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Effects of Sand Quality on Compressive Strength of Concrete: A Case of Nairobi County and Its Environs, Kenya

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Abstract

Failure of concrete structures leading to collapse of buildings has initiated various researches on the quality of construction materials. Collapse of buildings resulting to injuries, loss of lives and investments has been largely attributed to use of poor quality concrete ingredients. Information on the effect of silt and clay content and organic impurities present in building sand being supplied in Nairobi County and its environs as well as their effect to the compressive strength of concrete was lacking. The objective of this research was to establish level of silt, clay and organic impurities present in building sand and its effect on compressive strength of concrete. This paper presents the findings on the quality of building sand as sourced from eight supply points in Nairobi County and its environs and the effects of these sand impurities to the compressive strength of concrete. 27 sand samples were tested for silt and clay contents and organic impurities in accordance with BS 882 and ASTM C40 respectively after which 13 sand samples with varying level of impurities were selected for casting of concrete cubes. 150 mm × 150 mm × 150 mm concrete cubes were cast using concrete mix of 1:1.5:3:0.57 (cement:sand:coarse aggregates:water) and were tested for compressive strength at the age of 7, 14 and 28 days. The investigation used cement, coarse aggregates (crushed stones) and water of similar characteristics while sand used had varying levels of impurities and particle shapes and texture. The results of the investigations showed that 86.2% of the sand samples tested exceeded the allowable limit of silt and clay content while 77% exceeded the organic content limit. The level of silt and clay content ranged from 42% to 3.3% for while organic impurities ranged from 0.029 to 0.738 photometric ohms for the unwashed sand samples. With regard to compressive strength, 38% of the concrete cubes made from sand with varying sand impurities failed to meet the design strength of 25 Mpa at the age of 28 days. A combined regression equation of $Fcu28 = -23.20SCI - 2.416ORG + 25.57$ with R^2 = 0.444

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was generated predicting compressive strength varying levels of silt and clay impurities (SCI), and organic impurities (ORG) in sand. This implies that 44% of concrete's compressive strength is contributed by combination of silt and clay content and organic impurities in sand. Other factors such as particle shapes, texture, workability and mode of sand formation also play a key role in determination of concrete strength. It is concluded that sand found in Nairobi County and its environs contain silt and clay content and organic impurities that exceed the allowable limits and these impurities result in significant reduction in concrete's compressive strength. It is recommended that the concrete design mix should always consider the strength reduction due to presence of these impurities to ensure that target strength of the resultant concrete is achieved. Formulation of policies governing monitoring of quality of building sand in Kenya and other developed countries is recommended.

Keywords

Sand Quality, Silt and Clay Impurities, Organic Impurities, Concrete Cube Compressive Strength, Buildings Collapse, Buildings Failure

1. Introduction

Quality of constituent materials used in the preparation of concrete plays a paramount role in the development of both physical and strength properties of the resultant concrete. Water, cement, fine aggregates, coarse aggregates and any admixtures used should be free from harmful impurities that negatively impact on the properties of hardened concrete. Sand is one of the normal natural fine aggregates used in concrete production [1]. Past researches identify the major causes of buildings failure as dependent on the quality of building materials used (sand, coarse aggregates, steel reinforcement, water), workmanship employed in the concrete mix proportioning and construction methodology, defective designs and non-compliance with specifications or standards [2]-[7]. This investigation focuses on the quality of building sand in terms of having the silt and clay content and organic impurities within the allowable limit as set out in British Standard (BS) 882.

Quality assurance of building materials is very essential in order to build strong, durable and cost effective structures [8]. When construction is planned, building materials should be selected to fulfill the functions expected from them. In Kenya over 14 buildings have been reported to collapse in the last 10 years leading to deaths and injuries (see Appendix 1) and various cause of building failure have been suggested. Use of poor quality construction materials (such as quality of sand, aggregates or water) result in poor quality structures and may cause structures to fail leading to injuries, deaths and loss of investment for developers. Impurities in building sands contribute to reduced compressive strength. Olanitori [9] asserts that the higher the percentage of clay and silt content in sand used in concrete production, the lower the compressive strength of the hardened concrete. Although many studies mentioned above have shown that use of poor quality materials is one of the major contributing factors to collapse of buildings, testing these materials has not been carried out to examine the impact of impurities in building sands to the overall performance of concrete. In addition, where tests have been carried out [10], testing of both clayey, silts and organic impurities has not been carried out to determine their combined effect on the concrete strength. To prevent buildings failure, careful selection of construction materials including building sands is paramount to ensure they meet the set construction standards. Impurities in sand impact negatively on compressive strength as well as bond strength between steel reinforcement and concrete and may cause buildings failure. BS 882 [11] specifies the tests for suitable aggregates.

