Evaluation of Hazardous Waste Management by Using VIKOR: A Case Study of USA States

Mohsin Ali[1,2], Amit Yadav[2], Maira Anis[2] & Rajeev Kumar Shah[2]

[1] Department of Environmental Science, Inernational Islamic University, Islamabad, Pakistan

[2] School of Management & Economics, University of Electronic Science & Technology of China, Chengdu, China

Correspondence: Mohsin Ali, Department of Environmental Science, Inernational Islamic University, Islamabad, Pakistan; School of Management & Economics, University of Electronic Science & Technology of China, Chengdu, China. Tel: 0086-18280048212 E-mail: mohsinali757@gmail.com

Abstract

Global warming is the major problem of the modern world due to environmental pollution, where hazardous waste disposal poses threat to the environment. USA is urbanized country but still going through hard time due to indecorous management of hazardous waste. To manage such problem are always difficult for the related parties because every individual have their own judgement. Which is difficult to put everyone opinions together for the decision making. The objective of this study was to elucidate hazardous waste problem of USA. This paper espouses VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje) methods which is prevalent method applied in multi-criteria analysis (MCA). The empirical studies ranked each state of USA from best to worst for hazardous waste management and will help EPA (environmental protection agency) to improve hazardous waste of each state by comparing with the best.

Keywords: hazardous waste, USA, VIKOR, MCA

1. Introduction

Hazardous waste is any unsolicited material or solid waste which is disposed in open environment and causes threat to it. It can be in any form such as explosive, emitting radiation, eroding materials, toxic etc. Sources of hazardous waste are timber treatment, petroleum product, metal finished, industrial waste, hospital waste etc. There are numerous ways to extravagance those waste such as neutralization, reduction, oxidation, hydrolysis, microorganisms, incineration, encapsulation and separation etc. It indicates identification and confirmation of the chemical and physical properties of waste, where this is done either by testing or applying knowledge of waste. If such hazardous waste were well managed then there would be clean environment and also not essential to perform any site remediation. Hazardous waste management prominence on hazardous waste storage necessities, above ground storage tanks, underground storage tanks, hazardous waste handling, hazardous waste transportation and disposal. In competitive worlds all countries are rushing towards development and most of the hazardous waste is generated by developed countries such as USA. A waste is considered hazardous when it stances a threat to human health or the environment stated by USA Resource Conservation and Recovery Act (RCRA) of 1978. Speedy improvement and upgrading of various industries machineries, products and practices normally increase the generation rate of hazardous substances.

As stated above most of hazardous waste producers are developed country and same as to USA. From oral view, related parties might find that USA is well managed and free of hazardous waste but the truth is different. Lot of projects in waste were piloted but many of them fail to achieve their goals, bring out social and environmental glitches in the community (Ng et al., 2001; Chui, 2003). Fung (2001) indorsed sustainability idea with the particular authorities and the related parties attempt to progress the design proposal. Competitive world makes rapid improvement of industrial technologies, products and practices frequently additionally alongside also generates hazardous waste. In this research hazardous waste data, information and condition in USA is collected by EPA (environmental protection agency). Evidence is achieved of the chemical and physical properties needed to effectively canned, process or regulatory, stored or disposed of the waste in accordance with authorization. Every state of USA has their own treatment facilities and those facilities have information of the safe and effective treatment of hazardous waste. It seems that it is well managed but the evidence is given by this study

that still there is lot to improve in the hazardous management. To know the condition of hazardous waste of each states some important variables are taken in consideration for analysis i.e. waste generated, received and managed, shipped offsite, received for transfer storage, population density and number of facilities. In order to ensure that final result is winning over author have used VIKOR method, which is popular method applied in MCA (multi-criteria analysis). The VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje) in other word means Multicriteria Optimization and Compromise Solution. The goal of this study is to manage hazardous waste of USA by comparing with the best ranked hazardous waste manage state, giving related officials to take idea from the well managed state and how they follow steps to manage hazardous waste to achieve pollution prevention and human health protection at the source of hazardous waste. Study will also show the condition of hazardous waste, population density and number of facilities in each state.

