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USE OF CHEMOMETRICS METHODS AND MULTICRITERIA DECISION-MAKING FOR SITE SELECTION FOR SUSTAINABLE ON-SITE SEWAGE EFFLUENT DISPOSAL

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Abstract

This paper presents a study undertaken to evaluate site suitability for sewage effluent renovation based on physico-chemical characteristics of the soil. The results obtained showed that as the soil becomes acidic, the phosphorus concentration in the soil reduces accordingly. The chloride ion concentration was found to be a reliable indicator for evaluating the soil capacity to remove nitrogen. A high cation exchange capacity (CEC) can enhance the renovation of sewage effluent. Soils with high quartz content had a low CEC with high organic matter content (OM) being able to compensate. Therefore, an understanding of the micro-nutrients in the soil, organic matter content and chloride ion concentration are important.

To facilitate a multi-variate approach for site selection, multicriteria decision-making methods (MCDM) methods, PROMETHEE and GAIA, were applied for analysis of a sequence of three matrices consisting of 8, 16, and 48 soil site objects respectively, and seven soil property parameters. Matrix models and the interpretation of results are discussed in detail. From these analyses, PROMETHEE II net outranking flows, ϕ , found that two sites were always among the top three ranks of the three matrix models, which suggested that they were the most suitable for sewage effluent renovation. The criteria CEC and OM, were particularly important for the selection of these better sites, but pH and Cl^- attributes discriminated the weaker performing sites from the better ones; as well the PO_4^{3-} and the $\text{NH}_3\text{-N}$ criteria were in general opposition to CEC, OM, pH and Cl^- but were much less effective as discriminators. Consideration of net outranking flows suggested an approach method for the selection of other possibly suitable sites for sewage effluent renovation.

Keywords: chemometrics methods; land capability; PROMETHEE and GAIA; sewage effluent disposal; subsurface effluent disposal.

1. Introduction

Understanding soil physico-chemical characteristics and their interactions is a key factor in solving serious environmental and public health problems caused by the common failure of soil disposal systems used for the application of effluent from on-site domestic sewage treatment systems. Contamination of soil, surface and groundwater due the effluent percolation through the subsurface soil horizons are the major concerns. The effluent disposal area is given high priority by regulatory authorities due to the significant impacts that can result from their failure. Septic tank together with subsurface effluent disposal is the most common treatment system employed and consequently most of the discussion in this paper relates to these systems. The subsurface effluent disposal area is an important part of the treatment train. A conventional septic tank/subsurface disposal area is shown in Figure 1. Figure 2 illustrates the major components and pathways involved in the subsurface flow of sewage effluent.

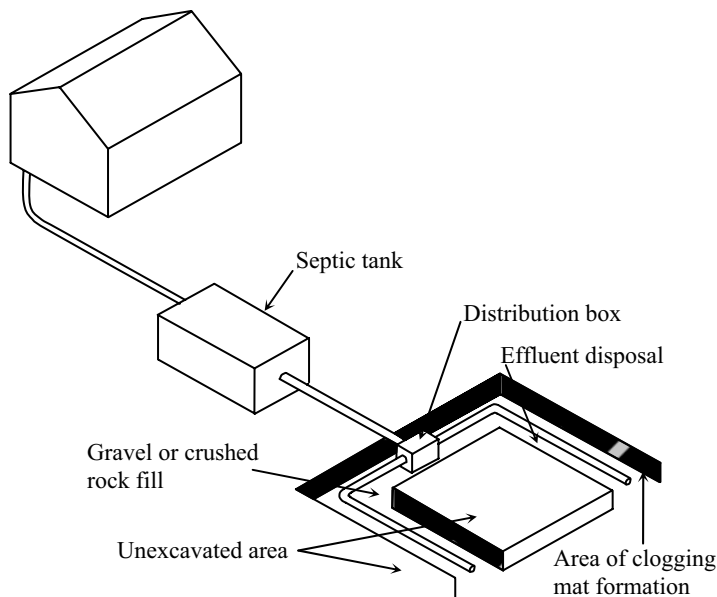


Figure 1 A typical septic tank-subsurface effluent disposal system

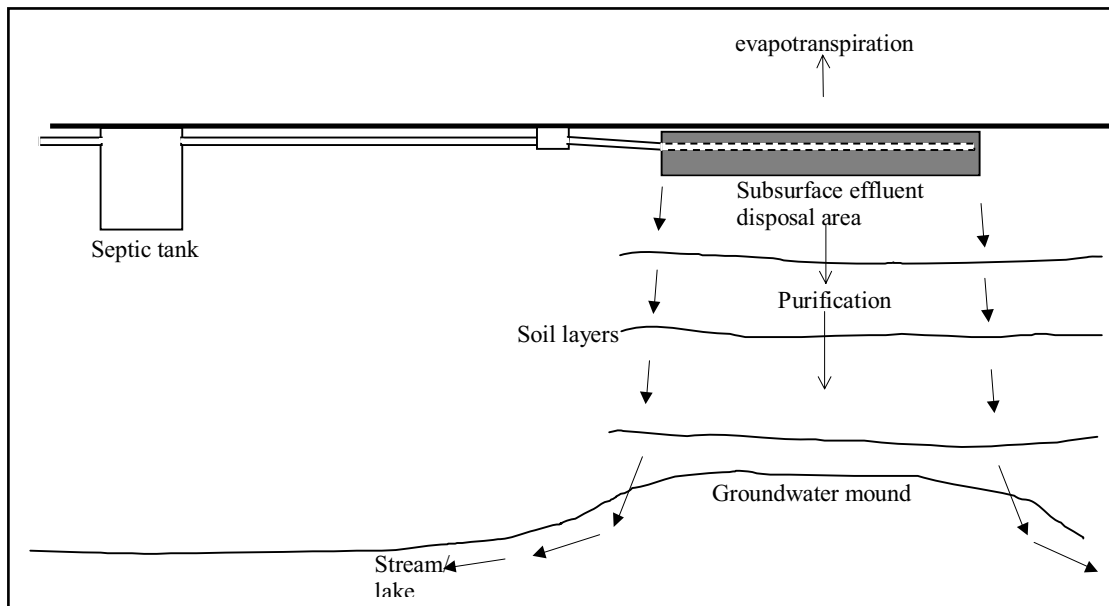


Figure 2 Major components and pathways in subsurface disposal of effluent

The impact of failure of on-site sewage treatment systems underlies the vital importance of employing reliable scientific techniques for the assessment of site suitability as effluent disposal areas. In the long-term, this approach is necessary to ensure the ecological sustainability of on-site sewage treatment, risk reduction and environmental best management practices to be implemented for protection of community well-being.

Within the context of land management, the sustainability of soil disposal of effluent should be assessed using, as indicators, chemical and physical properties of the soil. Land management is a key factor in economic development to ensure that human well-being is sustained over time, with environmental risk minimization a major factor in this regard [1]. Additionally, soil has been identified as the most important component in sustainable land management [2,3,4].

Physico-chemical characteristics of soil are the foundation for site suitability assessment for conventional on-site sewage treatment. The available scientific information can be employed to minimize numerous problems that occur due to the failure of the effluent disposal area. The capacity of natural soil to accommodate sewage effluent disposal will vary based on factors such as effluent characteristics, site vegetation, soil characteristics, topography and depth to the groundwater table

[5]. It is important to note that the physico-chemical characteristics of soil will vary between different types of soil and even within the same soil type due to interactions with relevant climate and location factors.

Soil analysis is complex, and generally, there is a large amount of data generated, which makes it difficult to manipulate or evaluate. This problem can be overcome by the use of multivariate chemometrics approaches whereby large volumes of data can be processed for exploring and understanding relationships between different parameters [6]. Multivariate ranking analysis can be used to evaluate the selected sampling sites with the aid of multicriteria decision-making methods (MCDM), and these are discussed below with an emphasis on the method called *PROMETHEE and GAIA*.