The Nigerian Standard Organization specifies the maximum quantity of silt in sand as 8% beyond which sand is regarded as unsuitable for construction work [10]. American Society for Testing and Materials (ASTM) C 117 [12] and Hong Kong [13] construction standards give an allowable limit of 10% for silt and clay content in sand. On the other hand BS 882 states that the percentage of clay and fine silts must not exceed 4% by weight for sand for use in concrete production [14]. Fine aggregates containing more than the allowable percentages of silt are required to be washed so as to bring the silt content within allowable limits. As a thumb rule, the total amount of deleterious materials in a given aggregate should not exceed 5% [15]. The methods of determining the content of these deleterious materials are prescribed by IS 383 [16], BS 882 [11], ASTM C 117 [12] and [17]. These include determination of contents organic impurities, clay, or any deleterious material or excessive fillers of sizes smaller than No. 100 sieve. This research also seeks to determine the level of silt and clay content and organic impurities present in building sand being supplied in Nairobi County and its environs and also the effect of these impurities to the compressive strength of concrete. It further seeks to establish the minimum allowable limits of silt and clay and organic impurities for concrete production based on the tested samples.

2. Materials and Methods

2.1. Materials

The research employed laboratory experimental methods. Sand samples were collected from eight main sand supply points in Nairobi City County and its environs namely Njiru, Mlolongo, Kitengela, Kawangare, Dagoretti Corner, Kariobangi, Kiambu and Thika in Kenya as shown in **Figure 1**.

Sand samples were labeled based on their point collection where NR , ML, KT, KW, DC, KB, KBU and TK was used to represent samples sourced from Njiru, Mlolongo, Kitengela, Kawangare, Dagoretti Corner, Kariobangi, Kiambu and Thika respectively. A digit number was further given to represent the sample number as collected from each supply point e.g. NR1, NR1, NR3 was used to label Njiru sample 1, Njiru sample 2 and Njiru sample 3 respectively for sand samples sourced from Njiru area. Two sand samples CL1 and CL2 were washed and used as control samples.

From each supply point, 50 kg the selected sand samples were procured for grading and testing. Course aggregates from crushed stones, ordinary Portland cement grade 32.5 and 12 mm diameter twisted steel reinforcement bars were sourced from local manufacturers in Kenya. Clean portable water from the University (JKUAT, Kenya) was used.

2.2. Methods

Sieve analysis was carried out on the sand samples to determine their degrees of fineness (see **Figure 2**). Percentages of sand passing and retained was analyzed and grading curved plotted for comparison. Control sand sample was prepared by thoroughly washing river sand with clean water to remove silt and clay and organic impurities present and dried. Physical examination of sand particle shapes and sizes was done as well as determination of specific gravity of sand using pycnometer glass vessel as detailed in the IS standard [16] equivalent to ASTM D854 [18]. Sand samples were further tested using Laser Diffraction and Particle Size Analysis (LDPSA) and Total X-ray fluorescence (TXRF) methods to determine the constituent chemical elements and results are shown in Appendix 2. From the preliminary test results on sand impurities found in 27 sand samples, thirteen sand samples were carefully selected for preparation of concrete cube for compressive strength testing in a bid ensure fair distribution and representativeness of all sand sample categories. **Figure 2** and **Figure 3** below show part of the organic impurities, and silt and clay content testing processes.

