Global J. Environ. Sci. Manage., 2(4): 381-388, Autumn 2016
DOI: 10.22034/gjesm.2016.02.04.007

CASE STUDY

Integrated environmental management model of air pollution control by hybrid model of DPSIR and FAHP

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Received 18 April 2016; revised 13 June 2016; accepted 14 July 2016; available online 1 September 2016

ABSTRACT: The aim of this study is to evaluate the obstacles due to a DPSIR model combined with fuzzy analytic hierarchy process technique. Hence, to prioritize the responses regarding the driving forces, pressures, states and impacts, the hierarchy of the model is established. Evaluations and prioritization of model results of urban transport situation in Tehran have provided a number of necessary issues for strategic planning to reduce local air pollution and emission of greenhouse gases by prioritizing their effectiveness in the implementation, including; a) development and improvement of public transport (R1), b) improvement of fuel quality (R2), c) improvement of vehicle emission standards (R3), d) vehicle inspection (R4), f) traffic management (R5). In this study, responses to improve the factors of pressure, stimulus, the current state and the impacts were examined and compared hierarchically. Finally, their priority relative to each other was achieved. Development and improvement of public transport, improvement of the quality of fuel, improvement of vehicle emission standards, vehicle check-up and finally urban traffic management were identified respectively as practical steps to control and reduce air pollution in Tehran.

KEYWORDS: *Air pollution; Analytic hierarchy process (AHP); DPSIR; Fuzzy theory; Tehran metropolis*

INTRODUCTION

Tehran metropolis with a population over 12 million people as the industrial, educational, medical, and commercial center faces shortages of roads and parking. Further, air pollution is trapped within the city due to climatic and topographic characteristics. It is estimated that over 3.5 million cars and about 3 million motorcycles are present in Tehran. The very low wind speed as well as topographic features would retain air pollutants within Tehran. Consumption of over 9 million liters of petrol per day (Karbassi *et al.*, 2009; Sekhavatjou *et al.*, 2011; Salehi *et al.*, 2016), has categorized Tehran as one of the most polluted cities in the world. The energy consumption in car fleets of Iran is generally high when compared with world average (Tehrani and Karbassi, 2005). Average fuel consumption of vehicles in the fleet of country is approximately 10.5 liters per hundred km, indicating higher fuel consumption in this city (Naddafi, 2012; Iqbal *et al.*, 2015). United Nations Environment Program (UNEP) has warned that many developing countries in Asia and Latin America are at the serious risk of air pollution (Hadad *et al.*, 2003). According to the World Bank report, annual compensation of air pollution in Iran is US$ 4 million, equivalent to 1.6% % of GDP of country (Atash, 2007). In addition, according to Air

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Note: Discussion period for this manuscript open until December 1, 2016 on GJESM website at the "Show Article".

Quality Control Company, approximately one million and 638 thousand tons of pollutants per year enter into Tehran air only from mobile sources. Out of this sum, carbon monoxide account for one million and 354 thousand tons. The other air pollutants include 19 thousand tons of suspended particulates (SPM), 109 tons of nitrogen oxides and finally 156 tons of hydrocarbons (Halek *et al.,* 2004).