These two different procedures belong to a collection of methods for data analysis, which facilitate the making of decisions when dealing with multivariate problems; hence, the name multi-criteria decision making methods. It should be noted that such methods in general, and PROMETHEE and GAIA in particular, have been discussed and developed in detail for decades in the operations research field but introduced into chemometrics comparatively recently. For example, PROMETHEE and GAIA was first discussed in this field in a detailed paper by Keller et al [7]; this paper includes a step-by-step example. The use of PROMETHEE and GAIA in chemometrics has not been extensive, but the methods have been successfully applied in some studies [8, 9] in analytical chemistry.

Salminen et al [10] compared the performance of PROMETHEE, SMART (Simple Multi-attribute Rating Technique) and ELECTRE III MCDM methods specifically because of their suitability in the context of environmental decision-making. The authors found little difference in performance between SMART and PROMETHEE but felt that ELECTRE III had some extra functionality. Interestingly, Massart et al [11] regarded PROMETHEE to be more refined than ELECTRE in that the former method quantifies the degree of preference of an object compared with another for each criterion. More recently, Lerche et al. [12], compared the partial order Hasse Diagram Technique (HDT) with some Multi-Criteria Analysis (MCA) methods including PROMETHEE, on the basis of external input i.e. on subjectivity and

transparency. They regarded HDT as best performing but placed PROMETHEE close to this method, and well above its possible alternatives such as NAIADE and ORESTE [13]. The literature generally underlines the fact that ultimately the choice of methodology especially of procedures, which perform roughly comparably, rests with the decision-maker. Some examples of application of PROMETHEE and GAIA to environmental problems include Martin et al's [14] use of the methods to assist with the development of the Saint Charles River alluvial plain; the methodology proved useful for reaching rational decisions based on scientific data and political considerations. Le Teno [15] found the same methods to be powerful tools for visualisation and interpretation of Life Cycle Assessment results, and Özelkan and Duckstein studied water resource alternatives [16]. More recently, collaborative studies reported at a number of different symposia, focussed on environmental issues concerned with air quality [17, 18, 19], and in 2003, a multi-disciplinary investigation combining organo-metallic chemistry with toxicology applied PROMETHEE and GAIA methods for the screening and ranking of anti-fungal agents [20]. Thus, the application of these two methods is quite appropriate to this investigation of site selection for sewage effluent disposal especially since Brans et al. [21], initially developed the methodology for site selection of factories and similar locations.

PROMETHEE and GAIA algorithms have been described in detail with worked examples and applications in the monograph [11] and research literature both in operations research, eg [10,22] and chemometrics [7]. In Section 2.3 a stepwise outline of the PROMETHEE algorithm is provided with brief comments on it and GAIA in accordance with reference [7]. Details and rationale for the model used in this study are described in Section 3.2.

Soil investigations reported in this paper, were firstly concerned with the measurement and interpretation of seven parameters with the use of conventional methods of data analysis to provide a general appreciation of the soil properties. This was followed by the application of PROMETHEE and GAIA MCDM methods to evaluate the ability of different soils to renovate sewage effluent discharged to a subsurface disposal area. The primary aims of the paper are to: (i) provide ranking information necessary to discriminate between the sites and their ability to renovate

sewage effluent application on the basis of physico-chemical parameters, (ii) assess the parameters influencing the differentiation of soils, (iii) explore the use of GAIA in the identification of the important criteria influencing the renovation. Additionally, it was hoped to demonstrate how the combination of the well regarded MCDM methods, PROMETHEE and GAIA, can contribute to the development of a comprehensive understanding in the study of soil properties and the relationships between the different physico-chemical characteristics in the context of the selection of soil for effluent renovation capacity.

2. Materials and Methods

2.1. Sampling Sites

The research undertaken involved extensive soil sampling, and testing for a wide range of soil physical and chemical parameters. The primary objectives of the soil analysis was to determine the important soil parameters which influence effluent renovation and to understand the relationships between different soil and site factors, and thereby relate these factors to the effluent renovation capacity of different soil types. The site selection for undertaking the detailed analysis was based on predetermined criteria, which took into consideration environmental sensitivity and planning issues.

Environmental sensitivity was primarily in relation to the presence of important surface water resources such as waterways and reservoirs. Planning issues related to the allowable minimum residential block size and allowable land use specified in the Town Plan. Environmental sensitivity and planning issues were integrated to develop a planning scheme risk zone map as shown in Figure 3. The project area was located in Logan City, which is a major regional population centre in Queensland State, Australia. About 50% of the area under the Logan City jurisdiction does not have a reticulated sewerage system. A total of forty-eight sampling sites were identified which also reflected the geological and topographical settings within the project area. The sampling sites selected are also shown in Figure 3.

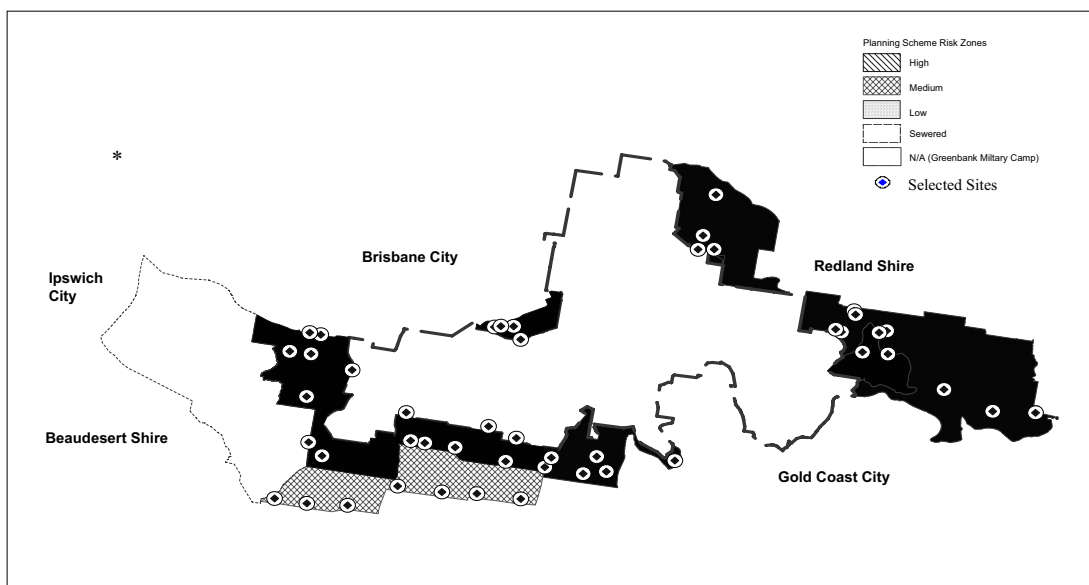


Figure 3: Planning scheme map showing the selected sites for physico-chemical analysis

2.2. Soil Testing

Soil samples were collected from the soil A-horizon to a depth of (0-600mm) and B-horizons to a depth of (600-1400mm). The changes in the soil profile through the different horizons were taken into consideration in the sampling process, and samples were collected from each soil horizon accordingly. The soil analysis discussed in this paper focussed on the B-horizon (600-1400mm), where the effluent is commonly applied and where the relevant chemical and biological processes take place. The soil testing undertaken is outlined in Table 1.

2.3 Chemometrics methods

2.3.1 PROMETHEE

PROMETHEE is a non-parametric method, which ranks a number of objects (or actions, in this paper - soil samples) on the basis of a range of variables or criteria. For each variable, one must indicate:

- a **preferred ranking** sense i.e. top down (maximised) or bottom-up (minimised).
- a **weighting** – set to 1 by default but can be altered, usually subjectively, if decision making experiments require analysis of alternative scenarios.

- a **preference function, P(a, b)** – defines how one object is to be chosen relative to another.

