International Journal of Advanced and Applied Sciences, 9(9) 2022, Pages: 61-69

Contents lists available at Science-Gate

International Journal of Advanced and Applied Sciences

Journal homepage: http://www.science-gate.com/IJAAS.html

Evaluation of grain size distribution of Wadi As Suqah, Northeast of Jeddah, Saudi Arabia

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ARTICLE INFO

Article history:
Received 18 February 2022
Received in revised form
14 May 2022
Accepted 6 June 2022

Keywords:
Gravel
Sand
Fine
Correlation
Relationship

ABSTRACT

Wadi As Suqah, Makkah Governate, Western Saudi Arabia, has surficial sediments covering 300-422 square kilometers. The deposits may be used for any suitable construction material. Therefore, thirty-one samples of the Quaternary sands were collected from different locations along the study area to achieve this goal. The natural surficial grain sizes of Wadi As Suqah deposits in the Makkah region were assessed geotechnically, spatially, and mathematically. Rarely comprehensive exploration methodology, such as sieve analysis, 3D modeling, triangulation, and GIS, have been used to categorize the content percentage of grain sizes. Statistics and mathematics were also used to evaluate the correlations and assess the relationship between the fractions. This sophisticated approach is adapted for the first time on Wadi As Suqah, which concludes different results compared to previous studies. According to the unified soil classification system, gravel, sand, and fine had an average content of 85.1%, 11.7%, and 3.2%, respectively. Therefore, Wadi As Suqah, based on the fractions percentage, is categorized into four spatially sandy zones. At a coefficient of determination, R^2=0.98, sand, and fine have a linear relationship. The major mathematical model is $y = -1.02\,x + 100.5$, in which y is the fine % content, and x is the sand % content. It can be merged with mineralogy for future studies to evaluate sediment from a geological engineering point of view.

1. Introduction

Sand, gravel, and fine sediments are important geological materials for construction. Based on ASTM (2010), gravel size ranges from less than 75 mm to the size of 4.75 mm, while sandy soil is defined as non-consolidated deposits with an average of more than 50% of the particle size that passes a No. 4 sieve (4.75 mm) and is retained on a No. 200 sieve (0.075m). Fine soil (silt and clay) sediment sizes, on the other hand, pass through sieve No. 200 sieve.

The Unified soil classification system, adopted by ASTM, is a standard method considering the grain size and texture for engineering usages (ASTM, 2010). Additionally, soil grain size significantly impacts the engineering strength and quality of the soil (Murthy, 2002; Handy, 2007). Also, it could reveal vital information about the sediments' provenance, transport history, and depositional situation (Blott and Pye, 2001).

From an engineering geology point of view, this study aims to evaluate the surficial distribution of gravel, sand, and fine grain size of Wadi As Suqah. Otherwise, correlations and significant relationships between them will be covered. Finally, the best mathematical model, which provides an understanding of the numerical behavior of the phenomenon, will be deduced.

2. Geology

The study region is a part of the Western Arabian Shield, which includes an igneous and platonic rock complex (Fig. 1). The central portion of the area consists of tertiary-age sedimentary rocks (which cover around 50% of the entire surface) overlaid by basaltic lava flows (El-Didy, 1998).

These sedimentary rocks include the Usfan and Shumaysi formations bands (El-Didy, 1998). The Usfan formation consists of sandstone, shale, marls, and wedges of fossiliferous carbonate, while the Shumaysi formation contains sandstone, siltstone, and oolitic ironstone bands (El-Didy, 1998).

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Otherwise, quaternary surface sediments (sand and gravel) are spread in broad valleys and coastal regions (Spincer and Vincent, 1984). Kotb et al. (1988) mentioned that the Wadi's upstream area has deposits of stones in layers alternating with coarse sand, while downstream, it changes continuously to silt and clayey silt. Structurally, the Red Sea fault system has influenced the rocks from the Precambrian to the Quaternary (Sharaf, 2011). Fig. 1 shows a digital geological map of the study area (Moore and Al-Rehaili, 1989).

