Application of DPSIR framework to analyze the groundwater pollution threats of municipal solid waste: Case study Médiouna Landfill, Morocco.

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Abstract. This study addresses the issue of groundwater resources quality affected by solid waste disposed of in the Médiouna dumping site. In this order, we applied the Driving force- Pressure- State- Impact Response model (DPSIR) model combined with external factors of SWOT analysis (Opportunities and Threats) to assess the environmental impact of waste from Médiouna landfill on groundwater. The analysis study revealed that the continuous demographic expansion and economic growth made solid waste a complex problem. The study highlights the urgent need for implementing new strategies and redesigning more effective, operational and realizable management projects to rehabilitate the Médiouna landfill. In addition, the integration of all stakeholders, including Médiouna residents and informal waste pickers, in the management operations is indispensable for the success of these operations. Further environmental impact assessment must be done while valuing the Médiouna dumping site by adopting landfill-mining concepts is mandatory for efficient waste conversion in Casablanca.

1 Introduction

Water is starting to be one of the biggest challenges facing the world. Because of the increasing pollution pressure, climate change, and the growing need for clean water, the protection and preservation of water resources is becoming of great concern for the decision-makers and stakeholders around the world [1-6]. Solid waste has also received increasing attention in recent years because it poses soil-groundwater resources-crops-the human systems at risk. Based on the World Bank Group (WBG) data, the total generation of municipal solid waste (MSW) worldwide is 2.01 billion tons year^{-1}, projected to reach 3.40 billion tons by 2050 [7]. This huge amount of MSW can result in environmental and health problems, mainly in low-income countries and middle-income countries, especially that the generated waste content and management rate are unbalanced.

The landfill leachate is produced by leaching soluble compounds through non-uniform and intermittent water filtration by the waste and organic substances bacterial degradation [8]. The quality and quantity of leachate could change according to water availability, weather conditions, characteristics of waste, the underlying soils, and the landfill's fermentation degree, among other factors [9-10]. When generated by solid waste disposed of in dumping sites, this leachate could seep through the soil and reach the water. This leachate contains various toxic elements, including persistent organic pollutants and heavy metals that might cause soil quality degradation [11] and groundwater contamination [12]. Landfill leachate will cause groundwater pollution and soil degradation resulting in aquagenic diseases if the human body is exposed to water polluted by leachates through drinking or bathing [12]. For instance, drinking water polluted by leachates (containing heavy metals such as arsenic and manganese) might cause a deficiency in intellectual functioning among kids, as reported in studies carried out in Bangladesh [13], in Korea [14] and U.S [15].

Médiouna is the biggest landfill site in Morocco, located in the old quarries of Casablanca (in the road connecting Casablanca to Marrakech). Because Médiouna dumpsite has not a bottom collection system of leachate generated during landfill processes [16], many studies were carried out in order to assess the contamination level of water [16-20], soil quality [21], and to find a solution for produced leachate by Médiouna landfill [22-24].

Médiouna landfill has operated since 1986 and receives about 5000 tons/day of waste from the whole of Casablanca while the piled up waste rises to around

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50 meters [25]. The type of solid waste that the landfill receives can be inorganic/organic, non-hazardous and hazardous [21, 26-27]. Waste dumping has been heavily affecting the environment because of leachate intensification in the ground soil and resulting dioxin gas from trash incineration [28]. These environmental challenges lead the government to delegate waste management activities to private operators [28]. The rehabilitation operations were unsuccessful, while stakeholders are still calling for its closure [29].

In the present study, we applied the DPSIR framework combined with external factors of SWOT analysis to help understand the effects of solid waste dumped in Médiouna landfill on groundwater, soil and environment and investigate what opportunities and threats can present this waste at economic, societal and ecological scales.

2 Methods and Material

2.1 Literature review

We conducted a literature review by exploiting available online databases and internet search tools including Science Direct, Web of Science, and Google Scholar to execute a bibliographic database based on peer-reviewed scientific publications, thesis and non-peer-reviewed consultancy, books, and technical reports. The literature review was focused on the studies related to groundwater pollution, leachate, municipal solid waste, ecological impact, impact on human health, landfill, Médiouna landfill, and solid waste management. The search was carried out in English and French.