This paper is organized in 5 sections, where section 1 summaries hazardous waste, section 2 give brief description about the past work on VIKOR and hazardous waste management, section 3 is followed by the methodology for analysis on hazardous waste, section 4 shows elucidation of data analysis and the final section explain the result and give views on improvement of hazardous waste in USA.

As recorded in the Annex III of the waste Framework Directive that waste is classified as being hazardous when it exhibitions one or more of the hazardous properties. The pertinent properties are gritty by property testing, concentration bases criteria. Where on other side, EPA (environmental protection agency) is essential to develop a National Hazardous Waste Management Plan that has esteem to the prevention and minimization of hazardous waste, the gathering and crusade of hazardous waste, the recovery of hazardous waste, disposal cannot be prevented or recovered. There are many facilities such as petroleum investigation, refinish, metal, mining, steel manufacturing etc. which are involved in generation of hazardous waste in USA (Reed et al., 2000). Those waste cause negative effect on the workers' health, land, water, air, flora, fauna and neighborhoods. Some of the major cause of such effect are due to hazardous waste dumped illegally just outside the city, exposure of the neighborhoods and communities to abandoned or close to the waste as well as industrial facilities, major industrial hazardous waste transported to municipal landfills and not securely stored, inadequately treated industrial process waste water causes water pollution etc. (Reed et al., 2000).

Hierarchy for decision making is the best methodology for managing any waste which addresses waste generated, received and managed waste, offsite shipping of hazardous waste, population density and number of facilities in each states of USA. Hazardous waste generation in each state are at various rates but with virtual views or looking at data of hazardous waste production that cannot decide the condition of hazardous waste management. To handle such complex decision making, multi-criteria decision making (MCDM) are worthful for making decision which cannot resolute straightforwardly. A summary equating the features of numerous MCDM methods and dealing with interdependent criteria as well local problems involving both quantitative and qualitative issues are explained by De Montis et al. (2000). Decision makers in multifaceted decision situation involving multi criteria arising from social, economic and environmental consideration helped by MCDA in decision making process (Figueira et al., 2005; Hwang & Yoon, 2012; Saaty, 1980; Keeney & Raiffa, 1976). Aiming at solving MCDM problems in which the weights of criteria are unequal using interval- valued fuzzy set concepts the interval-valued fuzzy VIKOR method is used (Vahdani et al., 2010). To solve the MCDM problems with contradictory or non-commensurable criteria the VIKOR method was developed (Opricovic 2009). VIKOR is prevalent method pragmatic in multi-criteria analysis (MCA) but have delinquent in solving MCDM problems. Chang (2010) developed a modified VIKOR method to evade numerical difficulties in resolving glitches by traditional VIKOR method. To confirm the upgrading of solution efficiency, several synthetic experiments were designed. Even the finest solution cannot gratify all criteria when contradictory criteria exist (Opricovic & Tzeng, 2004; Tong et al., 2007). VIKOR method and a hierarchy MCDM model created on fuzzy sets theory is proposed to deal with the supplier selection problems in the supply chain system (Sanayei et al., 2010). To deal with the evaluation of service quality problems in the international airport, the combined concepts of VIKOR and grey relation analysis (GRA), a new fuzzy MCDM method was proposed (Kuo & Liang, 2011). Tong et al. (2007) employs the VIKOR method which is a compromising ranking method used for MCDM and to optimize the multi response process.

Though VIKOR is beneficial tool for multiple criteria analysis but there are some glitches for which traditional VIKOR method has no solution (Hsu, 2008). This study used the anticipated VIKOR method for the ranking of USA states according to the condition of hazardous waste. Factors which affect the wizard of hazardous waste such as waste produced, conventional & managed, dispatched offsite, received for transfer storage, population density and number of facilities in each state are taken for analysis. The objective of this study was to propose a ranking of state according to well managed hazardous waste and the worse managed, then rendering to result

suggest the worse managed hazardous waste state to follow the well managed procedure for the improvement, illustrate lacking of worse manage state and effect of population on hazardous waste.