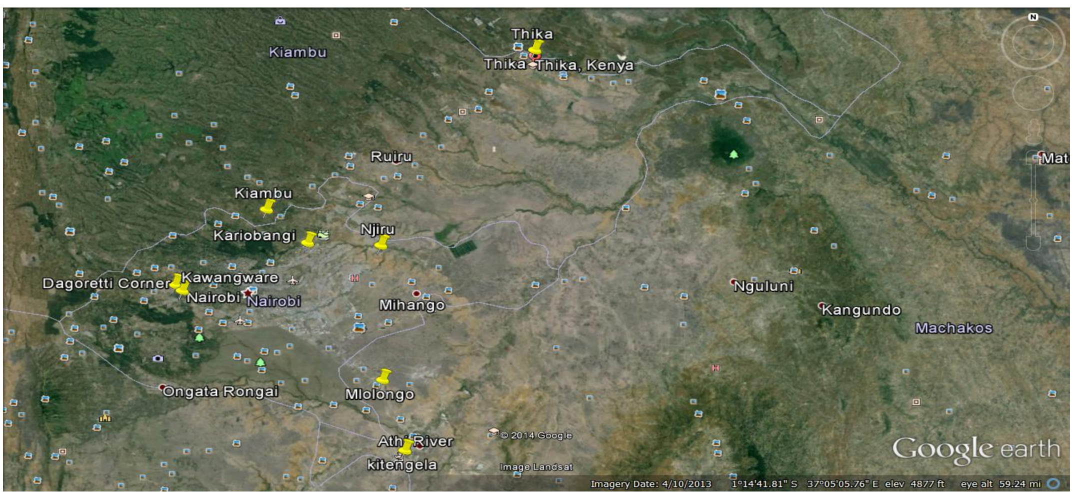

Figure 1. Main sand supply points in Nairobi City County and its environs (source: google earth, January 2014).

Figure 2. Organic impurities testing.

Figure 3. Silt and clay content testing.

Concrete mix ratio of 1:1.5:3:0.57 (cement:sand:coarse aggregates:water) as it is used for most low rise structural buildings was designed for an expected compressive strength of 25 MPa at 28 days using 20 mm maximum aggregates size and ordinary Portland cement. Coarse aggregates from crushed stones were subjected to sieve analysis to achieve a ratio of 1:2 for 10 mm and 20 mm respectively for use in all concrete castings.

Slump testing was done on fresh concrete (see **Figure 4**). 150 mm concrete cubes were prepared, compacted (see **Figure 5**), de-moulded 24 hours after casting (see **Figure 6**) and cured in a water tank at 200˚C ± 20˚C for 7 days, 14 days and 28 days. Compressive strength testing of the concrete cubes was carried out in accordance with ASTM C39-90 [19] (see **Figure 7**).

3. Results and Discussion

3.1. Texture and Particle Shape Results

Twenty six sand samples were subjected to texture and shape examination. 52% of the tested sand samples had rough texture compared to 26% that portrayed smooth and fine texture and 22% with rough and fine texture (see **Figure 8(a)**). 85% of the tested samples were observed to have irregular shaped particles while the rest had rounded shaped particles (see **Figure 8(b)**). Particles with rough and angular surfaces bind more securely with cement paste and course aggregates compared to the smooth and round shaped particles. Reasonable effect on compressive strength is realized when the slump is widely varied. Angular particles are known to require more water to achieve similar workability compared with the smooth particles.

Irregular and angular sand particles are common in river sands as a result of wave action and attrition forces in water. On the other hand, rounded particles are found in sand pits found on land where sand is mined.

Figure 4. Slump testing.

Figure 5. Compaction of fresh concrete.

Figure 6. De-moulding of concrete cubes.

Figure 7. Compressive strength testing.

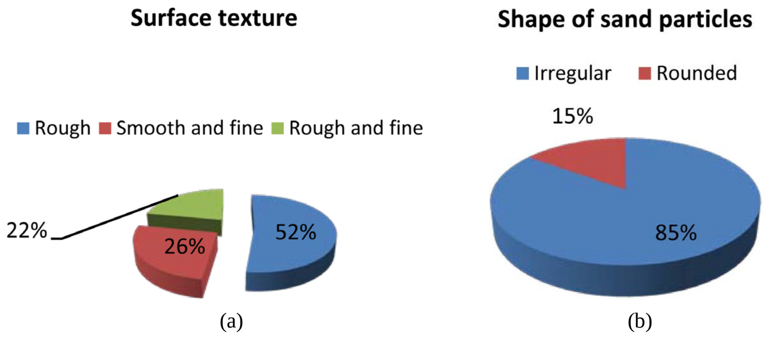

Figure 8. Texture and shape of sand particles.

3.2. Fineness of Sand

Sand samples were graded using the IS sieves [16] and were categorised into zones as shown in **Table 1**, **Table 2** and **Figure 9**.

Majority of sand samples (67%) were within Zone II of geological grading implying normal sand. A significant 7% of the tested samples comprised of very fine sand. Such fine grading requires proper mix design proportions to ensure that the quality of resulting concrete is not compromised. Sieve size 600 microns was used to determine degree of fineness in sands and soils.