2.2 Driver - Pressure (Opportunities-Threat) - State- Impact- Response (D.P.-(O.T.)-SIR)

Based on the recommendation of the European Environmental Agency (EEA) for establishing an approach for Integrated Environmental Assessment [30], the National Institute of Public Health and Environment (RIVM) proposed the utilization of a framework that define driving forces (D), pressures (P), states (S), impacts (I) and responses (R). Since then, this framework has been widely used by the EEA.

The DPSIR framework presents a chain of causal links. This chain starts with "Drivers or driving forces" mainly related to the human activities (e.g. industrial, agricultural and transport activities), which cause "Pressures" such as waste and pollutants emissions; this leads to "states changes" (e.g. biological, physical or chemical modification of a system). The change of a system state could impact ecosystems, human health, and functions according to the type of state change, leading to political "responses" (restoration and management projects, indicators). In the present study, we applied the DPSIR model to analyze the MSW and groundwater pollution to provide a coherent and comprehensible structure for integrating data and information of ecological and socio-economic interactions allowing practical environmental assessment [31-32]. We combine the DPSIR framework with external factors of the SWOT model (Opportunities and Threats) to provide solutions for solid waste problems, define the possible opportunities that MSW could provide, and analyze the possible threats related to mismanagement of MSW (Fig.1).

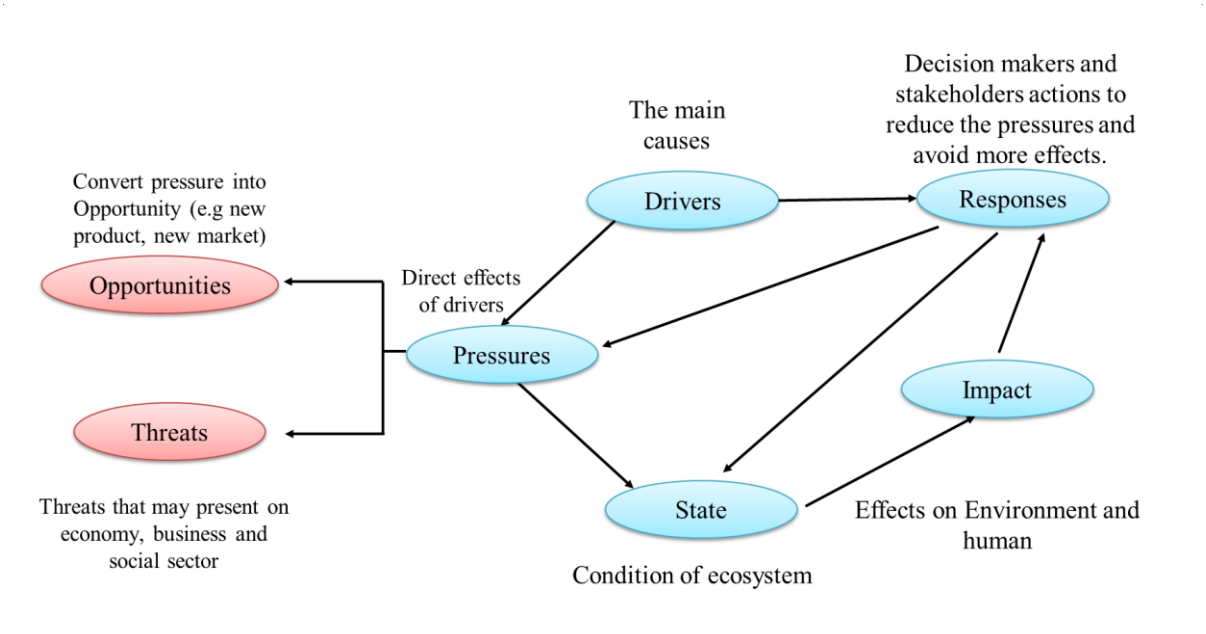

Fig.1. DPSIR Framework (Driver-Pressure (Opportunities-Threat)- State- Impact- Response (DP-(OT)-SIR)).

