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Development a Conceptual Framework for Industrial and Hazardous Wastes Rating Systems

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Abstract

Production of a large volume of industrial and hazardous waste with various compositions makes the need for comprehensive management and consequently the concept of waste rating more tangible. Despite numerous waste rating systems presented so far, analyzing the makeup of such systems play a significant role in meeting human health. In this study, the structure of 34 rating systems of industrial and hazardous waste have been analyzed based on both quantitative and qualitative standpoints and the results are presented as a formational-conceptual framework. Results showed that every rating system is formed of two parts of formational fundamentals and functional indices, which the first part has a longitudinal relation with the second. While lowly considered, this study is focusing on the formational fundamental part in the rating systems of industrial and hazardous waste, as intellectual prerequisites in suggesting a new system. Some of the factors in the first level are: dependence of the organization which determines the policy and general goals of a rating system, time of presenting the method during which remarkable changes take place in computing methods of the rating systems, infrastructures and facilities which are efficient in the accuracy and scope of the system and finally references and standards causing variations in definitions and final results of the rating system. Furthermore, factors such as: aspects of the study and style of use are identified in second level of formational fundamentals. Finally, the fundamentals are presented in a formational-conceptual framework for better perceiving and more effective use.

Keywords: Industrial and Hazardous Waste; Waste Rating Systems; Conceptual Framework; Formational Fundamentals; Functional Indices.

1. Introduction

In recent years, industrial developments and technology revolutions associated to human needs have made up negative footprints in environment such as serious damages to ecosystem, production of large amounts of waste (low or high hazard), environmental pollutions, destruction of certain species and even more important and jeopardizing human health and increase of death [1-6]. Industrial waste, more specifically hazardous ones after creating, has to be collected, stored, transported and finally recycled or disposed. In all of its activities, physical and chemical properties of species, particularly properties that are determining flammability, corrosion and reactivity play significant role [7]. Tracks of spread of such wastes in environment remain remarkable as long as treated, stored, transported and disposed incorrectly [8]. Although the definition of hazardous waste, at first stated by US environment protection agency and there is no unique and internationally accepted definition for it, identifying waste in every country is based on four main factor which are introduced by this organization, followed as: (1) flammability, (2) reactivity, (3) corrosion and (4) toxicity [9]. Various organizations such as World Bank [10], World Health Organization (WHO) [11], US Environment Protection Agency [12], Americans congress in protection and recycling of resources [13], Federal law

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[14, 15], have presented various definitions and scientific and practical guidelines for management of hazardous waste. In common opinion of all of these organizations, chemical and industrial wastes are a group of hazardous waste, if not managed properly, causes risks at different levels for human and environment and, various characteristics of hazardous waste leads to intensification of waste management troubles [16].

Generally, wastes have different levels of hazardous characteristics and damaging potential and it is not possible to treat them in the same way in different steps. For instance, there are a lot of differences in production of sludge waste of petrochemical industries and sludge resulted from treatment unit of detergent industry from the view point of collection and transportation as well as final disposal. Regarding the wide range of industrial superfluous materials generated in various sections, they can be categorized based on different standards such as: metagenesis, risk level and method of disposal [17]. This hazard based classification introduced a concept in 1980 as waste rating based on hazard and damage potential to human and environment. Researchers and various groups have presented multiple rating systems. The important point among all presented systems is the formation of a hazard rating system and intellectual foundation relying on it, which have not been taken care in previous studies and the main goal have been concentrated on indices and affecting routs of waste traits on hazard party (i.e. human or environment).

The aim of this study the formational analysis of rating systems of industrial and hazardous waste and proposing the most important fundamentals of these systems. In other words, fundamental indices of a rating system and enough attention to them leads to improvement in efficiency of a rating system in a formational-conceptual framework. The components of this framework are at different levels of precision and arouse sensitivity. According to conformity of a rating and scoring system of waste and its fundamentals, more accurate results are anticipated. Achieving these goals, the history of studies on rating systems of industrial and hazardous waste and theoretical and practical fundamentals used in them are assessed.

2. Methodology

2.1. Waste Rating

In environment engineering science, rating and scoring of waste are used for identifying and determining potential risks of hazardous materials. Also, a rating system is used for a wide range of purposes such as Regulatory measures, determining priorities and assessment of effects [18]. Rating of chemical and hazardous materials based on risk, is an assessment based on pernicious effects (in terms of human and/or environment), damage potential caused by exposure of species and all in all, a relative assessment of hazard. In this regard, using these important and useful tool results in significant provision of wellness for society and environment.