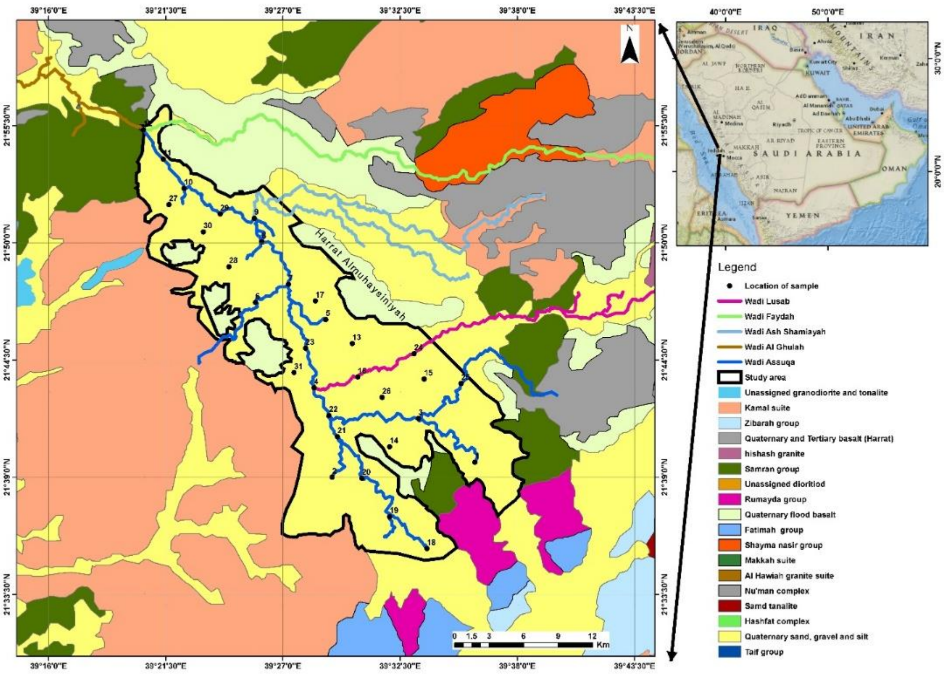

Fig. 1: Digital geological map of the study area (Moore and Al-Rehaili, 1989)

3. Methodology

System analysis of the processing of this research was illustrated in Fig. 2. For sampling purposes, 31 locations were selected based on the geology, geomorphology, and drainage pattern of Wadi As Suqah (Fig. 1). GIS was used to assess the locations based on the Landsat image and geological map. Disturbed sediment samples were collected from the tributaries' confluences using a shovel and then protected in sealed plastic bags.

Based on the Unified Soil Classification System (ASTM, 2017), a laboratory screen analysis was performed to determine the percentage of each soil fraction. Arc GIS v10.4.1 software was used to generate contour maps of various types of soil fractions. Statistical analysis such as correlation and hypothesis testing was used to correlate the similarity between different sizes of grains. Finally, Microsoft Excel v. 16 was also used for plotting and mathematical modeling. Compared to previous studies, this sophisticated approach is adapted for the first time on Wadi As Suqah. Fig. 2 shows the graphical workflow of the study.

With the help of the following formula below, the Pearson product-moment correlation coefficient (r) (Bailey, 2005), which ranges from-1 to+1, is utilized to determine the correlation between the grain size of gravel, sand, and fine sediment deposited:

$$r = \frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{[n(\sum x^2)-(\sum x)^2][n(\sum y^2-(\sum y)^2]}}$$

where, x and y are the two variables and n is the number of data pairs (Bailey, 2005).

4. Hypothesis testing

The null hypothesis test determines the significance of the correlations after deducing the correlation coefficients.

The A null hypothesis Ho: ρ=0 and alternative hypotheses, Ha: ρ≠0, are used, where ρ is the population correlation. Based on the number of samples and equality of claim, a t-test with two tails is taken into consideration (Bluman, 2009) as:

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$$

The P-value (probability value) approach is used to examine the significance of r at a significant level (α) of 5%. The level of 5 % was chosen for greater safety in making the decision (confidence level 95 %). Using Microsoft Excel v. 16, the TDIST function is used to determine the P-value as follows:

$$TDIST\ (x, deg\_freedom, tails)$$

where, x is the numeric value used to assess the distribution, Deg freedom is the number of degrees of freedom, and tails are the number of distribution tails to return. If the P-value≤α, the null hypothesis should be statistically rejected at the 95% confidence level (i.e., accept the alternative hypothesis).