Results indicate that 26% (7 out of 27) of the samples had over 60% of the samples passing sieve size 600 microns (see **Table 2** and **Figure 10**). This implies that a significant 84% comprised of fine sand samples. Comparatively, 66% of the tested sand samples had over 50% of the samples passing the same sieve.

3.3. Silt and Clay Content in Sand

Based on the 27 sand samples tested, the maximum silt and clay content was 42% for NR1 sample compared with the minimum 3.3% for TK1 sand sample (see **Figure 11**). CL1 (clean sample 1) and CL2 (clean sample 2) were clean control river sand samples that were washed using clean water and sun dried. They had 0.7% and 0.3% silt and clay content after washing. CL2 was used in casting of concrete cubes because it had the lowest level of silt and clay impurities, and organic impurities hence selected to be the control sample.

BS 882 recommends that no more than a maximum of 4% silt and clay content for fines aggregates be used in

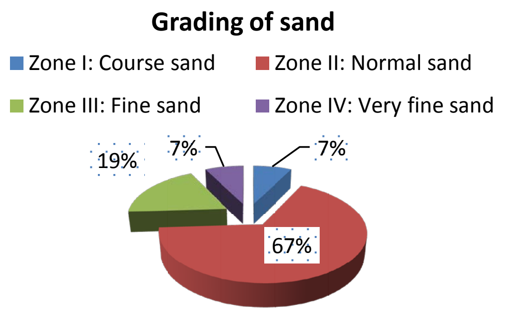

Figure 9. Zoning of sand samples based on fineness.

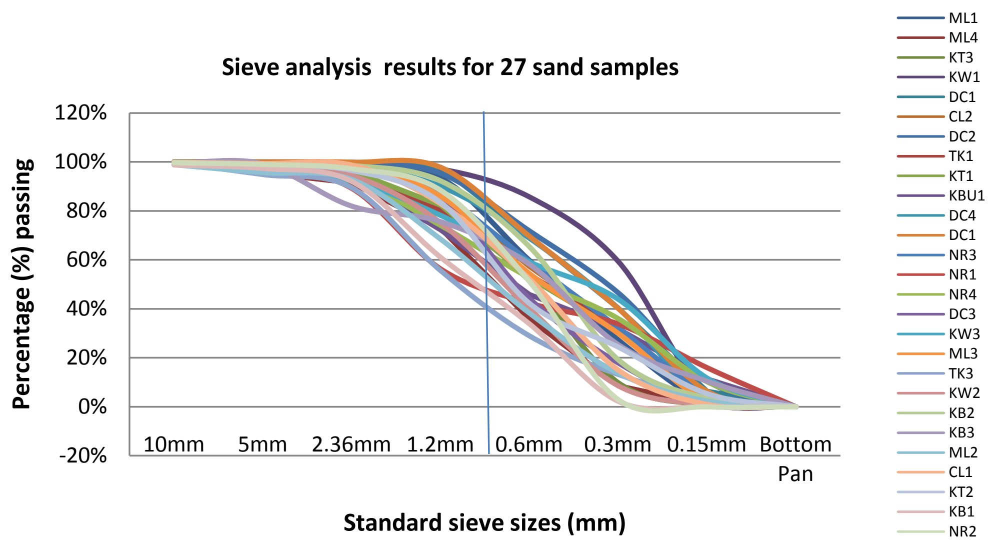

Figure 10. Sieve analysis results.

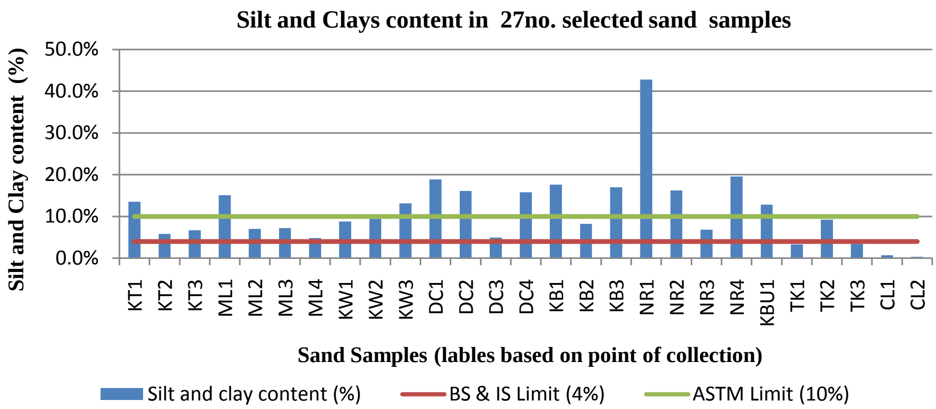

Figure 11. Silt and clay content in sand.