2.2. Components of Waste Rating Systems

Waste rating systems, often use a similar framework of rating as in the first look, operate in the same manner. Each of waste rating systems, consider a set of indices regarding some important issues, which this study discusses on. In an operational trend, rating systems may include a set of mathematical rules, algorithms, theories and assumptions and they will introduce the conclusion in form of a model. In fact, rating the risk level of the industrial and hazardous waste is a set of elements, which identifies and calculates the nature of waste in all aspects at first. Then, classifying the wastes based on the fundamentals that are introduced in continuation. Figure 1 shows the fundamentals of industrial and hazardous waste rating system.

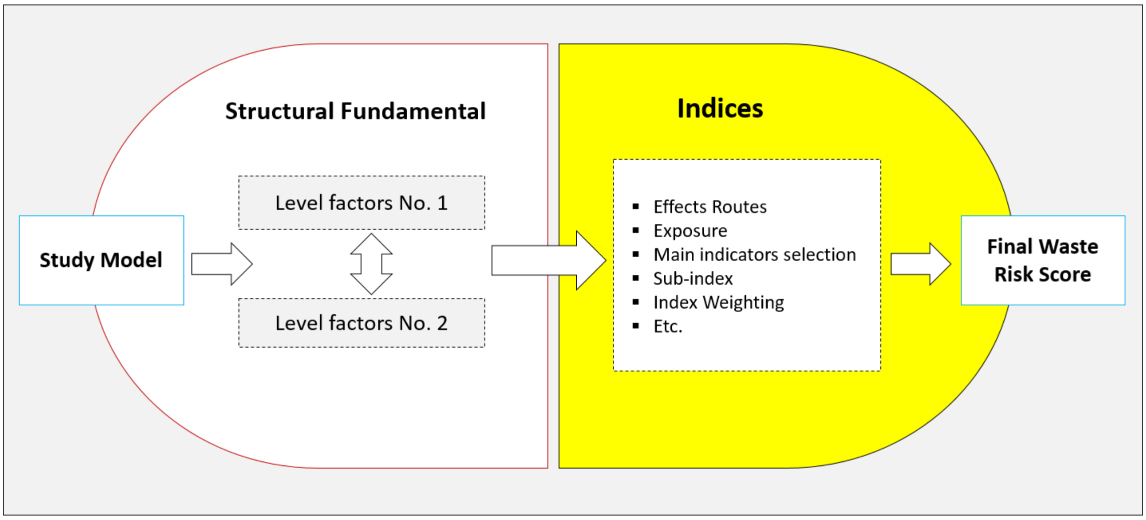


Figure 1. Fundamentals of an industrial and hazardous waste rating system

As illustrated in Figure 1 generally every waste rating system is made up of two parts. For the first part, formational fundamentals and indices are necessary. Commonly, the focus of researchers has been on indices, while proper recognition and setting of the components are indispensable in this part (i.e. formational fundamentals). Originally, the first part is the pre-requisite for identifying effective parameters and indices in ranking systems of industrial and hazardous waste. Thus, the aim of this study is on the formational fundamentals and their components and factors that affect this concept.