2. Methodology

The VIKOR method compromise ranking method used for MCDM and to optimize the multi-response process. It was originally developed by Duckstein & Opricovic (1980) to solve decision problems with contradictory and non-commensurable (different units) criteria, assuming that compromise is acceptable for conflict resolution, the decision maker needs a elucidation that is the closest to the ideal, and the alternatives are evaluated according to all established criteria. VIKOR ranks alternatives and determines the solution named compromise that is the closest to the ideal. The idea of compromise solution was introduced in MCDM by Po-Lung (1973), and Zelrny (1973).

Opricovic (1990) named VIKOR acronym for "VIseKriterijumska Optimizacija I Kompromisno Resenje" that means Multicriteria Optimization and Compromise Solution, with articulation: VIKOR. The real applications were presented in 1998 (Opricovic, 1998). Opricovic & Tzeng (2004) contributed to the international recognition of the VIKOR method.

The compromise-ranking method VIKOR is an applicable technique for MCA. It was developed for multi-criteria optimization in complex systems. The VIKOR method focuses on ranking and selecting from the alternatives with conflicting criteria (Tzeng et al., 2005). Assuming that each alternative is evaluated according to multiple criterion functions, the compromise ranking is performed by comparing the measure of closeness to the ideal alternative (Opricovic 1998; Tzeng et al., 2002; Opricovic & Tzeng, 2004). The compromise-ranking algorithm of the traditional VIKOR has following steps.

Step 1: The various alternatives are denoted as $x_1, x_2, \ldots\ldots, x_m$. for an alternative x_j, the merit of the ith aspect is denoted by f_{ij}, i.e., f_{ij} is the value of ith criteria function for the alternative x_j. Where, m is the number of alternative and n is the number of criteria.

$$f_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} X^2_{ij}}}, i = 1, 2, .., m; j = 1, 2, .., n \tag{1}$$

Where x_{ij} = performance of alternative A_i

Step 2: Determine the maximum f_i^* and minimum f_i^- values of all criteria functions, $i = 1, 2, 3, \ldots\ldots n$.

$$f_i^* = j \max f_{ij} = \max[(f_{ij}) \mid j = 1, 2, \ldots\ldots, m] \tag{2}$$

$$f_i^- = j \min f_{ij} = \min[(f_{ij}) \mid j = 1, 2, \ldots\ldots, m] \tag{3}$$

Step 3: Compute the values S_j & R_j, $j = 1, 2, 3, \ldots\ldots m$.

$$S_j = \sum_{i=1}^{n} w_i (f_i^* - f_{ij}) / (f_i^* - f_i^-) \tag{4}$$

$$R_j = i \max[w_i (f_i^* - f_{ij}) / (f_i^* - f_i^-) \mid i = 1, 2, \ldots\ldots n] \tag{5}$$

Where S_j and R_j represents the utility measure and the regret measure, respectively, for the alternative x_j. w_i are the weight of ith criterion, which represents the relative importance of criteria.

Step 4: Compute the values of $Q_j, j = 1, 2, \ldots\ldots m$.

$$Q_j = v \left[\frac{S_i - S^*}{S^- - S^*} \right] + (1 - v) \left[\frac{R_i - R^*}{R^- - R^*} \right] \tag{6}$$

$$S^* = j \min S_j = \min[(S_j) \mid j = 1, 2, \ldots\ldots, m]$$

$$S^- = j \max S_j = \max[(S_j) \mid j = 1, 2, \ldots\ldots, m]$$

$$R^* = j \min R_j = \min[(R_j) \mid j = 1, 2, \ldots\ldots, m]$$

$$R^- = j \max R_j = \max[(R_j) \mid j = 1, 2, \ldots\ldots, m]$$

Where v is the weight for the strategy of maximum group utility and 1-v is the weight of the individual regret. 'v' is usually set to 0.5 (Kackar, 1985; Opricovic, 1998).

