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Contribution to the evaluation of the environmental risks induced by the worn-water discharges of an Algerian tannery

Saadia Saadi, Mebarek Djebabra and Wafa Boulagouas
Institute of Health and Safety, University of Batna, Batna, Algeria

Abstract

Purpose – The purpose of this paper is to evaluate the environmental risks of the worn-water discharges of an Algerian tannery.

Design/methodology/approach – It consists of a proposal for a combined methods based on the simultaneous use of the environmental structured analysis and design techniques and environmental failure mode and effect analysis (EFMEA).

Findings – In the contribution, the authors insist on the complementarity between these two methods to the identification and measurement of the environmental parameters of an Algerian tannery. The identified environmental impacts were prioritized on the environmental priority number combined with the improvement possibility (F).

Research limitations/implications – The contribution makes it possible to deduce the environmental aspects and, consequently, to emphasize the contribution of the environmental risk assessment on the environmental performance evaluation.

Practical implications – The contribution constitutes an invaluable help to the implementation of environmental performance evaluation process.

Originality/value – The employing coupled structured analysis and technical design and EFMEA methods have remarkably reduced the significance of the environmental impacts of an Algerian tannery.

Keywords Risk management, Assessment, Case study, Industrial wastewater

Paper type Technical paper

1. Introduction

Leather industry in Algeria is characterized not only by the high water consumption but also by the important discharges that are significant in volume and carrying very high pollutant loads. Indeed, the tanneries' discharges are more polluted. They contain protein colloids, greases, tannins, debris of flesh and hair, dyes as well as toxic elements such as chromium and sulfides (Kowalski, 1994; Song *et al.*, 2000; Khan, 2001; Azom *et al.*, 2012). These very polluting discharges give rise to unpleasant smells that impede all the aquatic life in the receiving environment that generally is the fluvial ecosystem (Ros and Ganter, 1998; Burbridge *et al.*, 2012).

To deal with this environmental problem, caused by the tanneries, several studies have been conducted on this subject from different points of view: chemical pollution (Arslan, 2009; Lofrano *et al.*, 2013), waste pollution (Hu *et al.*, 2011), discharges' toxicity (Shakir *et al.*, 2012), etc.

These studies, which are concerned with evaluating the potential impacts of the tannery' wastewater discharges, have evolved over time from a hazard identification inherent to the intrinsic property of a pollutant discharge to the risk evaluation that combines data on the severity, the frequency and the exposure duration (Archeti and Salvador, 2000; Tigini *et al.*, 2011). In this context, the US Environmental Protection Agency during 1990s (USEPA, 1998) is one of the main reference frameworks of the environmental risk assessment (ERA).

Moreover, one of the advantages of the ERA is its possibility to be applied to the tanneries: upstream, at the level, and downstream of the wastewater discharges produced by the tanneries (Ball, 2002; Aven and Kristensen, 2005). In this regard, the ERA

World Journal of Science, Technology and Sustainable Development
Vol. 14 No. 4, 2017
pp. 268-278

2042-5945
DOI 10.1108/WJSTSD-12-2016-0064

deployment is supported by the most widely used methods such as the environmental failure mode and effect analysis (EFMEA) that aims to minimize the environmental impacts at the source for the prevention (Josi and Salati, 2012).

The starting point for the deployment of the EFMEA method is the activities' identification as well as the associated environmental aspects and impacts. This identification is crucial for the ERA because the environmental risk obeys the relationship aspects/impacts. To minimize an impact, it is necessary to act on the aspects. For this purpose, it will be necessary to know, in the smallest details, the activities that are the sources of the polluting discharges. Consequently, the identification of these activities determines the relevance and the quality of the risk assessment of the environmental aspects using the EFMEA method.

The functional description of the industrial activities widely helps the analysts to better frame the relationship between the environmental aspects/impacts. However, this functional description of the activities requires the use of specific methods. Our contribution is in this context which consists in preceding the EFMEA with a functional description of the activities using the structured analysis and technical design (SATD) method, also known as the IDEF0 (integration definition for the function modeling). Thus, we propose the ERA using the combined SATD-EFMEA method.