Table 1 Soil Analysis

Parameter	Test method
pH	<ul style="list-style-type: none"> Method (4A1 pH of 1:5 soil/water suspensions) as described by Rayment and Higginson [23]. Measurements based on a soil/water ratio of 1:5 at 25⁰C.
Cation exchange capacity (CEC)	<ul style="list-style-type: none"> Ammonium selective electrode method developed by Borden and Giese [24]. Ammonia standards were made according to method 4500-NH₃ E as defined by APHA [25].
Organic matter content (OM)	<ul style="list-style-type: none"> Determined by initially oxidising with hydrogen peroxide and then subjected to 1300⁰C temperature. Weight loss taken as the organic matter content.
Total Nitrogen (TN)	<ul style="list-style-type: none"> Measured using the wet oxidation method [26]. Digestion method for converting organic nitrogen adopted from the HACH manual [27], and the analytical method adopted from APHA [25]. Ammonia selective electrode method by Borden and Giese [24] used to measure the ammonia level in the digested solution.
Total Phosphorus (TP)	<ul style="list-style-type: none"> Measured using method 4500-P described in APHA [25]. Soluble phosphorus sample obtained by filtering the soil/water 1:5 extract at room temperature for measurement using a data logging Spectrophotometer.
Electrical conductivity (EC)	<ul style="list-style-type: none"> Testing conducted according to the method (3A1 EC of 1:5 soil/water extracts) [23].
Chloride ions concentration (Cl ⁻)	<ul style="list-style-type: none"> A 1:5 soil/water extract mixed with silver nitrate and ferric cyanide was used. Chloride ion concentration was determined according to the method (5A1 chloride 1:5 soil/water extracts, potentiometric titration) [23].
Exchangeable Cations (Mg, Al, K, Fe, Ca and Na)	<ul style="list-style-type: none"> Measured using a Varian AA6 Flame Atomic Absorption Spectrophotometer. Acetylene flame used to measure iron (Fe), propane to measure sodium (Na) and potassium (K). Nitrous oxide gas used to measure calcium (Ca), magnesium (Mg), aluminium (Al).

The stepwise procedure is presented below:

Step 1 Transformation of the raw data matrix to a difference matrix.

For each criterion, the column entries, y , of the raw data matrix are subtracted from each other in all possible ways to create a difference, d , matrix.

Step 2 Application of the preference function

For each criterion, the selected preference function $P(a, b)$ is applied to decide how much the outcome a is preferred to b . In the commercially produced software Promcalc [28] or the one used for this study, Decision Lab [29], six choices for preference functions are available, and are described in Table 2.

Step 3 Calculation of an overall or global preference index, π

$$\pi(a, b) = \sum_{j=1}^k w_j \times P_j(a, b) \quad (1)$$

w_j = weightings

This relationship provides an overall or global index, π for comparison of preference of object a over b

Step 4 Calculation of outranking flows

$$\varphi^+(a) = \sum_{x \in A} \pi(a, x) \quad (2)$$

$$\varphi^-(a) = \sum_{z \in A} \pi(x, a) \quad (3)$$

The positive outranking flow, (φ^+) , indicates how an object outranks all others while the negative outranking flow, (φ^-) , shows how all others outrank each object. The higher the φ^+ and the lower the φ^- the higher the preference for an object.

Step 5. Comparison of outranking flows.

Application of the rules below for pairwise comparisons (of a and b) of all results produces a partial ranking or partial pre-order of the objects:

1. a outranks b if:

$$\varphi^+(a) > \varphi^+(b) \text{ and } \varphi^-(a) < \varphi^-(b) \quad (4)$$

or

$$\varphi^+(a) > \varphi^+(b) \text{ and } \varphi^-(a) = \varphi^-(b) \quad (5)$$

or

$$\varphi^+(a) = \varphi^+(b) \text{ and } \varphi^-(a) < \varphi^-(b) \quad (6)$$

2. a is indifferent to b if:

$$\varphi^+(a) = \varphi^+(b) \text{ and } \varphi^-(a) < \varphi^-(b) \quad (7)$$



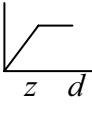

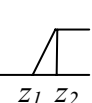

3. a cannot be compared with b:

Step 6 Calculation of net outranking flow

$$\varphi(a) = \varphi^+(a) - \varphi^-(a) \quad (8)$$

This relationship eliminates the rule where a cannot be compared to b, thus removing the partial pre-order; the expression of net outranking flow, φ , is intuitively more convenient but the information is less reliable.

Table 2 List of preference functions

Preference Function	Shape	Mathematical Justification
Usual (No threshold)		$y(z) = 0 \begin{cases} z < 0 \\ y(z) = 1 \end{cases} \begin{cases} z \geq 0 \end{cases}$
U-shape(q threshold)		$y(z) = 0 \begin{cases} x < 1 \\ y(z) = 1 \end{cases} \begin{cases} x \geq 1 \end{cases}$
V-Shape (p threshold)	 <i>Slope = m = 1/z</i>	$y(z) = mz \begin{cases} z < d \\ y(z) = 1 \end{cases} \begin{cases} z \geq d \end{cases}$
Level (q and p thresholds)		$y(z) = 0 \begin{cases} z < d \\ y(z) = \frac{1}{2} \\ Y(z) = 1 \end{cases} \begin{cases} z = 0 \\ z > d \end{cases}$
Linear (q and p thresholds)		$y(z) = 0 \begin{cases} z, z_1 \\ y(z) = mz + c \\ y(z) = 1 \end{cases} \begin{cases} z_1 > z < z_2 \\ z > z_2 \end{cases}$
Gaussian (s threshold)		$y(z) = \frac{e^z}{1 + e^z}$

2.3.2 GAIA

GAIA is a visualisation method, which complements the PROMETHEE ranking providing guidance regarding the principal criteria, which contribute to the rank order of the objects. Also, GAIA is crucial for experimenting with different criteria weightings; in this context a special sensitivity decision vector, π , is plotted. In essence, a GAIA plot is simply a PC1 (principal component) versus PC2 biplot obtained from a matrix that has been formed from a decomposition of the PROMETHEE net outranking flows as described in detail by Keller et al [7]. The interpretation of the GAIA plot requires little elaboration as it is identical to the well known PCA biplot. In addition, Espinasse et al. [22] provide an extensive listing of rules for the interpretation of GAIA plots; these are illustrated by examples, which demonstrate how the decision axis, π , should be interpreted.

3. Results and Discussion

3.1 Preliminary analysis

It is essential that the renovation processes taking place in the soil system in a sewage effluent disposal area are clearly understood in order to minimize possible environmental and public health hazards resulting from their failure. The data obtained from the soil analysis is given in Table 3, and presents the soil analysis for the B-horizons (600-1400mm) for the selected forty-eight sites, which were investigated in this study.

The data obtained indicated that the soil pH range was between 4.5 and 6, which meant that all the samples tested were acidic. The salts' concentration was reflected in the values of electrical conductivity (EC) and the values obtained varied between 1 and 90 μ S/cm. The nutrient concentrations (nitrogen and phosphorus) were investigated in order to develop an understanding of the background concentrations in the soil. In general, the phosphorus concentration which was measured in the form of orthophosphate was found to be in the range of 0.01 to 3mg/kg. Nitrogen was measured in the form of ammonia nitrogen and the concentrations varied significantly between the sites. Some of these sites reported high nitrogen concentrations either due to the type of soil or the land use such as the presence of plant nurseries.

Soils would rapidly adsorb phosphorus until their capacity is reached. Furthermore phosphorus can be precipitated in the soil. The linear relationship between orthophosphate and pH given in Figure 4 shows that as the pH value reduces, the phosphorus concentration also reduces roughly proportionately. Therefore, it could be surmised that the pH has an impact on phosphorus concentration in the soil. This would mean that as the soil becomes acidic, the concentration of phosphorus or the orthophosphate in soils would reduce accordingly.