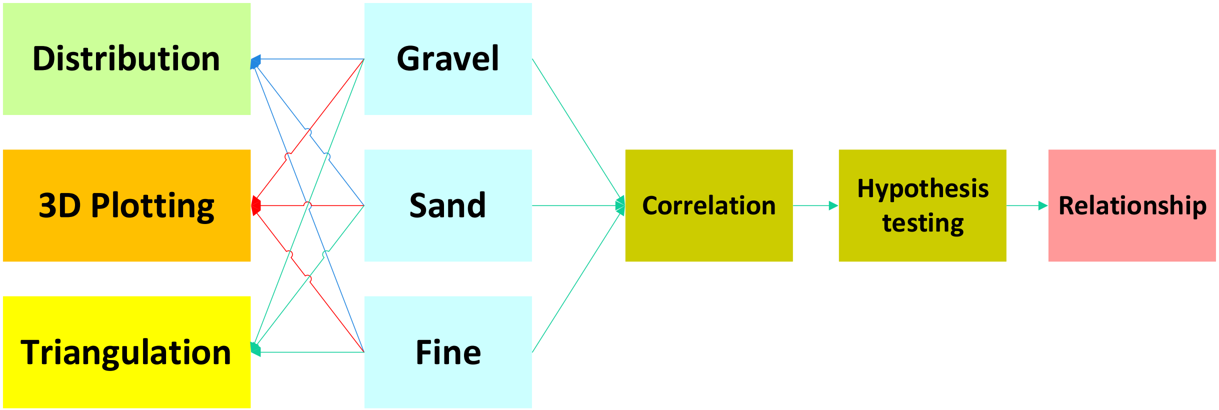

Fig. 2: Graphical workflow of the study

5. Results

According to the unified soil classification system, the gravel, sand, and fine percentage were deduced and tabulated in Table 1. It shows the grain size percentage of gravel, sand, and silt at different stations on the surface of Wadi As Suqah.

Depending on the available data and the above calculation methods, Table 2 presents the results of the significant and insignificant correlations between the various fractions.

6. Grain size distribution

For assessment and evaluation purposes, the variation of each fraction percentage was traced using the contour map technique (Figs. 3, 4, and 5).

Table1: The coordination of soil sampling and grain size content %

Station No.	station symbol	Latitude E	Longitude N	Gravel %	Sand %	Fine %
1	S1	21 39 42	39 36 00	3.5	92.2	4.3
2	S2	21 39 0.002	39 29 18.001	1.2	90.5	8.1
3	S3	21 41 45	39 33 21	0.3	97.4	2.3
4	S4	21 43 12	39 28 27	0.5	98	1.2
5	S5	21 46 24.002	39 29 0.001	18.2	63	18.8
6	S6	21 47 12	39 25 42	0	97.5	2.5
7	S7	21 48 3	39 27 15	14.8	84.1	1.1
8	S8	21 50 3.002	39 26 0.001	1.5	76.2	22.3
9	S9	21 51 9.002	39 25 39.001	0	60.9	39.1
10	S10	21 52 31	39 22 22	0.2	83.7	16.1
11	S11	21 53 55.67	39 21 22.33	0	59	41
12	S12	21 55 18.002	39 20 27.001	7.6	91.6	0.8
13	S13	21 45 1	39 30 16	1.5	85	13.5
14	S14	21 40 25.89	39 31 59.71	1.3	92.1	6.6
15	S15	21 43 36.40	39 33 36.98	1	67	32
16	S16	21 43 42	39 30 30	2.2	79.8	18
17	S17	21 47 16.45	39 28 31.1	17.9	67.7	12.5
18	S18	21 35 39	39 33 45	1.9	97.2	0.9
19	S19	21 37 9.0	39 32 00	1.8	94.5	3.7
20	S20	21 38 57	39 30 42.001	2.4	97.4	0.2
21	S21	21 40 54	39 29 33	0	90	10
22	S22	21 41 54	39 29 09	9.1	89.3	1.6
23	S23	21 44 59	39 28 17	0	78.1	21.9
24	S24	21 44 48.002	39 33 9.001	0.5	91.8	7.7
25	S25	21 43 24	39 38 21	3.9	88.4	7.7
26	S26	21 42 44.921	39 31 38.703	1.9	88.8	9.3
27	S27	21 51 47.46	39 21 38.38	0.3	95.7	4
28	S28	21 48 52.717	39 24 27.996	0.57	87.9	11.5
29	S29	21 51 21.002	39 24 3.001	0	86.78	13.21
30	S30	21 50 30.79	39 23 15.57	3.5	80	16.5
31	S31	21 43 54	39 27 31	0	86.7	13.3
Mean				3.2	85.1	11.7
Range				18.2	39	40.8
Standard Deviation				5.08	11.3	10.8

Table 2: Significant and insignificant correlations between gravel, sand, and fine grains

size name	r	t	p-value	0.05	Sig/Insig
fine/sand	-0.89	10.38	0.009	< 0.05	Significant
gravel/sand	-0.32	1.83	0.209	>0.05	Insignificant
gravel/fine	-0.15	0.82	0.501	>0.05	Insignificant

