeaux, 2015).

Water distribution and consumption is focused on improving access to drinking water. Water treatment is carried out by specialized operators, while the potability of the water is regularly monitored by SEMAF's Limnology laboratory and every six months by the National Water Laboratory of Mali (SEMAF, 2023). The water towers supply drinking water to the entire village of Manantali and the surrounding area.

Local recruitment has as one of its IES, local job creation. Staff recruitment at

SEMAF follows a well-established procedure. This process begins with the expression of a need, followed by the drafting of a job description. Recruitment notices are published in the official newspapers of OMVS member countries for managerial positions, while advertisements for non-managerial staff are only published in Mali.

Fuel consumption is linked to emissions of fine particles and pollutants (VOCs, NOx, etc.) into the atmosphere, the main problem being health and the increase in greenhouse gases. Toxicological studies have been carried out to assess the biological effects of particles produced by diesel combustion, using various approaches in vitro (cell cultures), in vivo (in animals) and in humans exposed to exhaust gases (AFSSET, 2009). Diesel particles are respirable particles with mutagenic and carcinogenic properties. Like all fine particles (below 10 µm and even below 2.5 µm), they have harmful effects on the respiratory and cardiovascular systems. The toxicity of engine emissions, resulting from the combustion of hydrocarbons, is all the more complex as the products of which they are composed are multiple. The toxicity of engine emissions is linked to particles made of carbon (free carbon or solid products very rich in carbon) and to the gaseous phase (consisting mainly of carbon monoxide, nitrogen oxides, sulfur dioxide and its derivatives, and polycyclic aromatic hydrocarbons) (CERES-ERTI, 2015). In terms of the carbon footprint of fuel use, diesel produces 2729 g eq·CO_2/liter and gasoline 2317 g eq·CO_2/liter (MELCCFP, 2022). In addition to fuel consumption, it should be noted that, according to the World Commission on Dams, all reservoirs sampled to date by scientists produce greenhouse gases, like natural lakes, as a result of the decomposition of vegetation and carbon inputs from the catchment area (CMB, 2000). However, the volume of these emissions is highly variable. A Brazilian researcher, Fearnside, has produced results showing that some artificial reservoirs release very large quantities of greenhouse gases (CO_2 and methane). For example, the Balbina reservoir near Manaus in Amazonia is said to have released 10 million tons of CO_2 and 150,000 tons of methane in its first year of operation in 1988 (Fearnside, 1997).

The release of heat and smoke from waste incineration has been identified as an AES and is often associated with a health risk. Scientists have identified over 200 toxic substances resulting from incineration, including heavy metals, unburned substances and new chemical compounds obtained by molecular recombination, which can be potentially more toxic than the initial ones. High-temperature combustion releases metals (lead, cadmium, arsenic, mercury, chromium) in the form of micro-particles (DPPR, 2007).

Clearing brush and weeds destroys habitats and ecosystems, degrades the landscape and disrupts biodiversity. The width of the corridor (right-of-way) reserved for the 225 kV line is 40 metres (20 metres on either side of the line axis). This corridor is one of the components of the RIMA and has been declared to be in the public interest. This reserved right-of-way width has been established to ensure the safety of the line itself and the local population (OMVG, 2019). To prevent vegetation from causing problems on HV lines and pylons, the right-of-way is regularly maintained. In the case of lines crossing wooded areas, clearing brush and weeds can alter and disrupt the terrestrial habitat and, in particular, have adverse effects on avian species, thus increasing the risk of forest fires (IFC, 2007).

Dam failure leads to flooding and destruction of property. Considering all dam failures in the world since 1800, whatever the height of the dam, there have been 144 dam failures: 71 without casualties, 31 with fewer than 10 deaths, 17 with 10 to 99 deaths, 25 with 100 or more deaths (MEDD, 2004). The states that make up the OMVS, as elsewhere, face a number of natural disaster risks, in particular meteorological and hydrological catastrophes such as droughts, floods, storms and so on. In response to these hazards, OMVS has embarked on the construction of major structuring works. However, certain natural flood risks remain significant, and other technical risks (failure of structures, breakages, etc.) can be added to them. It is against this backdrop that we propose to set up a warning plan for the Senegal River basin, based on a failure scenario involving a combination of stress and a failure mechanism under the effect of this stress (OMVS, 2021). Given the seriousness of dam failure, all the measures proposed in the warning plan must be implemented.

Fires and explosions result in soil, air and water pollution, as well as an increase in the volume of waste. They are generally distinguished by the nature of the products initially involved, with impacts on the atmosphere via fire fumes and induced deposits, as well as impacts on soil and water via extinguishing water (INERIS, 2023). Given the seriousness of fires and explosions, emergency management measures must be identified, planned and implemented.

When the reservoir exceeds elevation 208.05 m, the dam's operating instructions impose a certain amount of spill through the surface gates to prevent them from being submerged (Bader, 2001). This situation causes a rise in the water level downstream of the dam, which can lead to flooding, resulting in damage to people, economic losses and temporary degradation of the environment. In view of the fact that a number of people living downstream of reservoir dams believe they are protected from flooding, in the event of an intense flood event the reservoir would no longer be able to store water above a certain limit (Metzger & Linton, 2016).

4. Conclusion

Environmental measurements, including noise levels, luminosity, airborne particles, magnetic and electric fields, and waste inventories based on different consumption patterns, have enabled risk areas to be mapped. This mapping was essential in determining the areas requiring mitigation and attenuation measures in order to effectively manage environmental impacts and improve the management of significant aspects. The in-depth environmental analysis made it possible to classify the aspects and impacts according to their significance. At the same time, some positive significant environmental aspects were identified to highlight the benefits associated with the operation of the hydroelectric facilities and works.

The study is based on data collected at company level and does not specify the various measures to be implemented. Further studies are needed to determine the mitigation measures to be implemented using a Results-Based Management (RBM) approach, which will make it possible to determine the activities to be implemented, the outputs and the effects in order to achieve the final results known as the objectives. These measures can be used to determine environmental management strategies for the operation of hydroelectric facilities and structures. Once the objectives have been set, the environmental performance indicators can be identified and compared with the indicators from the construction phase.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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