Based on conducted studies, annual losses resulting from air pollution, especially for vulnerable groups (elder men and women, children and pregnant women, patients with pulmonary disorders, cardiovascular diseases, asthma, etc.) are high. Accordingly, it has been estimated that 13,200 deaths were caused by particles during 2005. It has also been estimated that over 10000 deaths were caused by nitrogen oxides and sulfur (Hosseinpoor *et al.,* 2005). One of the problems in improving the current air quality of Tehran is weakness in the integrated management system. Most of measures conducted in Tehran to reduce emissions have been sectional, and they do not follow smart and integrated policy. Therefore, it can be stated with certainty that the creation of an integrated and strategic approach in the executive and practical measures can be very helpful .In recent decades; various models of strategic management have been proposed to tackle environmental issues (Maat and Zakaria, 2010). Strategic planning is an important part of developing strategic management (Apenteng *et al.,* 2015). It is possible to use an analytical approach to monitor internal and external environment in comparison with competitors (Aich and Tripathy, 2014). Strategic planning explains promoting the current situation (organization mission) to a desired one that refers to the organization's vision (Austin, 2007). Before the year 2000, all activities conducted in Iran in order to reduce and control air pollution of metropolitan cities had passive nature, lacking the appropriate monitoring and evaluation. However, through the review of previous studies and especially the use of Swedish and Japanese research teams and Iran Academy of Sciences since 1999, comprehensive plan of Tehran air pollution reduction was approved by the Cabinet in 1999. Then, comprehensive plans of other metropolitan cities were also developed and approved by Planning Deputy of Governorships. In addition to Tehran, Arak has also comprehensive plan approved by the Board of Ministers. Since that time, a systematic plan and specified scheduling were determined to confront with air pollution in metropolises. Comprehensive plan to reduce Tehran pollution is based on seven axes that most of them have been considered also in other metropolises and some of them have been implemented in the form of national plans. These measures may include replacement of old cars with new ones along with improvement of fuel quality. One of the problems with this comprehensive plan is none availability of priorities. With regard to integrated management, approaches and models, some studies have been conducted around the world that the most effective of them are related to air pollution (Beamon, 2005; Massoud et al., 2015; Ju *et al.,* 2009; Tayibi *et al.,* 2009; Emery *et al.,* 2007; Adams and Kanaroglou , 2016; Halkos and Papageorgiou, 2016; Zhong *et al.,* 2015). In this study, a DPSIR model in a fuzzy analytic hierarchy process (Chen and Chen, 2010) is conducted based to develop a comprehensive decision making model for control/reduction of air pollution in Tehran. In addition, due to the experts' judgments the priority of responses based on driving forces, pressures, states and impacts are computed. The present study is carried out in Tehran metropolitan city during 2014 to 2015.

MATERIAL AND METHODS

The Driving forces - Pressures - State - Impact - Responses (DPSIR) model was used to conduct the hierarchical structure for responses to develop appropriate policies. It should be noted that the responses are considered as the alternatives and the driving forces, pressures, states and impacts are considered as the criteria. Subsequently, DPSIR, AHP and the fuzzy rankings are explained. The analytical hierarchy process structure of decision-making is illustrated in the Fig. 1.

In this study the individual judgments of ten experts namely five environmental engineers, two urban planner and three related academic professor, are considered. It should be noted that opinion of some of the experienced persons in industry field are also collected and used.

DPSIR

DPSIR is a causal framework for describing the interactions between society and the environment. This framework has been adopted by the European Environment Agency. The components of this model are; Driving forces, Pressures, States, Impacts and Responses.

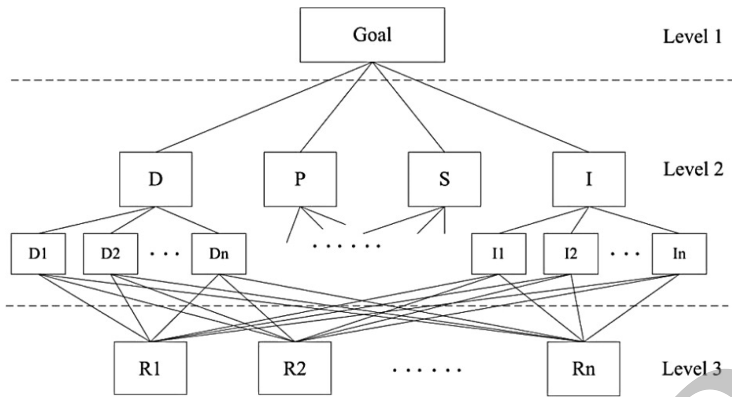

Fig. 1: The analytical hierarchical structure of decision-making

The DPSIR approach is based on causality in which human activities cause a change in the environment, which in turn stimulates a management response, typically a policy. Although it is widely used, the conceptual model has been criticized for its bias towards a preservationist worldview, which may limit its use by managers (Svarstad *et al.,* 2008). Some research has used this technique to bring out weaknesses (Maxim *et al.,* 2009). It should be noted that economic and risk analysis can lead to a better decision while considering environmental aspects (Emerya *et al.,* 2007; Taylana *et al.,* 2014). One approach used in DPSIR studies is to redefine the framework according to the purposes of its application. The present study has compiled a matrix of the definitions of the five following terms:

- Drivers: Social and economic forces that cause environmental pressures
- Pressures: Human activities caused by drivers that affect the state of the system.
- States: The condition of the system at a specific time.
- Impacts: Ecological, social and economic changes in the state caused by drivers and pressures.
- Responses: Measures taken to address impacts, drivers and pressures.

