Using the Leopold Matrix Procedure to Assess the Environmental Impact of Pollution from Drinking Water Projects in Karbala City, Iraq

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Abstract
The Environmental Impact Assessment (EIA) procedure is designed to identify and predict the impacts of bio-geophysical environments on human health. In this study, the Leopold matrix was applied to predict the pollution impacts of seven water projects in Karbala city in Iraq based on water quality data collected for the period January to December 2018. The results showed that the impacts of Ca and SO4 in treated water were unacceptable in most cases due to uncontrolled dosage of alum and lime added during water treatment processes. The results also demonstrated that the maximum environmental impact (EIV) for raw water was 51.21 at Al-Hendiya Al-Qadeem water treatment plant (WTP) while that for treated water was 99.97 at Hay Al-Hussein WTP. The obtained impact values of treated water quality parameters in this study occurred due to the use of old techniques in water treatment and demonstrate the need to upgrade these techniques. The Leopold matrix was, however, shown to be good process for sifting out or mitigating the negative effects of such projects on humans and the environment.

Keywords: EIA; environmental impact; impact magnitude; Leopold matrix; Rapid assessment; sever impact rank.

1. Introduction:
Environmental Impact Assessment (EIA) is a procedure for assessing the effects that are likely to arise from any major project the environment [1]. This procedure requires consideration of the environment and public cooperation in the decision-making process of any project development [2]. The EIA may be either a direct legal requirement or enforced indirectly under general planning, health, or pollution control powers [2], and EIA systems are commonly applied to real projects by individuals or companies [3]. The most popular concept of EIA is as a planning tool [4], and in this regard, the EIA system may not be significant for small projects; however, it is a necessity for large scale projects [5]. EIA was recommended by the National Environmental Policy Act (NEPA) in
the USA in 1969, and the influence of this NEPA recommendation was not limited to the USA alone. By the beginning of the 1990s, over 40 countries had begun to utilise the EIA system [3][1], and in 2000, the Environmental Impact Assessment act was issued as a legal requirement [2] being imposed even on countries without formal environmental programmes [3]. The description of EIA as a planning tool has been called the “technocratic paradigm”, and it makes EIA an element of “rational model” planning and decision making. In the rational model, the objectives and criteria for assessing alternative projects are identified at the outset. Thus, as a planning tool, EIA serves greatly to inform interested parties of the likely environmental impacts of a proposed project and the impacts of alternatives [6]. The description procedure of EIA processes for any development project consist of several sequential elements, as explained in Figure (1):

![Diagram of EIA process]

*Figure 1: Major steps in the EIA process [7].*

The methods (i.e. tools) of EIA range from simple to complex, with different data requirements and formats, and varying expertise levels and technological difficulty needed for their explanation [8]. The EIA Analysis method includes identifying, predicting, and assessing the relevant impacts, and then mitigating them [9][10]. Several EIA methods are used for predicting impact; the most popular methods are

- **Matrices:** the main functions of this tool are to identify the preliminary impacts, make a comparative analysis of alternative impact assessments, and present the evaluation results. There are two type of matrices used: Simple and Stepped.
- **Networks:** These methodologies integrate impact causes and consequences through identifying interrelationships between casual actions and the impacted environmental factors.
- **Checklists:** The principle of this tool is to develop a framework for EIA users so that they do not omit any relevant points. Various checklists are available, including Simple, Descriptive, and Questionnaire [11][12].
- **The Batelle method:** the principle of this tool is to split the environmental impacts into four major categories: ecology, pollution, aesthetics, and human interest [5][2], so that the EIA can be implemented with regard to any activities.
Josimovic et al. addressed the possibility of employing the Leopold matrix in executing EIA for the Kladovo Wind Farm in Serbia as a case study. The novelty in their study was in the evaluation of the planned project activities relative to a group of criteria, and their results enabled them to precisely identify the possible environmental impacts of the project[13].