Table 1. Summary of sieve analysis and geological grading zones classification.

Grading zones	Frequency (no)	Dominance (%)	Description
Zone I	2	7%	Course sand
Zone II	18	67%	Normal sand
Zone III	5	19%	Fine sand
Zone III	2	7%	Very fine sand

Table 2. Sieve analysis, degree of fineness and grading zone classification for 27 sand samples.

Sieve size / Sample No.	Percentage passing standard sieve sizes (%)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Sieve size	ML1	ML4	KT3	KW1	DC1	CL2	DC2	TK1	KT1	KBU1	DC4	DC1	NR3	NR1
10 mm	99	100	100	100	100	100	100	100	100	100	100	100	100	100
5 mm	98	96	96	100	100	100	100	97	99	99	100	100	99	98
2.36 mm	97	92	93	99	100	99	100	94	96	94	98	100	97	89
1.2 mm	93	73	81	97	98	87	95	81	82	72	90	98	88	56
0.6 mm	60	36	51	86	70	57	72	54	53	46	69	70	59	42
0.3 mm	27	9	10	59	40	32	47	32	31	32	40	40	32	34
0.15 mm	2	1	1	5	6	2	11	3	3	11	3	6	3	16
Bottom pan	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Degree of fineness (% passing 600 microns sieve)	60	36	51	86	70	57	72	54	53	46	69	70	59	42
Grading zone classification	III	II	II	IV	III	II	IV	II	II	II	III	III	II	II

Sieve size / Sample No.	Percentage passing standard sieve sizes (%)												
	15	16	17	18	19	20	21	22	23	24	25	26	27
	NR4	DC3	KW3	ML3	TK3	KW2	KB2	KB3	ML2	CL2	KT2	KB1	NR2
10 mm	100	100	100	100	100	99	100	100	99	100	99	99	100
5 mm	97	99	96	99	95	98	99	99	96	99	99	97	99
2.36 mm	93	98	92	98	89	94	99	82	93	99	97	92	97
1.2 mm	74	85	78	86	56	75	92	76	68	83	83	61	88
0.6 mm	53	44	59	54	29	40	65	58	38	52	42	34	51
0.3 mm	36	18	44	30	13	9	19	25	14	15	24	2	3
0.15 mm	10	1	12	3	3	1	3	10	2	1	5	0	0
Bottom pan	0	0	0	0	0	0	0	0	0	0	0	0	0
Percentage of fines (600 microns)	53	44	59	54	29	40	65	58	38	52	42	34	51
Grading zone classification	II	II	II	II	I	II	III	II	II	II	II	I	II

concrete production. Only four samples out of 27 samples met this limit, representing only 14.8%. An overwhelming 86.2% failed to meet the standard set in BS 882. Comparatively, the ASTM's allowable silt and clay content in sand used for concrete production is 10% by weight. 15 samples met this limit, implying a failure rate of 44.4% of the tested sand samples by ASTM's standard.

From **Figure 11**, the maximum silt and clay content registered from 27 samples was a significant 42%. This implies that for one tonne of sand, 420 kg is composed of silt and clay impurities. Therefore when such sand is bought for construction, value for money is not achieved since over half of the sand quantity comprises of silt and clay impurities.

3.4. Organic Impurities in Sand

With regard to testing for organic impurities in sand, the standard requires that the color of sodium hydroxide solution in sand should be lighter than the solution of sodium hydroxide mixed with tannic acid, both solutions having been preserved for 24 hours after mixing as detailed in ASTM C40 and IS standard [16]. Out of the 27 sand samples tested, only 6 samples indicated lighter color than the standard solution 24 hours after mixing. This indicates that 23% of the collected were within the organic content limit as set in ASTM C40, indicating a failure rate of 77%.

Further, color analysis was carried out using photometric equipment and results are shown in **Figure 12**. It was found that the maximum value of photometric resistance for clean sample was 0.205 ohms for CL1. CL2 recorded the lowest color resistance of 0.023 ohms indicating the lowest level of organic impurities. Consequently assuming 0.205 ohms for the washed sand sample to be the upper limit for organic impurities, only 13 samples indicated value of less than 0.205. This implies over 50% of the sand samples exceeded the maximum organic content for the washed control sample.

