*JKAU: Earth Sci.,* **Vol. 17,** pp: 43-67 (2006 A.D. / 1427 A.H.)

# Satellite Imagery and Engineering Geological Studies of a Proposed Sewage Dumping Site, Jeddah, Saudi Arabia

Mohammed H. Qari and Bahaaeldin H. Sadagah

*Faculty of Earth Sciences, King Abdulaziz University, Jeddah, Saudi Arabia*

Received: 23/5/2005 Accepted: 23/10/2005

*Abstract.* The City of Jeddah extends 45 kilometers in length along the eastern Red Sea coast, and about 15 kilometers in width. About 2.5 million inhabitants live in the city. Dumping of the sewage waste is forming always problems. Two sewage dumping sites, one banned site, and another site which is currently in use, are causing environmental problems. Accordingly, selection of a new site is a must. The site investigation study used screening method which envolved stages, start with the selection of a number of available site subjected to a set of preferences and rating. Upon maximum rating scores, the best site is chosen. Intensive *in situ* field study followed the selection stage, include performing detailed tests such as soil sieve analyses, permeability tests, field density, and Mackintosh tests. In addition, lineament analysis was performed as well. The investigation could prove the suitability of the new site to be used as a sewage dumping site for Jeddah city.

## 1. Introduction

Jeddah city lies at the east coast of the Red Sea. Sewage waste, of 2.5 million people, causes a continuous issue of where to dump it. An integrated research of remote sensing and engineering geology was accomplished to find out a solution to the existing problem of rising water table and groundwater pollution in the city of Jeddah, and to propose a new sewage-dumping site.

As a result of increased environmental awareness, questions regarding the geological barriers and geoenvironmental effects of waste disposal and waste contamination in general are arised. More emphasis has been placed on multi-disciplinary site investigations and site evaluation. For this reason a new guide for a site selection, Langer (1995) has published investigation and evaluation for waste. The interaction between engineering geology, soil mechanics and rock mechanics has attained today such a level as to ensure efficiency. However, problems still remain as in some cases current attitudes and practice still reflect earlier difficulties. Langer (1989) presented an example of a specific geotechnical investigation and safety concepts of waste disposal site based on hydrogeological model and geotechnical stability.

The role of engineering geology in this project is to select new sites for the dumping of the sewage water. The new site is chosen as the best available site, according to a process of comparison between some available possible sites. All of the available sites are in the vicinity of the City of Jeddah. The selected site is chosen according to satellite imagery and engineering geological bases, concerning the location and properties of both rocks and soils in the selected site(s). Screening process of the rocks and soil properties of all proposed sites point out to the new site to be selected as the best sewage-dumping site.

The procedure of the selection of the new site followed the traditional scientific bases of site investigation proposed by Head (1986), starting with the desk studies, collection of the available data (aerial photographs, satellite images, contour maps, reports, etc.), field trips, and *in situ* tests.

## 2. Brief Geology

Jeddah city lies along the Red Sea coast over a mixture of layers formed of Quaternary deposits, thick Tertiary deposits (Schmidt, *et al*., 1982), limestone is underlain by silt and gravel (Laurent, *et al*., 1973), floodplain deposits in the vicinity of Jeddah are composed of coarse sand and consisting of angular to subangular grains of Precambrian rocks (Laurent, *et al.,* 1973). Detailed study of the soils is given by Morris (1975) and Al-Qahtani (1979).

The Precambrian rocks have been studied by many authors (Brown, *et al*., 1963; Al-Shanti, 1966; Nebert, *et al*., 1974; and Moore and Al-Rehaili, 1989). The basement rocks in the study area, (Fig. 1) consist of the following: i) The Precambrian layered rocks are formed of, from old to young: regionally metamorphosed andesite, basalt and dacite related to Madrakah formation, conglomerate is overlain by volcaniclastic deposits related to Fatima group, ii) the Precambrian intrusive rocks are formed of metagabbro and gabbro, Kamil suite composed of diorite, tonalite, granodiorite and monzogranite. Kamil suite comprises 3 complexes a) Dighbij complex, consists of hornblende diorite and quartz monzogranite, b) Hafnah complex, consists of tonalite and monzogranite,

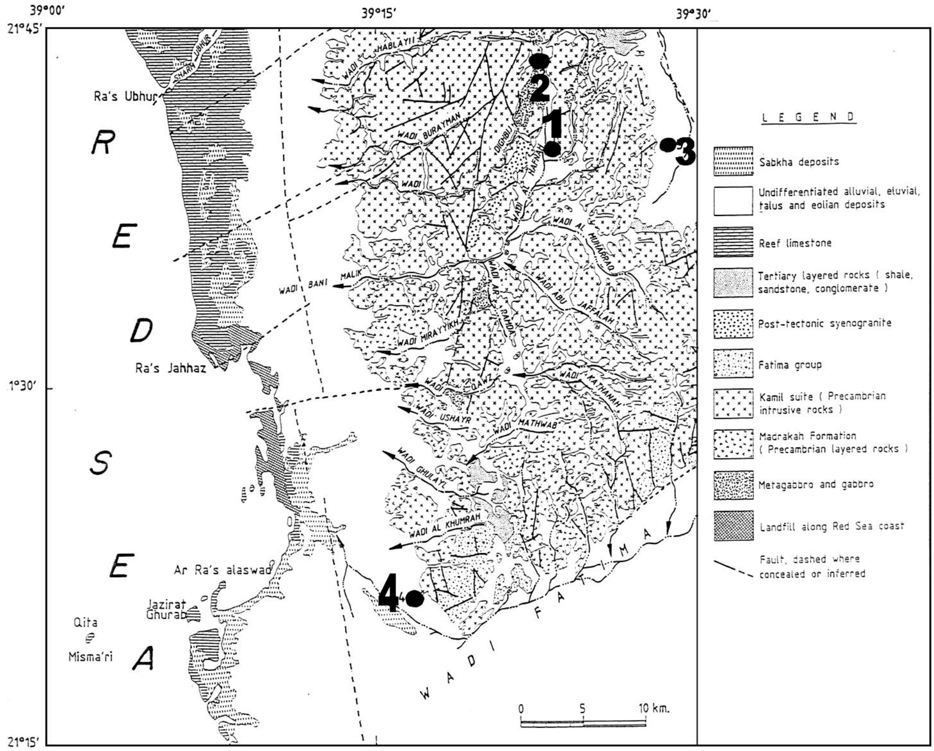


**Fig. 1. Geology of the study area, and location of the available 4 sewage dumping sites.**

c) qattanah complex, consists of monzogranite and granodiorite, iii) post tectonic syenogranite formed of unmetamorphosed syenogranite. Details of the geologic setting are given by Moore and Al-Rehaili (1989) and Qari, *et al*. (2001).

Jeddah city lies at the foothills of the Precambrian and metamorphic rocks exposed in the east. The igneous and metamorphic rocks form eroded hills of small to medium elevation. The ground relief slopes generally from north to south, and from east to west. Accordingly, the Wadis upstreams are located at the east, and the downstreams at the west, towards the Red Sea.

## 3. Site Investigation Plan

### *3.1 Planning and Design of Site Investigation*

Guidance on planning and design of site investigation is not explicitly included in the British Standard BS 5930, the Code of Practice for Site Investigation (1981). Guidelines on how to develop an appropriate strategy including categorization of investigation, preliminary design assessment and detailed site work are given by Head (1986).

Site investigation is part of the design process. It is the key to adequate and economic design because the collected data forms the basis of the site assessment and the foundation solutions subsequently produced.

Successful investigations only result from thorough planning and design. Lack of planning is probably the prime contributory factor leading to poor or inadequate solutions, as well as to additional problem costs. Long-term maintenance liabilities may also result. Unfortunately, the Code of Practice for Site Investigation (1981) does not lay sufficient emphasis on these important aspects.

It is believed that the method of procurement of ground investigation has a profound effect on the quality of the information produced. The more that is known about the site before examining it in the field, the more usefully can the time in the field be spent, and attention can be concentrated on the important locations causing potential engineering geological problems.

### *3.2 Site Investigation Program*

The purpose of the site investigation program is the evaluation of the ground conditions and hazards i) affecting the planning, design construction and maintenance of the new works, and ii) concerning the defects, failure, safety and maintenance of the existing works (Sadagah, 1998).