Table 3 Raw physico-chemical data matrix (48 x 7) for the sampling sites

Site No	pH	EC ($\mu\text{S/cm}$)	Cl ⁻ (mg/mL)	PO ₄ ³⁻ (mg/mL)	NH ₃ -N (mg/mL)	CEC (meq/100g)	OM %
1	4.99	23.5	65.0	1.60	378	2.21	4.69
2	5.45	25.2	53.0	0.85	160	2.54	1.26
3	4.94	14.8	29.5	0.45	67.7	0.98	0.41
4	5.38	31.8	56.0	1.25	94.0	4.95	2.45
5	5.41	15.3	45.5	1.25	136	1.65	1.49
6	4.73	27.0	57.0	2.95	136	25.1	5.48
7	4.90	23.4	46.5	1.15	125	10.6	1.86
8	5.91	33.0	12.0	1.00	125	10.6	1.19
9	5.75	11.7	63.5	0.85	125	2.10	0.87
10	5.91	17.6	44.5	0.65	65.0	1.30	0.99
11	5.39	20.6	56.5	0.90	76.6	2.42	2.10
12	5.64	8.31	38.5	0.45	120	0.77	0.15
13	5.64	13.1	46.5	1.20	73.5	2.10	0.80
14	5.13	22.0	52.0	0.90	154	1.73	9.12
15	4.94	8.20	29.5	0.50	67.7	2.79	1.65
16	5.13	48.3	21.5	3.50	94.0	65.0	6.78
17	5.39	61.7	11.2	1.45	120	11.7	6.25
18	5.68	32.8	11.5	1.10	67.7	11.7	1.99
19	5.04	37.8	14.0	1.15	125	68.2	9.11
20	4.93	51.4	62.0	1.00	83.1	3.54	8.24
21	4.82	38.5	14.5	0.01	83.1	7.97	4.26
22	5.01	41.6	80.0	1.25	395	59.1	11.2
23	5.35	91.1	55.5	2.25	167	16.3	2.90
24	4.65	22.1	10.0	1.70	142	59.1	6.13
25	4.75	45.1	70.0	1.50	111	86.6	3.93
26	4.51	36.4	43.0	0.85	76.6	75.0	3.98
27	4.98	36.2	53.0	1.85	181	82.5	7.26
28	4.98	63.0	62.0	1.00	106	33.4	2.14
29	5.19	68.5	78.5	2.35	181	5.19	2.93
30	4.91	12.0	1.00	0.01	130	44.7	3.38
31	5.20	137	85.0	0.50	111	38.5	6.30
32	4.58	2.00	1.00	0.40	96.3	16.3	8.00
33	4.67	37.0	7.50	0.18	48.2	44.4	3.04
34	4.85	32.0	280	0.06	180	71.5	3.09
35	4.61	55.0	0.50	0.05	96.0	10.6	7.02
36	4.57	48.0	16.0	0.01	39.0	3.90	13.5
37	4.63	22.0	191	0.96	38.6	8.36	4.55
38	4.84	30.0	65.0	0.24	120	8.36	1.19
39	5.05	1.00	413	0.96	16.0	10.6	5.21
40	4.26	89.0	393	0.40	132	2.00	8.35
41	4.72	1.00	120	0.24	68.0	20.7	4.06
42	4.62	96.0	150	0.01	69.0	16.3	1.05
43	4.80	1.00	158	0.96	149	10.6	4.16
44	4.90	38.0	0.3	0.28	230	9.20	5.41
45	4.52	2.00	395	0.28	289	28.9	7.17
46	4.72	3.00	70.0	1.00	168	7.25	9.17
47	4.68	37.0	7.50	0.01	187	7.97	7.40
48	4.81	1.00	3.75	0.01	120	8.43	5.99

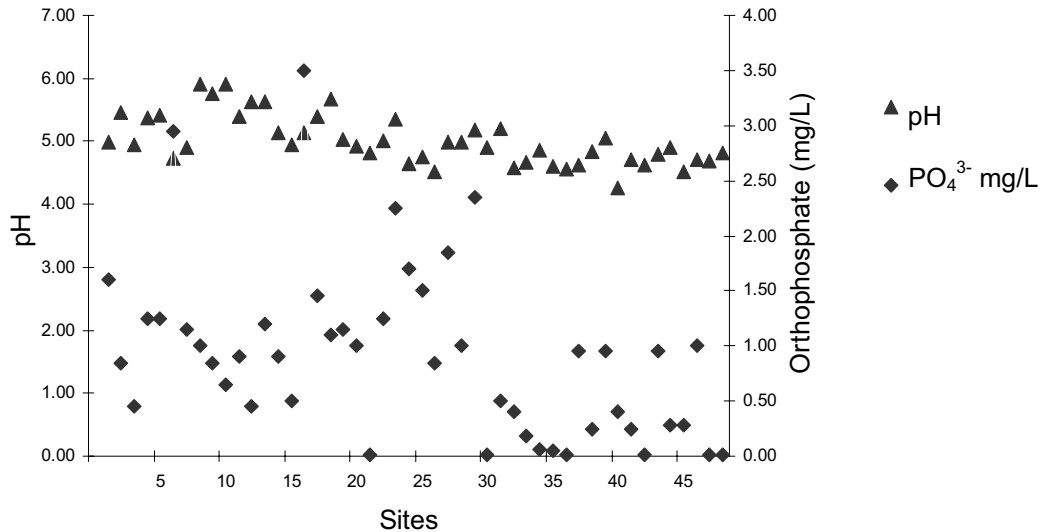


Figure 4 Relationship between pH and orthophosphate content in soil

As indicated earlier, all soil sampled had a pH value less than 6.0. The data analysis presented in Figure 4 was for locations, which are currently not subjected to sewage effluent disposal. However, in the future, if these sites are used for sewage effluent disposal, the soil physico-chemical characteristics of the soil will change. For instance, the pH of wastewater is generally above 7, which will cause the soil pH to rise with continued application. However, Ellis [30] reported that for pH values above 7, the phosphorus solubility will be limited by calcium phosphate in the soil. Therefore, the presence of calcium phosphate in the soil will result in low phosphorus removal from wastewater effluent. Consequently, the long-term effluent application will affect the status of the soil such as phosphorus availability [31].

Figure 5 shows that in most sites the concentration level of nitrogen increases in direct proportion with the chloride ion concentration. Therefore, the concentration of anions present such as Cl^- would be a reliable indicator for evaluating the soil capacity to remove nitrogen from the applied effluent. Hence, it is necessary to understand the influence of factors such as the initial micro-nutrients present in the soil as well as the chloride ion concentration and how these factors affect the soil capability for effluent renovation.

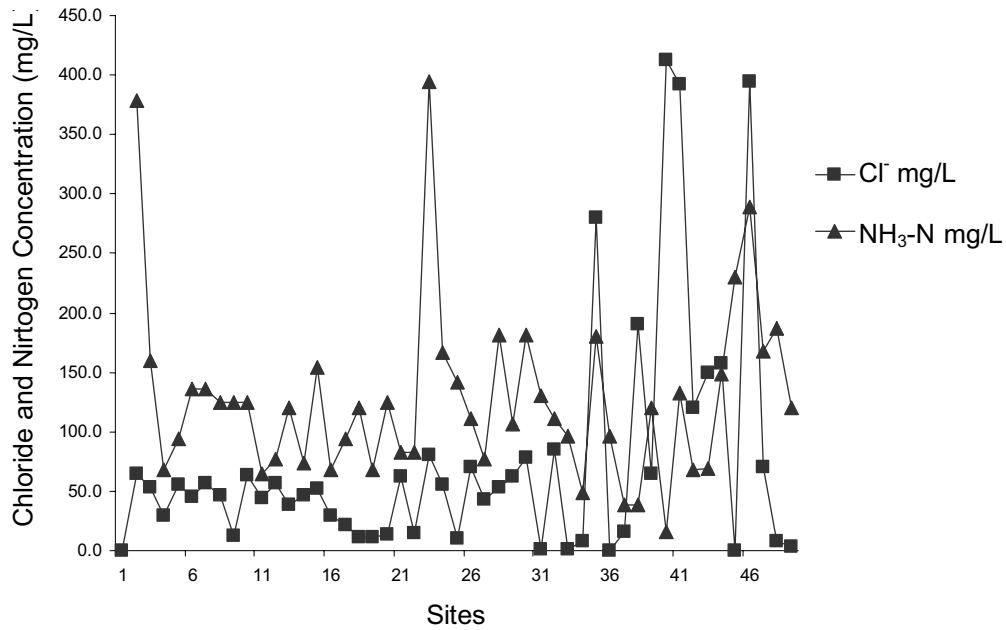


Figure 5 Correlation between the chloride ion and nitrogen concentration

A high cation exchange capacity can enhance the renovation of sewage effluent. The highest CEC value was for Site 25 and the lowest for Site 3 and 12. The controlling factors which influenced CEC varied between the clay type and the organic matter content. The mineralogical analyses of the soil samples indicated that soils with high quartz (sand) content have a low CEC. However, a high organic matter content can compensate to increase the CEC. Usually, organic matter content in the B-horizon was considerably lower when compared to that present in the A-horizon. This is to be expected due to vegetation on the ground surface.