Analytic hierarchy process (AHP)

Analytic hierarchy process is a multi criteria decision making technique which is based on the rational comprehensive theory. According to Saaty, AHP's focus is on achieving the goal that will generate the rational decision, which is the best decision among any goal that will be achieved by decision makers (Saaty *et al.,* 1994; Saaty *et al.,* 2000). AHP can be conducted in seven steps which are as follows:

1. Establishing pairwise comparison matrix for each decision alternative to each criteria
2. Synthetization
3. Establishing Pairwise Comparison Matrix for each criteria
4. Establishing the Normalized Matrix
5. Establishing the Preference Vector
6. Calculating overall value for each decision alternative
7. Determining the rank of alternatives according to the value acquired in the previous step

A sort of AHP method is appropriate to be used in making decision that involves decision element comparison, which is difficult to be assessed quantitatively (Saaty, 1994). This matter is based on the assumption that human beings' natural reaction when facing a complex decision making, is by grouping the decision elements according to its common characteristics. This grouping process includes ranking the decision elements, and then comparing between each pair in each group in a form of matrix. Afterward, inconsistency ratio and weight for each element will be acquired. Thus, it will provide ease in testing the data consistency. The ratio-scale form is used as an input in the AHP method, which states one's perception when facing the decision-making situation. The values in the ratio are then organized in a matrix, which is called the *pairwise comparison matrix*. Due to the limitation of human beings' brain capability, the ratio-scale is limited as well. In the AHP method, the scale range is assumed as Eqs. 1 - 9 representing human beings' perception.

$$CI = \frac{maks\ .\ eigenvalue\ - n}{n - 1} \tag{1}$$

$$maks.eigenvalue = \sum_i w_i .c_i \tag{2}$$

After acquiring Consistency Index (CI), the next step is calculating consistency ratio (CR) by using Eq. 3:

$$CR = \frac{CI}{RI} \tag{3}$$

Description:
n = Amount of items compared
w_i = Weight
c_i = Sum of column
CR = Consistency Ratio
CI = Consistency Index
RI = Random Consistency Index

Random consistency Index (RI) can be used based on many references such as Saaty's research (Saaty, 2000). The test of consistency result will be very useful in the AHP method. If $CR \geq 10\%$, the data acquired is inconsistent and If $CR < 10\%$, the data acquired is consistent (Taylan *et al.,* 2014).

Fuzzy number ranking methods

There are many fuzzy ranking number methods which can use with AHP technique (Chang *et al.,* 2009; Nieto-Morote *et al.,* 2012; Pan, 2008; Tamošaitienė *et al.,* 2008; Zeng *et al.,* 2007). The fuzzy environment and equivalent fuzzy numbers of the crisps are given in Table 1.

Deng *et al.* (2006) provided a method for comparing fuzzy with radius of Gyration (ROG) method. They used gyration radius that is one of the mechanical engineering science topics to compare fuzzy numbers. The procedure is described below (Nasseri and Sohrabi, 2010; Deng *et al.,* 2006).

Consider trapezoidal fuzzy number $A = (a_1, a_2, a_3, a_4)$ as shown in Fig. 2. This is divided into 3 levels. If in the trapezoidal fuzzy number A,a_2=a_3 , the trapezoidal fuzzy number is converted to a triangular fuzzy number.