The Battelle method was used by Azom et al. to analyse and assess the effects on soil and river water environments for area surrounding the tanneries of Hazaribag in Dhaka. An EIA was done for several of the physical, ecological, human usage, and socioeconomic factors of these environments, and the results of the applied Battelle method revealed that the tanning activities involved serious environmental hazards [14].

A Leopold matrix was applied in 2010 to evaluate the impact of polluted air and water from some industrial activities in the middle Euphrates region in Iraq. The impact magnitude of the chosen parameters were determined by division concentration of any parameter in a working state on standard limits, while the importance of the impacts was selected as being between 0 and 5 [2].

The Second Sydney Airport was also selected for a case study in which a procedure for a typical EIA was applied according to recent Australian guidelines. These researchers described the method utilised input–output analysis, a top-down linear macroeconomic approach to describe industrial structure, to determine the indirect effects of a development proposal in terms of several indicator variables. The results showed that the gross impacts were much higher than the on-site impacts for selected assessment indicators, and the researchers concluded that utilising input-output analysis to develop a conventional EIA allowed mandatory elements to be combined into EIA standards. [15]

It is very important to study the EIA as it offers an effective way to sift out or mitigate negative project effects on human and the environment. This study thus aims to study the impact of water quality of some of the main water projects in the province of Karbala.

2. Methodology

2.1. Constructing a matrix

The Leopold matrix is the best-known matrix method available for predicting the impact of a project on the environment [5]. This method was thus adopted in this study in order to evaluate the impact of seven water projects in Karbala city. The Leopold matrix is a two-dimensional cross-referencing matrix which displays

- The activities linked to the project that may have an impact on humans and the environment;
- The existing environmental and social conditions that could possibly be affected by the project [5].

To construct the Leopold matrix, the following steps must be followed:
1. Identify all actions of the proposed project in the term of magnitude.
2. A slash is placed diagonally from upper-right to lower-left of each block, which represents significant interaction [16]. Figure (2) shows the general form of each Leopold matrix box.

![Figure 2: General form of the Leopold Matrix](image)

The Magnitude of each possible impact is placed in the upper left-hand corner of a box of the matrix. Although impact magnitude can be more readily evaluated on the basis of facts, the importance of impact evaluation is generally based on the value judgment of the evaluator [16]. The following equations was used in this study to determine the magnitude of impact.
Magnitude (M) = \frac{\text{pollutant concentration (in working state)}}{\text{standard limits (concentration)}} \hspace{1cm} \text{Equation (1)}

Magnitude (M) = \frac{\text{pollutant concentration (in working state)}}{\text{element concentration (in design state)}} \hspace{1cm} \text{Equation (2)}

Eq. (1) is used where there are existing guidelines for the element, while Eq. (2) is used where there are no existing guidelines [2]. Eq.(1) was thus used in this study, as all water quality parameters have standard limits.

The importance of each impact is placed in the lower right-hand corner of the relevant box of the matrix [2]. The importance of each environmental impact must include consideration of the consequences of changing a particular condition for other factors in the environment [16]. The scale of the importance ranges from 1 (very low interaction) to 10 (very important interaction) [5]. The importance scale of pollutant parameters in this paper ranged from 0 to 10 based on health impacts on humans and the environment. The importance of possible impacts was evaluated based on the opinions of experts in relevant fields such as doctors, chemists, biologists, agriculture directorate representatives, water directorate representatives, environmental directorate representatives, and professors of environmental engineering. Figure (2) shows the Leopold matrix adjustment adopted in this study.

