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An Approach Towards the Development of Environmental Quality Index for Evaluation and Categorization of Environmental Impacts

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During systematic analysis of environmental data, Quality Index (QI) and Quality Matrix (QM) studies have proved to be much useful techniques. An attempt has been made to develop an approach for the evaluation of environmental data through index analysis. Based on the sensitivity function evaluation and derivation of Impact Index and Quality Index related to individual parameters of the various components, Integrated Quality Index (IQI) has been derived. Further, IQI for various environmental components have been carried over to matrix analysis to have over all visualization in the form of Environmental Quality Matrix (EQM). The results can be easily evaluated using defined Environmental Quality Index Classification System (EQICS).

Introduction

Environmental Impact Assessment (EIA) is a task to assess the quality of environment. It involves data collection, analysis, prediction and modeling exercises. During analysis of environmental data on various components such as water, air, land, noise, ecology, health and socio-economic, generally a systematic approach substantiates the success of the assessment. This type of systematic approach in data analysis could be mooted through the estimation of Quality Index (QI) for each parameter of various environmental components and then compiled through Quality Matrix (QM) analysis.

The Envionmenvtal Quality Index (EQI) depends upon the various environmental parameters, which directly or indirectly, are related to the impacts of the physical, biological, and social attributes in the surrounding. So far, it is complicated concept among the environmental researchers, though there are several methods already existing in the area of environmental impact assessment[1-3]. All these methods are based on different weightages assigned to each parameter and the net result of validation may vary from person to person during evaluation, according to the importance given by themselves to a particular parameter. It finally causes different results in the assessment of IQI[4]. In this paper, an attempt has been made to develop a generalised methodology.

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Definition of Some Fundamental Concepts

Quality Interval

Every environmental parameter has its own recommended value (r) or recommended range ($r_1 \leq x \leq r_2$) and also minimum (I) and maximum (u) permissible limits (in mathematical language these limits are called lower and upper limits respectively) from the quality point of view for a definite use. The closed interval $[l, u]$ in which the recommended value or recommended range falls is said to be the Quality Interval of the parameter.

The semi-closed -sub-interval (l, r_1) is called as Increasing Quality Region (IQR) whereas the semi-closed-sub-interval $(r_2, u]$ as Decreasing Quality Region (DQR). The closed-sub-interval $[r_1, r_2]$ is called Excellent Quality Region (EQR) or Excellent Quality Point (EQP) in case of singleton set. These various regions of quality interval are shown in Figure 1.

Sensitivity Function

Sundara-rajan, *et al.*[5] have defined the sensitivity function of a parameter on its quality interval. This may be modified on real number system as follows:

The projection mapping defined on the real number system f_p: $R \rightarrow [-1, +1]$ is said to be sensitivity function of a parameter 'p' if it is defined as follows:

Sensitivity Number

Each image $f(x)$ for every x of the sensitivity function, defined on the domain R is said to be sensitivity number.

$$f_p(x)=\begin{cases} -1 & \text{if } x<l \\ \dfrac{x-r_1}{r_1-l} & \text{if } l \leq x<r \\ 0 & \text{if } r_1 \leq x \leq r_1, \\ \dfrac{x-r_2}{u-r_2} & \text{if } r_2 < x \leq u \\ +1 & \text{if } x>u \end{cases} \quad ...(1)$$

The negative sensitivity number indicates that the value of the parameter is less than the recommended value, whereas the positive number indicates that the value of the same is more than the recommended range or value. The zero sensitivity number shows that the value of the parameter lies in the recommended range. The sensitivity function is shown in Figure 2 for a parameter having recommended range, minimum and maximum permissible limits as $r_1 \leq x \leq r_2$, l and u respectively.