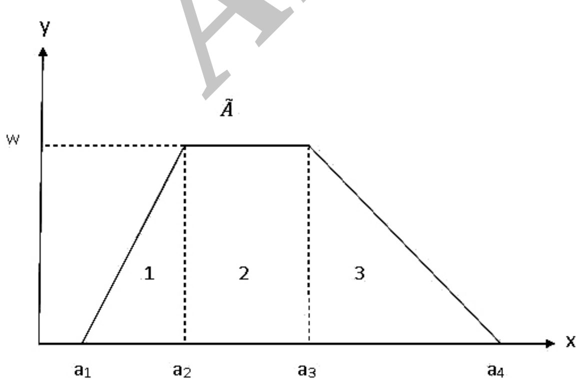

Fig. 2: Trapezoidal fuzzy number A

To rank fuzzy numbers, radius of gyration radius method (ROG) was used. Generally, the three following steps must be considered:
Step 1: First, moment of inertia of each level to axes of x and y must be calculated as Eqs. 4 to 9.

$$(I_x)1 = \int y^2\, d \;= \int_0^w y^2 \frac{(a_2-a_1)(w-y)}{w}\, d \;= \frac{(a_2-a_1)w^3}{12} \tag{4}$$

$$(I_y)1 = \int x^2\, d \;= \frac{1}{36}(a_2-a_1)^3 w + \left[\frac{(a_2-a_1)w}{2}\right]\left(a_1+\frac{2}{3}(a_2-a_1)\right)^2 \tag{5}$$

$$(I_x)2 = \frac{1}{3}(a_3-a_2)w^3 \tag{6}$$

$$(I_y)2 = \frac{1}{12}(a_3-a_2)^3 w + (a_3-a_2)w\left(\frac{a_3+a_2}{2}\right)^2 \tag{7}$$

$$(I_x)3 = \frac{1}{12}(a_4-a_3)w^3 \tag{8}$$

$$(I_y)3 = \frac{1}{36}w(a_4-a_3)^3 + \left(\frac{2a_3+a_4}{3}\right)^2\left(\frac{(a_4-a_3)w}{2}\right) \tag{9}$$

Step 2: Then, using following equations, radius of gyration relative to x and y exes is calculated as Eqs. 10 and 11:

$$r_x = \sqrt{\frac{(I_x)1+(I_x)2+(I_x)3}{(((a_3-a_2)+(a_4-a_1)w)/2}} \tag{10}$$

$$r_y = \sqrt{\frac{(I_y)1+(I_y)2+(I_y)3}{((a_3-a_2)+(a_4-a_1)w)/2}} \tag{11}$$

Step 3: in the last step, the Eq. 12 is calculated:

$$R_{\tilde{A}} = r_x + r_y \tag{12}$$

Next, to compare fuzzy number A and B, we do as Eq. 13:

$$\begin{cases} \tilde{A} > \tilde{B} & \text{if} \quad R_{\tilde{A}} > R_{\tilde{B}} \\ \tilde{A} = \tilde{B} & \text{if} \quad R_{\tilde{A}} = R_{\tilde{B}} \\ \tilde{A} < \tilde{B} & \text{if} \quad R_{\tilde{A}} < R_{\tilde{B}} \end{cases} \tag{13}$$

It should be noted that to get non-fuzzy amount of pairwise comparisons, fuzzy numbers to each other should be divided and achieved by radius of gyration method, and should divide smaller R to larger R so that obtained numbers should be smaller than 1. For coding the radius of gyration ranking method the visual basic for applications software should be used.

Comparison of the two triangular fuzzy numbers, $\tilde{A}$ (a, b, c) and $\tilde{B}$ (d, e, f) shown in Fig. 2, is carried out by comparing their equivalent crisp numbers.

RESULTS AND DISCUSSION

DPSIR is a proper technique to evaluate different factors affecting environmental quality. According to the DPSIR terminology, social and economic developments (Driving forces, D) exert Pressures (P) on the environment and, consequently result to changes in the State (s) of the Environment. This study has applied the DPSIR framework model for evaluation of air pollution factors. In this framework, the combination of DPIR model and FAHP are considered to develop a comprehensive decision making model for control and reduction of air pollution caused by vehicles in Tehran. The factors considered in DPSIR analysis are given in Table 1. In accordance with AHP method, driving forces, pressures, states and impacts are assumed as the criteria whereas the responses are considered as the alternatives in Fig. 1.