Step 5: Rank the alternatives by Q_j. The greater the value of Q_j is, the better decision of the alternative is. Since it provides a maximum group utility of the "majority" and a minimum individual regret of the opponent", the obtained compromise solution is acceptable by decision makers (Opricovic & Tzeng, 2007; Tong et al., 2007).

3. Data Analysis

The massive majority of hazardous waste in the U.S. is treated or apt off on-site by the generator. For a developed country like U.S. hazardous waste is one of the major problems because as country move towards development, the rate of hazardous waste gears up due to manufacturing products, industrial waste or disposal, chemical use etc. The U.S. Resource Conservation and Recovery Act (RCRA) of 1978 stated that hazardous waste is such waste which causes threat to human health. To prepare sustainable hazardous waste management proposal researchers still have to give an effort to work out the elaborated design based on the resources accessible. Data of hazardous waste had been poised from RTKNet (Right to Know Network) and use of VIKOR made it convenient to discriminate condition of hazardous waste in each state of U.S. To make decision effective and satisfy the majority researcher have taken value of waste generated, received and managed, shipped offsite, received for transfer storage, population density and number of facilities for analysis as shown in Table 1 The basic structure of an MCDM problem established the 50 state of U.S. named 'A' and labeled as 'A1-A50' in Table 2.

Table 1. Hazardous waste data of U.S.

Alternatives	Waste Generated (Tons)	Received & Managed (Tons)	Shipped Offsite (Tons)	Received for Transfer Storage	Population Density (Million)	Number of Facilities
Alaska	2523	12	2009	5	1.2	46
California	561105	136700	428557	46391	239.1	1269
Colorado	31900	40219	34643	3621	48.5	158
Hawaii	423609	139	1301	51	211.8	51
Idaho	3742	112054	6353	184	19.0	40
Montana	5883	5	5956	4	6.8	45
Nevada	12309	76324	11928	2427	24.6	102
Oregon	93525	54642	77380	532	39.9	181
Utah	49831	135537	79516	10068	33.6	113
Washington	349564	15835	75735	36068	9856.5	420
Wyoming	4079	5	4078	6	5.8	19
Arizona	202987	13051	26498	4833	56.3	229
New Mexico	1037437	4227	10387	510	17.0	46
Oklahoma	44783	93288	29979	989	54.7	203
Texas	15683408	613952	607323	39663	96.3	1020
Illinois	686911	369826	207880	11344	231.1	1123
Indiana	888062	452403	389390	10662	181.0	517
Kansas	51008	267	50698	303	54.5	161
lowa	4399787	462718	516502	23542	104.9	371
Michigan	318617	422980	177234	20798	174.8	490
Minnesota	354706	165633	70561	3450	66.6	324
Missouri	253941	149297	81411	3090	87.1	343
Nebraska	35438	33716	43668	3714	23.8	84
North Dakota	455867	102	1178	193	9.7	19
Ohio	1617571	583683	565414	37391	282.3	917
South Dakota	1344	2	1390	102	10.7	42
Wisconsin	289401	44004	173035	8848	105.0	541
Alabama	588903	234002	192984	12211	94.4	245
Arkansas	991143	233161	206635	7436	56.0	144
Florida	203410	551	33514	10229	350.6	451

Georgia	211462	2615	42260	1247	168.4	389
Kentucky	1245285	261193	135493	1056	34.9	220
Louisiana	208464	89505	181969	16882	109.9	274
Mississippi	1828969	17880	73084	46	63.2	132
North Caroli	83317	3852	90479	8424	196.1	608
South Carol	177294	150184	171165	4429	153.9	290
Tennessee	90138	22530	52837	6324	153.9	336
Virginia	74881	7	71644	535	202.6	391
West Virgin	62539	5940	39475	486	77.1	143
Connecticut	25010	6441	24073	2385	738.1	297
Delaware	43287	114	42972	3	460.8	59
Maine	2495	8	2326	139	43.1	66
Maryland	44254	43878	54571	12584	594.8	134
Massachusetts	36915	2303	42057	6614	839.4	450
New Hampshire	3950	3	3950	2	147.0	152
New Jersey	297706	227285	328125	15113	1195.5	689
New York	186486	74867	165802	8542	411.2	1476
Pennsylvani	321891	384524	262670	43850	283.9	853
Rhode Island	8597	4019	16222	5988	1018.1	93
Vermont	2813	10	2591	1506	67.9	52