Table 1. Rating systems of industrial and hazardous waste from 1981 until now

	Study/ year	Style of Use	Aspects of Study	Organization / Team
1	Toxics Integration Program: Scoring of Selected Pollutants for Relative Risk, 1981	Quantitative	Human	Clement Associates
2	Hazard Ranking System (HRS), 1982	Qualitative	Environment - air, water & soil	United States Environmental Protection Agency(EPA)
3	Groundwater Pollution Priority System (GWPPS), 1983	Quantitative	Human & Environment - groundwater	Hutchinson & Hoffman
4	CERCLA Reportable Quantities (RQ) , 1985	Quantitative	Human	Environmental Monitoring and Service , Inc
5	Notes on Ranking Chemicals for Environmental Hazard, 1986	Quantitative	Environment	Halfon & Reggiani
6	Korean Chemical Ranking and Scoring System (CRS-Korea), 1986	Quantitative - Qualitative	Environment	Hoa-sung Park et al.
7	Michigan Critical Materials Register (MCMR), 1987	Quantitative	Environment - water	Michigan DNR
8	WMS Scoring System, 1988	Quantitative	Environment - air, water - soil & aquatic biota	Könemann & Visser
9	Chemical Scoring System for Hazard and Exposure Identification, 1988	Quantitative	Environment	O'Bryan & Ross
10	Chemical Scoring by a Rapid Screen of Hazard (RASH) Method, 1988	Quantitative	Environment	Jones et al.
11	The Environmental Hazard Ranking System ("Schmallenberg"), 1988	Quantitative	Environment - air, water & soil	Klein et al.
12	Systematic Data Collection and Handling for Priority Setting, 1989	Qualitative	Environment	European Communities (EC)/Gjøs et al.
13	Existing Chemicals of Environmental Relevance, 1989	Qualitative	Environment - air, water & soil	Society of German Chemists (GDCh)/ Behret, H.
14	A Classification System for Hazardous Chemical Wastes, 1990	Quantitative	Human & Environment	Crutcher & Parker
15	Substances and Preparations Dangerous for the Environment, 1990	Qualitative	Environment	Nordic Countries/ Gustafsson & Ljung
16	Criteria for Identifying High Risk Pollutants, 1991	Qualitative	Environment - air	Bureau of National Affairs
17	Review of Region VII TRI Strategy, 1991	Quantitative	Human or Environment	Region VII TRI work group / Bouchard
18	TRI Environmental Indicators Methodology (draft), 1992	Quantitative	Human & Environment- TRI chemicals	EPA / Abt Associates, Inc.
19	ATSDR, "CERCLA Section 104 Third Priority List" , 1992	Quantitative	Human	ATSDR and EPA
20	Candidate Substance List for Bans or Phase-outs, 1992	Quantitative - Qualitative	Environment- surface waters	Ontario's Ministry of the Environment/ Socha et al.
21	Identifying Chemical Candidates for Sunsetting, 1993	Qualitative	Environment	George Washington University / Foran & Glenn
22	A new Hazardous Waste Index (HWI), 1999	Qualitative	Environment	Gupta& Suresh Babu
23	Rating Systems for Pesticide Risk Classification on Different Ecosystems, 2001	Quantitative	Environment	Finizio et al.
24	Hazardous Materials Identification System (HMIS), 2002	Qualitative	Human & Environment	American Coatings Association
25	Comparison of the combined monitoring-based and modelling-based priority setting scheme,2002	Quantitative	Human & Environment	Lerche, Sørensen et al.
26	Prioritizing Industrial Chemical Hazards, 2005	Qualitative	Human & Environment	Hauschild and Bratt
27	A Rating System for Determination of Hazardous Wastes, 2005	Quantitative - Qualitative	Human & Environment	Ilhan Talınlı et al.
28	An aggregate fuzzy hazardous index for composite wastes, 2006	Qualitative	Human & Environment	Musee et al.
29	Fuzzy theory, 2008	Quantitative - Qualitative	Human & Environment	Musee et al.
30	NFPA Hazard Rating System, 2012	Qualitative	Human & Environment	National Fire Protection Association
31	Development of Copeland Score Methods for Determine Group Decisions, 2013	Quantitative	Human & Environment	Zuhairi, Hartati et al.
32	Canadian Council of Ministers of the Environment (CCME), 2013	Qualitative	Environment	Environment Canada
33	Chemical Risk Ranking and Scoring (CRIRS) Method, 2014	Quantitative	Human	Saemi Shin et al.
34	Ranking and Screening Hazardous Chemicals for Human Health in Southeast China, 2014	Quantitative	Human & Environment	Jining, Chen et al.

3. Results and Discussion

In addition to the similarities in general make up of rating systems of industrial and hazardous waste, there are notable nuances in them. With an accurate analysis and engineering look, the most important components in the formational fundamentals of these waste rating systems, which are the main cause of the diversity in these methods, could be identified. Based on our analysis over previous studies, some literatures from 1980 until now are presented in Table 1 and categorized into two levels of 1 and 2. This type of classification is due to the differences exist in the nature of identified factors. Four factors as organizational affiliation, time, infrastructures and references and standards are suggested in the first category form the intellectual concepts of formational fundamentals of a waste rating system. Two factors namely the style of use and aspects of study affect this concept practically. These two are supposed to be the effective factors in the second level in this classification.