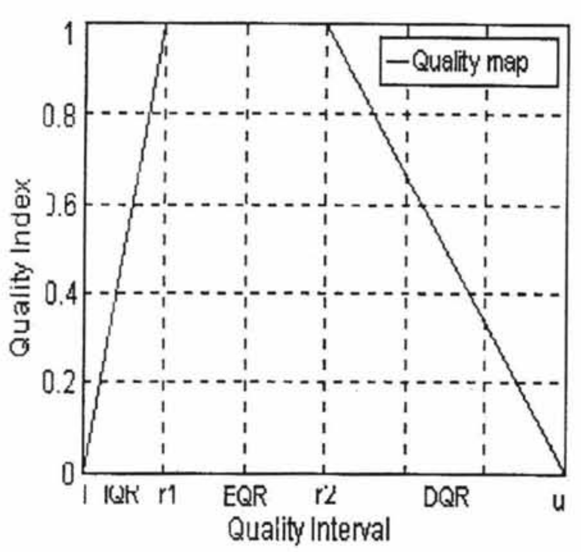

Figure 1— Shows quality map of a parameter

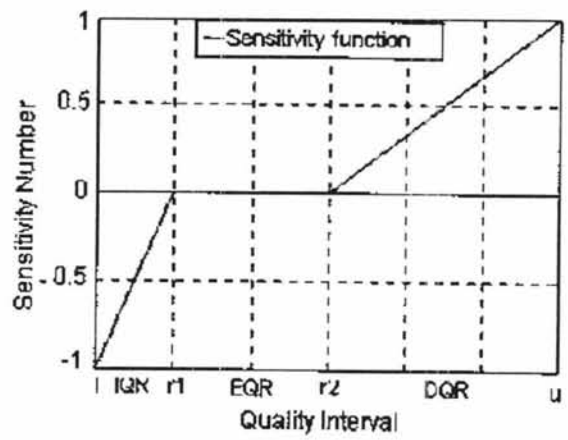

Figure 2— Shows sensitivity function of a parameter

Impact and Quality Index of a Parameter

The absolute value of the sensitivity number of a parameter is called as Impact Index (II) and is denoted by 'p'. Based on II 'p', the Quality Index (QI) 'q' is derived as follows:

Since II lies in the interval [0, 1], the sum of II and QI must be always unity, i.e., $p + q = 1$. Therefore,

$$q = 1 - p \quad ... (2)$$

Microscopic Number

The QI always lies in the closed interval [0, 1], just like II. This range may be enlarged as [0, 100], [0, 1000] and [0, 10000] by multiplying with 100, 1000 and 10000, respectively, for micro-level analysis. These multipliers are called Microscopic Numbers (MN). It is clear that the QI obtained by multiplying with 100 will give quality percentage (QP).

The Proposed Approach

IQI of an Environmental Component

In any environmental component, there may be some parameters that can merit or demerit the quality of the component, subject to the indented use. In such cases, it is necessary to assess the overall quality of the component, which may be called as IQI.

Let p_i ($i = 1, 2, 3, \ldots, n$) be II of n considered parameters and q_i ($i = 1, 2, 3, \ldots, n$) be QI calculated using Eq. (2) for particular component 'C' of the environment. Then IQI of the environmental component '*C*' is defined as follows:

$$Q_C = 0.5 \text{ x} \left[\left(\frac{1}{n} \sum_{i=1}^{n} q_i + \prod_{i=1}^{n} q_i \right)^{1/n} \right] \text{x } M. \quad ...(3)$$

IQI may be calculated from Eq. (3) for the major environmental components as such water, air, land, noise, ecology, health an socio-economic separately.

EQM of a Study Area

If N environmental components C_k $(k = 1,2,3, \ldots, N)$ of a particular study area is considered, and the study area is divided into M equal grids G_j $(j = 1,2,3, \ldots, M)$, then the overall environmental quality (EQ) may be visualised in the form of Environmental Quality Matrix (EQM).

