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Methodological Limitations of Determining Global Pollution Index as a Tool for Environmental Impact Assessment and a Proposed Extension

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Abstract In *Global Estimation Methodology for the Ecosystem State*, Rojanschi (1991) used the geometric correlation method to assess the impact of human activity on environment and derived an indicator termed as Global Pollution Index (I_{pg}). The index is capable of describing the real state of environment at a particular location in respect to the national or international standard. However the method is only applicable when at least three environmental components (such as water, air, soil) are considered. In 2005 Popa proposed *Alternative geometric correlation method* which is also applicable when minimum two environmental components are investigated. However Popa's method suffers from the limitation of taking average of average values of investigated data and lack geometric figure which show the real status of all the corresponding environmental components. Hence in several cases (as shown in the current paper), the Popa's pollution index gives misleading information. In this paper, limitations of both Rojanschi's and Popa's methods are discussed and to rectify their limitations, a new scheme termed as 'Extended Rojanschi's Method' is proposed. The proposed method includes concentric/eccentric circle technique for one and two environmental components in addition to the basic Rojanschi's method. Thus the new method is applicable to any number of environmental component from literally one to infinite. It also provides an option to calculate pollution index from actual investigated data instead of their average value (as in Rojanschi's method) or average of average value (as in Popa's method). In proposed method the geometric figures are also capable of representing real status of all the investigated environmental components in respect to their ideal state (which is impossible in Popa's method) and pollution index can be calculated even from one or two environmental component (which is impossible in original Rojanschi's method).

Keywords Global Pollution Index, Environmental Impact Assessment, Geometric Correlation.

1. Introduction

Environmental Impact Assessment is an effective tool for environmental policy-making, awareness raising, participation and global environmental governance. Impact assessment aids the planning stage of an industry to reduce its adversity on local environment [1]. This type of assessment also helps decision making of environmental authorities for existing plants. Thus environmental impact assessment strategy not only saves the environment from human activity but also economically benefits the industrialist by avoiding waste treatment costs and saving additional expenses related to the impacts of laws-regulations [1].

The impact on environment due to the human activities can be assessed in more than 20 different methods [2, 3]. Estimation of Global Pollution Index (I_{pg}) is one of them. It is a simple method to understand the real situation of an environment due to human activities through numerical values and geometric figures. Many researchers from different countries all round the globe used 'global pollution index' method to assess the environmental impact in case of numerous field of applications [4-7]. However, the method itself suffers from few limitations which were partially overcome by Popa's *alternative geometric correlation method*. Unfortunately, Popa's method also suffers from few critical limitations. The current paper discusses limitations of both these methods and proposed an extension to the basic Rojanschi's method as to come up with an environmental impact assessment technique which is free from the limitations of its predecessors.

2. Rojanschi's Method

In *Global Estimation Methodology for the Ecosystem State*, Rojanschi [8] proposed the idea of Global Pollution Index (I_{pg}), a index which gives a relationship between ideal and real state of the environment. The method presents intricate appreciations for various environmental components like air, water, soil etc. The appreciations are made from realistic analysis of different quality parameters of each of the considered component. Simultaneously the method also graphically represents the real sate of the environment in relation to the desired ideal state.

There are two key terms which are frequently used in the Global Pollution Index method. The first one is the 'Environmental Component', which will be presented as 'EC' in current paper and another is 'Quality Indicator', which will be presented as 'QI'. EC can be any component of the environment like air, water, soil etc and QI can be any quality parameter of a certain EC. As an example, QI for water can be pH, Total Dissolve Solid (TDS), BOD (Biological Oxygen Demand) etc and QI for air can be the amount of Carbon monoxide (CO) or Sulpher Dioxide (SO_2) in unit volume of air. In assessing the environment of a selected location, firstly the evaluator needs to decide how many EC will be evaluated and then what will be the QI for each of the selected EC. At next step, the QIs are measured in standardized methods by investigating the real environmental situation of the location. Then a grade point is declared for all the quality parameters (which will be termed as 'Quality Grade (q) in this paper') on a scale of 1 to 10 depending on their actual investigated value in respect to the national standard.