Site investigation program is changing according to the type of the problems. The site investigation, which embraces site selection, identification of environmental constraints, methods of administration, and other essential preliminary assessments, is assumed to be carried out previously. The site investigation code treats site appraisal and ground investigation as a series of isolated tasks and events with no development or discussion of an overall strategy. Planning and design of investigations is covered only by implications. There is no explicit guidance for formulating a plan, for establishing a program, or on how to produce a structure for the administration of investigations. The site investigation code should cover different types of development and types of investigation related to the various soils or rocks to be encountered in the problem.

Codes of site investigation vary according to the purpose of the investigation program and the nature of the problem encountered. In this study the code of site investigation is divided into 2 codes. First code is to choose a site, as a best site, among a number of available sites (Table 1), while the second code is to perform a code to investigate the chosen site (Table 2). The second code should follow the first code. Both codes could be similar in some aspects and steps of investigation. The simplified sequences recognized for site selection are presented in Table 1. Site investigation process essentially covers the desk study, site inspection, reconnaissance, construction, and maintenance stage.

**Table 1. Simplified site investigation code approach for site selection purpose.**

| Site investigation stage | Tasks |
|---|---|
| I. Preliminary | 1. Collection of various types of available data<br>2. Desk study of the collected information |
| II. Reconnaissance | 1. Reconnaissance<br>2. Field sampling<br>3. Ground investigation |
| III. Site selection (feasibility) | 1. Screening of the proposed sites<br>2. Selection of the best site |
| IV. Design and Construction of the elected site | 1. Detailed *in situ* testing<br>2. Laboratory testing |
| V. Post-construction | 1. Reporting and recommendations<br>2. Maintenance<br>3. Monitoring |

**Table 2. Site investigation code approach for a site investigation.**

<table>
<tr><th>Site investigation phase</th><th colspan="4">Details</th></tr>
<tr><td rowspan="6">I. Pre-construction</td><td rowspan="5">1. Preliminary stage</td><td rowspan="4">Reconnaissance</td><td rowspan="2">Desk study</td><td>General info</td></tr>
<tr><td>Special info</td></tr>
<tr><td rowspan="2">Site inspection</td><td>Aerial survey</td></tr>
<tr><td>Walk-over survey</td></tr>
<tr><td colspan="3">Feasibility</td></tr>
<tr><td colspan="4">2. Design stage</td></tr>
<tr><td>II. Construction</td><td colspan="4">Construction stage</td></tr>
<tr><td>III. Post-construction</td><td colspan="4">1. Operation and maintenance stage<br>2. Monitoring stage</td></tr>
</table>

The early sections of the code could be rationalized to cover the planning and design aspects of investigations. Identifying published materials, as references that the engineering geologist should consult, would refer to detailed guidance on the various aspects.

Planning includes the desk study but also considers all the other necessary activities that are prerequisites for a thorough preliminary assessment.

It should be mentioned that the site investigation code of site selection (Table 1), include minor site investigation code, in the design and construction stage, designed for the detailed study of various rocks and soils located at the selected site.

## 4. Data Acquisition

This stage of site investigation is called preliminary stage in post-construction phase (Clayton *et al.*, 1982). The collected data at this stage of site investigation consist mainly of aerial photographs, satellite images, contour maps, technical reports, documentary reports, and other reports. Intensive investigation of the collected materials was commenced during this stage of the research.

As the City of Jeddah extends 45 kilometers in length along the Red Sea coast, and about 15 kilometers in width, the aerial photographs, satellite images and contour maps indicate that the city could be divided, geomorphologically, into 5 major regions (Fig. 2). These regions are as follows:

i) The soil deposits where the majority of housing is built. This region of the city starts from the Red Sea coast at west and extends eastwards almost to the edge of the mountain range at the east. The slope of the ground is gently inclined mainly from east to west.

ii) The eastern region, which extends from the edge of the mountain range at left side and extends rightward to Wadi Al-Haffnah at the east. The slope of the ground is mainly from east to west and from north to south. This part includes the banned, and currently used sewage disposal sites (Fig. 2).

iii) This region starts from Wadi Al-Haffnah at west and extends eastwards to the Makkah-Madinah highway at the east. The slope of the ground is mainly from north to south and from west to east.

iv) This region fringes the southern part of the city, south of Jeddah-Makkah highway, starts from the edge of the mountain range and extends westwards to the Red Sea coast. Although the slope at this part is very gentle, it is mainly from east to west.

v) This region includes the main course of Wadi Fatima, starts from the southeastern edge of the plutonic rocks and extends eastwards to the fringe of the satellite image. The slope is from northeast to southwest.

Region number 1 includes almost 90% of the City of Jeddah which is the prime object of the current study, where all efforts are made to protect it from being polluted by the sewage.

## 5. Desk Study

Desk studies, aerial photographs interpretation, reports and reconnaissance are the main elements in the early preliminary stage, which is a part of the reconnaissance stage of site investigation, and unless they are done properly the whole site investigation may be inadequate. West (1981) commented on how these subjects are dealt with by BS 5930 (British Standard Institution, 1981).

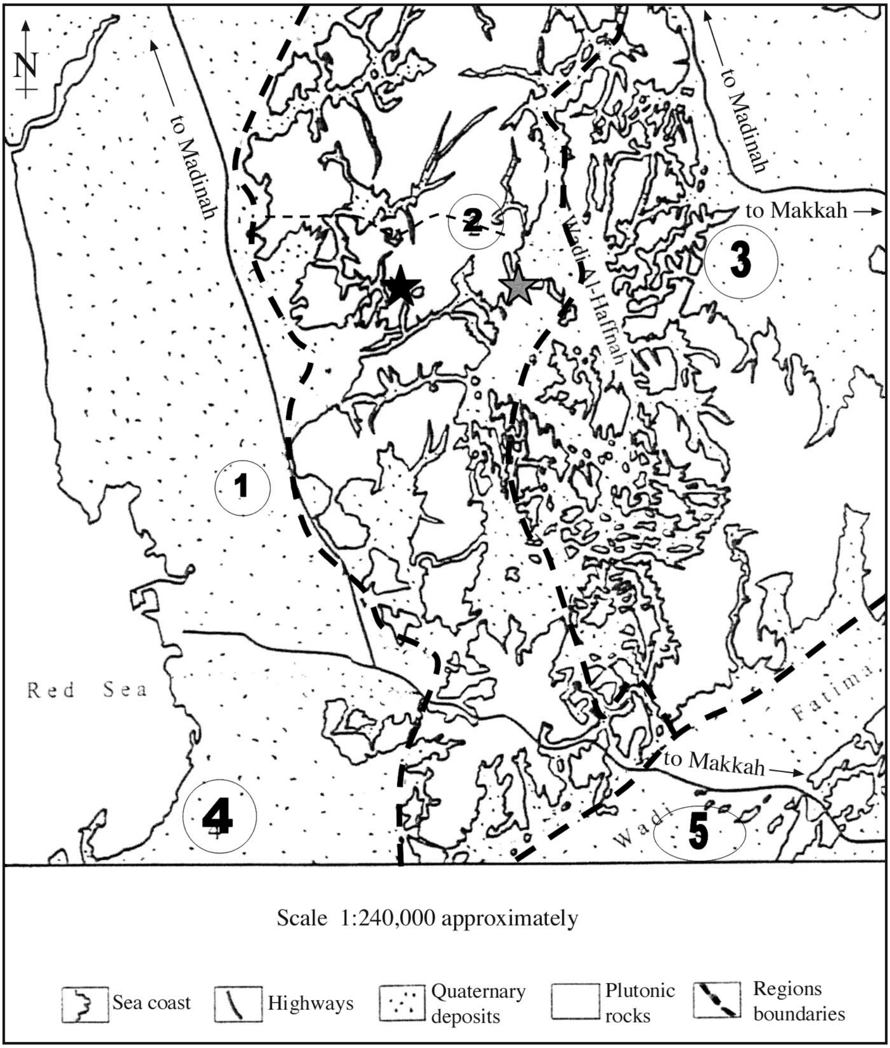


**Fig. 2. Jeddah city and vicinity divided into 5 major geomorphological regions, where the banned sewage dumping site (black star) and the used site (grey star) are shown.**

Four proposed sites were selected for possible future use, for the process of a preliminary site evaluation for the purpose of selecting the best suitable site to fulfill the sewage site requirements. This screening method is used for the selection of future sewage disposal site. Selection of these four sites was based upon the available topography east of Jeddah. In order to dump a liquid waste, soil deposits are required. However, it is clear from the geologic map and satellite images that the soil covering east of the city is very limited. The location of the selected 4 sites is given in Fig. 2.