Let $Q_{j,k}$ $(j = 1, 2, 3, \ldots M$ and $k = 1, 2, 3, \ldots N)$ be the IQI of k^{th} component in j^{th} grid, calculated by using Eq. (3). The matrix $<Q_{M,N}>$ of order M x N is said to be an EQM and can be derived also for site or time instead of grids. This may be defined for M grids as follows:

$$< Q_{M,N} > = \begin{bmatrix} Q_{11} & Q_{12} & Q_{13} & \cdots & Q_{1N} \\ Q_{21} & Q_{22} & Q_{23} & \cdots & Q_{2N} \\ Q_{31} & Q_{32} & Q_{33} & \cdots & Q_{3N} \\ - & - & - & & - \\ - & - & - & & - \\ - & - & - & & - \\ Q_{M1} & Q_{M2} & Q_{M3} & \cdots & Q_{MN} \end{bmatrix} . \quad ...(4)$$

Environmental Quality Index of a Grid

EQM may be evaluated as EQI for each grid and finally it may be reduced into a column matrix. The element of j^{th} row of the column matrix may be evaluated from the elements of j^{th} row of EQM given in Eq. (4), as follows:

$$I_j = 0.5 \text{ x} \left[\left(\frac{1}{N} \sum_{k=1}^{N} Q_{j,k} + \prod_{k=1}^{N} Q_{j,k} \right)^{1/N} \right]. \quad ...(5)$$

The Eq. (5) may also be applied for the sub--grids so that the impact analysis of the environmental data may be possible at micro-level, as well.

Criteria for EQICS

The environment of a particular grid, in turn, entire study area may be classified into different categories according to EQI, calculated by using Eq. (5) and Environmental Quality Index Classification System (EQICS), which is presented in Table 1.

Application

Any environmental assessment necessarily needs to have an effective methodology to assess the recommended value or recommended range for various parameters and also the maximum and minimum permissible limits to formulate sensitivity function in different components of the environment such as water, air, land, noise, ecology, health, and socio-economic. The present approach could be effectively used for this purpose. For example, in water environment among various parameters, pH may be considered here. Based on the pH parameter, generally water is used for different purposes such as drinking, cooking, bathing, agriculture, aquaculture, and industrial benificiation. For drinking purpose, the recommended pH value is 7 (neither acidic nor alkaline). The minimum permissible pH limit is, 6.5 and the maximum permissible limit is 8.5. Here, the EQR is singleton set, *i.e.*, r_1 and r_2 coincide together. Therefore, $r = r_1 = r_2 = 7$, $l = 6.5$ and $u = 8.5$. Similarly, for all parameters of water component, the quality interval may be evaluated in the same manner. Now take a parameter of socio-economic component that the number of primary schools in a particular

Table 1— Categorisation of EQI

Range of EQI	Category	Remarks
100 - 91	Excellent	Most appreciable
90 - 81	Very good	Appreciable
80 - 71	Good	Fairly appreciable
70 - 61	Satisfactory	Preventive actions are needed
60 - 51	Fair	Serious mitigative and control measures have to be planned
50 - 0	Poor	Treatments are required in all components

village. The village actually needs five primary schools at different locations. Then the recommended value is $r = r_l = r_2 = 5$ and the minimum permissible limit is l=0. Here the EQR is singleton set and the decreasing quality interval is an empty set, *i.e.,* the maximum permissible limit u and the recommended value r coincide together. Thus, the required data for sensitivity functions of various parameters in different environmental components should be investigated. Some of the data are already available as Indian and International Standards. Then environmental data can be analysed by using the approach discussed here.

The components of environment and their parameters are coded properly for computational purpose. The parameters and the corresponding monitored or analysed data are punched in input file #1. The parameters and their recommended values or ranges with maximum and minimum permissible limits are punched in input file #2. The IN, QI and IQI are computed and stored in the output file #1. The method of the execution is briefly presented as a flowchart in Figure 3.