3 Results & Discussion

3.1 Literature review

The Médiouna landfill is situated on the fringes of Casablanca city (Fig. 2). It extends over 70 hectares and receives 5000 tons/day of waste. This landfill was

opened in 1986, and until today, it receives waste from the whole of Casablanca, which contains domestic, industrial, medical, and hospital waste discharged directly without prior treatment [16, 20]. Around 3500 tons of domestic waste reached the Médiouna landfill by 750 garbage compactor trucks and discharged into the trash mound that currently reached 50m in height, while 3000 tons of industrial and hospital waste without pretreatment are daily discharged also in the landfill [33].

The huge amount of waste the landfill receives without a leachate collector system or waterproof device has increased the concern about the consequences of landfill leachate on the environment and human health. The reported quantity of leachate in 2007 was 1277 m3/day, which poses a threat to the groundwater as stated in [16-19, 21]. In the latest study on the landfill's impact on groundwater quality [18], significant degradation of groundwater quality was recorded while the metals concentrations exceeded the standards values for drinking water and irrigation water. Besides, a study carried out by Fekri et al. 2007b [34] aimed to assess the origin of groundwater contamination by using stable isotopes as an index of groundwater pollution has confirmed the presence of leachate contamination. It should be noted that the first detection of aquifer contamination by landfill leachate was reported in 1990 by [35].

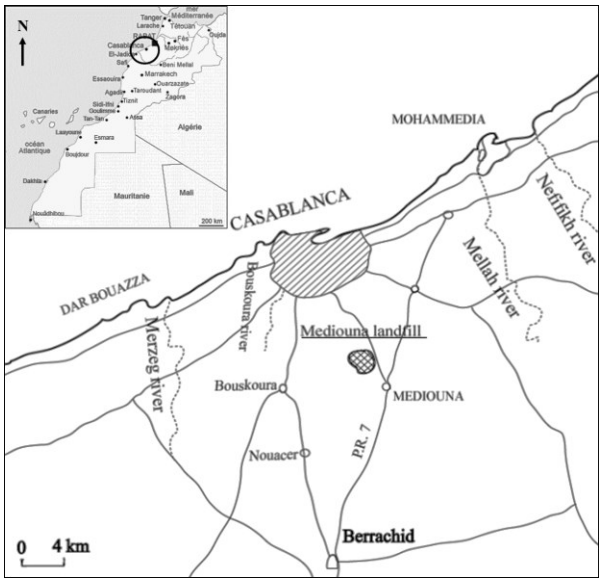

Fig. 2. Study area.

3.2 Driver-Pressure (Opportunities - Threat) – State - Impact- Response (D.P.-(O.T.)-SIR)

3.2.1 Driving forces

The demographic expansion that known Moroccan kingdom since the early 90's where the urbanization rate had increased from 26% in 1950 to 46% in 1990 [36], and environmental migration resulting from the severe drought events that dominated the country during the 1980s and 1990s has increased the urban population where the rural migration to urban areas such as Casablanca has significantly increased [37] which contributed to MSW increase. Besides, a study carried out to understand Morocco's environmental migration showed that people leave their home villages to big cities to look for jobs and because there are more schools and medical facilities [38]. These factors lead to consumption increase, human needs and demand rise, leading to waste disposal increase. Therefore, the industrial and agricultural activities growth in response to population needs and demand are among the factors contributing to the increase of related waste disposal. Worthily noted that the opening to new industrial activities such as tourism [39], especially Casablanca, is the largest Moroccan city known as the 'cosmopolitan, industrial and industrial economic heart of the country; thus, the city has known a significant growth of the business tourism. Accordingly, the growth in such type of tourism was supported by implementing several projects and facilities, including hotels and restaurants where Casablanca hosts more than 780 restaurants [40] which means more food waste will reach the Médiouna landfill.