The required properties characterizing future sewage site is described as follows:

1. Area: the area of the selected site should be as large as possible.
2. Rocks quality: the available rocks should be, geologically, free of structural defects (Billings, 1972; and Hobbs *et al*., 1976), and characterized by very large joint spacing.
3. Soils quality: the soil should have good quality (Terzaghi and Peck, 1967; and Lambe & Whitman, 1969).
4. Population: the population in the selected site should be very low as possible.
5. Slope angle: it should be very low as possible, to break the surface propagation of the sewage liquid.
6. Possible endangered area(s): it should be as low as possible, and should be free as possible from population, engineering structures, groundwater and agriculture.
7. Environmental effect: it should not endanger the environment.
8. Pollution: it should stop the increase of pollution in the site, and not to cause pollution to a clean neighbor sites.
9. Distance to the city: the distance to the city dwelling area should be within the acceptable limits and as short as possible for easy and fast dumping, if not, 1) the sewage trucks will dump the sewage in any place secretly within the city area, and 2) long distance will increase the dumping sewage prices.
10. Accept engineering structures: the selected site should be as large as possible to accept future construction of engineering structures, such as sewage water refinery(s).

The evaluation of each site depends upon rating of each property to the characteristics of every site. Each property has its own importance concerning the final use of the site. This importance is expressed as weighing factor. The weighing factor values are ranging from 1 (lowest importance) to 10 (highest importance), (Table 3). Each weighing factor value is multiplied by the rating of the site regarding this value, (Table 3). The site rating starts from excellent to not acceptable. Each rating takes values starting from 5 to 0 respectively. The best site characteristics should include higher property quality, and in turn takes higher grades. The evaluation process takes place, and the result showing the characteristics of each site are given in Table 3.

The screening method shows that site 4 has the highest rating score, which means that it is the best available site among the selected 4 sites (Fig. 2). This does not mean that site No. 4 has all ideal characteristics to be a sewage disposal site, but it is the best available site based on desk studies. Other unforeseen defects could be treated at the time of construction of the site,

**Table 3. Characteristics of each proposed sewage site.**

| Site property | Weight factor | Grades of sites | | | |
|---|---|---|---|---|---|
| | | Site 1 | Site 2 | Site 3 | Site 4 |
| | | Weighting factor × rating | | | |
| 1. Area | 5 | 2 | 2 | 5 | 5 |
| | | $5 \times 2 = 10$ | $5 \times 2 = 10$ | $5 \times 5 = 25$ | $5 \times 5 = 25$ |
| 2. Rocks quality | 5 | 3 | 3 | 0 | 0 |
| | | $5 \times 3 = 15$ | $5 \times 3 = 15$ | $5 \times 0 = 0$ | $5 \times 0 = 0$ |
| 3. Soils quality | 5 | 3 | 3 | 3 | 3 |
| | | $5 \times 3 = 15$ | $5 \times 3 = 15$ | $5 \times 3 = 15$ | $5 \times 3 = 15$ |
| 4. Population | 10 | 5 | 5 | 4 | 4 |
| | | $10 \times 5 = 50$ | $10 \times 5 = 50$ | $10 \times 4 = 40$ | $10 \times 4 = 40$ |
| 5. Slope angle | 7 | 2 | 1 | 2 | 5 |
| | | $7 \times 2 = 14$ | $7 \times 1 = 7$ | $7 \times 2 = 14$ | $7 \times 5 = 35$ |
| 6. Possible endangered area(s) | 10 | 0 | 0 | 2 | 5 |
| | | $10 \times 0 = 0$ | $10 \times 0 = 0$ | $10 \times 2 = 20$ | $10 \times 5 = 50$ |
| 7. Environmental effect | 9 | 0 | 0 | 2 | 5 |
| | | $9 \times 0 = 0$ | $9 \times 0 = 0$ | $9 \times 2 = 18$ | $9 \times 5 = 45$ |
| 8. Pollution | 10 | 0 | 0 | 0 | 5 |
| | | $10 \times 0 = 0$ | $10 \times 0 = 0$ | $10 \times 0 = 0$ | $10 \times 5 = 50$ |
| 9. Distance to the city | 8 | 3 | 3 | 0 | 5 |
| | | $8 \times 3 = 24$ | $8 \times 3 = 24$ | $8 \times 0 = 0$ | $8 \times 5 = 45$ |
| 10. Accept additional engineering structures | 8 | 0 | 0 | 5 | 5 |
| | | $8 \times 0 = 0$ | $8 \times 0 = 0$ | $8 \times 5 = 40$ | $8 \times 5 = 40$ |
| Sum of grades | | 128 | 121 | 177 | 340 |

Rating of sites 5 = excellent, 4 = very good, 3 = good, 2 = poor, 1 = very poor, 0 = not accepted.

according to the site investigation code.

It should be noted that the proposed sites 1 and 2 have 0 grade in site property (possible endangered area(s), environmental effect, and pollution). This is because site 1 is already close to the current site, causing danger to the City of Jeddah and the vicinity. Also site 2 is further to the northeast of the city, and lies far north along Wadi Al-Haffnah, which will increase the cone of endangered and polluted areas in Jeddah and vicinity. Take into consideration that site 3 has a poor grade, regarding the same site properties, because if it is used in the future, it could cause pollution to a new unpolluted area along Makkah-Madinah highway similar to the pollution caused by the current site.

## 6. Fine-Tuned Selection

Site selection process has become more restricted because of the lack of suitable development sites. As a result, there is now a requirement to redevelop or consider marginal sites with poor engineering properties. This necessitates a more specialist evaluation of ground characteristics and potential remedial measures. Wasteland areas may vary enormously and haphazardly in their properties and often overlie ground with poor characteristics.

This necessitates the performance of the site investigation code (Table 2) in details, starting with pre-construction phase design stage. The purpose of the design stage after selection of the new sewage site is to provide the design parameters by making a siting & supervision of bore holes (if possible), pits, trenches, sampling and to numerous forms of *in situ* as well as laboratory tests on the selected site.

## 7. Geomorphology of the Site

The site area is formed of very gentle slope of Wadi deposit of loose sand. The slope of the site surface area is very gently dipping toward west and south of the site.

## 8. Lineament Study

In order to imagine the structural lineament distribution in the proposed new dumping site, lineament map was prepared by visual interpretation of aerial photographs (Fig. 3) at a scale of 1:60,000. Mirror stereoscope was utilized in order to clear cut the lineament extension in three-dimensional vision. Lineament interpretation was easily conducted in the bedrock areas; however, these lineaments were inferred in the alluvium (wadi deposits) areas within the proposed new dumping site. These interpreted lineaments were recorded on a transparent overlay as ruled lines. The significance of the 192 interpreted lineaments was analyzed using distribution curves for frequency and length and the azimuthally distribution analyses of non-smoothed and smoothed lineament trends were prepared (Fig. 4). Interpretation of the smoothed azimuthal distribution of lineaments frequency for the proposed new dumping site showed that there are three major distinguished directions based on their occurrence frequency. These directions may have implications related to the Cenozoic tectonism of the area.