Matrix 1: Default Leopold matrix

| Environmental Media | Pollutant | Temp | Turb | pH | E.C | T.H | Ca | Mg |
|---------------------|-----------|------|------|----|-----|-----|----|----|
| IV                  | M         |      |      |    |     |     |    |    |
| R                   |           |      |      |    |     |     |    |    |
| Raw or treated      | Cl        | SO4  | T.D.S | T.S.S | Na | K   | Al |
| water               |           |      |       |     |     |     |    |    |
| Total               | Sum(I)    | Sum(M) | EIV  |     |     |     |    |    |

The impact value (IV) of each pollutant on the environment can be calculated from Eq. (3), and the total environmental impact value (EIV) and the ratio of pollutant (R) from Eqs. (4) and (5), respectively [2].

\[
\text{Impact value for each pollutant (IV)} = I \times M \hspace{1cm} \text{Equation (3)}
\]

\[
\text{environmental impact value (EIV)}=\sum_{i=1}^{n} I_i \times M_i \hspace{1cm} \text{Equation (4)}
\]

\[
\text{Ratio of impact pollutant from total (R)} = \frac{\text{IV}}{\text{EIV}} \hspace{1cm} \text{Equation (5)}
\]

2.2 Study area of application EIA

Seven water treatment projects within Karbala province were selected for evaluation of the impact of pollutant parameters from raw and treated water. Four of these projects are within Karbala city centre while others are within Al-Hendiya city the biggest discrete outer region of Karbala. The projects selected were Karbala, Al-Mowahed, Madenat Al-Hussain, Al-Safi, Hay Al-Hussain, Al-Hendiya Al-Jadeed, Al-Hendiya Al-Qadeem, and Al-Hendiya Al-Mowahed. These projects were labelled project1, project2, project3, project4, project5, project6, and project7, respectively. The water projects selected use the same technique of water treatment techniques, including coagulation, flocculation, and sedimentation [17]. The intake of project 1 is located at the
Al-Musayab river; the intakes of project2, project3, and project4 are located at the Al-Hussainya river, and the intakes of project5, project6, and project7 are located at the Euphrates river. Human health was the main cause for selecting these water projects as a case study, as up to 80% of the population of Karbala city use treated water from these plants for drinking.

2.3 Sample Collection and Standards used
Fourteen physio-chemical parameters were selected to assess the possible environmental impact of water treatment projects, as explained in matrix (1). For more accuracy, three to four samples were tested and average values calculated for monthly impact assessments during the study period. The tests were done at Karbala water directorate laboratories using traditional methods for measuring the concentration of the selected parameters. The unit of measurement for the pollutants investigated were NTU for turbidity, °C for temperature, pH, and µs for electrical conductivity, with all other pollutants measured in mg/l. The Iraqi standard IQS/417/2001 for drinking water and the Iraqi standard for conservation of rivers and public water from pollution IQS/25/1967 for raw water were used to determine the extent and impact magnitude of these pollutants.

3 Result and Discussion

3.1. Impact and Rank of the Impact severity
Impact assessment is a major tool of environmental management, and it is an effective way of assessing water pollution within a study area. The impact values (IV) from Eq.3 were accepted if the impact magnitude (M) for each pollutant as calculated using Eq.1 was greater than one, suggesting that the concentration of pollutant exceeded the standard specification. Figure (3) to Figure (9) show the impact value of pollutants for raw and treated water in these water projects. These figures show that the greatest impact was from Ca and SO4 for treated water was unacceptable impact due to uncontrolled use of alum and lime during the water treatment process therefore the concentration of this salt exceeding the specification. The turbidity of raw water was also unacceptable due to low water levels at the intakes, while the PH impact values before and after treatment were generally unacceptable.

![Figure 3: Impact (IV) of pollutant for Karbala Al-Mowahed](image1)

![Figure 4: Impact (IV) of pollutant for Madenat Al-Hussain](image2)
The pollutants were ranked to illustrate the impact severity, with the maximum impact (IV) taking the first rank of impact severity and the minimum impact (IV) taking the seventh rank based on the number of water projects of the case study. Tables 1 and 2 show the rank of impact severity for each element for raw and treated water.