3.2.2 Pressures (Opportunities & Threats)

The demographic development and economic activities growth result in many pressures on the environment. These pressures can be translated by the increasing trend of generated waste resulting from mismanagement, inadequate disposal of waste, and the absence of sorting waste culture among the population. The possible impact of the huge amount of waste dumped in the Médiouna landfill was widely studied but not enough to identify them accurately. The studies carried out in the landfill area, and surrounding areas show evident contamination of groundwater and soil by landfill leachate [16, 20]. In addition, the emission of toxic pollutants through the incineration of waste affect the air quality. Furthermore, the landfill occupied 70 hectares of land, which is a form of overuse of the land area. Another form of pressure caused by the landfill of Médiouna is the visual pollution, especially the piled up waste that rises to a height of around 50 meters [33].

We choose to combine opportunities and threats with pressure and not with another causal link because if we convert these pressure into opportunities while reducing related threats, the state will not largely change. Through our investigation, we recognized that the continuous disposal of different types of waste in the Médiouna landfill threatens soil, air, and groundwater because of the mismanagement of this waste and mainly due to the disposal of waste without prior treatment. However, these pressures that pose waste disposal in this dumping site could be converted into opportunities (Adopting landfill-mining concept), which consist of the following steps:

1) Creating a centre for recycling waste and integrating informal waste pickers and rubbish pickers

- First, adopting the concept of sorting waste at the source and making people aware of the importance of sorting waste before disposal.

- Secondly, provide informal waste pickers and rubbish pickers by the protective equipment and safety items, integrate and make their work more formal.
- Creating a centre for recycling waste, recruiting and training the informal waste pickers and rubbish pickers as they are used to collect and sort waste (Plastics, papers, ..).

2) Producing/ ecological landfill-mining/Energy recover

The opportunities could be producing new products/ items based on recyclable plastic waste, paper, glass or metals, as shown in figure 3. The products and items could be reusable and eco-friendly bags, Agri tools (e.g. nylon), recycled fibre from plastic bottles used for making textile and clothing (e.g. Aquafil company).

Converting these pressures related to the Médiouna landfill into such opportunities would make the rehabilitation of this dumping site easier, minimize the related threats, and provide local environmental and social benefits. Besides, energy recovery through waste incinerators seems to be an adequate and efficient solution for managing Casablanca waste. A study carried out by Chouihi, 2016 [28] applied the circular model and showed that Médiouna's landfill comprises a great potential but is poorly exploited. The estimated total capacity is 3.09105MWh, with 59475 tons of compost and recyclable material with an NPV of about 12 billion MAD.

It is worth noting that MSW threatens the environment and the economic sectors at all scales, reduces industrial and economic investment, and threatens the tourism industry as it is mainly based on environmental quality [39].

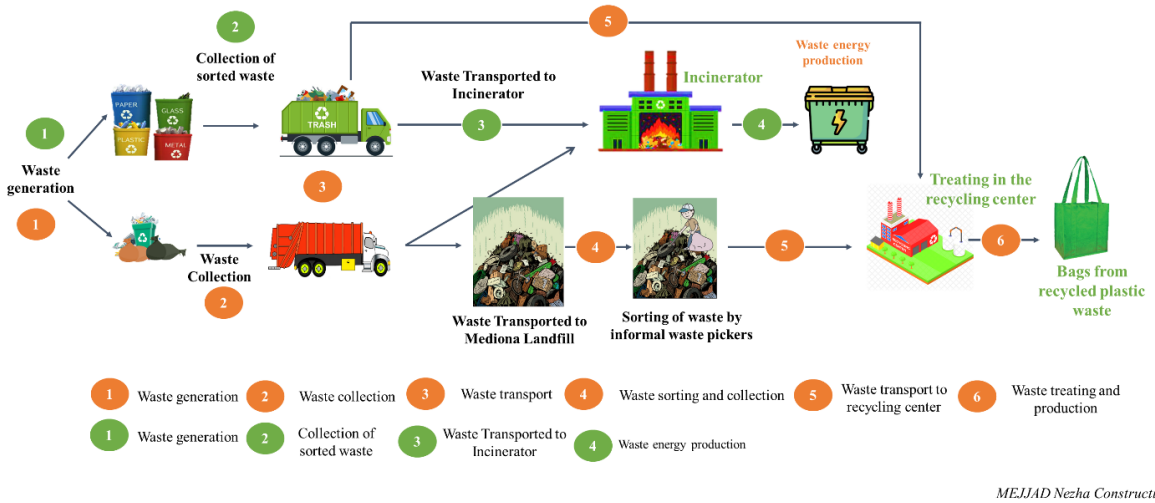

Fig. 3. Recycling waste steps from waste generation to waste-mining.