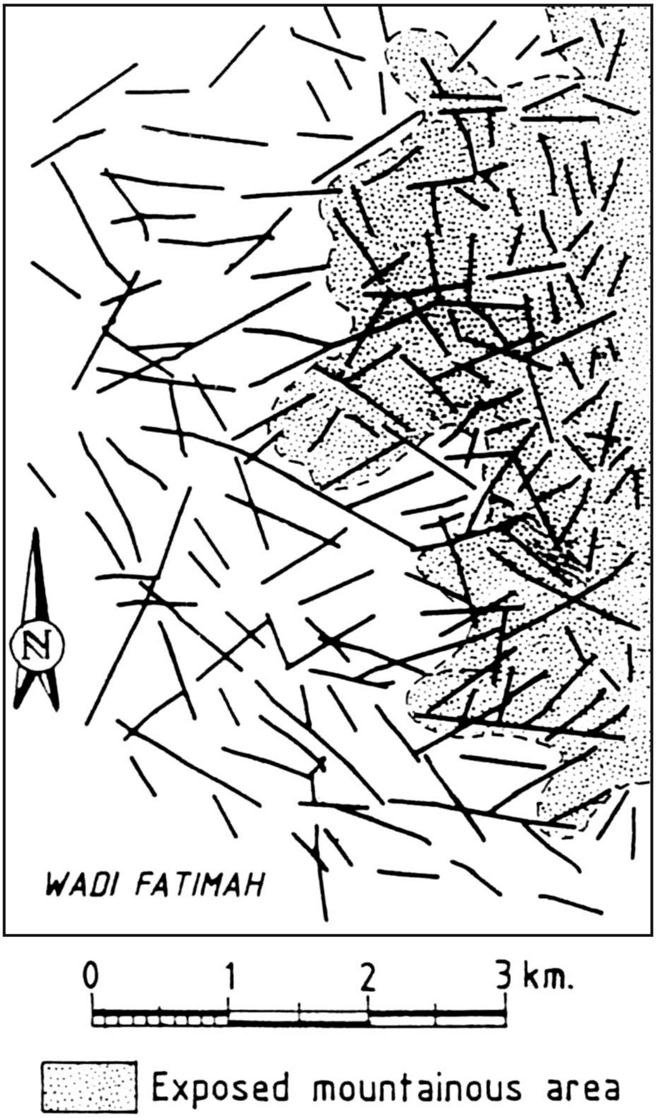


**Fig. 3. Lineament map of the proposed new dumping site.**

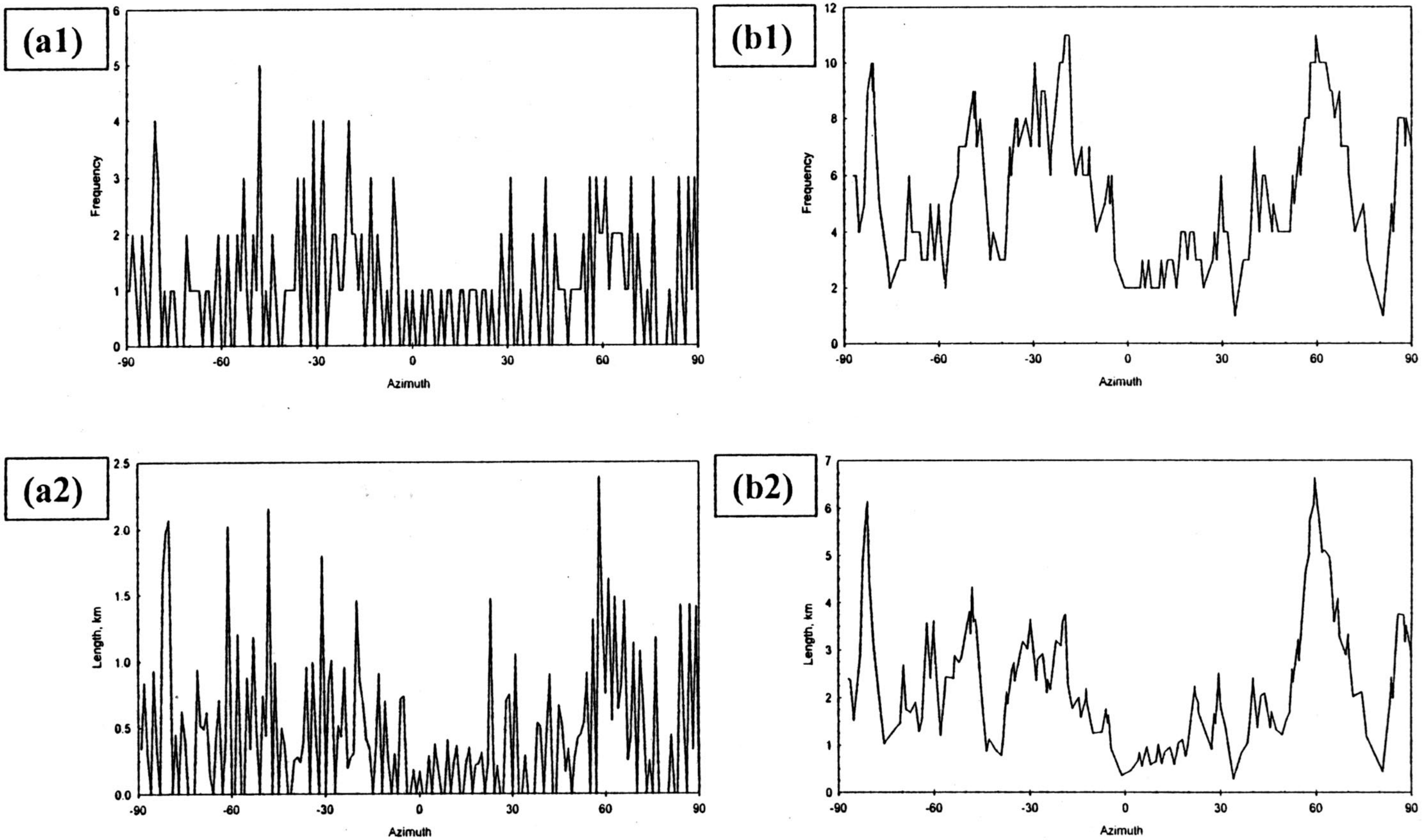


**Fig. 4. Azimuthal distribution of lineament trends for the proposed new dumping site by number and length, (a1 and a2) for the non-smoothed data, (b1 and b2) for the smoothed data.**

The lineament map was also divided into a grid of square cells, hence, contour maps showing isolines of (i) number of lineaments within each cell (Fig. 5), (ii) total length of these lineaments within the cell (Fig. 6), and (iii) the number of line-to-line intersections within each cell (Fig. 7) were prepared and also examined for the pattern of concentration. One concentration is prevailed in all three contour maps, *i.e.* in the middle of the mapped area.

It was found that the proposed new dumping site is located in the middle western area in these contour maps where number, total length, and lineament-to-lineament intersection is decreasing in amount towards the west of these contour maps, which reflects the suitability of the proposed site to be used for sewage dumping in the future. In addition, this proposed site is located within the very gentle slope of loose sand wadi deposits of the coastal plain of the Red Sea, where the permeability characteristics are very low, ranging between 0.64 to 1.21 mm/sec.

## 9. Engineering Geological Study

The proposed sewage-dumping site was subdivided into 9 stations forming a mesh of stations, (Fig. 8). In each station, the next engineering geologic study of the soil had been commenced, as follows:

### *9.1 Sieve Analyses*

The grain size analysis test was performed in each square of the proposed site (minor site), in order to get the detailed change and type of the soils. The grain size distribution curves of every tested sample are shown in Fig. 9. Properties of the soils in the whole site are shown in Table 4. The grain size varies between fine gravel to fine sand all over the site. Soil characterized by minor changes in the size of sand particles. In addition, the soil cover condition all over the minor sites varies between loose soil cover in the northern side of the site to compacted soil cover in the southern side of the site. Soils are compact between Wadi Al-Khomra and Wadi Fatima (Fig. 1), and continue to be more compact further south due to route flow change of valley tributaries.

### *9.2 Density*

As the site was divided into 9 squares (stations), the *in situ* tests of density were performed in the field in every square of the site. The field density results are shown in Table 4. The soils characterized by high porosity as indicated and proven by the permeability tests.