Exchangeable sodium percentage (ESP) in the soil is used as an indicator to evaluate the possible hazard created by increased soil sodicity due to water irrigation [32]. The data given in Table 4 gives the concentrations for six individual exchangeable cations, namely, Ca, Mg, Na, K, Al and Fe for the soil samples analysed. This data was used to calculate ESP percentage based on the cation exchange capacity. The results are reported as soil sodicity where;

$$\text{ESP} = (\text{exchangeable Na})/(\text{CEC}) \text{ expressed as a percentage.}$$

The soil sodicity has been rated by Northcote and Skene [33] where $ESP < 6\%$ is considered as non-sodic, $ESP = 6-15\%$ as sodic and $ESP > 15\%$ as strongly sodic. The values for ESP given in Table 4 shows that 50% of the sites investigated are strongly sodic, 20% are sodic and the remainder are non-sodic.

Figure 6 shows the relationship between EC or the salts concentration in the soil and ESP. It is clear that the increase in the salts concentration will lead to a decrease in ESP and the level of sodicity could increase with depth [33]. ESP has a significant impact on the physical properties of the soil, where for instance in sites with strong sodicity, soils will lose aggregation and develop clay dispersion leading to reduced permeability and formation of a surface crust. This results in unsatisfactory conditions for irrigation and will adversely affect the soil ability to renovate sewage effluent.

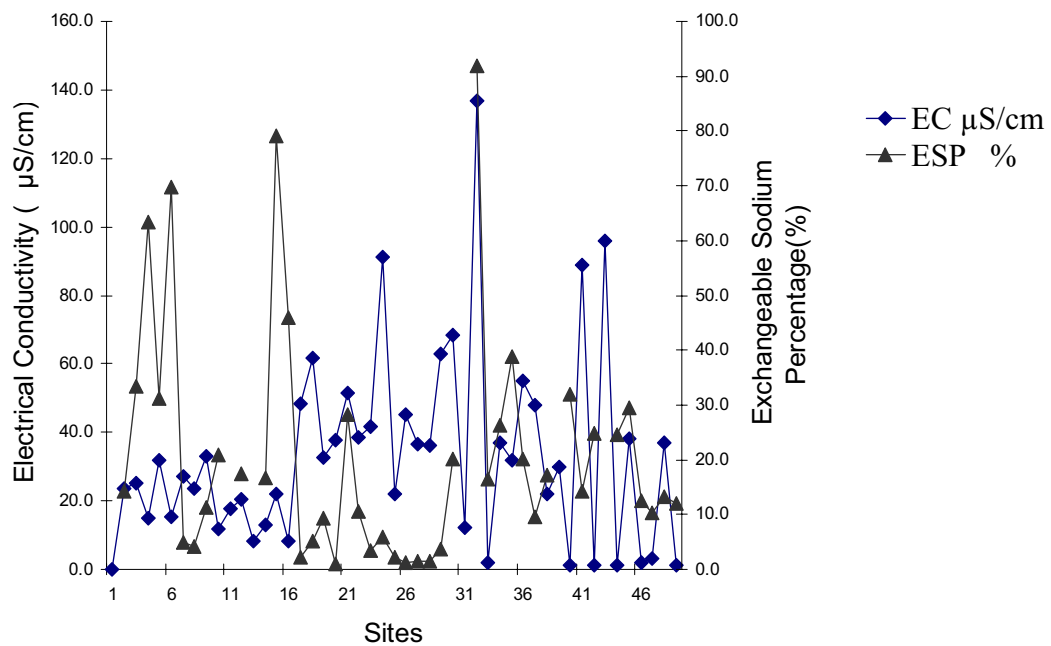


Figure 6 Relationship between electrical conductivity and exchangeable sodium percentage

Table 4 Exchangeable cation data for the forty eight sampling sites

Sites No	Ca ²⁺ ppm	Mg ²⁺ ppm	Al ³⁺ ppm	Na ⁺ ppm	K ⁺ ppm	Fe ³⁺ ppm	ESP %
1	0.30	2.00	0.60	0.85	0.38	0.11	14.2
2	1.40	4.50	0.60	1.54	0.34	0.13	33.5
3	0.90	2.10	0.90	1.21	0.73	0.14	63.3
4	0.40	2.80	0.60	1.21	0.44	0.18	31.1
5	0.70	2.40	1.30	1.48	0.65	4.98	69.7
6	0.90	3.50	1.70	0.83	0.37	0.07	4.83
7	0.70	2.60	0.60	1.37	0.70	0.13	4.24
8	0.60	2.50	0.90	1.51	0.72	0.10	11.4
9	0.50	1.50	1.10	1.10	0.71	0.11	21.0
10	0.60	2.20	0.60	1.00	0.42	0.04	114
11	0.80	2.30	0.60	2.06	0.78	0.14	17.4
12	0.70	2.00	0.60	1.30	0.60	0.14	108
13	0.80	2.70	0.90	1.15	0.63	0.13	16.7
14	1.00	2.60	1.10	1.23	0.56	0.16	79.2
15	2.60	21.5	1.30	3.55	0.54	0.06	45.9
16	1.40	3.00	0.60	1.31	0.52	0.16	2.32
17	1.60	3.40	0.90	1.20	0.61	0.13	5.14
18	0.90	2.00	1.10	1.30	0.55	0.14	9.42
19	3.60	14.3	1.30	2.87	0.74	0.13	1.07
20	0.30	1.60	1.50	1.20	0.58	0.07	28.3
21	0.90	3.20	1.10	1.31	0.59	0.13	10.5
22	0.80	5.40	1.10	1.59	0.56	0.14	3.49
23	0.40	1.20	0.60	0.94	0.50	0.13	6.01
24	0.80	5.40	1.10	1.59	0.56	0.14	2.20
25	0.40	1.20	0.60	0.94	0.50	0.13	1.11
26	0.30	2.00	0.60	0.85	0.38	0.11	1.53
27	1.40	4.50	0.60	1.54	0.34	0.13	1.50
28	0.90	2.10	0.90	1.21	0.73	0.14	3.69
29	0.40	2.80	0.60	1.21	0.44	0.18	20.2
30	0.70	2.40	1.30	1.48	0.65	4.98	105
31	0.90	3.50	1.70	0.83	0.37	0.07	91.9
32	0.70	2.60	0.60	1.37	0.70	0.13	16.4
33	0.60	2.50	0.90	1.51	0.72	0.10	26.4
34	0.50	1.50	1.10	1.10	0.71	0.11	38.8
35	0.60	2.20	0.60	1.00	0.42	0.04	20.1
36	0.80	2.30	0.60	2.06	0.78	0.14	9.66
37	0.70	2.00	0.60	1.30	0.60	0.14	17.1
38	0.80	2.70	0.90	1.15	0.63	0.13	241
39	1.00	2.60	1.10	1.23	0.56	0.16	32.0
40	2.60	21.5	1.30	3.55	0.54	0.06	14.4
41	1.40	3.00	0.60	1.31	0.52	0.16	24.9
42	1.60	3.40	0.90	1.20	0.61	0.13	124
43	0.90	2.00	1.10	1.30	0.55	0.14	24.5
44	3.60	14.3	1.30	2.87	0.74	0.13	29.4
45	0.30	1.60	1.50	1.20	0.58	0.07	12.6
46	0.90	3.20	1.10	1.31	0.59	0.13	10.3
47	0.80	5.40	1.10	1.59	0.56	0.14	13.2
48	0.40	1.20	0.60	0.94	0.50	0.13	12.1

3.2 Chemometrics analysis

The relatively large raw data matrix (48 sites x 7 variables, Table 3) constructed from analysis of the soils, illustrates the difficulties in discriminating between the sites and the complexities involved in data analysis. This is due to the range of variables influencing the soil ability for effluent renovation, and hence, the many physico-chemical parameters relevant to soil evaluation. In the case of this study, pH, EC, Cl⁻, PO₄³⁻, NH₃-N, CEC and OM were considered important to the envisaged evaluation.