3.1. Organizational Affiliation

The first factor of the formational fundamentals (which lead to diversity in rating systems of hazardous and industrial waste), is organization, natural or legal affiliation and in fact study moderator in order to achieve this tool. On the topic of rating industrial and especially hazardous waste, various international organizations and groups such as US Environment Protection Agency (EPA) [18, 19, 21], Environment Canada [45], National Fire Protection Association (NFPA) [44], Clement Associates, Inc [53] and universities [37] invested and supported in this area and, during years, carried out some investigations or using other research teams and cooperated and proposed numerous models according to environmental necessity. For instance, US Environment Protection Agency (EPA) have used Abt Associates in 1992, to propose a rating system for waste and hazardous species. Also, the National Fire Protection Association (NFPA) proposed a rating system on its own. Due to the focus of this association to fire, combustion conditions and related issues, the proposed rating system covers hazard of flammable materials besides other indices. Among these, nearly 47 percent of introduced rating systems (16 studies), have been carried out under support of government organizations and the rest 53 percent of studies over rating systems have been presented in form of journal literatures. Thus, organizational demands, goals and adopted policies, has made the researches to take the first direction in studies and guided scientific and investigational achievements toward this area.

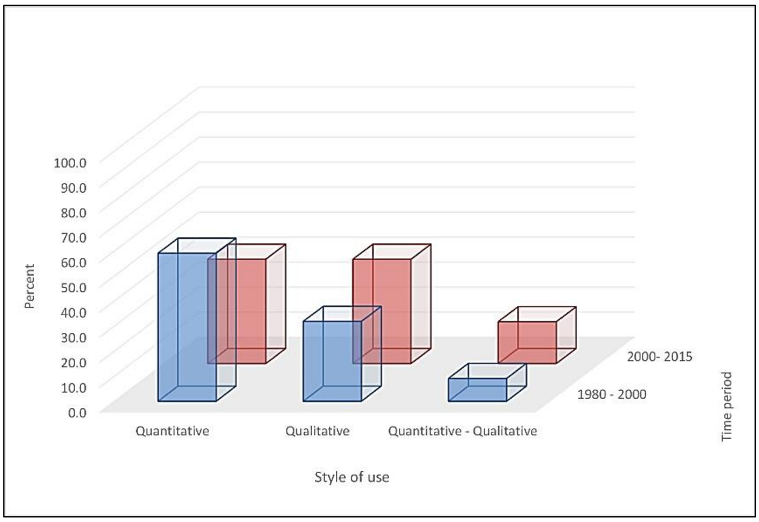
3.2. Time

Throughout the time, researchers used numerous methods and aspects in rating systems. Waste rating systems, if analyzed based on date of study and introduction, significant results obtained. These results, considering two concepts, the style of use and study aspect are presented in Table 2. After starting study on the waste rating concept from the early 1980 until 2000, almost all of the rating systems (86 percent) have considered the study style and only 13.6 percent of the studies were covering human and environment health, yet from 2000, meaningful modifications gradually appeared in the number of studies on both aspects. Centralized investigations concerning environmental standpoint had 56 percent reduction in number of the literatures. There has been more than 60 percent increase in number of the studies concerning both human and environmental standpoints in addition to remarkable improvements in this area. With 5% of reduction in the number of studies from human standpoint, not a significant change can be observed (Figure 2.a).

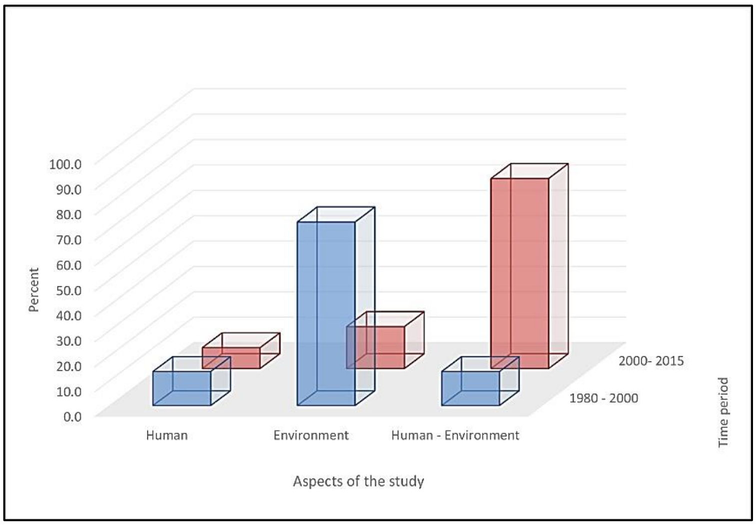
Table 2. Style of use and aspects of the Study vs time