3.5. Combination of Silt and Clay Content and Organic Impurities for Selection of Test Samples

Based on the results for levels of impurities obtained for the 27 sand samples, 13 samples with varying level of impurities were selected for casting of concrete cubes for compressive strength testing. To ensure even distribution of sand samples of various levels of impurities in the final set of samples selected for casting, samples were categorized under classes of pre-set ranges of levels of impurities starting with the lowest intervals of 5%. Results of silt and clay content 1% - 5%, 5% - 10%, 10% - 15%, 15% - 20% and 20% - 50% while organic impurities were categorized into classes of 0.2 - 0.3, 0.3 - 0.4, 0.4 - 0.5, 0.5 - 0.6, 0.6 - 0.7, and 0.7 - 0.8 ohms. In the selection process for the final list of samples, a minimum of 30% of the samples falling in each class was chosen to ensure fair representation from each class for silt and clay content as well as organic impurities levels. Where 30% was not achieved, the process entailed replacement of the sand sample until this representation was achieved. Since the results obtained from 27 samples were within the range of above classes and due limitation of standard concrete casting molds, cost and time, 13 samples selected for casting of concrete are shown in **Figure 13**.

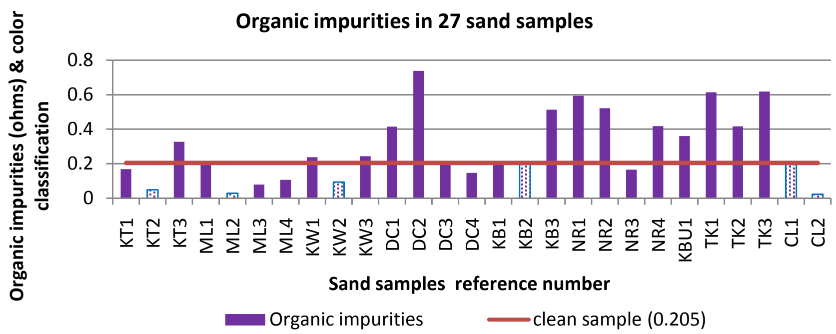

Figure 12. Organic impurities in 27 sand samples.

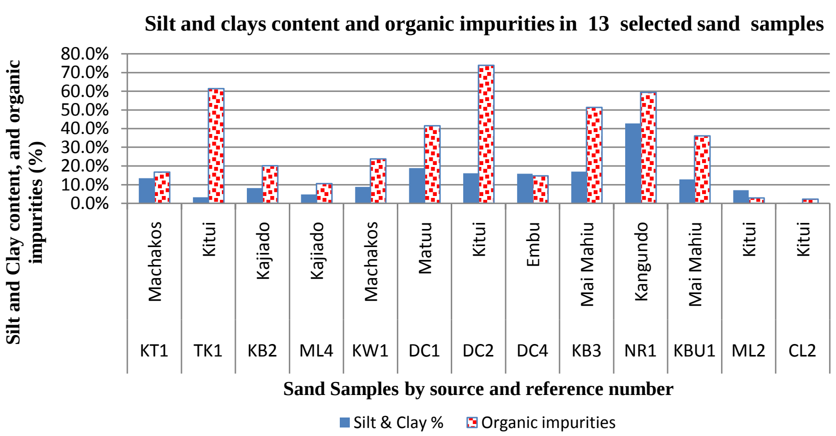

Figure 13. Organic impurities and silt and clay content in 13 selected sand samples.

The 13 sand samples selected for casting of concrete cubes were a good representative of the 27 samples collected.

3.6. Specific Gravity of Sand Samples

Sand samples were subjected to specific gravity tests as detailed in IS standard [16] equivalent to ASTM D854 [19] for aggregates less than 10mm diameter using the pycnometer glass vessel. Results showed that the average apparent specific gravity was 2.7 while the average water absorption of dry mass was 2.9. This compares well with the expected specific gravity values of 2.7 for sand used in concrete production, implying that the sand used in this research represent the commonly used normal sand used in concrete making. This indicates that the sand samples used were within the normal range for building sand. Bulk specific gravity is used for calculation of the volume occupied by the aggregate in various mixtures such as concrete. Apparent specific gravity pertains to the relative density of the sand making up the constituent particles not including the pore space within the particles that is accessible to water. Bulk density varied from 2.54 to 2.81 for TK2 and KT3 respectively. This explain why the slump observed and water absorption by pores was specific to a particular sand sample based on mode of sample formation e.g. river sand and pit sand.