We note that the SATD formalism will be simplified and focuses mainly on the identification of the environmental data (aspect/impact); for this, we propose to call it the environmental structured analysis and technical design (ESATD).

2. The suggested combined ESATD-EFMEA method

2.1 Why the choice of the ESATD-EFMEA combination?

The ERA requires the use of specific methods that focus mainly on the environmental impacts. In this context, the EFMEA method is the most commonly used in ERA (Chen and Wu, 2013), despite these well-known constraints and heaviness (Xiao *et al.*, 2011). To overcome these constraints, the EFMEA method is supported by software that allows making statistics on the data associated with the environmental aspects and impacts (Josi and Salati, 2012). Despite this informatics' support, the problem that remains unsolved lies in the identification of the environmental aspects and impacts that is a principal input of the EFMEA method (Lindhal, 1999).

To facilitate this deduction, some authors (Tingström and Karlsson, 2005) have suggested exploiting the complementarity that exists between the most used methods in the assessment of the environmental performance which are the EFMEA and the life cycle analysis (LCA). The purpose of combination is that EFMEA should be utilised as soon as the product targets are set, and the inventory information is aggregated on the EFMEA-chart. When certain problem areas have been identified, the EFMEA work is finished and the more detailed assessments are made via LCAs. This means that the EFMEA team is used to define the overall frame of the product-system that is being analysed. The evaluation is then continued via an LCA inventory of energy and materials flows. However, Dandres (2012) also recommends for the LCA a functional analysis of the activities whence the trend in this paper that consists of an ESATD-EFMEA combination.

This combination is justified by the fact that the ERA problem, referred to in the Introduction, consists of a systematic deduction of the environmental aspects and impacts. Hence the interest of, the proposal to exploit the complementarity between the two methods commonly used in systemic which are the SATD adapted to the environmental analysis (ESATD) and the EFMEA. More precisely, we suggest the combined use of these two methods that respect the order described in Figure 1.

In Figure 1, the combination of the ESATD and the EFMEA methods for the ERA is initiated by the well-known complementarity between the functional and dysfunctional methods of the risk analysis. This complementarity between these two methods is detailed in

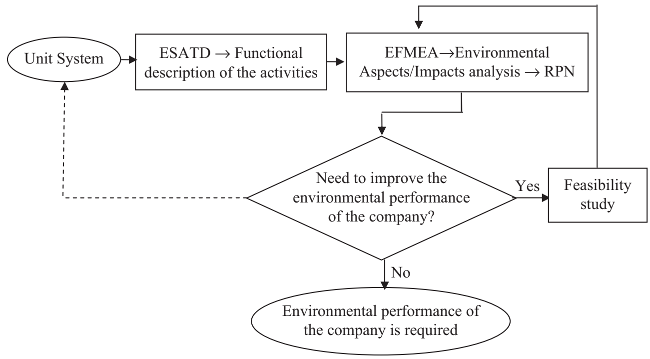

Figure 1.
Proposed combination of the ESATD and the EFMEA methods

Figure 2 where the ESATD formalism shows that each box represents a given activity of a tannery and that its inputs are the data transformed by this activity into outputs. Controls are data whose presence triggers or constrains the activity. Finally, the mechanisms are the means that support the activity (Ross and Ganter, 1998). From this description, the ESATD model has been established (Kossoy and Sheinman, 2007).

2.2 How to exploit the combination of ESATD-EFMEA in the ERA?

The use of the ESATD allows feeding the first part of the EFMEA (environmental characteristics in Figure 2). Thus, the tasks column of the EFMEA is filled directly from the titles of the ESATD' boxes (ESATD' tasks). The environmental aspects and impacts are deducted from the boxes' inputs (in form of: raw materials, energy materials and water), mechanisms and the tasks controls as well as of the boxes' outputs of the ESATD (as analyzed materials).