| Pollutant | Turb | PH | T.H | Ca | Mg | Cl | SO4 | T.D.S | Na | Al |
|-----------|------|----|-----|----|----|----|-----|-------|----|----|
| Max. Rank | 1    | 1  | 1   | 1  | 1  | 1  | 1   | 1     | 1  | 1  |
| Project   | P3   | P2 | P2  | P2,4| P2,3,6| P7 | P2  | P3    | P7 | P6 |
| Min. Rank | 7    | 4  | 7   | 6  | 4  | 5  | 7   | 7     | 7  | 2  |
| Project   | P5   | P1.4| P3 | P5.7| P1  | P1,2,3| P4 | P1    | P1 | Except6 |

Table 1: The rank of severe impact for pollutant of raw water of treatment projects
Table 2: The rank of severe impact for pollutant of treated water of treatment projects

| Pollutant | Turb | PH | T.H | Ca | Mg | Cl | SO4 | T.D.S | T.S.S | Na | Al |
|-----------|------|----|-----|----|----|----|-----|-------|-------|----|----|
| Max.Rank  | 1    | 1  | 1   | 1  | 1  | 1  | 1   | 1     | 1     | 1  | 1  |
| Project   | p2,3,4 | p6,7 | p2  | p4  | p3  | p7  | p2  | p4    | p2    | p7  | p4  |
| Min.Rank  | 5    | 5  | 6   | 6  | 4  | 6  | 7   | 7     | 6     | 7  | 7  |
| Project   | P5   | P5 | P3,4| P5,7| P1  | P1,3| P4  | P1    | P5,7  | P1  | P2  |

3.2 Assessment of Leopold matrix (LM)

This rapid assessment procedure allows for quick estimation of pollutant releases to the environment, and it enables a firm to manage environmental affairs in a planned and systematic way, easily identifying ways of improving environmental performance to benefit business performance [18]. The Leopold matrix was applied in this study because

- It is applied extensively in the reports issued by the United Nations Environmental Programme UNEP,
- It is simple to follow,
- It allows easy comparison among different projects, and
- It is comprehensive in terms of covering all physical, biological and socio-economic environmental impacts [19].

The result of the application of EIA to raw and treated water using a Leopold matrix for the seven water treatment plants at Karbala city is shown in the following matrices containing

- The importance and magnitude of water quality parameters;
- The impact values of all water quality parameters on the environment for raw water and on human health for treated water; and
- The impact rate of parameters affecting environmental and human health. For raw water, the maximum and the minimum environmental impact values (EIVs) were 51.21 and 42.96, respectively, at the Al-Hendiya-Jadeed project, while for treated water, the maximum and minimum environmental impact values (EIVs) were 99.97 and 73.19 at Hay Al-Hussain and Al-Hendiya Mowahed projects, respectively. All values for environmental impact in the matrices below are summarised in Figure (10) for all water treatment plants in this study.
### matrix 3: Leopold matrix for raw and treated media of project 2

| Pollutant | Temp | Turb | pH | E.C | T.H | Ca | Mg | Total |
|-----------|------|------|----|-----|-----|----|----|-------|
| Raw water |      |      |    |     |     |    |    |       |
| Cl        | 0.5  | 1.36 | 1.54 | 0   | 0.53 | 0.49 | 0  | 62    | 15.03 |
| SO4       | 3.5  | 4.08 | 3.08 | 0   | 3.18 | 4.41 | 0  |       | 47.22 |
| T.D.S     | 0.07 | 0.09 | 0.07 | 0   | 0.07 | 0.09 | 0  |       | 1     |
| T.S.S     |      |      |      |     |      |      |    |       |
| Na        |      |      |      |     |      |      |    |       |
| K         |      |      |      |     |      |      |    |       |
| Al        |      |      |      |     |      |      |    |       |
| Drinking Water |      |      |      |     |      |      |    |       |
| Cl        | 0.02 | 0.09 | 0.09 | 0.01 | 0.07 | 0.07 | 0.05 |       |       |
| SO4       | 4.55 | 5.19 | 3.12 | 24  | 6.24 | 8.64 | 6   | 82    | 17.66 |
| T.D.S     | 0.05 | 0.05 | 0.03 | 0.24 | 0.06 | 0.09 | 0.06 |       | 0.98  |