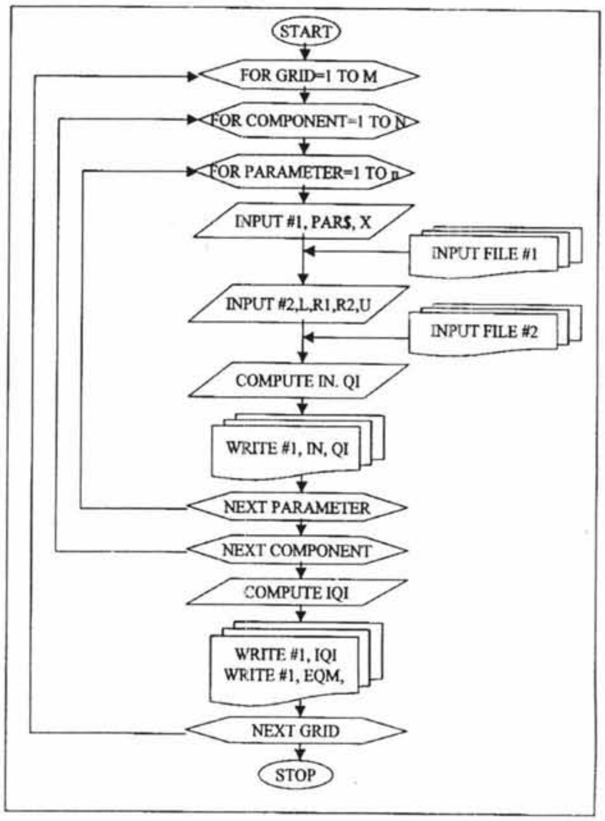

Figure 3 — Flowchart describes the execution of the computer programme

Conclusions

In order to analyse and evaluate various environmental data, an approach has been developed, based on II and QI for individual parameters. All parameter indices of individual components are further analysed through IQI. IQI pertaining to all environmental components are further evaluated through EQM analysis. The results are scaled by the proposed EQICS. Using this approach, all parameters of environmental components can easily be assessed, evaluated, and classified. The approach may be used in carrying capacity studies to detect hotspot areas by converting the values of various parameters of different significant systems into indices like II, QI and IQI. The proposed approach has a wide spectrum of scope for further development related to micro-level evaluation, as well.

Notations

$f_p(x)$	–	Projection map of a parameter 'p' whose concentration is x
I_j	–	EQI of j^{th} grid
l	–	minimum permissible limit
M	–	microscopic number
n	–	number of parameters considered in component 'C'
N	–	number of components considered
q_i	–	QI of i^{th} parameter
Q_C	–	IQI of the component 'C'
Q_{jk}	–	QI of the k^{th} component of j^{th} grid
$<Q_{m,n}>$	–	EQM of N environmental components at M grids of the study area
R	–	Real number system
r_l	–	Lower limit of recommended value of a parameter for particular use
r_2	–	Upper limit of recommended value of a parameter for particular use
x	–	variable represents the concentration or value of particular parameter

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References

1 Krauskopt T M. & Dennis C B, *Evaluation of environmental impact through a computer modelling process, environmental impact analysis: philosophy arid methods*, edited by Robert Ditten and Thomas Goodale (University of Winconsin Sea Grant Program) 1972.

2 Luhar A K & Khanna P, Computer aided rapid environmental impact assessment, *Environ Impact Assess Rev*, **3**(1) (1988) 9-25.

3 Bees W E, Role of environmental assessment in achieving sustainable development, *Environ Impact Assess Rev*, **3**(1988) 273-291.

4 Dee N, *et al*, Environmental evaluation system for water resource planning, in Final report, Battelle Columbus Laboratories, Columbus, Ohio, USA, 1972.

5 Sundararajan M *et al.*, Mathematical model for water quality impact assessment and its computer application in coal mine water, *Proc Int Symp Impact Min Environ – Probl Solut* (Oxford & IBM Publishing Co, Pvt Ltd, New Delhi) 1994, 91-98.