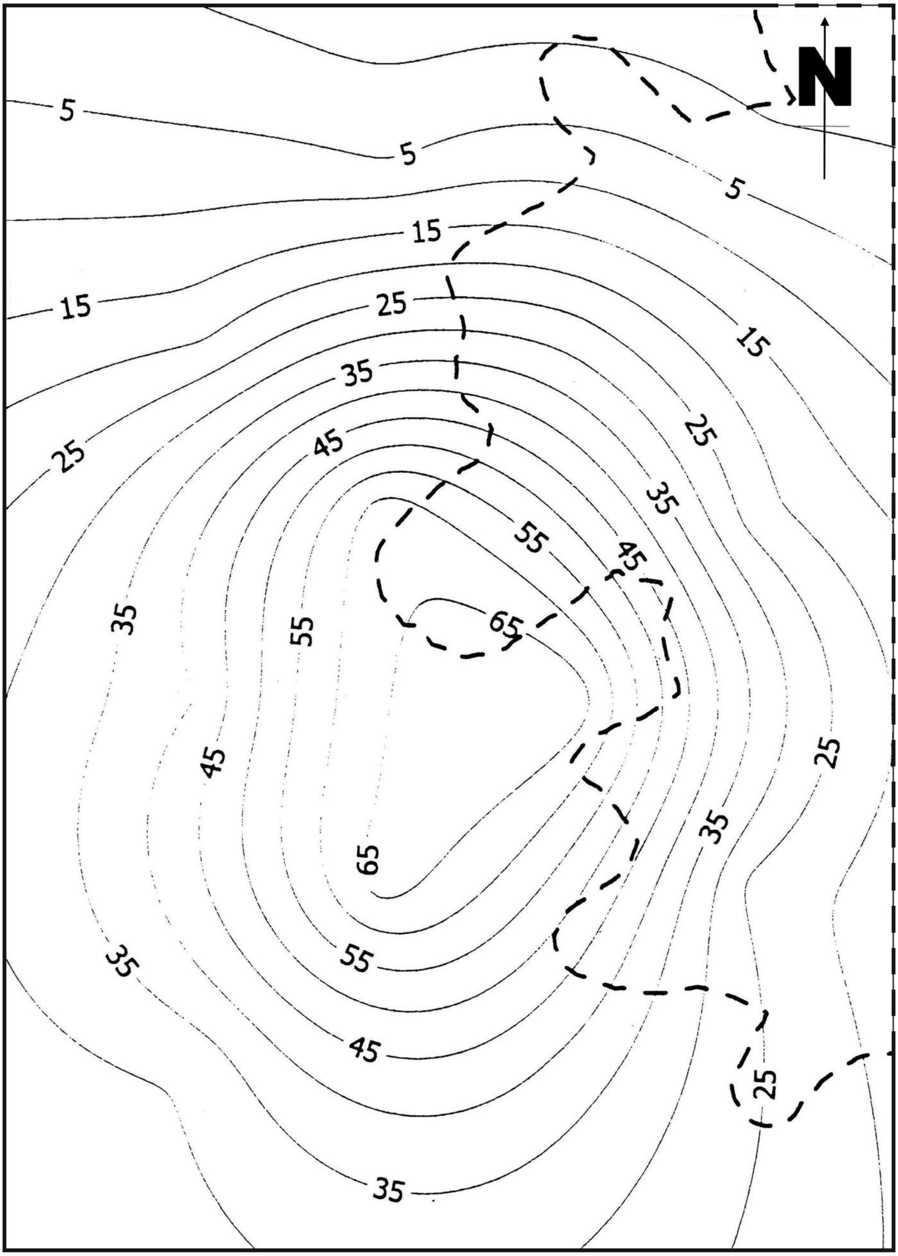


**Fig. 5. Lineament density contour for the proposed new dumping site, dashed contact denotes the western limit of the exposed mountainous area.**

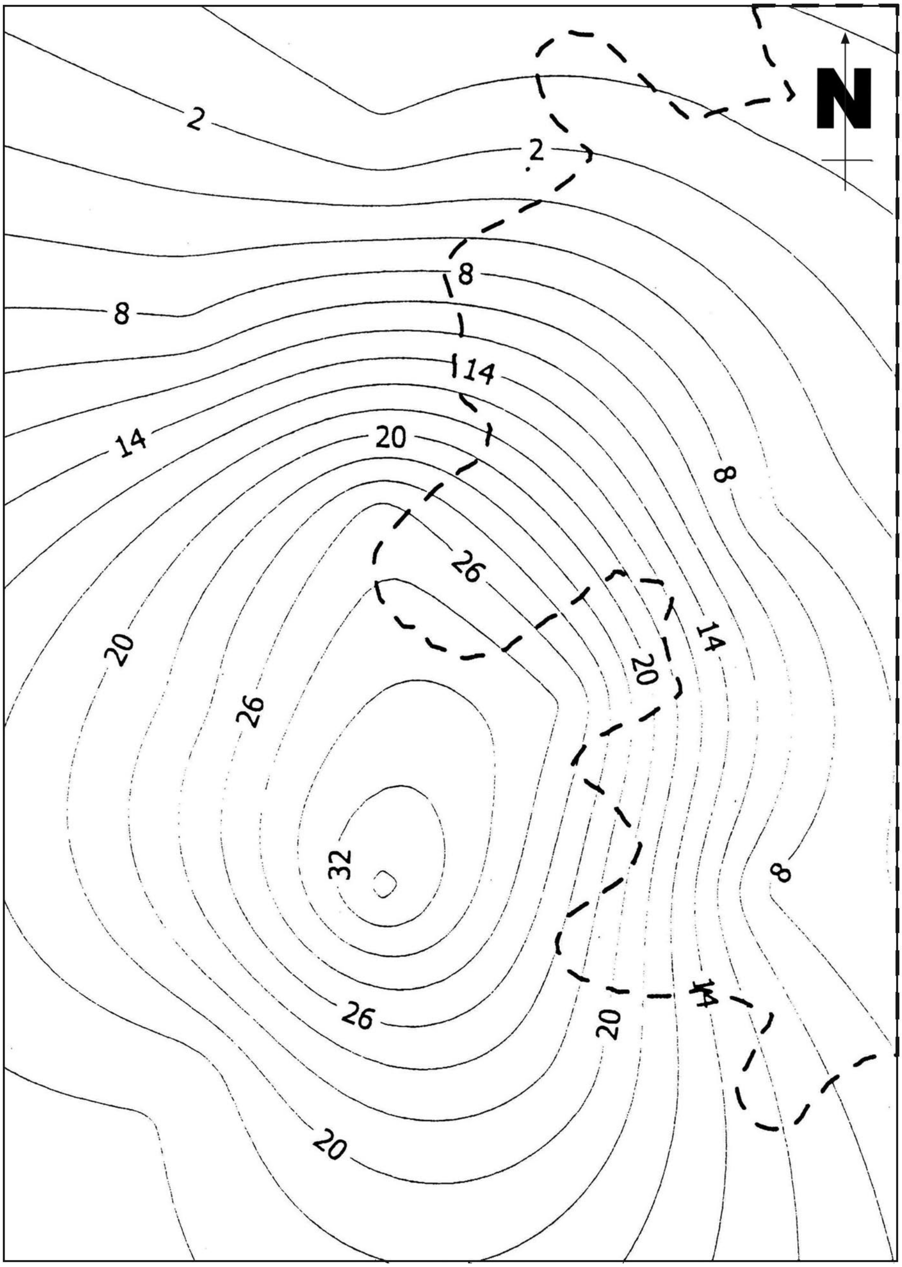


**Fig. 6. Lineament length contour map for the proposed new dumping site, dashed line denotes the western boundary of the exposed mountainous area.**