Based on the Table 2 output, there are 18 criteria and 5 alternatives. It should be mentioned that, simple DPSIR analyze usually present the responses that have effects on the driving force and pressure factors. But, it cannot prioritize the responses and provide clear strategies. Besides, it cannot figure out what responses should carry out first. However, DPSIR combined with a FAHP method can provide the priorities and consequently is considered as a better plan. As a whole, the work has tried to find a new fuzzy number ranking method for reduction of human errors on decision making. In this way a more flexible

Table 1: DPSIR factors in Tehran metropolitan city

Driving forces (criteria)	
D1	Rather low driving culture
D2	Dense urban population
D3	Inefficient controlling roles
D4	Inefficient system of guidance and driving penalties
Pressures (criteria)	
P1	Old car fleets
P2	Dense traffic
P3	High custom rate on imported cars
P4	Low quality of domestic cars
P5	Inappropriate public transport
States (criteria)	
S1	Lower numbers of day with clean air
S2	High air quality index
S3	Higher numbers of people with respiratory problems
S4	High concentration of air pollutants
Impacts (criteria)	
I1	Damage on human health
I2	Dense traffic
I3	Damage on plant cover
I4	Cumulative impacts
Responses (alternative)	
R1	Development of public transport
R2	Promotion of fuel quality
R3	Promotion of air standards for cars
R4	Car technical check up
R5	Traffic management

results might be achieved. This is proved by many studies (Chen *et al.*, 2010; Ham, 1998). After the pairwise questionnaires are gathered from the experts the average value of the comparisons are calculated and transferred to the fuzzy environment (Table 2). The inconsistency ratios are checked and assurance was made that all of them are lower than 0.1. Then, as per the fuzzy number ranking method the weights of the fuzzy matrices are gained. The numbers in Table 2 shows that there are little differences amongst the judgments and the effects of all 4 responses (alternatives). However, the importance of the main criteria groups are assumed equally and the sub criteria are also considered equal and just the pair-wise comparison of the alternatives due to each criterion were considered. Finally, the total weights are calculated and shown in Table 3.

Investigation and prioritization of the urban transport situation in Tehran have provided a number of necessary issues for strategic planning to reduce local air pollution and also emission of greenhouse gases by considering their effectiveness prioritization in implementation. These strategies are as follows:

Development and improvement of public transport R1

Promotion of an efficient public transport system in terms of energy consumption requires investment-related decisions. This may be come into reality if transport services are priced efficiently and effectively. Currently, the public transport system in Tehran suffers from real pricing. Also authors suggest:

a) Various forms clean fuel to be used in the cars (including hydrogen, electric and hybrid fuel) to meet with European air emission standards. The percentile of cars running on electric, hydrogen or hybrid is less than one percent that is too low when compared with (about 10%) European countries.
b) The use of natural gas that it has lower harmful environmental effects compared to gasoline and petrol.
c) The use of other fuels such as alcohol derived from sugar cane and bagasse.

Improving the fuel quality R2

The use of reasonable price of fuel can have a significant impact on the effects of air pollution at the local and global level. Low fuel price, poor quality of fuel, along with inefficient cars, is some critical factors involved in high level of air pollution caused by transport systems.

Improving the vehicle emission standards R3

More strict emission standards must be set by Department of the Environment. Such standards can

Table 2: FAHP final weights

Driving Force (D1)		Pressure (P1)		State (S1)		Impact (I1)	
R1	0.18	R1	0.198	R1	0.197	R1	0.188
R2	0.225	R2	0.204	R2	0.198	R2	0.211
R3	0.225	R3	0.197	R3	0.204	R3	0.195
R4	0.191	R4	0.197	R4	0.204	R4	0.195
R5	0.179	R5	0.204	R5	0.197	R5	0.211
Driving force (D2)		Pressure (P2)		State (S2)		Impact (I2)	
R1	0.188	R1	0.188	R1	0.224	R1	0.205
R2	0.214	R2	0.214	R2	0.224	R2	0.205
R3	0.214	R3	0.214	R3	0.184	R3	0.208
R4	0.214	R4	0.214	R4	0.184	R4	0.208
R5	0.169	R5	0.169	R5	0.185	R5	0.176
Driving force (D3)		Pressure (P3)		State (S3)		Impact (I3)	
R1	0.204	R1	0.214	R1	0.200	R1	0.205
R2	0.204	R2	0.214	R2	0.200	R2	0.176
R3	0.197	R3	0.169	R3	0.204	R3	0.208
R4	0.197	R4	0.188	R4	0.204	R4	0.208
R5	0.198	R5	0.214	R5	0.192	R5	0.205
Driving force (D4)		Pressure (P4)		State (S24)		Impact (I4)	
R1	0.197	R1	0.215	R1	0.224	R1	0.186
R2	0.204	R2	0.205	R2	0.224	R2	0.176
R3	0.204	R3	0.183	R3	0.184	R3	0.192
R4	0.198	R4	0.183	R4	0.184	R4	0.223
R5	0.197	R5	0.215	R5	0.185	R5	0.223
		Pressure (P5)					
		R1	0.179				
		R2	0.191				
		R3	0.225				
		R4	0.180				
		R5	0.225				