3.7. Compressive Strength of Concrete for Various Levels of Silt, Clay and Organic Impurities

13 samples were selected for cube compressive strength testing according to ASTM C39-90 [20] and BS 1881 [18]. For each sample, a total of 9 cubes were cast and cured under water at room temperature. Three concrete cubes made from each sand sample were tested at the age of 7 days, 14 days and 28 days after casting using a universal testing machine. The average was obtained from 3 cubes tested and results are as shown in **Figure 14**. The expected compressive strength at day 7 (E7DS), day 14 (E14DS) and day 28 (E28DS) are also shown.

It is important to note that a uniform mix design used for most low rise structural buildings was adopted, that is 1:1.5:3:0.57 for cement:fine aggregates:coarse aggregates:water. For KBU1 sample, the slump was zero (too stiff, extremely low) hence water: cement ratio adjusted to 0.58 hence slump of 9 mm was obtained. KBU1 was made from volcanic pit sands and it was observed that it requires more water during mixing to achieve medium to low workability levels. It was noted that this sample requires more water to achieve normal and had irregular shaped and rough texture.

From the above results, three samples (that is NR1, ML4 and KB2) failed to meet the minimum strength expected at day 7, one sample (ML4) failed at day 14 and 5 samples (NR1, KW1, KT1, ML4, KB2) failed to meet the compressive strength expected at day 28. This represents 38% failure rate at 28 days. Since all the samples were subjected to similar casting and curing conditions, this failure is largely attributed to the presence of silt and clay content and organic impurities in sand and to some extent to particles shapes, sizes and texture. It was observed that all the samples that failed at day 7 and day 14 also failed at day 28. However not all samples that failed at day 28 had indicated failure at day 7 and day 14. These include KW1 and KT1 that had passed the

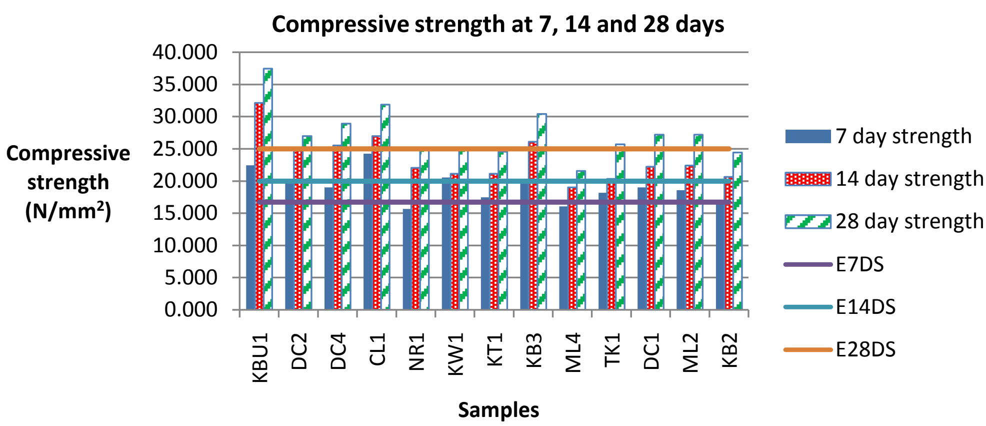

Figure 14. Compressive strength of concrete cubes at age of 7, 14 and 28 days.

strength requirement at day 7 and 14 but failed at day 28. This affirms the importance of concrete strength testing up to 28 days maturity.

Table 3 shows the characteristics of samples that failed. It is deduced that the lowest level of impurities is 4.8% while the lowest level for organic impurities was 0.106 ohms photometric color classification. It can be taken that any sample having of 4.8% silt and clay content and 0.106 ohms for organic impurities or more is likely to fail. Two (ML4 and NR1) of the five samples that failed on compressive strength testing had smooth particles implying that particles sizes play some role in concrete compressive strength. It is noted that 3 (KB2, KT1 and KW1) of the failed samples that portrayed rough and irregular particles had higher silt and clay content of more than 8%.

Smooth and round sand surfaces provide a weak interlocking bond between cement and course aggregates thus contributing to reduced compressive strength of concrete. Since 3 out of 5 samples that failed to meet the expected compressive strength at day 28 had rough texture and irregular shape particles, it implies that besides silt and clay and organic impurities in sand, particle sizes and shapes form a significant factor in determination of compressive strength of concrete.