In Figure 2, we recall that the boxes' inputs of the ESATD allow deducing two categories of environmental aspects. The first category characterizes the natural resources' depletion that is deduced from the data of the ESATD boxes (environmental aspects that reduce the natural

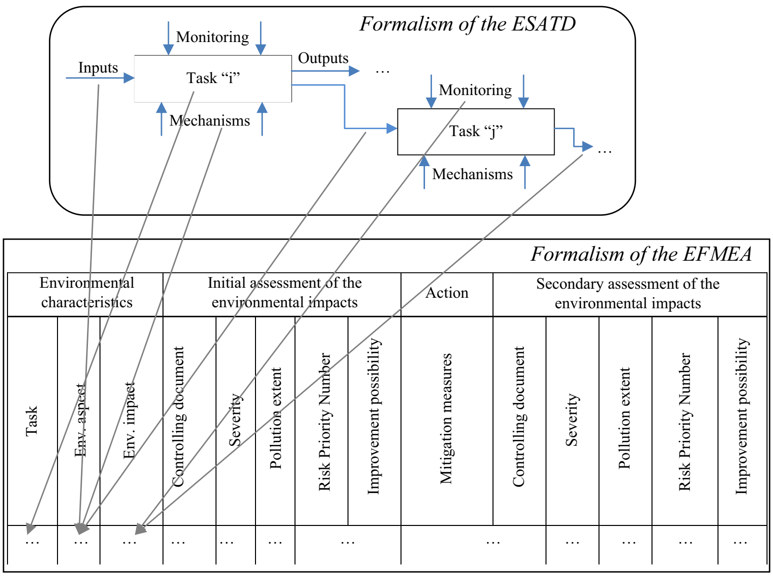

Figure 2.
ESATD and EFMEA complementarity

resources due to the indiscriminate consumption). On the other hand, the mechanisms and the ESATD boxes' controls make it possible to deduce the second category of the environmental aspects that characterizes the different pollution types (environmental aspects that cause emissions or produce different types of pollution, waste and sewage in the environment).

We also recall that if an input of the ESATD box is, at the same time, data and a control, it will be placed as a control of the ESATD box and, therefore, it contributes to the identification of the environmental impact. Similarly, if an output of the ESATD box is an input of another ESATD box, it will be considered as data of that latter box and these data, therefore, will be used to identify the environmental aspect. Thus, these considerations, commonly practiced in the SATD (Marca and McGowan, 1987), allow us to avoid an ESATD attribute (input, mechanism, control and output) contributing in the simultaneous identification of an environmental aspect and impact.

The first part of the EFMEA has been deducted from the ESATD model; the remainder part of the EFMEA table is dedicated to the evaluation and prioritization of the environmental impacts in order to select those on which we must act.

We note that the assessment criteria vary from one company to another. In our case, and since our interest is focused on a tannery's wastewater discharges, we have retained the scoring criteria summarized in Table I (Nilson *et al.*, 1998). Obviously, for the retained criteria, we do not take into account "the occurrence probability" because our study focuses on a tannery's waste discharges whose probability of occurrence is high (daily discharges). Similarly, we retained the "controlling document" parameter because the studied tannery has already been an object of the environmental aspects' assessment. Consequently, this parameter characterizes the monitoring documents established during the initial assessment of the environmental aspects.

From the Table I parameters, we obtain the environmental priority number (EPN) through the following equation:

$$\mathrm{EPN} = C + S + P \tag{1}$$

The values that the parameters C, S and P can take show that the EPN parameter is rated on a scale of 3 to 9: 3 = negligible, 4 = marginal, 5 = serious, 6 = major limited to a part of the workshop, 7 = major limited to the workshop, 8 = major limited to the natural environment, and 9 = major limited to the natural and urban environments.

Finally, to complete the assessment of environmental impacts, a last parameter called improvement possibility (F) that is combined with the EPN parameter makes it possible to establish the assessment matrix.

The values of the parameter F vary from 1 to 9: 1 = No improvement opportunity, and 9 = the best improvement opportunities.