3.2.3 state of change

Médiouna landfill is still receiving the whole Casablanca waste, and the mound height still increasing. Several landfill fires, widespread leachate outbreaks, and plumes of toxic smoke were incessantly running and blowing off the area. The state of Médiouna landfill exhibits poor environmental quality linked to mismanagement and the absence of sorting waste culture for recycling purposes. Besides, the lack of awareness among the area residents regarding the landfill danger to human well being (health, socio-economic components) made its management and rehabilitation more challenging. Some initiatives are aimed at recycling waste, but it is still not enough to face the increasing quantity of waste the Médiouna landfill receives daily.

3.2.4 Impacts

The direct impacts of the Médiouna landfill are on human health and the environment. The mismanagement and the disposal of untreated solid waste in this open dumpsite result in the emission of toxic and hazardous substances that impact groundwater, soil, crops, and consequently, human health. The impacts of MSW can be understood through defining the main dangerous substances generated, which are as follow:

Toxins are venomous substances, particularly protein, formed by organisms or living cells and can cause disease when they penetrate the body tissues, but at the same time, this protein is often capable of prompting neutralizing antitoxins or antibodies [39].

Leachates is defined as a liquid that leaches or drains from a landfill. This liquid composition varies according to the landfill ages and type of waste that it contains. In the Médiouna landfill, the daily estimated amount of generated leachate was 1277 m3/day, recorded in 2007 [18]. Hydrochemical analysis carried out on groundwater in the vicinity of the dumping site has shown that the analyzed groundwater is rich in organic and inorganic chemicals (e.g. cadmium; Chromium, chloride) mainly related to the leachate infiltration to the aquifer, causing the quality deterioration of water, soil degradation.

Greenhouse gases (GHG): The organic waste (e.g. food scraps) disposed of in an open dumpsite usually is compacted and covered, leading to oxygen removal and its break down in an anaerobic process. Ultimately this releases methane, a GHG that is 23 times more

dangerous than carbon dioxide [41]. The implications of this gas for climate change and global warming are vast [42].

These generated toxic substances and GHG emitted by MSW have surly an impact on the environment and consequently human life, health and well being. To our knowledge, there is no scientific study or case study that analyzed how the released substances or gas affect the resident population of Médiouna. Thus, we will focus our analysis on the impact on groundwater and the socio-economic components of the city.

We understand now that the mismanagement and negligence of the waste pre-treatment before the disposal in such a landfill with particular characteristics (open dumpsite, without the waterproof device, deprived of leachate collector) put pressure on the water table and the whole system, including soil and plants. This has lead to a state change in water quality since 1990. Fekri et al., 2007b [34] reported that a leachate plume has polluted the Médiouna local aquifer and highlighted a progressive movement of this plume in the direction of the Casablanca town with a continuous deterioration of groundwater quality as the majority of analyzed water samples collected from wells shown poor quality.

Groundwater pollution impacts human health and social and economic sectors [43]. The deterioration of water quality directly affects the agriculture industry as it mainly depends on water, leading to food depletion and increasing the dependency on the international agrifood market. It was reported that the groundwater aquifer quality of zones situated near to Médiouna landfill is poor [44]. [45] stated that the surface water quality is generally degraded, especially at Oued Hassar Médiouna, where the recorded concentration of dissolved solids was 1400mg/l. The water and soil quality degradation could affect farmers, households, agricultural shops, and markets, leading to job losses; especially, the agricultural surface of Médiouna covers 14,862 ha, representing 22% of the regional surface area Casablanca region [46]. Besides, other economic industries can also be impacted, such as tourism and aquaculture/fisheries, which depend on environmental quality and ecosystem services, while the investment rate could be threatened as well. To be noted that the agricultural area declined during the period extending from 1976 and 1996 by 11,876ha (21% of the UAA) in Grand Casablanca, which included a loss of 363 farms [47].