Morrás [34] investigated the influence of a small number of physico-chemical variables on the soil capability for effluent renovation. However, there have been very few investigations, which have encompassed such a range of variables together. The challenge for this investigation was not only to define a single site capability for effluent renovation but to discriminate between groups of sites, which have the same climatic conditions and topography.

As discussed in the Introduction, MCDM methods are particularly suitable for assistance with multi-variate problems; of the several possible methods, PROMETHEE and GAIA were designed for site selection, and also, found suitable for environmental project applications. Thus, these two methods were chosen to explore the ranking and to investigate relationships between the physico-chemical criteria and the sites considered, which were explored with the use of Decision Lab 2000 Software [35].

The bases of the PROMETHEE and GAIA algorithms were outlined in Section 2.3, and here the assignment of the ranking sense (maximise/minimise), choice of the preference functions, P(a,b), and any associated threshold values (q and p) for the seven criteria are discussed. The specific preference functions, P(a ,b), defined for each criterion are shown in Table 5, and the rationale for the selection of various parameters is discussed below.

Table 5 Data required for ranking by PROMETHEE

	pH	EC	Cl⁻	PO₄³⁻	NH₃-N	CEC	OM
Function Type	Level	V-shape	Gaussian	V-shape	V-shape	V-shape	V-shape
Minimized	FALSE	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE
P	2.00	200	-	4	400	100	10
Q	0.1	0	-	0	0	0	0
S	-	-	100	-	-	-	-
Unit		μS/cm	mg/mL	mg/mL	mg/mL	meq/100g	%
Weight	1.00	1.00	1.00	1.00	1.00	1.00	1.00

V-shape preference function was selected for EC, PO₄³⁻, NH₃-N, CEC and OM. Electrical conductivity (EC), was minimised because it is related to the increase in salt concentration in the soil, which at high concentrations could lead to a salinity problem [36]. The threshold, p, for EC was selected as 200μS/cm, which implies that higher values of difference would be accorded a P(a,b) of 1. Differences between soil values less than the set threshold were ranked linearly.

Orthophosphate, PO₄³⁻, and nitrogen, NH₃-N, were selected to be minimised because lower nutrient levels available in the soil will enhance the chance for a better effluent renovation process [37]. The threshold, p, selected for the two analyses was 4mg/L and 400mg/L respectively. Also, differences between soil values less than the set threshold were ranked linearly based on their respective differences.

The cation exchange capacity, CEC, was maximised, and this was related to the concept of the higher the CEC in the soil, the more electrical charges are available for attraction of effluent contaminants [38]. The threshold, p, for CEC was selected to be 100meq/100g, providing the largest differences between compared CEC values. Thus, a preference of 1.0 was given to soil samples with higher CEC readings when calculated differences exceed this threshold.

Organic matter, OM, content was maximised because the increase in organic matter content in the soil will help reduce the nutrients reaching the subsurface B-horizon by phosphorus up-take and nitrogen fixation [37]. The threshold, p, for OM was selected to be 10%, providing the largest difference between compared OM values.

Thus, a preference of 1.0 would be given to soil samples with higher OM readings when calculated differences exceed this threshold.

Preference functions called LEVEL (Table 1) were used for pH to allow analysis of the different soil conditions, with pH between 5 and 9. pH was maximised because it is related to the acidic pH below 5.5. This condition will lead to an increase in the availability of aluminium in the soil, which in turn will increase the amount of toxic metal cations. Such ions can eliminate some of the biological activity, which is beneficial for sewage effluent renovation [39]. The threshold, p , was selected to be 2, which represents the largest difference that is considered decisive by the decision-maker. The threshold q was selected to be 0.1, which indicates the smallest difference that is considered negligible between soil samples.

A Gaussian preference function was applied to Cl^- to allow analysis of the different soil conditions, which have a Cl^- value between 100 and 400 $\mu S/cm$. Cl^- was minimised to maintain reasonable effluent percolation through the soil layers before reaching the groundwater table. The chloride ion was selected to be the indicator for soil permeability due to the chloride ion being one of the easiest salts to be traced in the soil and can highlight the soil's ability to percolate effluent [40]. The threshold, s , was calculated to be 100 $\mu S/cm$.

A pre-evaluation study of the forty-eight sites was carried out based on the OM content and the CEC values, which are controlled by the soil mineralogy. Sites with high CEC values facilitate effluent renovation, i.e. Sites such as 25, 27, 34, 26, 19, 16, 22 and 24 (maximised ranked order CEC). Sites with low CEC are poor for effluent renovation, i.e. sites such as 12, 3, 10, 5, 14, 40, 9 and 1 (minimised rank order). It was not intended for this pre-evaluation to account for the effect of any other soil physico-chemical criteria analysed. Four sites were drawn from the first series viz. Sites 25, 27, 26, 19, and four from the second viz. Sites 12, 3, 5, 15. They were selected as set for assessment by PROMETHEE and GAIA, which clearly demonstrated either the preferred or poor soil properties (on the basis of CEC and OM) for sewage effluent renovation.

The 8X7 data matrix of the above selected samples was submitted to PROMETHEE for analysis with the criteria models and threshold parameters set as discussed previously. The PROMETHEE II net ranking flow, ϕ , order (Table 6) shows that the sites from the first set of samples representing the preferred soils for effluent renovation occupy the first four ranks in order 19, 27, and (26, 25) – the last two sites having practically the same ϕ values. To that extent the PROMETHEE II is in complete agreement with the conventional selection process. However, the inclusion of the entire set of variables appears to have influenced the preferred order, which was based only on the CEC and the OM criteria. It is possible to attempt to obtain extra information on the order of the soil samples by investigating the partial outranking flows using PROMETHEE I. The results of such calculations (Figure 7) indicate that the general rank order of the samples is the same as for PROMETHEE II except that for three sets of samples, (26, 25), (12, 15) and (5, 3) the members of each pair cannot be compared. However, because their outranking flows are so similar little more can be deduced from this information.

Table 6 PROMETHEE ranking of the selected eight sampling sites

Rank	Site	Φ
1	s19	0.12
2	s27	0.06
3	s26	0.00
4	s25	-0.01
5	s12	-0.01
6	s15	-0.04
7	s5	-0.06
8	s3	-0.05

Interestingly, the GAIA biplot for the same matrix (Figure 8) provides valuable information additional to the PROMETHEE ranking. Firstly, the preferred soils for effluent renovation are separated on PC1 (positive scores) from the weak soils (negative scores) in the form of tight clusters. The preferred soils are strongly separated on the basis of the CEC and OM criteria (highest values), and the weak soils with the lowest CEC and OMs, are influenced moderately by the pH, which is somewhat higher than that of the positive cluster. The tight PC1 clusters are separated on PC2 with Sites 3, 15, 25 and 26 forming a group with positive scores while Sites 5, 12, 19 and 27 forming a tight cluster with negative scores. Criteria OM and pH strongly discriminate the latter cluster from the one with positive scores.