At third stage, the evaluator determines the grade point of all the selected EC by calculating the arithmetic mean of all Quality Grades (q) of the respective EC. This grade point of an EC is termed as 'Evaluation Grade (b)'. In the grading scale , the grade-1 represents irreversible degradation of the environment or very severe situation of the studied EC and grade-10 denotes ideal situation , i.e. the EC is not affected by human activities [7, 9-11]. The subdivisions between these maximum and minimum values are define as appropriate like the example given in Table 1 as described by Mocanu [4].

Table 1. Evaluation grades of pollution and their corresponding effects

Grade	Effects on the environmental component and human health
10	The EC is not affected by the economic activity. Environmental state is Natural
9	The EC is affected by the economic activity. The effect can not be quantified.
8	The EC is affected, but under the maximum admissible limits - level 1. Alert level: Potential effects
7	The EC is affected , but into maximum admissible limits - level 2. Intervention level: potential effects.
6	The EC is affected, over the maximum admissible limits - level 1. The effects are pronounced.
5	The EC is affected, over the maximum admissible limits - level 1. The effects are harmful.
4	The EC is affected, over the maximum admissible limits - level 1. The harmful effects are pronounced.
3	Degraded EC - level 1. The effects are lethal to the average exposure
2	Degraded EC - level 2. The effects are lethal at short times of exposure
1	The EC is improper for life

Finally, these Evaluation grades (b) are used to draw the correlated geometric figure of real state of environment (S_r) inside the ideal state of environment (S_i) and also to calculate the Global Pollution Index of that ecosystem. The geometric figure for real sate of environment is drawn by all the values of 'b' (Rojanschi's method) or by the average value of them (Popa's method) whereas the geometric figure for ideal state of environment is drawn by the maximum grade (i,e 10). Thus the Rojanschi's figures could be a triangle, square or polygon and Popa's figure is always a circle as shown in Figure 1.

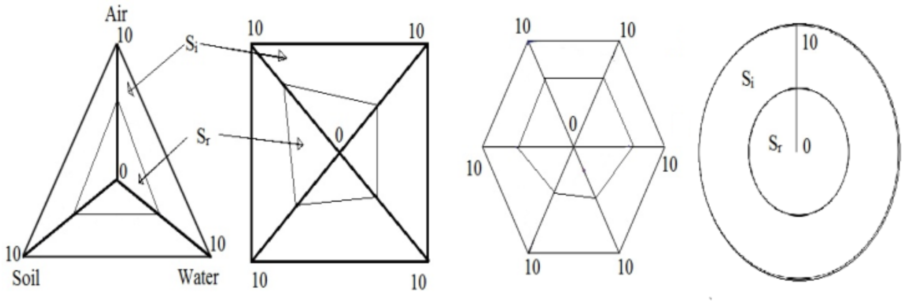


Figure 1. Rojanschi's (First three from left) and Popa's (Right most) geometric model.

Global Pollution Index (I_{pg}) is the ratio of surface areas of ideal and real state of environment. Rojanschi and other researchers [6, 12-14] provided a table (Table 2) where the relation of I_{pg} value with the environmental state of ecosystem is shown.

Table 2. Correlation between I_{pg} and environmental effect on life form

Value of Global Pollution Index	Effects Upon the ecosystem	Class of the ecosystem
$I_{pg} = 1$	Natural environment not influenced by human activities.	A
$1 < I_{pg} < 2$	Environment changed by human activities in the acceptable limits.	B
$2 < I_{pg} < 3$	Environment changed by human activities causing discomfort to life form	C
$3 < I_{pg} < 4$	Environment changed by human activities causing distress to life form	D
$4 < I_{pg} < 6$	Environment changed by human activities hazardous for life form	E
$I_{pg} > 6$	Polluted environment not proper for life forms.	F

2.1. Limitation of Rojanschi's Method

Firstly, Rojanschi's formula for calculating the global pollution Index (I_{pg}) is not valid when the value of 'n' is equal to 1 or 2, though Rojanschi claimed that the value of n = 1 to ∞ and secondly, no state geometry were defined in case of n =1 or 2.

Rojanschi's equations (Equation 2 to 4) were derived from the basic equation of calculating the surface area of a triangle. It is known that the surface area (S) of a triangle,

$$S = \frac{1}{2} \times \sin \Theta \times A \times B \quad (1)$$

Where, 'A' and 'B' are the length of two sides of a triangle and 'Θ' is the contact angel between them.