Score	Parameter	Description
3	The controlling documents (C)	No follow-up
2		Partial follow
1		Full monitoring
3	The severity (S)	Severe: potentially harmful or destructive/high loss or consume of resources
2		Medium: relatively hazardous/moderate loss or consume of resources
1		Low: low potential for harm/low consumption or loss of resources
3	The pollution extent (P)	Locally (urban and natural environments of the tannery)
2		At the level of the whole tannery
1		At the level of a part of the tannery

Table I. Parameters of the environmental degradation

The advantage of this matrix is that it informs us about the corrective measures to be implemented. For example, let us consider the example of the D box where the EPN and F values are high. In this case, the recommended action is to propose a technical change. On the other hand, if the EPN/F combination corresponds to C box, the recommended action is to propose a new technique.

Once these recommended measures are implemented, the last stage of the EFMEA is to ensure the success of these environmental improvements (third part of the table related to the EFMEA formalism in Figure 2).

3. Results and discussions

The tannery of Batna, in eastern Algeria, has been the subject of this case study. This tannery, created in 1973 and named MEGA-Batna, ensures the transformation of raw animal skins into leather. Like any tannery, MEGA-Batna consumes large amounts of water that, once used, are evacuated through two networks: river workshop's network and the tanning workshop. This water is treated at the wastewater treatment plant (WWTP) before being thrown out into the natural environment. The characteristics of the discharged water after purification are given in Table II.

From the Table II data, we proceeded to the deduction of the unitary pollutant load expressed in kg/ton by considering that 4,000 skins correspond approximately to five tons of raw skins. The obtained results are then compared with those of the US-EPA. Table III shows that these results are consistent with those of the US-EPA. However, what we had observed on the ground showed that the failures of the WWTP of the MEGA-Batna tannery are frequent and, in most cases, are of a technical nature. Consequently, during those repetitive failures of the WWTP, the retained tannery discharges, into the natural environment, large quantities of chromium (300 mg/L), sulfides (800 mg/l), suspended solids (to 7,000 mg/L) and with large changes in the pH (between 4 and 12).

The objective of this part of the paper is to highlight the second strong point of the approach that we do propose, i.e. the assessment of environmental impacts in the degraded mode (WWTP dysfunction). The EFMEA allows, therefore, covering all the life phases of the WWTP (design, operation, normal operation, degraded operation, etc.). Indeed, as a result of the frequent failures of the WWTP of the MEGA-Batna tannery, the discharges of wastewater are directly thrown out into the natural environmental. This results in an

Table II. The physic-chemical characteristics of wastewater from the retained tannery

Parameter	On average/day sample	In peak
pH	6.5-8	
MES (mg/L)	150	200
DBO5 (mg/L)	300	400
DCO	700	800
Sulfides S^{--} (mg/L)	0.5	1
Chromium Cr^{+++} (mg/L)	1	2
Oils and greases (mg/L)	40	60

Source: Authors

Table III. Unitary pollutant load of the retained tannery

	Flow (m^3/T)	MES (kg/T)	DCO (kg/T)	DBO_5 (kg/T)
Retained tannery	60	86	214	93
US-EPA	53-60	140	260	95

environmental degradation, according to the case, of either D or C class. Figure 3 summarizes an extract of the ESATD of water use in the retained tannery.

Table IV details the parameters of the ESATD boxes of Figure 3.

Figure 3 shows that the wastewater of the retained tannery contains solids, soluble and insoluble concentrated materials, and organic and inorganic materials. These wastewaters are mainly charged with agents such as lime, proteins, sulfides, chromium salts, sodium carbonate, oils, petrol, detergents, the sand and hairs. Furthermore, our finding, on the site, also shows that these wastewaters are characterized by a variable color and the unpleasant smells.

From these data, we deduce the environmental aspects summarized in Table V.

From these environmental aspects, we seek to determine the environmental impacts based on the data provided by the ESATD and completed with the quantitative data (see Table VI).

Exploiting the data provided in the Table VI, with reference to the scales presented in the Table I, allows us to conduct a first environmental analysis of these environmental impacts (Table VII).