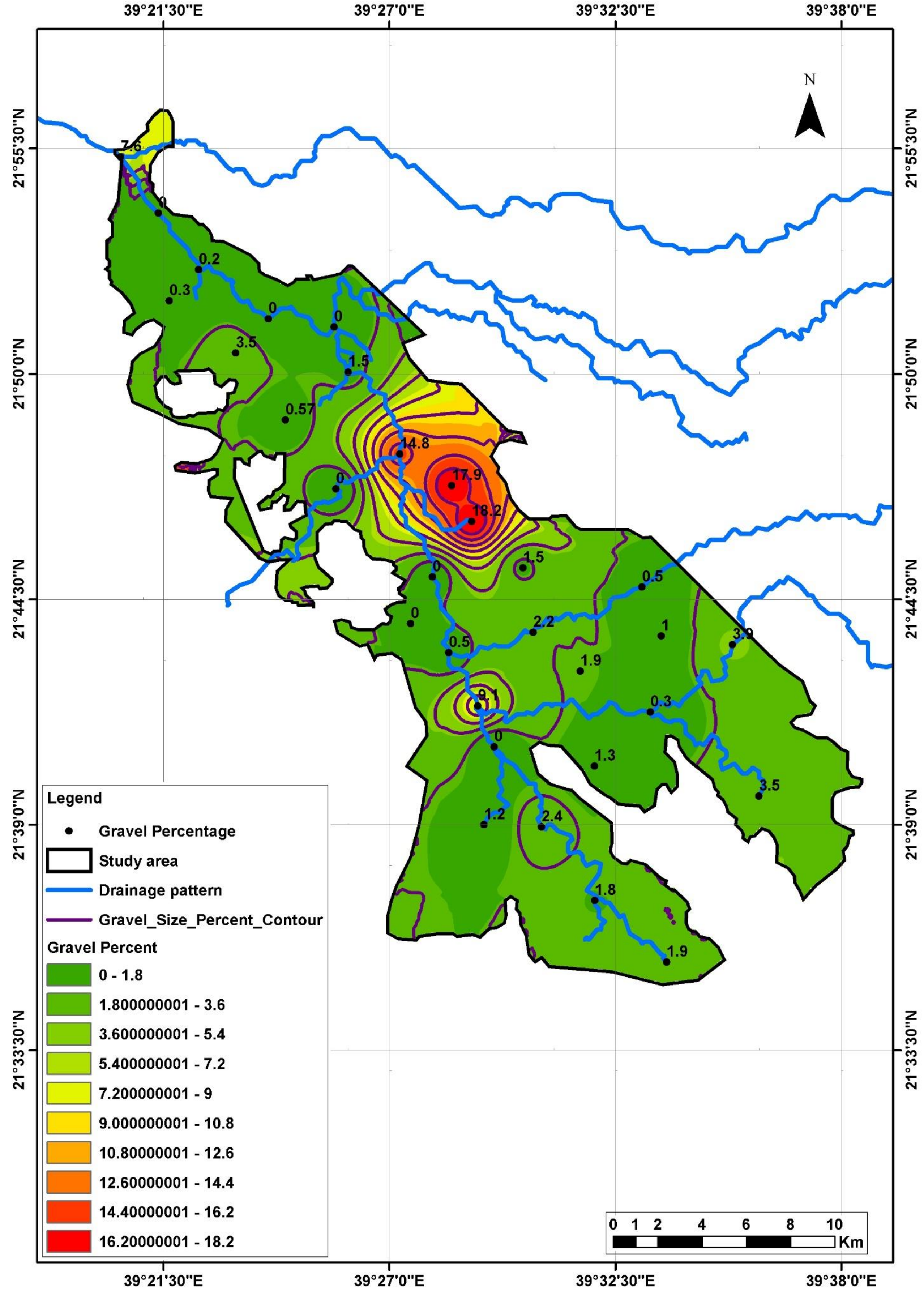

Fig. 3: Distribution of the gravel grain size of Wadi As Suqah

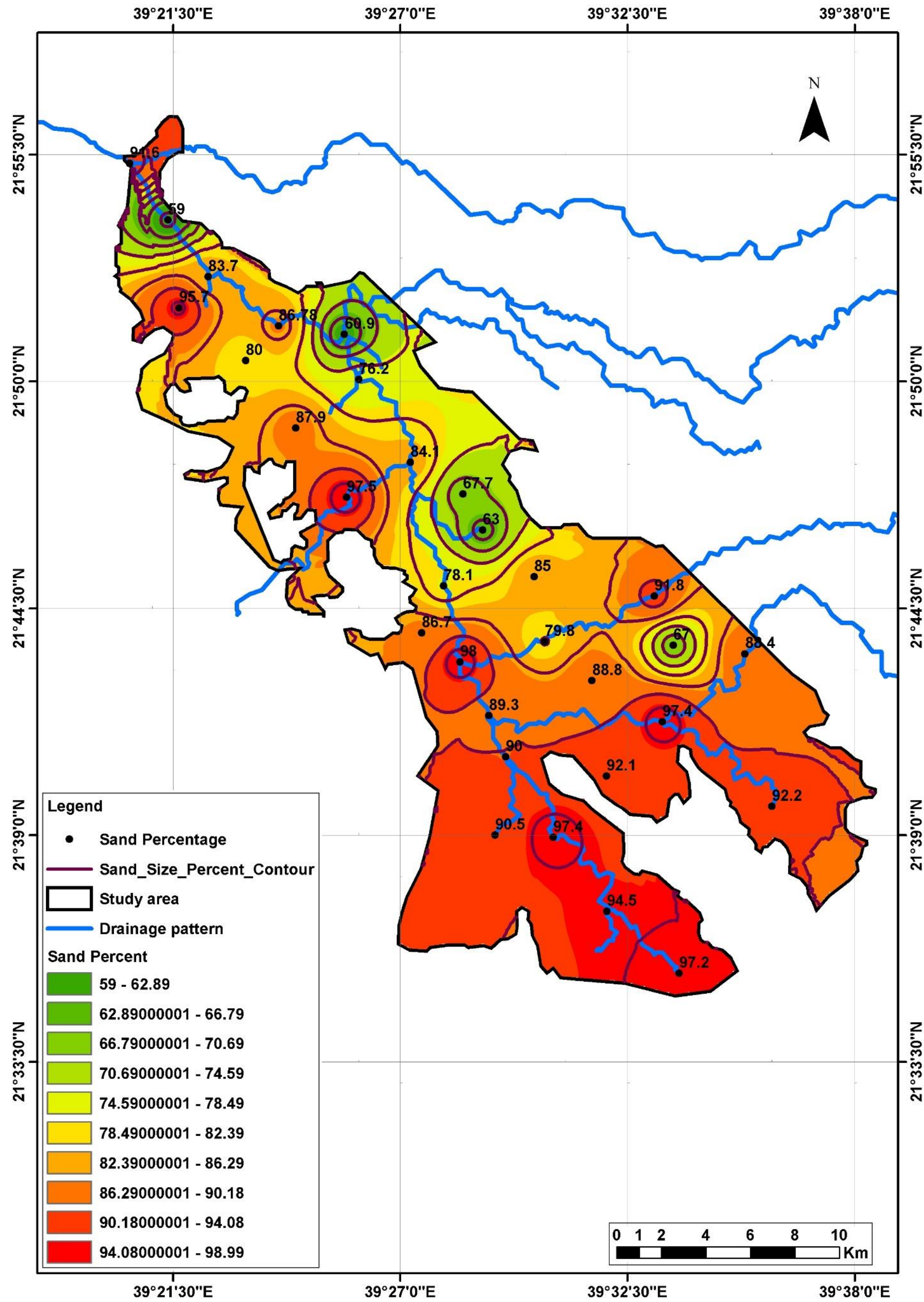

Fig. 4: Distribution of the sand grain size of Wadi As Suqah

18.2% of the gravel content is found in the Middle East of Wadi As Suqah behind Harrat Almuhaysiniyah in the area between Wadi Al-Lasab and Wadi Al-Shamiya.

The amount of gravel constantly varies from the southeast to the northwest. It begins in the first fifth of the Wadi with a relatively high amount of gravel ranging from 1.8% to 3.9%. Then, it decreases during the second fifth barely reaching 1.3%. Finally, except for the confluence with wadi Faydah, the downstream content of gravel went down to 1.3%. This change may indicate repeated sedimentation cycles over time.

In an inverse relationship between the amount of sand and fine, the northeast side of the Wadi has plenty of fines and some sand. The fine amount has reached 41%, while sand is 59%. Meanwhile, the southwest part has little fine and a lot of sand with percentages ranging from 78.1 to 98 while fine content ranges from 2 to 20%. These modifications indicate the impact of the Wadi al-Lasab and Wadi al-Shamiya deposits on Wadi As Suqah. The largest granular size is located upstream of these two wadis and the smallest downstream. These changes can be attributed to geomorphology drainage patterns, and the red sea paralleled structural faults.

7. Engineering geological zoning

According to the geostatistical analysis of Wadi As Suqah, the content percentage of gravel, sand, and fine are 3.2, 85.1, and 11.7%, while the standard deviation is 5.08, 11.3, and 10.8. Therefore, based on the similarity of the fraction content at a different station, the sediments of Wadi As Suqah were classified into four zones (Figs. 6 and 7).