### matrix 4: Leopold matrix for raw and treated media of project 3

| Pollutant | Temp | Turb | pH | E.C | T.H | Ca | Mg | Total |
|-----------|------|------|----|-----|-----|----|----|-------|
| Raw water |      |      |    |     |     |    |    |       |
| Cl        | 0.5  | 1.3 | 1.51 | 0   | 0.53 | 0.49 | 0  | 62    | 15.14 |
| SO4       | 3.5  | 3.9  | 3.02 | 0   | 3.18 | 4.41 | 0  |       | 47.19 |
| T.D.S     | 0.07 | 0.08 | 0.06 | 0   | 0.07 | 0.09 | 0  |       | 0.99  |
| T.S.S     |      |      |      |     |      |      |    |       |
| Na        |      |      |      |     |      |      |    |       |
| K         |      |      |      |     |      |      |    |       |
| Al        |      |      |      |     |      |      |    |       |
| Drinking Water |      |      |      |     |      |      |    |       |
| Cl        | 0.02 | 0.1  | 0.1  | 0.01 | 0.07 | 0.08 | 0.06 |       |       |
| SO4       | 4.48 | 4.92 | 3.14 | 16  | 6.18 | 8.64 | 7   | 82    | 16.84 |
| T.D.S     | 0.05 | 0.05 | 0.03 | 0.18 | 0.07 | 0.1  | 0.08 |       | 90.72 |
| T.S.S     |      |      |      |     |      |      |    |       |
| Na        |      |      |      |     |      |      |    |       |
| K         |      |      |      |     |      |      |    |       |
| Al        |      |      |      |     |      |      |    |       |
| Total     |      |      |      |     |      |      |    |       |

### matrix 5: Leopold matrix for raw and treated media of project 4

| Pollutant | Temp | Turb | pH | E.C | T.H | Ca | Mg | Total |
|-----------|------|------|----|-----|-----|----|----|-------|
| Raw water |      |      |    |     |     |    |    |       |
| Cl        | 0.51 | 1.29 | 1.55 | 0   | 0.54 | 0.49 | 0  | 62    | 13.8  |
| SO4       | 3.57 | 3.87 | 3.1  | 0   | 3.24 | 4.41 | 0  |       | 45.97 |
| T.D.S     | 0.08 | 0.08 | 0.07 | 0   | 0.07 | 0.1  | 0  |       | 1     |
| T.S.S     |      |      |      |     |      |      |    |       |
| Na        |      |      |      |     |      |      |    |       |
| K         |      |      |      |     |      |      |    |       |
| Al        |      |      |      |     |      |      |    |       |
| Drinking Water |      |      |      |     |      |      |    |       |
| Cl        | 1    | 9    | 8   | 2   | 4   | 5   | 6   |       |       |
| SO4       | 2    | 1    | 1.16 | 0.62 | 1.65 | 1.43 | 0.86 |       |       |

8
**Drinking Water**

| Cl  | SO4 | T.D.S | T.S.S | Na  | K   | Al  |
|-----|-----|-------|-------|-----|-----|-----|
| 2   | 9   | 9.28  | 1.24  | 6.6 | 7.15| 5.16|
| 0.02| 0.09| 0.09  | 0.01  | 0.07| 0.07| 0.05|

**Raw Water**

| Cl  | SO4 | T.D.S | T.S.S | Na  | K   | Al  |
|-----|-----|-------|-------|-----|-----|-----|
| 0.65| 1.63| 1.58  | 2     | 1.05| 0.96| 1.2 |
| 4.55| 4.89| 3.16  | 20    | 6.3 | 8.64| 12  |
| 0.05| 0.05| 0.03  | 0.02  | 0.06| 0.09| 0.12|