Rojanschi proposed different geometric figures such as triangle, square, pentagon and so on. However, to calculate the area of any of these geometric figures, she internally divided them into smaller triangle to develop a unique equation which is applicable for all of her geometric figures (Figure 2).

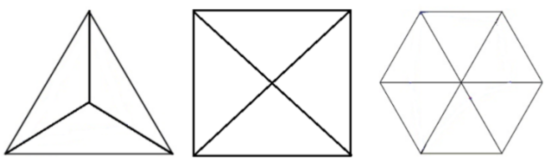


Figure 2. Rojanshi's geometric figure of ideal state of the environment for 3, 4 and 6 number of ECs. All the figures are divided into triangle to derive a common equation based on surface area of triangle.

Thus, from the basic formula of a triangle, she proposed the following standard equations for all her ideal and real state of the environmental geometric figures.

$$S_{ideal} = \frac{1}{2} \times \sin(360^\circ/n) \times n \times b^2_{max}\ ;\ (b_{max} = 10) \quad (2)$$

$$S_{real} = \frac{1}{2} \times \sin(360^\circ/n) \times \left[b_1 \times b_n + \sum_{i=1}^{n-1} b_i \times b_{i+1} \right] \quad (3)$$

Now, the Global Pollution Index,

$$I_{pg} = \frac{S_{ideal}}{S_{real}} = \frac{100 \times n}{b_1 \times b_n + \sum_{i=1}^{n-1} b_i \times b_{i+1}} \quad (4)$$

Where, 'n' is the number of EC with the value of n = 1 to infinite; b_i is the evaluation grades of corresponding EC with the value of i= 1, 2…n.

As the final equation (Equation 4) is based on calculating the area of triangle and triangle cannot be drawn with only one or two points, hence Rojanschi's equation is not valid for a circle or any other geometric figure which cannot be divided into triangle. For the same reason it was not possible for Rojanschi to draw the geometric figure of ideal and real state of environment in case of one or two EC.

3. Popa's Method

To simply the Rojanschi's method of I_{pg} calculation, in 2005 Popa [12] proposed an alternative method where the index is calculated by using only the arithmetic mean of the evaluation grades of the ECs as follows.

$$I^*_{pg} = \frac{100}{(\bar{b})^2} \quad (5)$$

Where $\bar{b}$ is the arithmetic mean of the evaluation grades ($b_1, b_2, \ldots b_i \ldots b_n$). I^*_{pg} is the mean index of global pollution. The I^*_{pg} and I_{pg} bear the similar values as shown in Table 2 [12].

3.1. Limitation of Popa's Method

Popa's method has three limitations.

Firstly, this method failed to present a geometric figure where actual status of all the individual ECs can be presented.

Secondly, Popa's index is not capable of judging the reality of the situation in all cases. Often it provides misleading information by hiding true facts.

Thirdly, while Rojanschi's geometric models provides closely true idea of the environmental situation, Popa's model represent the idea which is closer of the closer to the true situation.

3.1.1. Explanation of First Limitation

Rojanschi's geometric figure of real state of environment is capable of showing the severity or normality of each of the considered EC. If any one of the evaluation grade of any selected Environmental Component lies in danger zone, Rozanschi's method will show it in figure, even though the overall I_{pg} may be in safe range (Figure 3). But in Popa's method, state geometry is drawn by using an average value. Hence it is not capable of showing the individual state of all the concerned ECs. As a result, even though if any component found harmful during investigation, it will not be visible in final presentation of the figure by using Popa's geometry. Thus, the method fails to provide information of actual situation of the individual environmental components.

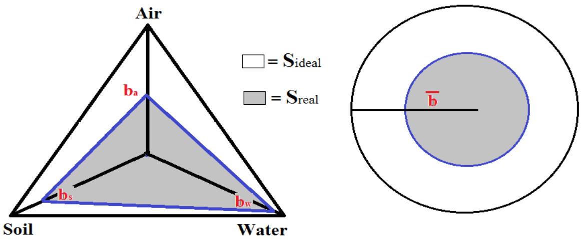


Figure 3. Comparison of the Ideal and real state of environment in Rojanschi's method and 'extended Rojanschi's method' (left) to Popa's method (right) in case of three ECs.