Time Period	Aspects of the Study			Style of Use		
	Human	Environment	Human - Environment	Quantitative	Qualitative	Quantitative - Qualitative
1980-2000	13.65	72.7	13.65	59.1	31.8	9.1
2000-2015	8.3	16.7	75	41.7	41.7	16.6

Considerable results in two periods are observed about the application of rating systems. Within 1980-2000, less than 10 percent of the proposed systems include both quantitative-qualitative analysis and scoring, while more than 90 percent of the proposed systems tend to discuss about only one style of quantitative or qualitative scoring. The point is that this trend has also nearly been continued within 2000-2015 without a significant slope (Figure 2.b). With 10 and 7 percent of increase for qualitative and quantitative-qualitative styles respectively and 17 percent decrease for quantitative one, not a meaningful change has appeared in use of them. Figure 2.a and 2.b shows the details of the style of use and aspects of study in various periods of time.



(a): Aspect of the study within 1980-2015



(b): Style of use within 1980-2015

Figure 2. Rating systems studies vs time

3.3. Infrastructures

Infrastructures and facilities are of important components in process of rating waste treatment systems, while their place is not clear enough. Studying of previous studies show that the systems complexities, style of use, study standpoints, sensitivity and precision of results and some other components of an industrial and hazardous waste rating system highly depend on the level of infrastructures and facilities. Naturally, this is known to be the main limitation for access to some experimental information and tools [Musee et al., 2008, Park, Kim et al., 1986, Könemann and Visser, 1988]. For example, for the toxicity index which has got a number of subsidiary parameters for it, such as instant or chronic toxicity, carcinogenicity and germ cell mutagenicity have only sufficed with the TCLP experiment in the US Environment Protection Agency which is one of the international references in this field. One sort of waste is known as hazardous, if only it can tolerate one of the 43 chemical species in the experiment. This difficulty in identifying of waste is due to the lack of facilities and high expenses of compounds analysis [Ilhan Talınlı, 2005]. Handling these limitations, some researchers have also sufficed with the information presented on analized characteristics of wastes and chemicals provided from government references and regulations [7, 47] such as American Institute of Chemical Engineers (AIChE) guide*. Also in this case, the science scope will not be extendible for more investigations of the scholar over wastes with novel composition until they join the references guides.

3.4. References and Standards

One of the other natural differences of fundamentals in this style in waste rating systems is in the standards and indices considered by related agencies. Depending on what type of standards the presenter group or organization consider, some differences appear in the formational fundamentals of rating systems. For instance, subsidiary

* DOW

parameters are defined for the waste flammability index, such as boiling point, flash point, auto ignition temperature and fire point. Active official organizations of the world in this context such as National Fire Protection Association (NFPA), US Department of Transport (DOT) and European Union (EU) determined various quantitative and qualitative constraints regarding the infrastructures and facilities [Musee et al., 2007]. Among all, selection of any of organization as reference of defining the index for industrial and hazardous waste rating system, changes the final result. This is the same as in the other indices for instance corrosion, toxicity and waste resistance.

Therefore, factors of level 2 associated with formational fundamentals of industrial and hazardous waste rating systems are evaluated. The two components namely style of use and aspects of study of the systems are described in the remainder.

3.5. Aspects of the Study (Human and Environment)

One of the most important bases that cause differences inside the industrial and hazardous waste rating systems, the study standpoint, which is quantitatively discussed above in time factor over two time periods. Each rating system can focus on one or both of human and environment aspects, concerning the need of organization, team or researcher. In fact, an ideal and comprehensive waste rating system is one that can gives a clear view of all aspects which may be subjected to danger and presents a response appropriate with the hazard [Davis, G et al., 1994]. It’s obvious that production of every type of industrial and hazardous waste can have harmful effects on the environment which would infect human directly or indirectly due to the relationship between them. Development of scientific level and investigational facilities, identifying new indices and different routes of affecting have resulted in the fact that a large portion of industrial and hazardous waste rating systems proposed in the recent decade focus on both the human and environment aspects. Each of human or environmental standpoints distinctly includes some indices with different peak levels and threshold. In case of which both aspects being included, their indices ranges are overlapping.