Moreover, presently the landfill presents a significant risk of explosion because of the amounts of biogas in case there is infiltration of oxygen. It should be noted that the biogas contains 65% of methane, which is an enormously flammable gas, and the risk increase when the quantity of biogas is large (Ecomed Casa).

3.2.5 Response

The continuous growth of waste amount in the Médiouna landfill, which is almost saturated (90%), leads the authorities to implement actions and plans for rehabilitating this landfill, especially citizens, national NGO's and associations were mobilized to increase the awareness about the threat that put this open dump to the environment and human health, and they called for its closure. For these reasons and as responses to these challenges, the government has decided to delegate the waste management activities of Casablanca to private operators in 2004 (Tecmed, Sogadema and Sita El Beida) [28]. The main events aiming at rehabilitating the Médiouna landfill since its opening in 1986 are depicted in figure 4.

The landfill site was prepared for renovation after the closing, while a new landfill and mechanical biological treatment were proposed to be set up next to the current landfill and cover 40ha. In 2008, Ecomed was delegated to manage Médiouna landfill MSW for a contract life period of 18 years. The contract clauses are as follow [48]:

- Dedicating the two first years for landfill rehabilitation and closure.
- Installing 48 biogas evacuation wells.
- Setting up a sorting zone of a surface of 7000m² and reintegrate around 250 rag pickers operating in the Médiouna landfill.
- Reduction of CO2 emissions.
- Producing fuel, among others sections.

Chouih, 2016 [28], in his study (carried out in 2016) has reported the main achievement of Ecomed as follow: i) the rehabilitation process was done through biological treatment of soil leachate (40cm); Gravel (drainage); Vegetal soil (60 cm), ii) installation of 4/48 wells for biogas evacuation. It was reported study also that the project progress has slow down because of many reasons, including [48]:

- The site community acts of vandalism, such as the destruction of a well.
- More than 900 scavengers are present on the site.
- Inability to confine the waste.
- Lack of security on the landfill (Municipalities do not take responsibility to ensure it).
- The management conditions are hard to achieve (e.g. low level of oxygen, low level of humidity; compact and confined waste).
- The difficulty in establishing "Home-sorting" and involving the citizen in this process is linked to social and financial feasibility.

After ten years (2018), the contract was suspended, and the city accuses the company of not fulfilling its obligations, such as the rehabilitation and closure of the landfill in the two first years while only three three biogas wells were constructed instead of 48 (The Climate Chance Observatory team, 2020). These three wells are currently blocked with piles of waste [48].

After the suspension of the contract with Ecomed, SOS NDD has taken the over management of Médiouna landfill since July 2018. The contract between the city council and SOS NDD includes only landfill waste management and does not include leachate management, which opens many questions about the soil and water quality deterioration because of leachate [48].

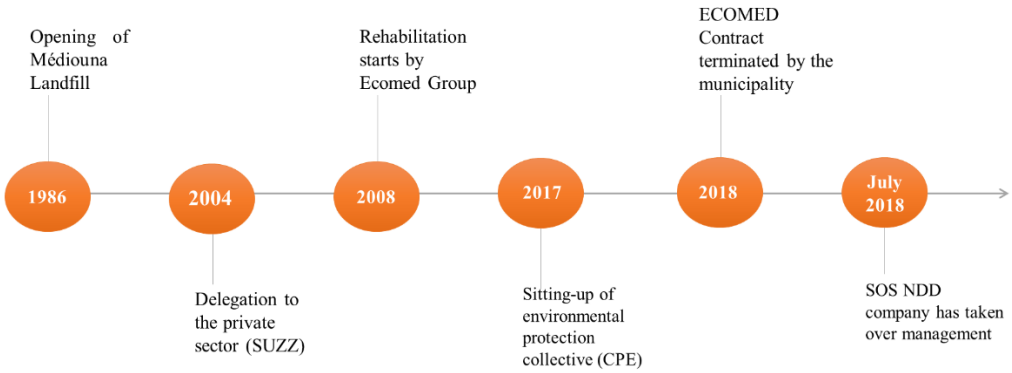

Fig. 4. Timeline of Médiouna's main events (1986-2018).