In Table 1, there are six criteria known as quantitative criteria which show the value of each criteria and those measure had been taken from RTKNet. Those variables are the main factors which affect hazardous waste management, where population density was derived from formula: total number of people in the state/ total area of the state in km (kilometers). The data is normalized between 0 and 1.

Table 2. Ranking of USA States for Hazardous Waste Management

Alternatives	Values S	Sorting S	Values R	Sorting R	Values Q	Sorting Q	Ranking
A1	0.697482	0.306695	0.2	0.175763	0.577889	0.074584	43
A2	0.406362	0.386276	0.195172	0.187954	0.200622	0.172273	4
A3	0.662911	0.392457	0.19904	0.19168	0.531532	0.182202	32
A4	0.700802	0.406362	0.199955	0.194263	0.58179	0.200622	46
A5	0.660227	0.439221	0.199639	0.194295	0.530642	0.204429	31
A6	0.696939	0.445481	0.199999	0.194842	0.577218	0.241664	42
A7	0.661688	0.460728	0.199525	0.195172	0.531981	0.253451	33
A8	0.656496	0.473008	0.199215	0.195334	0.524349	0.272699	28
A9	0.61874	0.482786	0.199342	0.196351	0.478455	0.303706	21
A10	0.392457	0.501663	0.194842	0.196477	0.182202	0.305521	3
A11	0.699521	0.550359	0.199999	0.196901	0.580391	0.405494	45
A12	0.667661	0.563422	0.198882	0.196901	0.536733	0.43809	34
A13	0.713471	0.58739	0.199679	0.197794	0.596252	0.438576	49
A14	0.646961	0.593894	0.198914	0.197894	0.51142	0.441683	25
A15	0.550359	0.59429	0.3	0.197896	0.799507	0.451706	50
A16	0.439221	0.598333	0.195334	0.197902	0.241664	0.452108	6
A17	0.445481	0.601722	0.196351	0.198109	0.253451	0.453265	7
A18	0.67924	0.608015	0.199914	0.198257	0.555119	0.461262	37
A19	0.482786	0.608308	0.197896	0.19846	0.305521	0.462577	10
A20	0.460728	0.616022	0.196477	0.198673	0.272699	0.472713	8
A21	0.608015	0.61874	0.198673	0.198691	0.462577	0.478455	19
A22	0.608308	0.626993	0.198257	0.198742	0.461262	0.488228	18
A23	0.670701	0.634595	0.199541	0.198746	0.543125	0.500175	35
A24	0.708161	0.635613	0.199967	0.198882	0.590884	0.501121	48
A25	0.306695	0.644404	0.194295	0.198888	0.074584	0.51142	1
A26	0.697551	0.646961	0.2	0.198914	0.577974	0.51242	44
A27	0.601722	0.651087	0.197894	0.19904	0.451706	0.522892	15