3.6. Style of Use (Qualitative-Descriptive (QD), Quantitative-Ordinal (QO), Qualitative-Weighted (QW))

Style of use of waste rating system is referred to the case in which indices are scored and rated. More obviously, in every waste rating system there are three different cases in which the risk level of a property such as toxicity and affecting routes is evaluated and expressed:

Case I: Use of QD scoring style which is expressed as high, medium and low or such phrases. Some of the advantages of this style is simple environment and free from complexity as well as applicability for a large volume of quantitative and qualitative information. In contrast, one of the drawbacks of this style is lack of proper and meaningful understanding of comparison between common parameters of different wastes. In addition, this style is more similar to classifying or categorizing rather than rating of the waste [Musee et al., 2006].

Case II: The QO style which is defined by 1, 2, 3, etc. and is more popular rather than the qualitative style. In this case of rating, the numbers that are used are not considered as ratio against each other. For example, allocating the ordinal number 2 to the first waste, while giving 1 to the second, doesn’t mean that the magnitude of hazard for the first waste is twice of the second [Finizio et al., 2001]. Unlike the application of scoring by QO style, which simply grades the properties of waste, QW style is used to include the magnitude of each property using numbers such as 1, 10, 100, 1000, etc. This style, which is the most common case in waste rating systems, needs an extremely accurate data for determining the ratio of hazard of one waste to that of another in the same property [Saemi Shin et al., 2014].

Some systems are two-style, i.e. applicability includes both quantitative and qualitative styles. Systems with this basis are someway more comprehensive than another ones. This type of system has preferabilities for better management of waste; Such as better understanding of waste risk level and availability of comparing it in various type of waste using numbers, as well as more comprehensive identifying of waste using risk quality of properties. Methods that emphasize on only one of qualitative or quantitative aspects may be useless for user in some conditions and situations. On the other hand, it is worth mentioning that proposing a rating system in which both of qualitative and quantitative approaches are used will not be convenient. Therefore, nearly 9 percent of the studies have been carried out before 2000 and about 17 percent, after that (Table 2).