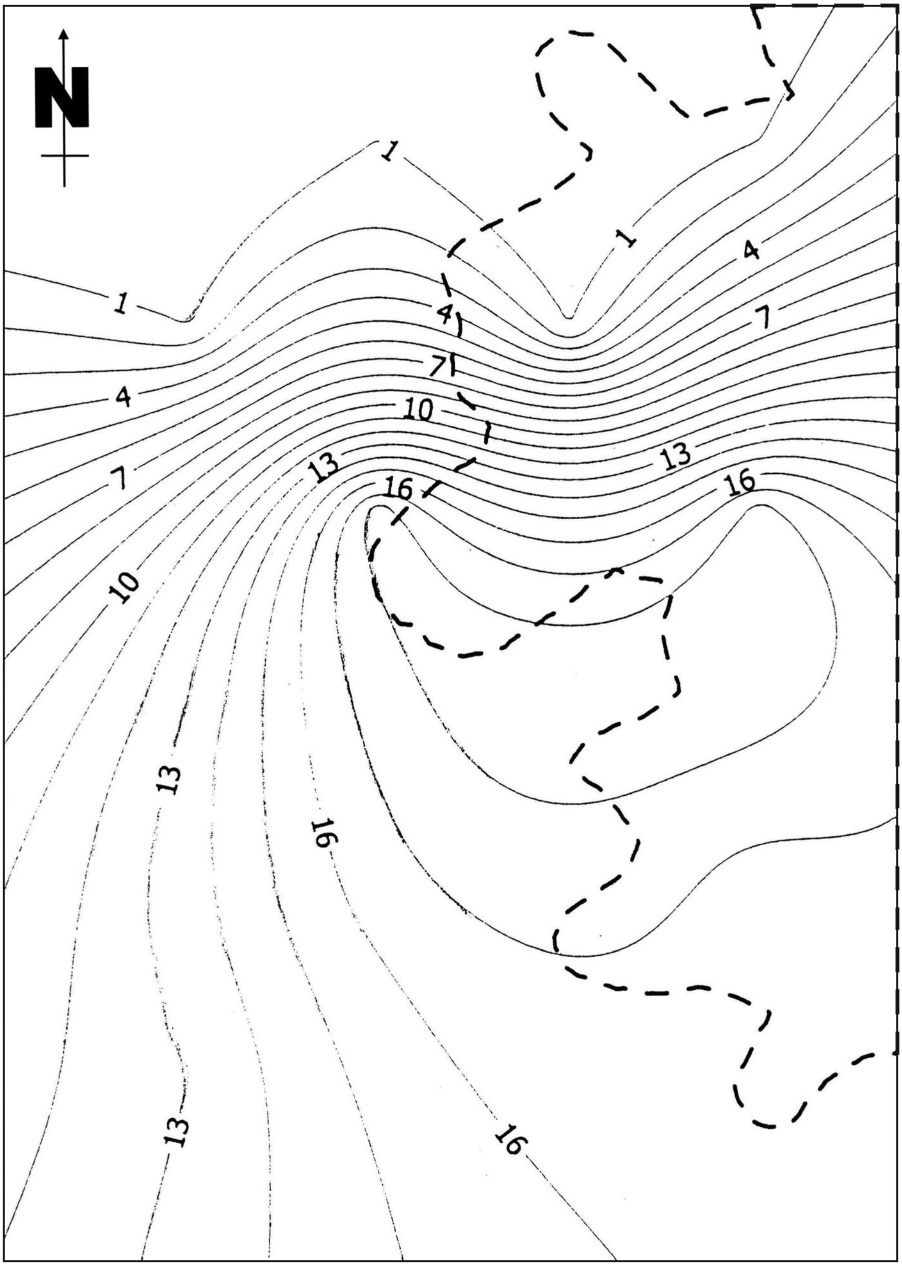


**Fig. 7. Lineament-to-lineament intersection contour map for the proposed new dumping site, dashed line denotes the western boundary of the exposed mountainous area.**

### *9.3 Permeability Test*

The permeability test was done in the field using double ring infiltrometer test in 9 stations. The permeability test plot at each station is shown in Fig. 10. It is clear from these curves that the infiltration rate ranges between 0.65 and 3.8 cm/hr.

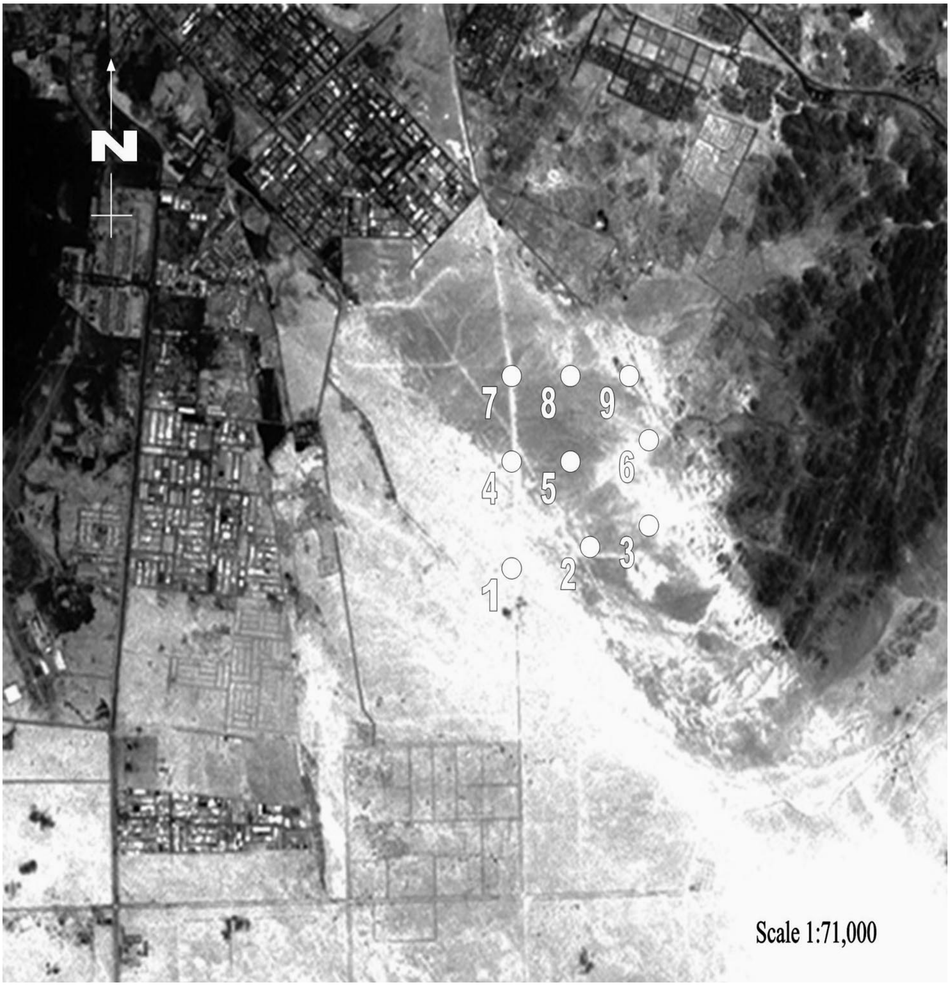


**Fig. 8. Location of the proposed sewage dumping site area southern Jeddah, where the power station locations are shown in numbers.**