4 Conclusions

The study tried to expose the current state of the Médiouna landfill through investigating the available data and information. The analysis consisted of using a conceptual framework to understand better the Médiouna landfill impact on groundwater resources and the environment, human health, and well-being. The analysis showed a lack of actions toward rehabilitation of this landfill, while the quantity of waste has become hard to manage.

We conclude that the absence of a long-term management strategy that assesses landfill waste is the leading cause of the current situation as the generated waste content with management actions rate are unbalanced. Besides, the lack of awareness among the area residents regarding the landfill danger to human well being (health, socio-economic components) made its management and rehabilitation more challenging or even impossible. Thus, we recommend starting with community awareness and integration in the decision-making to avoid the conflict of interest and successfully manage this dumping site.

However, further investigation and risk assessment of the Médiouna landfill leachate needs to be conducted as data and information remain insufficient to accurately analyze the current state and provide adequate recommendations for efficient waste conversion and exploitation of the Médiouna landfill.

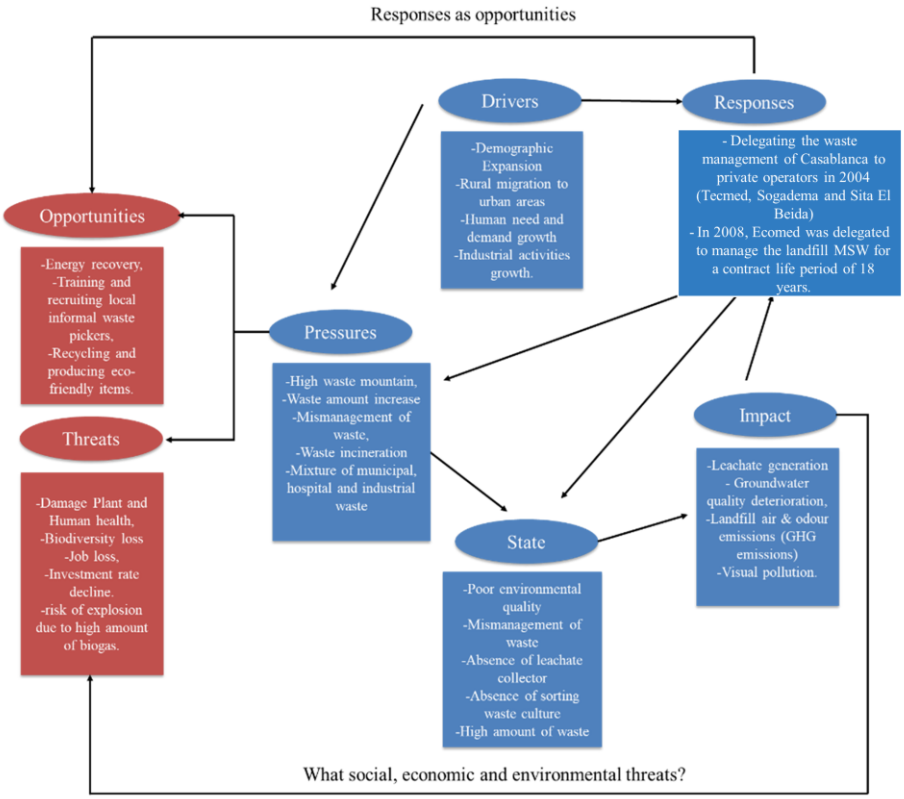

Fig. 5. Summary of the main Driver-Pressure (Opportunities-Threat)- State- Impact- Response of the Médiouna landfill.

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