**matrix 6: Leopold matrix for raw and treated media of project 5**

| Env. media | Pollutant | Temp | Turb | pH | E.C | H | Ca | Mg |
|------------|-----------|------|------|----|-----|---|----|----|
| Raw water  | Cl        | 0    | 1    | 9  | 0   | 4 | 5  | 6  |
|            | SO4       | 0.51 | 1.33 | 1.52| 0   | 0.54| 0.49| 0  |
|            | T.D.S     | 3.57 | 3.99 | 3.04| 0   | 3.24| 4.41| 0  |
|            | T.S.S     | 0.08 | 0.09 | 0.07| 0   | 0.08| 0.1 | 0  |

**Drinking Water**

| Cl  | SO4 | T.D.S | T.S.S | Na  | K   | Al  |
|-----|-----|-------|-------|-----|-----|-----|
| 0.51| 1.33| 1.52  | 0    | 0.54| 0.49| 0   |
| 3.57| 3.99| 3.04  | 0    | 3.24| 4.41| 0   |
| 0.08| 0.09| 0.07  | 0    | 0.08| 0.1 | 0   |

**matrix 7: Leopold matrix for raw and treated media of project 6**

| Env. media | Pollutant | Temp | Turb | pH | E.C | T.H | Ca | Mg |
|------------|-----------|------|------|----|-----|-----|----|----|
| Raw water  | Cl        | 0    | 1    | 9  | 0   | 4   | 5  | 6  |
|            | SO4       | 0.53 | 1.33 | 1.53| 0   | 0.53| 0.49| 0  |
|            | T.D.S     | 3.71 | 3.99 | 0   | 3.06| 3.18| 4.41| 7  |
|            | T.S.S     | 0.07 | 0.08 | 0   | 0.06| 0.06| 0.09| 0.14|

**Drinking Water**

| Cl  | SO4 | T.D.S | T.S.S | Na  | K   | Al  |
|-----|-----|-------|-------|-----|-----|-----|
| 0.53| 1.33| 1.53  | 0     | 0.53| 0.49| 0   |
| 3.71| 3.99| 0     | 3.06| 3.18| 4.41| 7   |
| 0.07| 0.08| 0     | 0.06| 0.06| 0.09| 0.14|

**matrix 8: Leopold matrix for raw and treated media of project 7**

| Env. media | Pollutant | Temp | Turb | pH | E.C | T.H | Ca | Mg |
|------------|-----------|------|------|----|-----|-----|----|----|
| Raw water  | Cl        | 0    | 1    | 9  | 0   | 4   | 5  | 6  |
|            | SO4       | 0.67 | 1.60 | 1.55| 1   | 1.06| 0.96| 0.80|
|            | T.D.S     | 4.69 | 5.07 | 3.1 | 16  | 6.36| 8.64| 8  |
|            | T.S.S     | 0.05 | 0.06 | 0.03| 0.18| 0.07| 0.1 | 0.09|

**Total**

| Cl  | SO4 | T.D.S | T.S.S | Na  | K   | Al  |
|-----|-----|-------|-------|-----|-----|-----|
| 16.73| 17.79| 0.99  | 10.53| 11.96| 12.79| 13.84|
| 89.55| 99.97| 1     | 43.82| 46.82| 51.21| 57.37|
| 1    | 1    | 1     | 1     | 1    | 1    | 1    |
| 9    | 9    | 9     | 9     | 9     | 9     | 9     |
| Env. media | Pollutant | Temp | Turb | pH | E.C | T.H | Ca | Mg | Total |
|-----------|----------|------|------|----|-----|-----|----|----|-------|
| Drinking Water | Cl | 0.70 | 1.70 | 1.54 | 0.4 | 1.08 | 0.94 | 0.7 | 15.04 |
| | SO4 | 4.9 | 5.1 | 3.08 | 4 | 6.48 | 8.46 | 7 | 73.19 |
| | T.D.S | 0.07 | 0.07 | 0.04 | 0.05 | 0.09 | 0.12 | 0.1 | 1.01 |

**Figure 10: Environmental impact (EIV) OF WTP**
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