3.1.2. Explanation of Second Limitation

The author acknowledges that Popa [12] was successful to simplify the Rojanschi's formula of index calculation. In fact, this simplification was their main goal as they stated 'the developing of this method was done under the premise that method should be faster one, easy to use' in their paper. To do this, they stressed more on the mathematical simplification of the formula and unfortunately ignored the importance of graphical representation of the actual state of the environmental components which was an important part of Rojanschi's method. As a result, their simplified formula becomes only a mean to derive a mere numerical value of pollution index rather than providing idea of actual environmental situation. Here an example is given to clarify the fact.

Suppose a site is considered where the pollutants mainly affect the air while the effects on water and soil are negligible. At this case when these three ECs- Air, Water and Soil are investigated to have an idea of the surrounding environment of that site, then following evaluation grades are achieved-

evaluation Grade of Air, $b_a = 5$,
evaluation grade of water, $b_w = 9$ and
evaluation grade of soil, $b_s = 8$
According to Popa's formula,

$$I^*_{pg} = \frac{100}{(\bar{b})^2} = 1.85$$

Now this pollution index will be submitted with its geometric presentation for decision making which can be misleading. Here the index value (1.85) means the environmental condition is 'in the acceptable limit' according to the value table (Table 2) of global pollution index [4, 6, 7, 12]. However this index will not tell that the air is 'level-1 polluted air' over the maximum admissible limits which is harmful for human health according to the evaluation scale (Table 1) [13-15]! Again, in Popa's method, the smaller inner circle in geometric figure (Figure 3) will also not help to understand that the air was found harmful to breath during investigation.

Now in this case when the air is not breathable but index shows environment is 'in the acceptable limit' and geometric figure also does not shows any abnormality, then anyone may be misguided. In fact it is not the index which is the defaulter but the method by which the index is derived. This situation could have easily been avoided if Rojanschi's method was used. The smaller irregular triangle of real state of environment, inside the bigger regular triangle of ideal environmental state would have clearly indicated the actual situation of all three ECs. Then it would have easily been seen that the air quality is mostly affected and the air is not breathable (Figure 3).

The above case is just one example where Popa's method fails to provide sensible idea for decision making depending on the realistic situation of the environment. If the number of EC increases, then it is more likely that one or more environmental component may slip out of sight which may have found in harmful grade for human health during investigation. Hence, there is no doubt that it is quite possible to arise thousands of similar situations if we just consider the pollution index and draw the geometric figure by Popa's method, ignoring the importance of individual EC's condition. This limitation can only be overcome if the importance is given in geometric figure rather than the index.

3.1.3. Explanation of Third Limitation

Popa considered the average value of all the evaluation grades to calculate the radius for the circle of real state of environment. According to author , her geometric circle does not represent the truly real state of the environment as it is the average of average value. Any average value of a group of facts may not be the true value of all the actual facts, but it is a value which is close to all of them. Hence, when the average of the average value is taken, it means that a value is taken which is not close to the true fact, but it is a value which is closer of the closer to the true fact. For this reason, Popa's geometric figure for 'real state' of the environment is not representing the truly 'real state', but a closer to the closer value of true 'real state'. This can be explained as follows.

Popa takes the average value of 'b_i' as the radius of her real state, where 'b_i' is the Evaluation grade of EC_i. According to Popa's method, the radius of real state geometric circle,

$$R_r = \bar{b} = \frac{\sum_{i=1}^{n} b_i}{n} \quad (6)$$

If, we consider the previous example of three ECs then,

$$\bar{b} = \frac{b_1 + b_2 + b_3}{3} \quad (7)$$

here b_1, b_2, b_3 is the Evaluation grade of EC_{air}, EC_{water} and EC_{soil}.

Now, let us look how b_1, b_2 and b_3 has been derived.

Different number of quality indicators (QI) were investigated for each individual EC to calculate the evaluation grade (b) of that particular EC.

In this case of three ECs , if 'm' number of QIs had been assigned for each of them, then the quality grade of the indicators could have found as follows-

$a_1, a_2 \ldots a_m$ is the quality grades of the indicators of EC_{air}.