Consulting the data matrix shows that sites 5 and 12 have quite low values of OM but relatively high pH values (of the four samples); conversely, the pHs of Sites 19 and 27 are low and OMs are quite high. The moderately strong criteria, $\text{NH}_3\text{-N}$ and PO_4^{3-} , are principally responsible for the separation of Sites 3, 15, 25 and 26 on PC2 from the cluster with negative scores; both the phosphorus and particularly the nitrogen content of these sample is quite high.

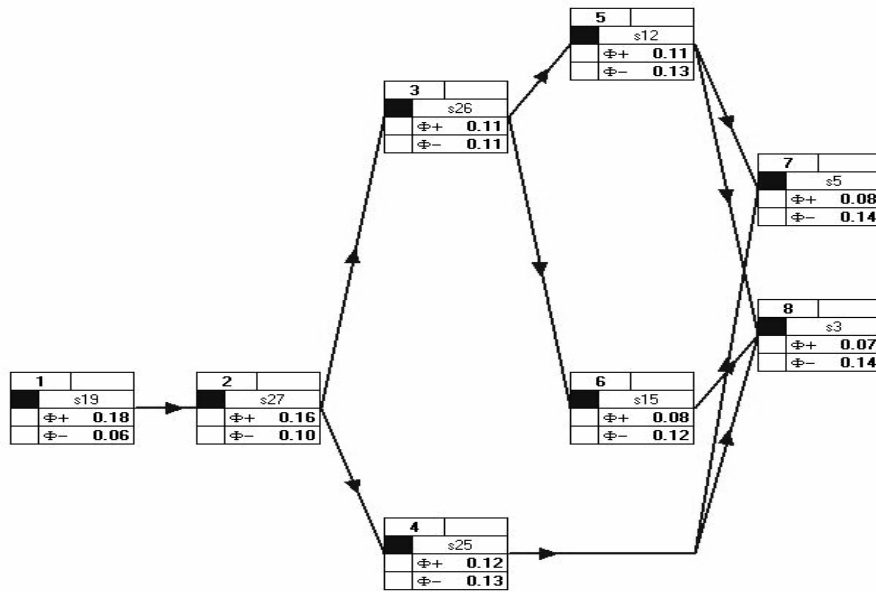


Figure 7 Partial ranking for 8 sites (first matrix) using PROMETHEE I

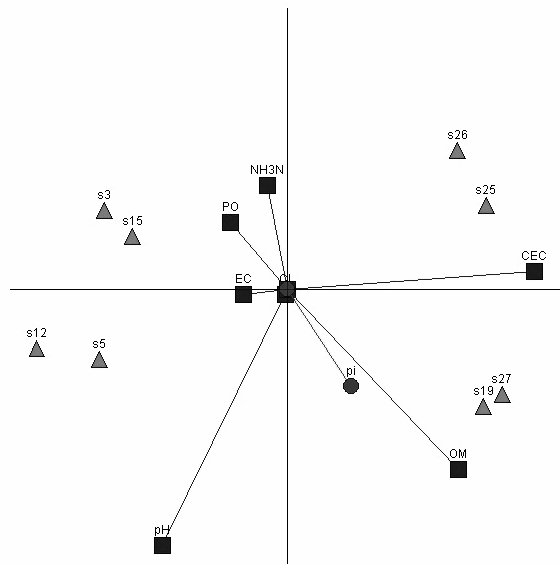


Figure 8 GAIA analyses for the eight sampling sites (from first matrix);

▲ Soil site objects; ■ soil parameter criteria; ● π (π), decision-making axis
 When the criteria vectors are examined, it is clear that CEC, OM and pH have a major influence on site selection for this data set. The two important criteria, CEC

and OM, used for conventional screening of the preferred sites, are also selected by PROMETHEE and GAIA; in addition, the strong effect of the pH (PC1), and the lesser effect of $\text{NH}_3\text{-N}$ and PO_4^{3-} on PC2, which is opposite to that of pH and OM on the same PC can be observed. Such relationships are not readily evident from the raw data matrix and cannot be realised easily by conventional means. The π decision axis is closely associated with the OM criterion rather than the CEC, which was the more influential criterion when screening the soils simply on the basis of measured values. Data variance or information described by the GAIA plane is large at 96%, which indicates that most of the information has been included in the analysis. In addition, the interpretation of this small data matrix based on the relatively well defined soils for sewage effluent renovation, provides a basis for comparison of similar PROMETHEE and GAIA analysis of larger matrices of soil properties.

A further eight sites were now chosen at random to make a new 16x7 matrix, which was analysed in the same way as described for the smaller one discussed above. The PROMETHEE II net outranking order (Table 7) shows that Site 19 and 27 remained the preferred ones although the former site is clearly ahead. From Site 27 onwards there is a trend along which sequential sites are not well discriminated but substantial ϕ differences exist, for example, between Site 27 (rank2, $\phi=0.06$) and 12 (rank 8, $\phi=0.00$) or Site10 (rank4, $\phi =0.03$) and Site 15 (rank 11, $\phi =-0.03$). Thus, whereas for the ranking in the of soils included in the small data matrix, there were no significant changes to rank order found by PROMETHEE and the conventional screening approach with the use of the CEC and the OM variables only. However, the inclusion of more soil samples, some with intermediate properties compared to those in the first set appears to influence this order, and GAIA analysis indicates the involvement of other criteria.

GAIA biplot for (16x7) matrix (Figure 9) provides valuable information additional to the PROMETHEE ranking. Firstly, the addition of eight extra objects shows less tightly formed clusters on both PC1 and PC2. In general, CEC and OM are again the major criteria separating the preferred soils on PC1 as shown by the high positive scores (but not the highest) of Sites 19 and 27. Site 22 has the highest PC1 score but is ranked only seventh. This indicates the influence of other criteria than just the two most important ones on PC1. It underscores the compromise aspect of the

PROMETHEE approach to finding solutions to multi-variate problems. Both OM and pH remain important with negative loadings on PC2 but in addition, PO_4^{3-} vector (positive PC2 loading) seems to have become more prominent. Also, the Cl^- loadings vector has increased considerably (negative on PC2). Thus, the set of important variables has grown from just the two conventional CEC and OM criteria used for the screening of samples, to include pH and PO_4^{3-} as well as $\text{NH}_3\text{-N}$ with the newly establishing and increasing Cl^- vector. These six vectors then result in the compromise ranking of the sites in the increased matrix albeit in different ways and to different extent. It is noted that the π decision axis is rather weaker but still closely associated with OM, and an acceptably high 75% of data information is described by the GAIA plane.

Table 7 PROMETHEE ranking of the selected sixteen sampling sites

Rank	Site	Φ
1	s19	0.13
2	s27	0.06
3	s30	0.05
4	s10	0.03
5	s16	0.02
6	s26	0.02
7	s22	0.02
8	s12	0.00
9	s25	0.00
10	s4	-0.02
11	s15	-0.03
12	s5	-0.04
13	s2	-0.04
14	s44	-0.05
15	s3	-0.06
16	s34	-0.08

Ranking of all of the 48 sites by PROMETHEE (Table 8) shows that three sites (19, 27 and 30) are present in the top four ranks of this data set. Site 19 ($\varphi=0.16$) remains the most preferred, followed by Sites 36 ($\varphi=0.11$) and 27 ($\varphi=0.09$) but from there on, no clear separations are evident between sequential sites giving a trend right down to one of the poorest, Site 1 ($\varphi=-0.12$) ranked 46th, followed by Site 42, the 45th ($\varphi=-0.15$) and the worst site is, Site 40 ($\varphi=-0.19$).