We note that in the case of the studied tannery, it is important to emphasize that the actions of type C or D depend on three fundamental criteria: the Algerian Regulation concerning the pollutants discharges, the available technologies and the economic situation of the tannery and that of the country (Algeria). Consequently, the implementation of these actions (C or D) sometimes requires a feasibility study aiming to assess the improvement of the environmental performance of the studied tannery (see Figure 1).

Depending on these feasibility studies and referring to the recommended actions in the "Action" column of Table VII, we suggest:

(1) For the depletion of water resources: a new technique based on monitoring and controlling the treatment water. It is about conducting regular maintenance and keeping a continuous monitoring and strict surveillance over the operations to avoid network leakages and, if necessary, to carry out the required repairs. Generally, it is about defining the best maintenance policy of the equipment and that of the water network. In this context, the FMEA method is very useful to determine the best maintenance policy of this equipment.

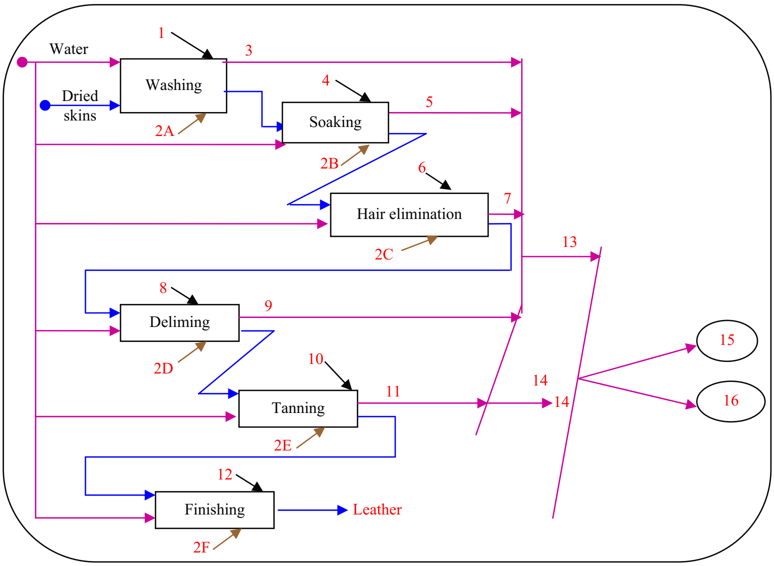

Figure 3.
Extract from the ESATD of the retained tannery

Parameter	Description
1	Control parameters of the operation such as time and temperature
2A-2F	Operations mechanisms of skins transformation (drums, basins, etc.)
3	Wastewater containing waste skins. In case of discharge in nature (rivers in our case), water pollution by BOD, COD, suspended solids, dissolved solids, salts and organic nitrogen
4	Parameters of the operation control such as time and temperature Chemicals: sodium sulfide, lime, caustic soda, wetting agents or lactic acid
5	In addition to the solid wastes and atmospheric pollution problems, wastewater discharged by this activity is polluted by BOD, COD, suspended solids, dissolved solids, salts and organic
6	Parameters of the operation control such as time and temperature Chemicals: either an alkaline solution based on pure lime, or a mixture of lime and sodium sulfide or a mixture of lime and arsenic sulfide
7	Wastewater containing debris of untanned wastes and effluents (free quick lime and sulfides in particular)
8	Parameters of the operation control such as time and temperature Chemicals: ammonium sulfate, conflicts, kerosene, sulfuric and formic acids, industrial salt, chromium and antiseptic
9	Wastewater containing dissolved mineral impurities, greases and effluents (salt, acids, solvents and chromium)
10	Parameters of the operation control such as time and temperature Chemicals: basic chromium salts such as chromium sulfate + Na_2CO_3
11	Wastewater presenting a considerable organic pollution. These waters are rich in chromium oxide
12	Parameters of the operation control such as time and temperature Finishing products: pigments, resins, waxes, varnishes, solvents and thinners, matting agents, touch agent and adjuvants
13	Wastewaters from the river workshop which are basic and contain 80 percent of the organic load
14	Wastewaters from the tanning workshop which are acid and contain 20 percent of organic load
15	Leading toward the wastewater treatment plant
16	Discharges into the environment in the case of wastewater treatment plant shutdown