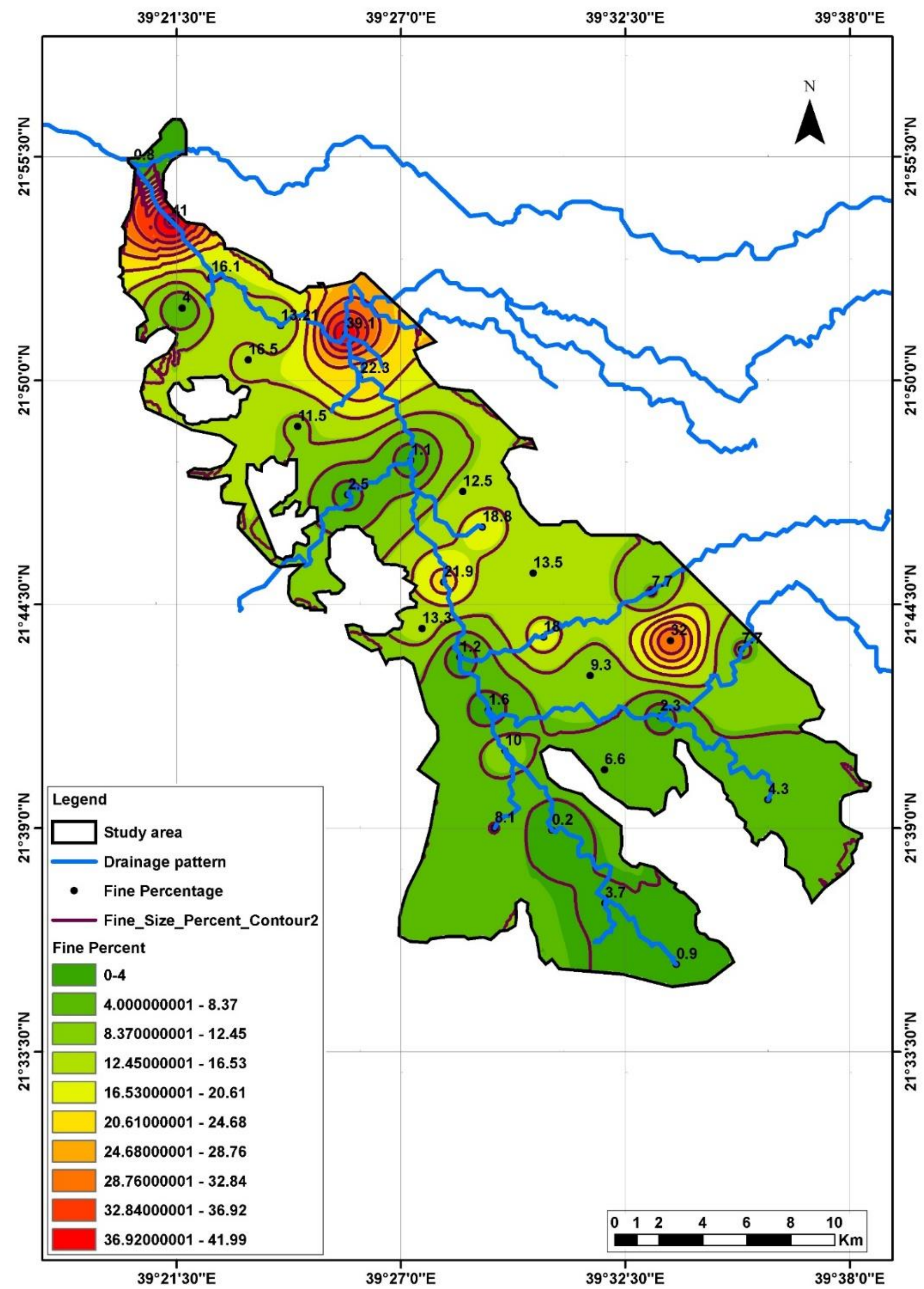

Fig. 5: Distribution of the fine grain size of Wadi As Suqah

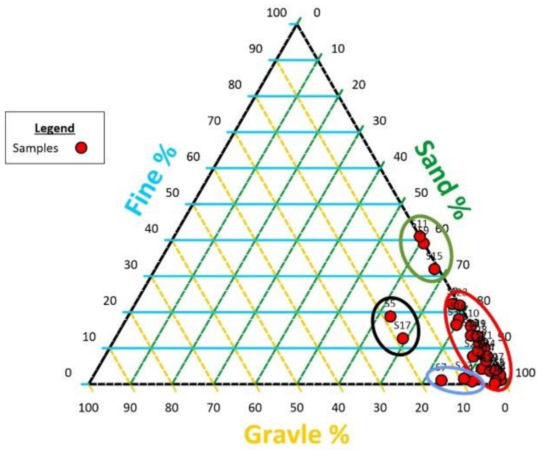

Fig. 6: Triangulation graph shows four groups (red, blue, green, and black) of gravel, sand, and fine content