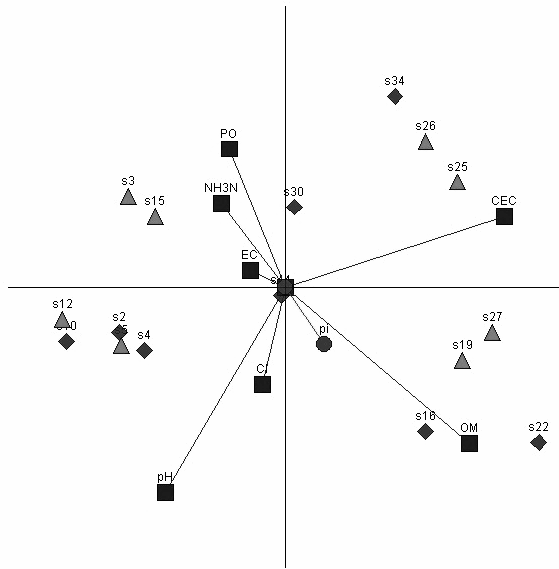


Figure 9 GAIA analyses for the sixteen sampling sites (from second matrix);
 ◆ the eight added objects; other labels are as in Figure 8.

Table 8 PROMETHEE ranking of the forty-eight sampling sites

Rank	Site	Φ	Rank	Site	Φ
1	s19	0.16	25	s41	0.01
2	s36	0.11	26	s13	0.01
3	s27	0.09	27	s9	0.01
4	s30	0.08	28	s47	0.01
5	s14	0.08	29	s15	0.00
6	s32	0.06	30	s4	0.00
7	s48	0.06	31	s44	-0.01
8	s22	0.05	32	s5	-0.02
9	s16	0.05	33	s3	-0.02
10	s10	0.05	34	s28	-0.02
11	s18	0.04	35	s2	-0.02
12	s25	0.04	36	s34	-0.04
13	s33	0.04	37	s38	-0.04
14	s17	0.04	38	s7	-0.05
15	s26	0.04	39	s39	-0.05
16	s20	0.04	40	s43	-0.06
17	s31	0.03	41	s37	-0.07
18	s24	0.03	42	s6	-0.08
19	s8	0.02	43	s23	-0.08
20	s21	0.02	44	s29	-0.11
21	s11	0.02	45	s42	-0.12
22	s46	0.02	46	s1	-0.12
23	s12	0.02	47	s45	-0.15
24	s35	0.02	48	s40	-0.19

In the GAIA biplot, (Fig. 10) the soil objects are more scattered around the plot and clustering is less clear. Nevertheless, the sixteen samples used in earlier trials remain in relatively similar positions eg. the well performing soils are still positive on PC1 and the weak soils have negative scores on the same PC. It is noted that the decision vector π is somewhat longer on a relative basis but the data variance described has dropped to 56%, which indicates that care should be taken for extensive decisions. However, since the best performing sites have remained more or less the same for the three consecutive PROMETHEE experiments, there is added confidence in the compromise solution for the selection of the preferred sites.

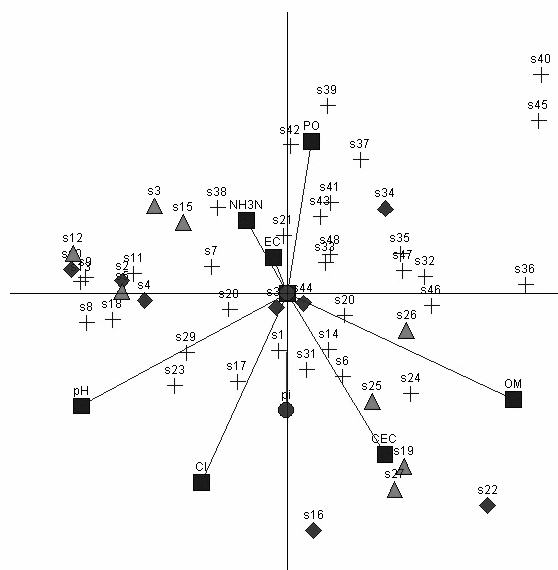


Figure 10 GAIA analyses for the forty-eight sampling sites (third matrix).
 + the added remaining 32 soil sites; other labels as in Figures 8 and 9.

The same four criteria, OM, CEC, Cl⁻ and pH, as noted in the second PROMETHEE experiment with 16 sites remain the strongest influences on site ranking although the OM and CEC vectors have exchanged positions with the former becoming dominant on PC1 and the latter exhibiting a strong influence on PC2. In addition, PO₄³⁻ continues to grow in importance but in general, in opposition to the other four criteria especially Cl⁻. The relationship suggests that when PO₄³⁻ levels are high, Cl⁻ ones are low. The NH₃-N criterion remains of moderate importance and, also in general opposition to the four principal criteria, especially CEC, which suggests that when the nitrogen levels are high, the CEC values are low.

From the above analysis, especially of the complete 48 site data matrix the compromise PROMETHEE solution for the selection of the preferred soil sites for effluent renovation suggested that Sites 19, 36 and 27 are the top contenders on the basis of the seven scientific criteria considered. It was found that the two criteria, CEC and OM, conventionally used for the initial appreciation of soil quality for this purpose, remain critically important for the selection of the best performing soils. However, the poorer soils tend to be discriminated from the better ones by pH and Cl⁻ levels, and in addition, PO₄³⁻ and to a lesser extent NH₃-N criteria provide further important discrimination of the sites. Thus, the compromise solution has to be based on the consideration of at least CEC, OM, pH, Cl⁻ as well as PO₄³⁻ and NH₃-N. Interestingly, EC seems to play a relatively low role in the site selection.

In so far as the global ranking and the selection of several sites for sewage effluent renovation, it is necessary to take into account the size of the π decision axis (just moderate size) and the fact that only 56% of data variance has been described. Some assistance may be obtained from the results of the first two PROMETHEE and GAIA experiments. The decision-maker may observe that in the second MCDM analysis Sites 10 and 12 ranked in the top eight samples but clustered with the poorer soils in the GAIA plot of the first two PROMETHEE experiments (negative scores on PC1); also the rank order of the 48 sites shows that five sites 19, 27, 30, 22, and 16, which ranked highly in the smaller matrix trials, appear in the first nine rankings before Site 10 (a poor site, ranking 10). Conservatively therefore, on the balance of information available additional six sites (ranking 4-9) prior to Site 10 could be further examined for the sewage effluent renovation application.

4. Conclusions

Forty eight soil samples were collected from sites for the purpose of assessment for sewage effluent renovation on the basis of seven attributes EC, CEC, pH, OM, Cl⁻, PO₄³⁻ and NH₃-N. General trends found were described, compared and interpreted. Findings were noted included phosphorus content is limited to soils with a pH < 6, and nitrogen content increases in rough proportion to that of the chloride. In addition,

it was possible to select those soils which were likely to be most suitable for effluent renovation with the use of conventional markers such as CEC and OM.

To facilitate a multi-variate approach for soil selection, well regarded MCDM methods, PROMETHEE and GAIA, were applied for a analysis of a sequence of three matrices, whose dimensionality increased from 8x7 to 48x7, and the modelling of the matrices and the interpretation of results were discussed in detail. From these analyses, PROMETHEE net outranking flows, ϕ , showed that in the compromise solution, two Sites 19 and 27 were always found among the top three ranks of the three matrix models. The criteria CEC and OM, in agreement with conventional analysis, are important for the selection of the better performing sites, but other criteria should be considered. This was especially apparent with the analysis of the largest matrix, which undoubtedly represents the common real world scenario, where more rather than less sites would be desirable to be tested and analysed together. In addition, it was found that the pH and Cl⁻ attributes were related to the discrimination of the weaker performing sites from the better ones, and the PO₄³⁻ and the NH₃-N criteria were in general opposition to CEC, OM, pH and Cl⁻ but were much less effective as discriminators (shorter loadings vectors).

Furthermore, by examining and comparing the net outranking flows from the three matrix models, it was shown that the decision maker could develop rational selection schemes for considering more than just a few of the consistently top performing sites. As indicated in the Introduction, PROMETHEE and GAIA, were developed especially for site selection, and this work illustrates how a decision-maker can systematically examine a complex problem in a balanced, scientific manner with a flexible and versatile MCDM tool.

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