Table IV.
Description of the ESATD parameters of the retained tannery

Environmental aspects	ESATD parameters involved in the deduction of the environmental aspects
Consumption of water	Common input to all of the boxes of ESATD (water)
Wastewater discharges	16 = 13 +14
Solid wastes	With: 13 = 3+5+7 et 14 = 9+11
Atmospheric emissions	

Table V.
The environmental aspects retained for the studied tannery

(2) For the H_2S toxicity: a separation of the chromium baths and those of the residual lime in order to avoid any accidental generation of H_2S. The solution consists of a deferred moment's spill of discharges of the liming and chrome tanning operations.

(3) For the Cr^{+++} toxicity: a use of titanium which is generally less toxic than chromium.

(4) For the pollution characterized by the pH, BOD, COD and MSS parameters: a use of fresh skins instead of dry ones and their conservation without salts or chemicals. In order to successfully integrate these technical changes, they must be accompanied by:

- threshing salted skins before the soaking operation;
- a mechanical hair removal before the liming operation, a re-use of the wastewater of liming;

Environmental impacts		Real data	Corresponding data Reference data (normative value or objective value)
Depletion of water resources		400-500 m^3/day	Reduction of 20%
Chromium and sulfides toxicity	H_2S	3 g/L	0.1-10 mg/L
	Cr^{+++}	4-5 g/L	0.2-2 mg/L
Organic pollution	pH	12.9	6.5-8.5
	BOD	900 mg/L	350 mg/L
	COD	22,100 mg/L	850 mg/L
	SS	1,690 mg/L	400 mg/L
Heavy metals effects	Cr	Traces	0.1 mg/L
	Ni	Traces	5 mg/L
	Zn	Traces	5 mg/L
	Cu	Traces	3 mg/L
Salts effects	Chlorides	Traces	700 mg/L
Toxicity of trace elements, detergents and adjuvants	Manganese	Traces	1 mg/L
	Iron	Traces	5 mg/L
Oils and greases		30-50 mg/L	30 mg/L

Source: Authors

Table VI. Environmental impacts caused by the studied tannery

Environmental impacts	Initial assessment of the environmental impacts C	S	P	EPN/F	Action	Secondary assessment of the environmental impacts C	S	P	EPN/F	
Depletion of water resources	3	3	3	9/7	D	1	1	3	5/7	A
H2S toxicity	3	3	3	9/7	D	1	1	3	5/7	A
Cr^{3+} toxicity	3	2	3	8/5	D	1	1	3	5/5	A
pH pollution	3	2	3	8/5	D	1	1	3	5/5	A
DBO pollution	3	3	3	8/5	D	1	1	3	5/5	A
DCO pollution	3	2	3	8/5	D	1	1	3	5/5	A
MES pollution	3	1	2	6/8	A	1	1	2	4/8	A
Cr pollution	3	1	2	6/8	A	1	1	2	4/8	A
Ni pollution	3	1	2	6/8	A	1	1	2	4/8	A
Zn pollution	3	1	2	6/8	A	1	1	2	4/8	A
Cu pollution	3	1	2	6/3	B	1	1	2	4/3	B
Chloride pollution	3	1	2	6/3	B	1	1	2	4/3	B
Sodium Sulfate pollution	3	1	1	5/3	B	1	1	2	4/3	B
Manganese pollution	3	1	1	5/3	B	1	1	2	4/3	B
Iron pollution	3	1	1	5/3	B	1	1	2	4/3	B
Phosphate pollution	3	2	3	8/5	D	1	2	3	6/5	A
Oil and grease pollution	3	3	3	9/7	D	1	1	3	5/7	A

Table VII. Risk assessment of the environmental impacts using EFMEA

- a reduction of the salt consumption in the stripping operation by reducing the baths volumes from 50 to 60 percent of the weight of the green skins; and
- a recycling of the stripping liquids at the end of the operation in order to reuse them during the stripping subsequent operations.