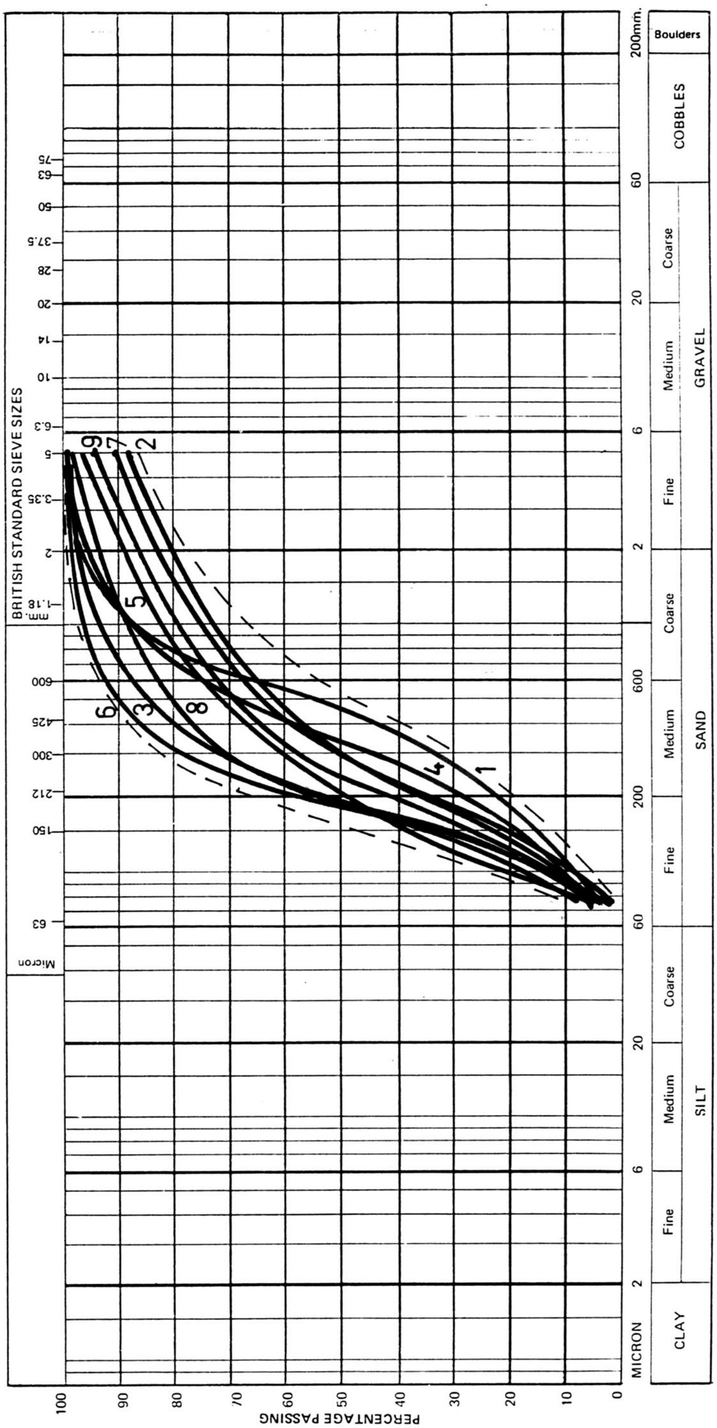


**Fig. 9. Grain size distribution of the soil at the site.**

**Table 4. Properties of the soil in the proposed sewage disposal site.**

| Station # | $D_{10}$, mm | $D_{30}$, mm | $D_{60}$, mm | $C_c$, mm | $C_u$, mm | Field density, gm/cm$^3$ | Infiltration rate, cm/hr | Permeability, mm/c |
|---|---|---|---|---|---|---|---|---|
| Sj1 | .09 | .25 | .55 | 6.11 | 1.26 | 1.71 | 1.3 | 1.21 |
| Sj2 | .085 | .2 | .42 | 4.94 | 1.12 | 1.74 | 0.65 | 0.9 |
| Sj3 | .083 | .148 | .26 | 3.13 | 1.015 | 1.81 | 2.6 | 0.64 |
| Sj4 | .08 | .15 | .42 | 5.25 | .67 | 1.74 | 2.2 | 0.81 |
| Sj5 | .077 | .1 | .28 | 3.64 | .464 | 1.90 | 2.4 | 0.72 |
| Sj6 | .08 | .125 | .23 | 2.88 | .849 | 1.65 | 2.0 | 0.72 |
| Sj7 | .09 | .2 | .37 | 4.11 | 1.2 | 1.70 | 2.1 | 1.21 |
| Sj8 | .08 | .1 | .235 | 2.94 | .532 | 1.77 | 3.8 | 0.9 |
| Sj9 | .09 | .175 | .35 | 3.89 | .972 | 1.79 | 2.75 | 0.9 |

The permeability of the soil is indirectly driven from the grain size distribution curves provided in Fig. 10, is shown in Table 4. This method was described by Raghunath (1982).

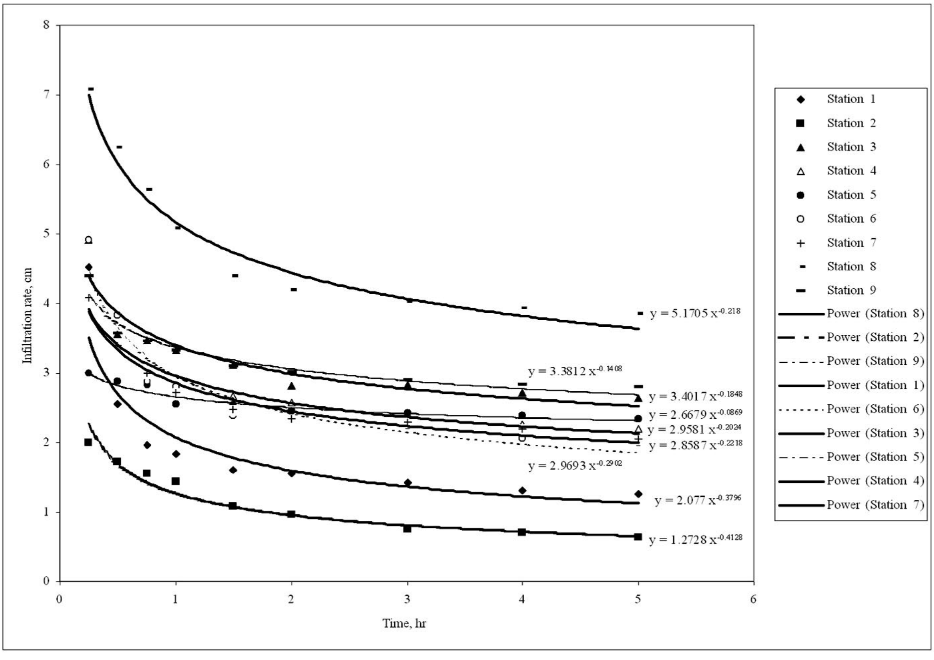


**Fig. 10. Permeability tests results of 9 stations at the proposed sewage dumping site area.**

### *9.4 Mackintosh Test*

Mackintosh test was done in each station in the proposed site, as well as the Standard Penetration Test (SPT), Lambe and Whitman (1969). The results are shown in Tables 5 to 13 inclusive, where M-value is the number of blows in Mackintosh test, and N is the number of blows in SPT test.

**Table 5. Mackintosh test at station sj 1.**

| Depth, cm | M | N | Relative density |
|---|---|---|---|
| 15 | 10 | 3 | v. loose |
| 30 | 85 | 10 | medium dense |
| 45 | 93 | 11 | medium dense |
| 60 | 100 | 12 | medium dense |
| 75 | 134 | 15 | medium dense |
| 90 | 148 | 17 | medium dense |
| 105 | 250/9 | 17 | v. dense |

**Table 6. Mackintosh test at station sj 2.**

| Depth, cm | M | N | Relative density |
|---|---|---|---|
| 15 | 40 | 6 | v. loose |
| 30 | 130 | 15 | Medium dense |
| 45 | 200 | 22 | Dense |
| 60 | 250/8 | – | v. dense |

**Table 7. Mackintosh test at station sj 3.**

| Depth, cm | M | N | Relative density |
|---|---|---|---|
| 15 | 30 | 5 | Loose |
| 30 | 120 | 14 | Medium dense |
| 45 | 250/11 | – | v. dense |

**Table 8. Mackintosh test at station sj 4.**

| Depth, cm | M | N | Relative density |
|---|---|---|---|
| 15 | 20 | 4 | v. loose |
| 30 | 50 | 7 | Loose |
| 45 | 84 | 10 | Medium dense |
| 60 | 117 | 14 | Medium dense |
| 75 | 158 | 18 | Medium dense |
| 90 | 250/13 | – | v. dense |

**Table 9. Mackintosh test at station sj 5.**

| Depth, cm | M | N | Relative density |
|---|---|---|---|
| 15 | 25 | 4 | Loose |
| 30 | 174 | 19 | Medium dense |
| 45 | 250/7 | – | v. dense |

**Table 10. Mackintosh test at station sj 6.**

| Depth, cm | M | N | Relative density |
|---|---|---|---|
| 15 | 26 | 4 | v. loose |
| 30 | 76 | 9 | Loose |
| 45 | 210 | 23 | Medium loose |
| 60 | 250/11 | – | v. dense |

**Table 11. Mackintosh test at station sj 7.**

| Depth, cm | M | N | Relative density |
|---|---|---|---|
| 15 | 20 | 4 | v. loose |
| 30 | 60 | 8 | Loose |
| 45 | 140 | 16 | Medium dense |
| 60 | 200 | 22 | Medium dense |
| 75 | 250/11 | – | v. dense |

**Table 12. Mackintosh test at station sj 8.**

| Depth, cm | M | N | Relative density |
|---|---|---|---|
| 15 | 10 | 3 | v. loose |
| 30 | 29 | 5 | Loose |
| 45 | 55 | 7 | Loose |
| 60 | 76 | 9 | Loose |
| 75 | 250/13 | – | v. dense |

**Table 13. Mackintosh test at station sj 9.**

| Depth, cm | M | N | Relative density |
|---|---|---|---|
| 15 | 40 | 6 | Loose |
| 30 | 94 | 11 | Medium dense |
| 45 | 150 | 17 | Medium dense |
| 60 | 190 | 21 | Medium dense |
| 75 | 250/8 | – | v. dense |

## 10. Recommendations

1. After deciding the final location of the sewage disposal site in area 4, then come the following stages, to ensure i) the performance of the new disposal site in the construction stage. The purpose of the construction stage is to make a comparison between the predicted and actual conditions encountered in the area of disposal (Rasul, *et al*., 1999) during the construction; ii) to ensure if it is confirmed to those on which the design stage has been based. Otherwise, additional investigation should be carried on, and/or changing in design should be made, where unforeseen conditions are encountered.

2. The geological solution to the problem of locating a new sewage site should be accompanied by an engineering solution. Otherwise, the sewage will go in every direction over the soil cover without any organization. The engineering solution should be the construction of sewage refinery of high capacity to recycle the sewage quantities collected from all over Jeddah City, or to increase the capacity of the existing water treatment station (El Sayed,

1999a). Otherwise the un-treatment of the dumped sewage in that area will have a number of side effects and more pollution to the environment in that area (Abu-Shanab *et al*., 1999; Niaz, 1999; and El Sayed, 1999b).

## References

**Al-Qahtani, M.B.** (1979) Preliminary Classification and Geotechnical Investigation of the Soils/ Rocks of the City of Jeddah, *Unpublished M.Sc. Thesis*, Faculty of Earth Sciences, King Abdulaziz University, 223p.