$w_1, w_2 \ldots w_m$ is the quality grades of the indicators of EC_{water},

$s_1, s_2 \ldots s_m$ is the quality grades of the indicators of EC_{soil}.

So,

$b_1 = \frac{\sum_{i=1}^{m} a_i}{m}$, which is more logical to write as $\bar{b}_1$,

$b_2 = \frac{\sum_{i=1}^{m} w_i}{m}$, which is more logical to write as $\bar{b}_2$;

and

$b_3 = \frac{\sum_{i=1}^{m} s_i}{m}$, which is more logical to write as $\bar{b}_3$.

Hence, $\bar{b} = \frac{\bar{b}_1 + \bar{b}_2 + \bar{b}_3}{3}$, which is more logical to write as $\bar{\bar{b}}$.

At this circustance, the Equation 6 can be rewrite as

$$R_r = \bar{\bar{b}} = \frac{\sum_{i=1}^{n} \bar{b}_i}{n} \quad (8)$$

From the Equation 8, it is clearly visible that the radius of real state of environment is a value which is average of average value. Hence the circle drawn using this value does not represent the truly real state of environment but represent a closer of the closer state to the truly real environment. The example given in section-5 shows how Popa's index deviated from true fact while Rojanschi's method comes more close to the actual situation.

4. The proposed Method: Extended Rojanschi's Method

The proposed method includes few additional assumptions with basic Rojanschi's method to overcome the limitations. The assumptions are as follows.

a) for n = 1 or 2, the pollution index will be calculated and geometric figure of ideal and real state of environment will be drawn from the quality grades (q_i) of assessed quality indicators (QI), instead of their average values (i.e, evaluation grades, b_i) or average of average values ($\bar{b}$).

In this case the equation to calculate the pollution index ($I^{/}_{pg}$) will be

$$I^{/}_{pg} = \frac{S_{ideal}}{S_{real}} = \frac{100 \cdot n}{q_1 \cdot q_n + \sum_{i=1}^{n-1} q_i \cdot q_{i+1}} \quad (9)$$

Here, 'n' is the number of QI with the value of n = 1 to infinite; q_i is the quality grades of corresponding QI with the value of i= 1, 2…n. The $I^{/}_{pg}$ and I_{pg} bear the similar values as shown in Table 2.

Equation 9 is also applicable for any number of EC and the calculated pollution index will be more accurate than any of the previous methods.

However, if the average values are preferred as usual to calculate the pollution index or when the number of quality grades are less than three, then

a1) for n = 1 , the geometric figures of ideal and real state of environment will be concentric circles where the pollution index will be calculated as.

$$I^{/}_{pg} = \frac{400}{d^2} \quad (10)$$

Here 'd' denotes the diameter of the real state geometric circle.

a2) For n = 2, the geometric figures of ideal and real state of environment will be either concentric or eccentric circles depending upon the values of evaluation grades. The pollution index will be calculated by the same formula as previous, i.e. by using Equation 10.

b) For n = 3 to ∞, the geometric figures of ideal and real state of environment will be polygons (triagon or triangle, tetragon or square, pentagon, hexagon and so on) and Global pollution index will be calculated as the basic Rojanschi's formula, i.e. with Equation 4.

c) All the geometric figure will be drawn in a single standard procedure as follows:

-- Firstly, the centre of the geometry of ideal state (0) will be placed.

-- Then 'n' number of fluxes will be drawn from the center at an angle 'ϴ',

where n = the number of EC (or QI in case of Equation 9 and 10) and ϴ = 360/n .

-- Maximum evaluation values (b_{max} = 10) will be cut from each fluxes to determine the boundary of ideal state and 'n' number of dots will be placed according to the value of b_i (or q_i in case of Equation 9) from the center on the fluxes of respective EC's.

-- Lastly, the geometric figure of ideal state will be drawn by connecting all the maximum values (b_{max}) and geometric figure of real state will be drawn by connecting all the real values of evaluation grades (b_i) or quality grades (q_i).