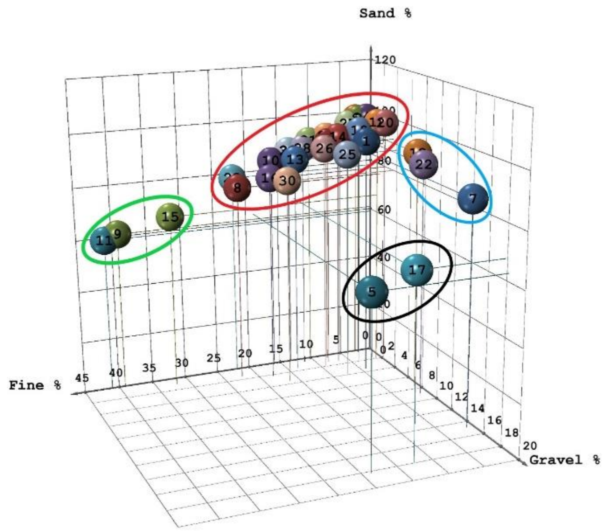

Fig. 7: 3D clustering shows four groups of soil sediments in Wadi As Suqah

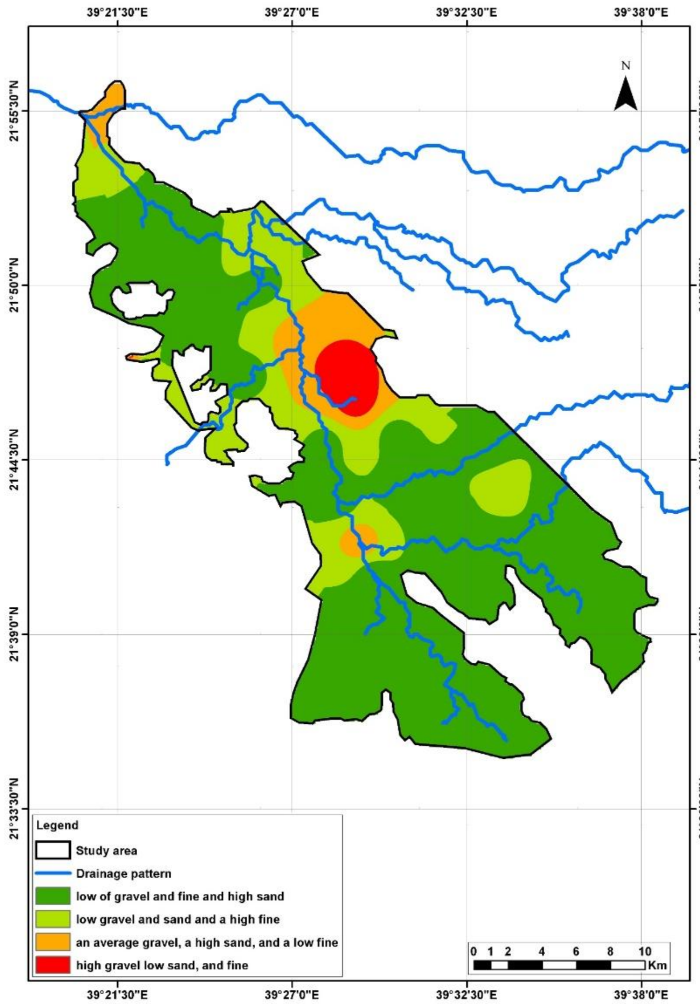

Fig. 8: Engineering geological map of different types of sediments at Wadi As Suqah

The first zone, which consists of 23 stations, contains low gravel content and fine and high content of sand. The second zone has a low gravel and sand content and a high fine content. The third zone contains an average gravel content, a high sand content, and a low fine material content. Finally, the fourth zone contains high gravel, low sand, and fine content. Based on this philosophy, a geologic engineering map was produced to show the distribution of each zone throughout Wadi As Suqah (Fig. 8). The description of the different grain size content of Wadi As Suqah is shown in Table 3.

8. Correlation and relationship

Depending on the hypothesis testing, only sand and fine grains show a significant correlation. Consequently, a plot of content percentage for both was shown in Fig. 9 to show their relationship. Two linear mathematical models can be established with R^2>0.93. The major one, which covers 90% of Wadi As Suqah, is $y = -1.02\,x + 100.5$, while the minor is $y = -0.61\,x + 55.6$ where x represents the sand percentage and y is the fine percentage. Fig. 10 shows the map of both models.