**Al-Shanti, A.M.** (1966) Oolitic Iron Ore Deposits in Wadi Fatima Between Jeddah and Mecca, Saudi Arabia, *Saudi Arabian Directorate General of Mineral Resources Bulletin*, **2:** 51.

**Abu-Shanab, M.A., Mandura, A.S.** and **Basaham, A.S.** (1999) Mangrove Vegetation on Khor Al-Kharrar, Red Sea, *Second Symposium on the Red Sea Marine Environment. Programme and Abstracts*, Faculty of Marine Science, King Abdulaziz University, Jeddah, 8-10 Nov. 1999, p.58.

**Billings, M.P.** (1972) *Structural Geology*, 3rd ed., Prentice-Hall, Inc., Englewood, Cliffs, N. J. 606p.

**British Standard Institution** (1981) *Code of Practice for Site Investigation*, BS 5930, HMSO, London.

**Brown, G.F., Jackson, R.O., Bogue, R.G.** and **MacLean, W.H.** (1963) Geology of the Southern Hijaz Quadrangle, Kingdom of Saudi Arabia, *Saudi Arabian Directorate General of Mineral Resources, Miscellaneous Geologic Investigations MaP* I-210A, 1:500,000 scale.

**Clayton, C.R.I., Simons, N.E.** and **Matthews, M.C.** (1982) *Site Investigation – A Handbook for Engineers*, Granada Publishing, 423p.

**El Sayed, M.A.** (1999a) Nitrogen and Phosphorous in Al Khumra Sewage Effluent (Jeddah, Eastern Red Sea): Their Daily Cycle and Flux and Their Distribution and Behavior in the Coastal Area, *Second Symposium on the Red Sea Marine Environment. Programme and Abstracts*, Faculty of Marine Science, King Abdulaziz University, Jeddah, 8-10 Nov., 1999, p. 59.

**El Sayed, M.A.** (1999b) Organic Carbon and Trace Metals Burden of Al Khumra Sewage Effluent (Jeddah, Eastern Red Sea) and the Consequences on Sediments and Suspended Matter in the Coastal Area, *Second Symposium on the Red Sea Marine Environment. Programme and Abstracts*, Faculty of Marine Science, King Abdulaziz University, Jeddah, 8-10 Nov. 1999, p. 62.

**Head, J.M.** (1986) Planning and design of site investigation, *In:* Hawkins, (Ed.) 1986. *Site Investigation Practice: Assessing BS 5930*, pp: 1-8.

**Hobbs, B.E., Means, W.D.** and **Williams, P.E.** (1976) *An Outline of Structural Geology*, John Wiley & Sons, Inc. 571p.

**Lambe, T.W.** and **Whitman, R.V.** (1969) *Soil Mechanics*, John Wiley & Sons, Inc. 553p.

**Langer, M.** (1989) Waste disposal in the Federal Republic of Germany: Concepts, Criteria, Scientific Investigations, *Bulletin of the International Association of Engineering Geologists,* **39:** 53-58.

**Langer, M.** (1995) Engineering geology and waste disposal: Scientific report and recommendations of the IAEG Commission No. 14, *Bulletin of the International Association of Engineering Geologists*, **51:** 6-29.

**Laurent, D., Daessle, M., Berton, Y.** and **Dehlavi, M.** (1973) Engineering Geological Map of Jiddah and Spot Information Map on Ground Conditions in Jiddah, Kingdom of Saudi Arabia, *Saudi Arabian Directorate General of Mineral Resources Geologic Map* GM-8, scale 1:10,000.

**Moore, T.A.** and **Al-Rehaili, M.H.** (1989) *Geologic Map of Makkah Quadrangle, Sheet 21D, Kingdom of Saudi Arabia: DGMR*, Geoscience map GM-107C, 1:250,000 scale.

**Morris, P.G.** (1975) Construction Materials, Non-Metallic Mineral Occurrences and Engineering Geology of the District Around Jeddah, Kingdom of Saudi Arabia, *Saudi Arabian Directorate General of Mineral Resources*, Technical Record TR-1975-1, 27p.

**Nebert, K., Al-Shaibi, A.A., Awlia, M., Bounny, I., Nawab, Z.A., Sharief, O.H., Sherbini, O.A.** and **Yeslam, A.H.** (1974) Geology of the Area North of Wadi Fatima, Kingdom of Saudi Arabia: King Abdulaziz University, Jeddah Saudi Arabia, *Center for Applied Geology Bulletin*, **1,** 30 p.

**Niaz, G.R.** (1999) Studies of Sewage Contamination Along Southern Coast of Jeddah, *Second Symposium on the Red Sea Marine Environment, Programme and Abstracts*, Faculty of Marine Science, King Abdulaziz University, Jeddah, 8-10 Nov., 1999. p. 61.

**Qari, M.H., Sadagah, B.H., Al-Dakheel, A.M., Bajabaa, S.A.** and **Al-Sari, A.M**. (2001) *Using Remote Sensing Technology to Determine Environmental Impacts and to Select New Sewage Dumping Site in Jeddah*, Final Report. Grant by King Abdulaziz City for Science and Technology, Grant No. AT-17-27, 267p.

**Raghunath, H.M.** (1982) *Ground Water*, Wiley Eastern Limited, New Delhi, India, 456p.

**Rasul, N.M., Basaham, A.S., El Sayed, M.A.** and **Al-Washmi, H.** (1999) Sedimentological and Geochemical Investigation of Al-Kharrar Coastal Inlet in the Eastern Red Sea, *Second Symposium on the Red Sea Marine Environment. Programme and Abstracts*, Faculty of Marine Science, King Abdulaziz University, Jeddah, 8-10 Nov., 1999. p. 78.

**Sadagah, B.H.** (1998) Site Investigations, *Engineering and Environmental Geology Course Notes*, Faculty of Earth Sciences, King Abdulaziz University, Jeddah, Kingdom of Saudi Arabia.

**Schmidt, D.L., Hadley, D.G.** and **Brown, G.F.** (1982) *Middle Tertiary Continental Drift and Evolution of the Red Sea in Southwestern Saudi Arabia*, Saudi Arabian Deputy, Ministry for Mineral Resources Open-File Report UGSG-OF-03-6, 56p.

**Terzaghi, K.** and **Peck, R.B.** (1967) *Soil Mechanics in Engineering Practice*, 2nd ed., John Wiley & Sons, Inc., 729p.

**West, G.** (1981) Desk Studies, Air Photograph Interpretation and Reconnaissance for Site Investigation, In: Hawkins, (Ed.) 1986, *Site Investigation Practice: Assessing BS 5930*, cs pp: 9-16.

# دراسات صور القمر الصناعي والجيولوجيا الهندسية لموقع نفايات سائلة مقترح، جدة، المملكة العربية السعودية

**محمد هداية اللّه قاري ، و بهاء الدين هاشم صدقـة**
*كلية علوم الأرض ، جامعة الملك عبد العزيز*
*جــــدة - المملكة العربية السعودية*

*المستخلص.* تمتد مدينة جدة ٤٥ كيلومترًا طولاً على الساحل الشرقى للبحر الأحمر، وحوالى ١٥ كيلومترًا عرضًا. يقطن مدينة جدة حوالى ٢,٥ مليون نسمة. يعتبر التخلص من النفايات السائلة لها مشكلة. يوجد الآن موقعين للنفايات السائلة، أحدهم مهجور، والآخر يستخدم حاليًا ويسبب مشاكل بيئية. ونظرًا لذلك، فإن اختيار موقع جديد يعتبر ضرورة ملحة. تم استخدام طريقة الأفضلية فى دراسة فحص المواقع، والتى تنفذ على مراحل، تبدأ باختيار العديد من المواقع المتاحة، والتى تعرضت للتفضيل فيما بينها، ومن ثم التقييم. تم اختيار أفضل موقع اعتمادًا على أعلى ناتج تقييم. أُتبعت مرحلة الاختيار بمرحلة القيام بدراسات حقلية مكثفة، اشتملت على اختبارات تفصيلية، مثل تحليلات نتائج تنخيل التربة، واختبارات النفاذية، والوزن النوعى الحقلى، واختبارات ماكنتوش. بعد الفحص أمكن إثبات صلاحية الموقع الجديد لاستخدامه كموقع نفايات سائلة جديد لمدينة جدة.