In case of circles, the radius of ideal state will always be the b_{max} (Figure 4). To draw the circle of real state, the center point and radius of real state will be determined by the half value of the summation of evaluation grades (Figure 4), i.e.

$$d = b_1 + b_2 \quad (11)$$

$$\text{and, } r = d / 2 \quad (12)$$

d) The formula derivation for n = 1 or 2, i.e. derivation of queation 10:

In case of one or two environmental component, the geometric figure is circle. Hence the surface area of ideal and real state of environment are,

$$S_{ideal} = \mu R^2 \quad (13)$$

and

$$S_{real} = \mu r^2 \quad (14)$$

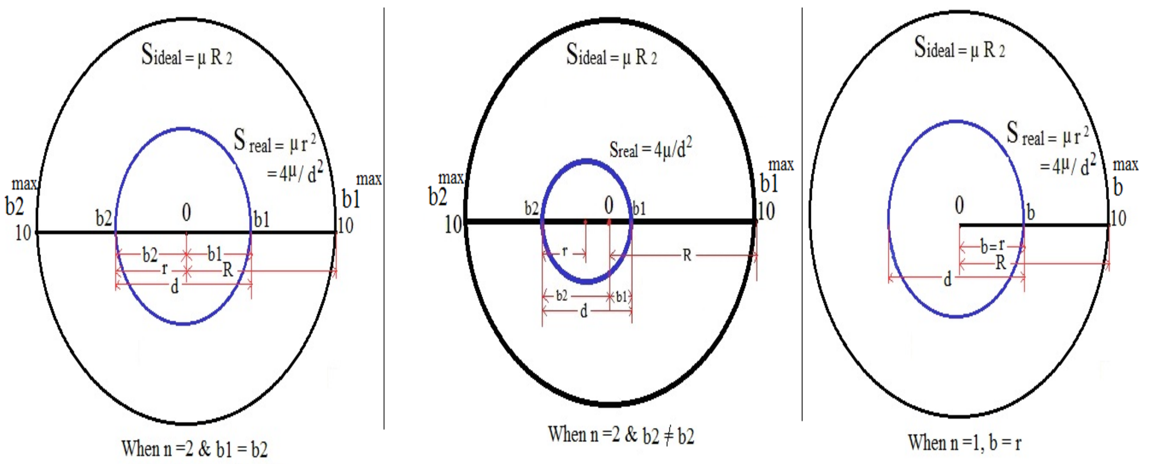


Figure 4. Proposed Geometric figure of the ideal and real state of environment in case of two and one Environmental Component (EC)

Now the formula for calculating the pollution index in case of two or one EC can be derived as follows-

$$I'_{pg} = \frac{S_{ideal}}{S_{real}} = \frac{\mu R^2}{\mu r^2} = \frac{10^2}{(d/2)^2}, \quad [\text{as } b_{max} = R = 10]$$

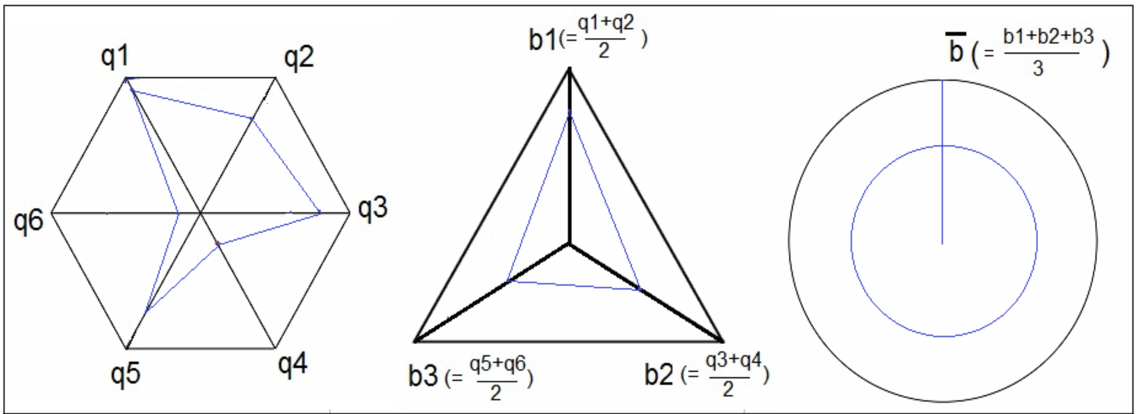
$$= \frac{400}{d^2}$$

From Equation 11 & 12, the Equation 10 can also be written as, $I'_{pg} = \frac{400}{(b_1 + b_2)^2}$ (15)

Thus by using either Equation 10 or Equation 15, the value of pollution index can be calculated in case of one or two environmental component. For three or more environmental component, original Rojanschi's equation, i.e. Equation 4 is applicable. Beside these, Equation 9 is also applicable for any number of environmental components when true values of investigated data are preferred over their average values.