Table 3: Final weights and the priorities

Responses	Final weights	Priority
R1	0.1994	3
R2	0.2052	1
R3	0.2006	2
R4	0.1987	4
R5	0.1962	5

improve fuel efficiency followed by reduced greenhouse gas emissions and conventional pollutants (CO, HC, and NOx). In this regard, it can be stated that the first priority is implementation of government's obligations in supplying the resources required for public transport development. In this direction, an integrated system is important so that, for example, bus stations and taxi terminal to be immediately established beside metro terminals.The second priority is the modernization of the existing taxi network since the current system is one of the main polluting factors in Tehran. For example, between 85,000 and 90,000 taxis are currently driven while 70% of the fleets are old. The third priority is using modern technologies and virtual capacity in order to increase public welfare and provide high-quality service for people. The fourth priority is improving the quality of public transport services that is already very low.

Vehicle technical check-up R4

Currently, check-up and maintenance of vehicles require improvement. "Current tests include only static test that has limited value in predicting the production of pollutants or fuel consumption. Therefore, it is necessary that a short test closer and more relevant to real driving condition to be conducted. Some of the cases that should be considered in this section are as follows:

a) An obligation to install canister (system to measure the exhaust emissions),
b) The technical check-up of vehicles should be done on yearly basis,
c) To impose high penalties on cars that does not follow the emission standards.

Traffic management R5

Although some measures have been considered to control traffic but their implementing mechanisms have not been appropriate. Therefor a more effective traffic plan must be developed. Such plan should consider parking lots along with the development of public transport. Also, Authors suggest that private cars with 3 or more passengers to be allowed to enter into the bus rapid transition (BRT) lanes.

a) The need to increase parking capacity in Tehran to 4 time of present capacity (900,000). Presently, vast areas of streets are occupied by the parked cars.
b) A more intelligent traffic lights must be used.
c) More attractive traffic education should be provided to the people.
d) More attention should be given to traffic engineering for the ease of movements.

CONCLUSION

As mentioned earlier, one of the problems of the management of air pollution control and reduction programs in Iran, especially in Tehran, is lack of examining the priority and effectiveness of each measure. Such shortage is damaging capital and human resources. Therefore, all the measures must be weighted and prioritized. The percentile of effectiveness of each measure on air pollution reduction must be brought out. Hybrid model of FAHP-DPSIR is suitable to find priority of environmental programs with a comprehensive and management approach taking into account the uncertainty of a hierarchical structure. In this study, responses to various factors were examined and compared hierarchically, and their priority relative to each other was achieved. Development and improvement of public transport, improvement of the quality of fuel, improvement of vehicle emission standards, vehicle technical check-up, and finally urban traffic management were identified respectively as the top most priorities. These priorities can control and reduce air pollution in Tehran. The model developed in this study is recommended to be used in similar cases, especially in developing countries like Iran facing managerial problems. This model has high flexibility and precision in prioritizing with a comprehensive approach. It should also be concluded that fuzzy theory overcomes the uncertainties and human decision errors.

ACKNOWLEDGEMENT

The authors of this study would like to thank Graduate Faculty of the Environment for providing the research facilities. Also thanks to Dr. A, Padash for his remarkable comments throughout the research performance.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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HOW TO CITE THIS ARTICLE

Mohammadizadeh, M.J.; Karbassi, A.R.; Nabi Bidhendi, Gh.R.; Abbaspour, M., (2016). Integrated environmental management model of air pollution control by hybrid model of DPSIR and FAHP. Global J. Environ. Sci. Manage., 2(4): 381-388.

DOI: 10.22034/gjesm.2016.02.04.007

URL: http://gjesm.net/article_20581.html