Table 3: Categories of surficial sediments of Wadi As Suqah (H: High, M: Medium L: Low)

Categories	Total content %	Gravel%	Sand%	Fine%
1	H	L	H	L
2	M	L	L	H
3	M	M	H	L
4	L	H	L	L

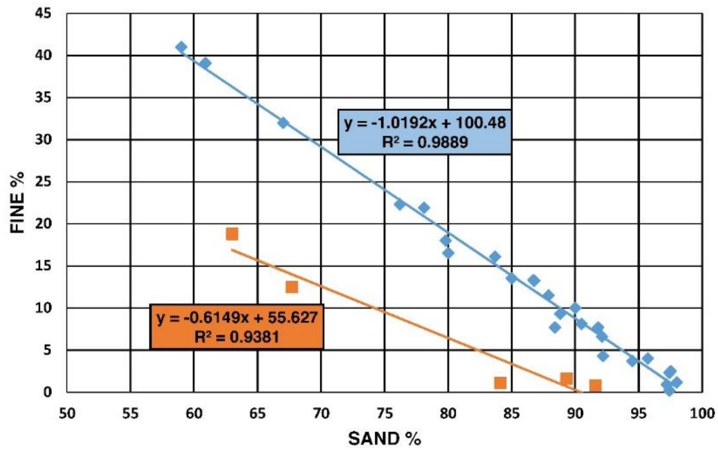

Fig. 9: Relationships between fine and sand content %

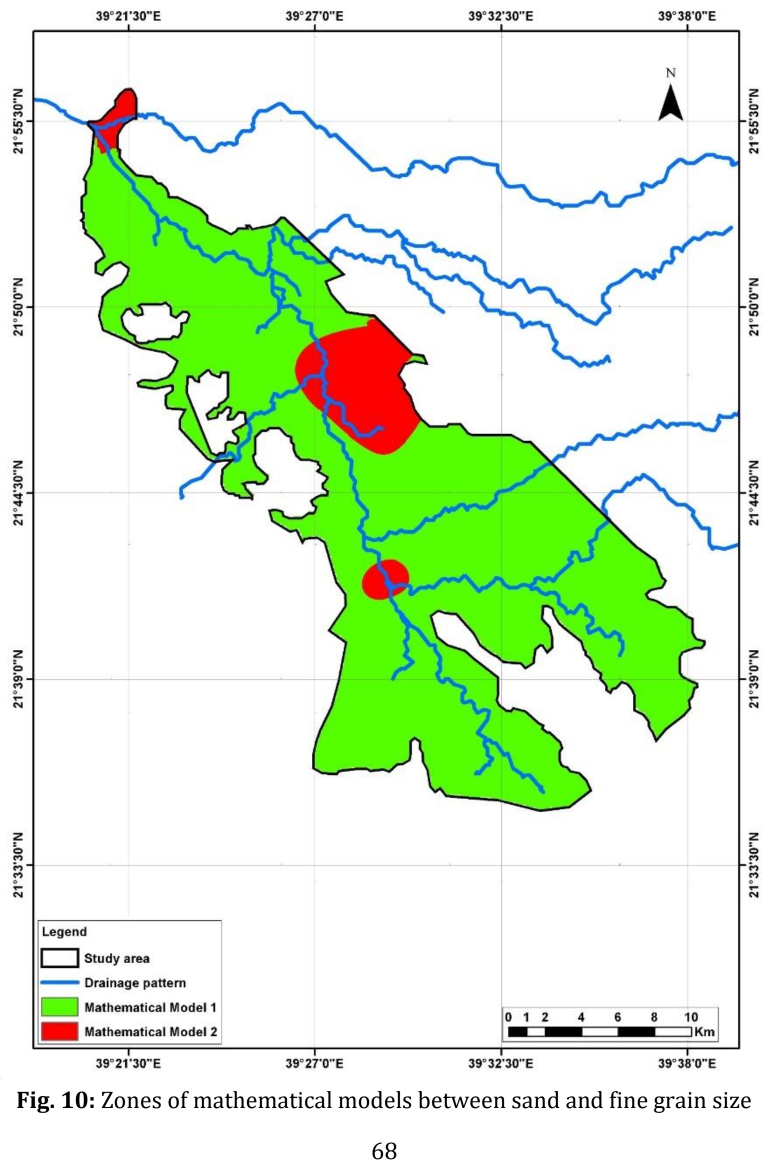

Fig. 10: Zones of mathematical models between sand and fine grain size

9. Conclusion

Based on the results analyzed and the interpretation of this study, the following conclusions were reached:

- According to the unified soil classification system, the surface of Wadi As Suqah includes 3.3% gravel, 85.1% sand, and 11.6% fine grains.
- From southwest to northeast, Sand distribution decreased from 97 % to 60%, fine grains size increased from 0.2% to 41%, while gravel size concentrated in the middle east with 18%.
- Wadi As Suqah consists of four engineering geological zones of grain sizes. The 1st zone contains a low gravel content with a high fine and sand content. The 2nd zone consists of low in gravel and sand and high in fine. The 3rd zone has a moderate gravel content, high sand content, and low fine matter content. Finally, the 4th zone includes high gravel, low sand, and fine content.
- A significant negative correlation between sand and fine grain size with a major linear mathematical model of $y = -1.02\,x + 100.5$, where x is sand content % and y fine content %.

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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