Table 3. Deviation of Index due to taking average value

	Air (b_1)		Water (b_2)		Soil (b_3)		$\bar{b}$	Index value		
	Amount of CO in mg/L (q_1)	Amount of SO_2 in mg/L (q_2)	Ph (q_3)	COD In mg/L (q_4)	Ph (q_5)	Extractible Compound in mg/Kg (q_6)		Rojanschi's method, having average value (Equation 4)	Popa's method having average of average value (Equation 5)	Having original value, (Equation 9)
Values of Quality Grades(q)	9	7	8	3	7	2	6	2.864	2.778	3.061
Values of Evaluation Grades(b)	8		5.5		4.5					



Index Value = 3.061	Index value = 2.864	Index Value = 2.778
Environment Class = D	Environmnet Class = C	Environment Class = C

Figure 5. Index Calculation with original value (left), average value (middle) and average of average value (right).

5. Evaluation of Proposed Method

The proposed extended Rojanschi's method is free from all the limitations of original Rojanschi's method and Popa's alternative method. Thus the new method has three advantages-

-- It is applicable to any number of EC from one to infinite,

-- pollution index can be assessed by using original values of investigated data instead of their average values (as in Rojanschi's mehtod) or average of average values (as in Popa's method)

-- and the actual situation of each of the investigated EC can be presented in geometric figure.

To justify these advantages, let consider a case with three EC such as air, soil and water. Now pollution index is derived by using Rojanschi's method, Popa's method and Extended Rojanschi's method. Let the investigated quality grades of three selected ECs have found as shown in Table 3. Table 3 shows how the pollution index varied when the average values is used instead of original data and Figure 5 shows how the new method can present the actual status of air, soil and water.

Here, the variation of pollution index is not the only fact to be noticed but also the geometric figures. The dangerous environmental status of two environmental quality indicators (COD in water and total extractible compound in soil) is clearly visible in left most figure, and the middle figure is showing the brief status of all the ECs whereas the right most figure absolutely fails to show the condition of any of the environmental component. Thus it is clearly visible from Figure 5 and Table 3 that the real state of environment derived by using Rojanschi's or Popa's formula is not the truly real state of environment. Truly real state of environment can only be calculated and drawn when we use true values of all the 'quality grades (q)' assigned by the evaluator instead of taking their average (b)' or 'average of average ($\overline{b}$)' value. It is also noticeable that if we consider the average values, then not only the geometric figure will be less informative, but also there is possibility that real Index value may not be obtained. The Table 3 shows how Index can be deviated from true value if average values are considered. It is also visible that the index value calculated through Rojanschi's method is more close to the original value.

For this reason, the author proposes to calculate the global pollution index by using the Rojanschi's method with taking the extended formula for one and two EC. Popa's method is less informative and without the extension, Rojanschi's method is also incomplete. Beside this, pollution index can also be calculated by using original values of investigated environmental quality grades of concerned ECs by using Equation 9.

6. Conclusions

Current Paper is an attempt to eliminate the limitations of index calculation as presented in *Global Estimation Methodology for the Ecosystem State* by Rojanschi and *Geometrical Correlation Method for Global Estimation of the Ecosystem State* by Popa. An extension to basic Rojanschi's method has been proposed which is also capable of overcoming the limitations of Popa's alternative correlation method. While the basic Rojanschi's method is applicable when at least three environmental components (EC) are investigated, the current paper proposed to include concentric/eccentric circle technique in Rojanschi's method for one and two EC. Though Popa's alternative method is also applicable in case of two EC, it is unable to show the actual status of investigated environmental component. In new method it is possible to represent the realistic situation of all the investigated EC in geometric figure. In case of two environmental components, Popa's concentric circle cannot show the severity of any component whereas the eccentric circle in new method clearly shows the actual state of both environmental components. Thus extended Rojanschi's method is applicable for any number of EC and free from all the limitations of earlier methods.

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