A28	0.563422	0.652745	0.198109	0.199149	0.405494	0.524349	11
A29	0.58739	0.656496	0.198888	0.199215	0.43809	0.525363	12
A30	0.635613	0.658515	0.199821	0.19925	0.501121	0.526566	24
A31	0.658515	0.659034	0.199149	0.199316	0.526566	0.530642	30
A32	0.598333	0.660227	0.199316	0.199342	0.453265	0.531532	17
A33	0.593894	0.661688	0.197794	0.199525	0.441683	0.531981	14
A34	0.707046	0.662911	0.198742	0.199541	0.584581	0.536733	47
A35	0.616022	0.667661	0.198746	0.199639	0.472713	0.543125	20
A36	0.59429	0.670701	0.196901	0.199679	0.438576	0.550338	13
A37	0.644404	0.67924	0.196901	0.199821	0.500175	0.555119	23
A38	0.652745	0.680111	0.199998	0.199914	0.522892	0.558297	27
A39	0.680111	0.681663	0.19846	0.199955	0.550338	0.562314	36
A40	0.651087	0.684812	0.197902	0.199964	0.51242	0.572276	26
A41	0.681663	0.692924	0.199964	0.199967	0.558297	0.574301	38
A42	0.694569	0.694569	0.199998	0.199997	0.574301	0.577218	41
A43	0.634595	0.696939	0.187954	0.199998	0.452108	0.577889	16
A44	0.626993	0.697482	0.19925	0.199998	0.488228	0.577974	22
A45	0.684812	0.697551	0.2	0.199999	0.562314	0.580391	39
A46	0.473008	0.699521	0.175763	0.199999	0.204429	0.58179	5
A47	0.501663	0.700802	0.19168	0.2	0.303706	0.584581	9
A48	0.386276	0.707046	0.194263	0.2	0.172273	0.590884	2
A49	0.659034	0.708161	0.198691	0.2	0.525363	0.596252	29
A50	0.692924	0.713471	0.199997	0.3	0.572276	0.799507	40

According to above steps, S, R and Q value had been evaluated as shown in table 2. Here min value of 'S', max value of 'S', min value of 'R' and max value of 'R' are shown below:

S^* =min value of S = 0.306, S^- =max value of S = 0.713, R^* = min value of R =0.175, R^- = max value of R = 0.3 & V= weight for the strategy of maximum group utility =0.5

Rendering to the Q values, ranking of each state is done with respect to analysis result of hazardous waste management.

4. Result

The final result had been shown in Table 2, which revel VIKOR based method for the ranking states of USA according to the ailment of hazardous waste. Result illustrate that Ohio is ranked 1st in the well managed hazardous waste in comparison to other states. Ohio with 282.3 million population density of state with number of facilities 917 for hazardous waste management is ranked 1st but Texas with less population density (96.3 million) and high number of facilities (1020) is ranked 50th. Even having higher number of facilities to manage hazardous waste in comparison to the 1st ranked, Texas ranked last which shows that there is lack of management in hazardous waste. Similarly, Pennsylvania is ranked 2nd with population density of 283.9 million and having 853 number of facilities. In some cases such as Washington has maximum population density (9856.5 million) in comparison to other states with 420 facilities of hazardous waste. Washington is ranked 3rd and it seems that hazardous waste management is sound but still need improvement to get the top ranking. New York is ranked 9th, but it have maximum number of facilities (1476) in comparison to other states and having population of 411.2 million. This shows that even having maximum number of facilities but lack of proper hazardous waste management cannot be accomplished. Similarly in California 2nd highest number of facilities is 1269 with population of 239.1 ranked 4th. California has less population and highest number of facilities in comparison to Ohio (ranked 1st).

5. Conclusion

Environmental degradation is major problem in the recent world and a developed country like USA. For enhancing multi-response problems, some methodical processes have been developed in recent years but in this study a systematic technique is used that involves applying the MCDM compromise ranking method VIKOR to optimize what factors are contributing to the hazardous waste of a developed country like USA. The steps followed for the analysis are computing the population density and number of facilities in each state, finding value of VIKOR and optimal condition, carrying out and analyze result of hazardous waste. To optimize the multi-response process the VIKOR index considers the utility and regret measure.

Overall analysis result shows even having maximum number of facilities with less population or highest population with maximum number of facilities doesn't have substantial hazardous waste management. If there is proper management then even with maximum population with lowest facilities hazardous free environment can be constructed. The result from VIKOR model ranked the states of USA rendering to state of hazardous waste. It is believed that this ranking result will be helpful for the EPA (Environmental Protection Agency) to improve hazardous waste of USA. Result will be also helpful for the EPA and the government in decision making, financial management and their policy making.

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