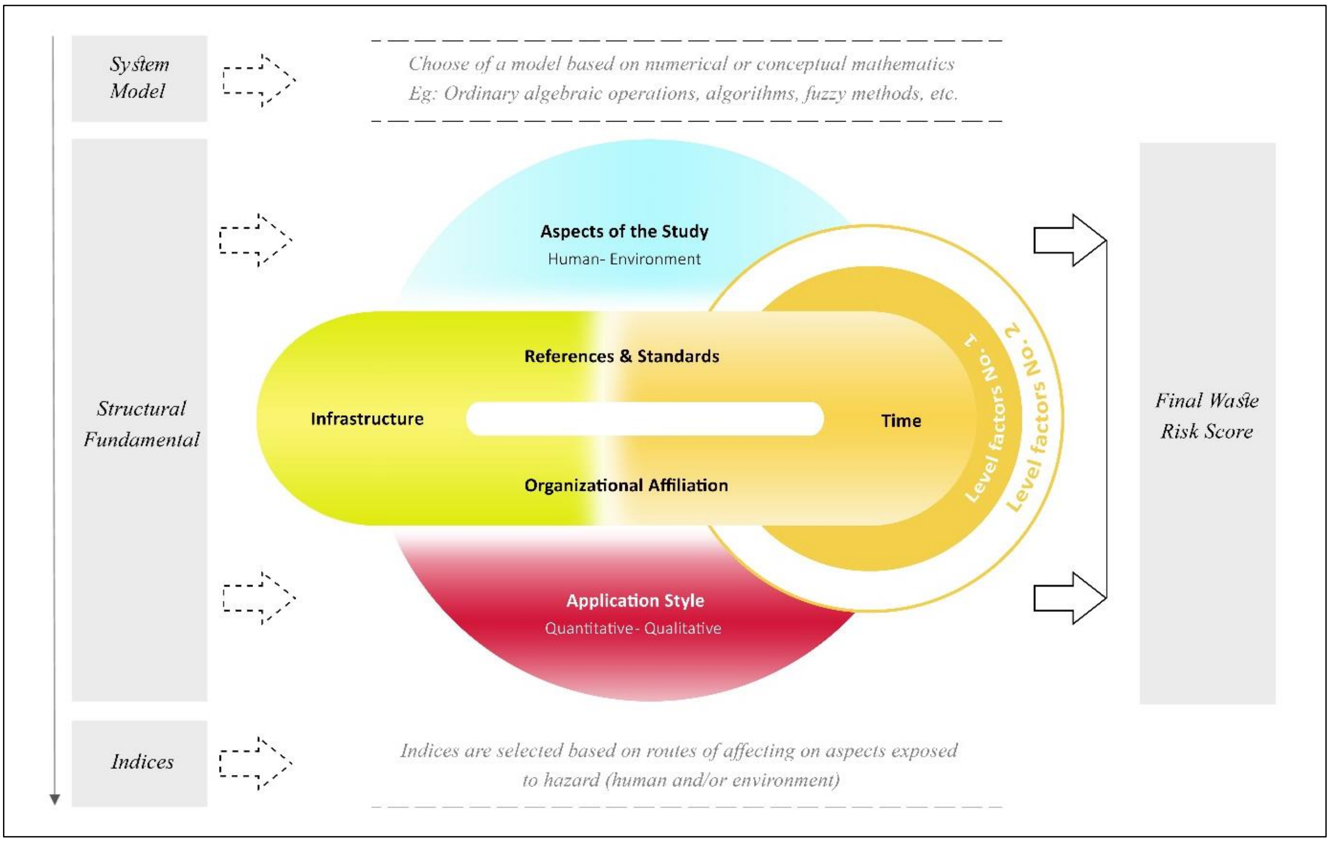


Figure 3. Formational-conceptual framework of the waste rating system

4. Conclusion

A waste rating system in general is made up of two parts, the formational fundamental and indices. This study investigates and analyses formational fundamentals of waste rating systems in two levels of 1 and 2 and the total factors that have been identified are presented in a formational conceptual framework (Figure 3.) Some of the effective factors in level 1 are: organizational affiliation (which determines general purposes of a rating system and direction), dates of proposing the methods (during which significant differences appear in calculation methods of these systems), infrastructures (which are determinant in precision and extension of the system) and finally references and standards causing differences in definitions and outputs of the rating system. In addition, factors such as aspects of study of a rating system (which are employed to determine the extent of hazard intimidating human and/or environment) and the style of use (which covers the operative aspect as well as the qualitative and/or quantitative scoring tool) are determining in level 2, both which are the link between formational fundamentals and indices in a waste rating system. Finally, all the factors in the model which are resulted by a set of operations and mathematical assumptions, simulations and algorithms, prove the final degree of hazard.

Analysis of industrial and hazardous waste rating systems showed that right now, researchers have come to agree that there is not an appropriate framework for assessment of undesired traces of hazardous waste on human and environment. Also there exist various degrees of complexity, the type and number of final points, approaches of choosing indices and data and finally, a method of weighting or combination of different aspects for assessment. Obviously, the considering goals of a rating and scoring tool influence on these factors. However, development of a standard framework which is compatible enough with numerous goals will be useful. Giving little attention to the formational fundamentals part on one hand and the key role of it in determining the policy of an industrial and hazardous rating system on the other hand resulted in this study and proposing a formational conceptual framework. Based on the results, a standard rating system is one that can meet the followings:

- Provide all the aspects in which possibility of hazard exist for living creatures. The hazard in general can include human and environment health
- Include both qualitative and quantitative aspects for better understanding by means of numbers and description of the result in a simple environment
- Being founded scientifically and logically
- Being compatible with the international and national monitoring programs
- Use the experiences of development of industrial and hazardous waste rating systems
- Being efficient for all users' levels
- Being available for planning all of the waste management steps (including collection, transport, process, recycling and disposal), with a proper knowledge of the risk level.

A number of authors have studied various hazardous and industrial waste rating systems, yet lack of sufficient accurate efforts for evaluation of risk level of each waste and reduction of scattered structures in proposed waste rating systems are tangible. Finally, it is suggested for further studies to investigate technical fundamentals and method of waste rating systems as well as their relationship to formational fundamentals.

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