(5) For the pollution caused by oils and greases: an implementation of the ginning that consists in scraping the green skins in the early stages of the tanning process. In addition to this technical change, consideration should be given to the recovery or the substitution of degreasing solvents.

It is important to note that in the case of the MEGA-Batna tannery, these actions of C or D type allow not only reducing the environmental impacts (see the last column of Table VII) but also saving raw materials. It should also be noted that the actions relating to the technical changes correspond either to the changes in the main production operations of the tannery or to the chemical substitutions that have the advantage of being less expensive. In addition, the feasibility study of the chemical substitutions is found, in our opinion, at two levels: re-assessment of the environmental impacts caused by such substitutions and re-assessment of the quality of leather produced.

4. Conclusions

This paper focuses on the ERA. In the case of the studied example (tannery), the environmental risk is assessed by the EPN which is the output of the suggested method. Their inputs are, therefore, the parameters of the controlling document, the severity and the pollution extent. These inputs summarize the issued data of the environmental aspects and impacts. Obviously, the environmental aspects and impacts are assessed with reference to the pollution data (physic-chemical data of the discharged wastewater and the polluting load of the tannery).

The proposed method (ESATD/EFMEA) forms an environmental communication tool (the state of the environment receiving the tannery discharges) and, at the same time, a tool for the environmental decision making. Certainly, this proposed method is qualitative. However, its contributions are remarkable, both academically and practically.

Academically, results provided by the combination of the ESATD and EFMEA methods allow reinforcing the complementarity between the qualitative and quantitative methods for assessing the environmental performance like the methods: ESATD→EFMEA→LCI. Another academic implication of our study is the possibility of formulating the environmental objectives associated with the environmental improvements suggested by the EFMEA. Indeed, from the results of the columns "EPN/F" in Table VII, we can allocate the global environment objective (which is defined by the environmental performance of the studied tannery) in the environmental sub-objectives (reduction of water consumption, reduction of chemicals toxicity and pollutants' reduction). This allocation of the global environmental objective in environmental sub-objectives allows planning its realization (Saadi *et al.*, 2011). The monitoring of this planning – in the time horizon – is materialized through the assessment of the risk reduction factors with reference to the risk priority number. A final academic implication of our study is that it can serve as a basic support for a finer quantification of the "improvement possibility" parameter (Zhuang *et al.*, 2014).

Practically, our study is carried out in an environmental project whose objective is to present an ecological tannery using natural and local products and taking advantage of such solid waste (sludge) as an agricultural fertilizer. As part of this unifying project (CPRAC, 2013), our Research Laboratory in Industrial Prevention attempts to make a modest contribution in the current efforts to promote the environmental best practices in the tanneries by designing two documents:

(1) A Manual for the Environmental Aspects Assessment which will be useful as a basic support for the environmental performance indicators' selection according to the Algerian tanneries' characteristics (in particular of their sizes).

(2) A Guideline for Environmental Impact Assessment (EIAG) which is the first attempt to systematize the identification of the environmental impacts of the Algerian tanneries. The second attempt of the EIAG guidelines is to guide these tanneries planning their environmental best practices and benchmarking reports by allowing the environmental objectives.

Glossary

ERA	Environmental risk assessment
SATD	Structured analysis and technical design
ESATD	Environmental structured analysis and technical design
FMEA	Failure mode and effect analysis
EFMEA	Environmental failure mode and effect analysis
LCA	Life cycle analysis
LCI	Life cycle inventory
US-EPE	United States-Environmental Protection Agency
RPN	Risk priority number
RLIP	Research Laboratory in Industrial Prevention
EAAM	Manual for Environmental Aspects Assessment
EIAG	Guideline for Environmental Impact Assessment
Symbol list	
C	Controlling documents
S	Severity
P	Pollution extent
EPN	Environmental priority number
F	Improvement possibility

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Corresponding authors
Mebarek Djebabra can be contacted at: djebabra_mebarek@yahoo.fr; and Saadi Saadia can be contacted at: saadi_lina@yahoo.fr