3.8. A Case of Compressive Strength with Constant Workability

In order the assess the effect of workability on the compressive strength of concrete made from selected sand samples having varying level of silt and clay and inorganic impurities, 4 sand samples were cast while maintaining workability constant. A set of concrete cubes was cast while maintaining workability to be within Very Low (0 - 25 mm) category as shown by KBU1 (a), DC 2 (a), CL2 (a) and DC4 (a). A second set was made from the same sand samples was cast using a constant workability of Medium (50 - 100 mm) category as shown by KBU1 (b), DC 2 (b), CL2 (b) and DC4 (b). The results are presented in **Table 4** and **Figure 15**.

Table 3. Characteristics of samples that failed on compressive strength.

	Sample	Strength at 28 days (MPa)	Silt and clay content (%)	Organic impurities (photometric ohms)	Workability	Source of sand (as per suppliers)	Particle texture and shape
1	ML4	21.552	4.8	0.106	56 mm	Kajiado	Smooth & fine, Irregular
2	KB2	24.403	8.2	0.202	79 mm	Kajiado	Rough & fine, Irregular
3	KT1	24.537	13.5	0.168	93 mm	Machakos	Rough, Irregular
4	NR1	24.937	42.8	0.594	3 mm	Kangundo	Rough, Smooth
5	KW1	24.955	8.8	0.238	4 mm	Machakos	Rough & fine, Irregular

Table 4. Compressive strength for selected samples with constant workability classification.

	Sample	Silt and clay content (%)	Organic Impurities (ohms)	7 day strength (N/mm^2)	14 day strength (N/mm^2)	28 day strength (N/mm^2)	Slump (using cone)	Workability classification	Source
1a	KBU1	12.8	0.361	22.45	32.13	37.45	9 mm	Very low	Mai Mahiu
1b	KBU1	12.8	0.361	12.93	16.55	20.73	86 mm	Medium	Mai Mahiu
2a	DC2	16.1	0.738	19.98	25.05	26.98	11 mm	Very low	Kitui
2b	DC2	16.1	0.738	16.19	19.35	24.05	69 mm	Medium	Kitui
3a	CL2	0.3	0.023	24.23	26.95	31.86	13.5 mm	Very low	Kitui
3b	CL2	0.3	0.023	16.05	19.20	24.68	58 mm	Medium	Kitui
4a	DC4	15.8	0.147	19.02	25.52	28.93	10 mm	Very low	Embu
4b	DC4	15.8	0.147	12.40	16.20	19.62	65 mm	Medium	Embu

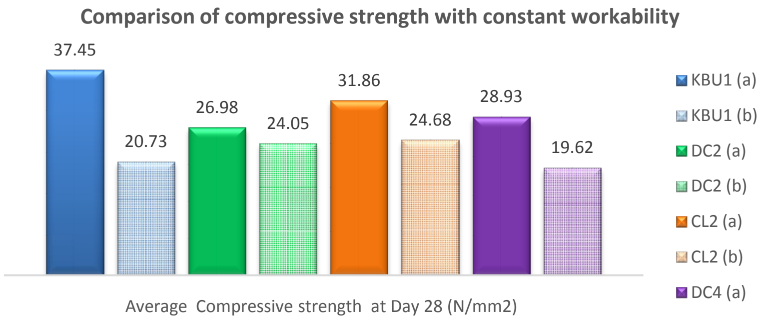

Figure 15. Compressive strength for samples with constant workability.

It is clear from the below results that workability plays significant role in determination of compressive strength of concrete. By varying slump from very low (0 - 25 mm) to medium (50 - 100 mm), it was observed that compressive strength reduced with a margin of between 17 N/mm^2 for KBU1 to 2 N/mm^2 for DC2.

At very low slump, KBU1 depicted the highest compressive strength of 37.45 N/mm^2 compared with DC2 that registered the lowest compressive strength of 20.73 N/mm^2. On the other hand, at medium slump CL2 registered the highest compressive strength while DC4 registered the lowest strength. Comparatively DC2 had the minimal strength effects of 2.9 N/mm^2 with changes in the slump level while KBU1 had the largest effect of 16.7 N/mm^2 on compressive strength with changes in slump level. This implies that DC2 is a better sand sample since significant savings can be made from reduction in the quantity of water used during casting without significant changes in compressive strength.

KBU1 had rough and irregular shaped particles while DC2 had smooth and sand rounded particles. DC4 had rough and fine particles that were irregular in shape while CL2 had irregular shaped rough particles. This implies that effect of workability on the compressive strength of concrete is more pronounced in rough and irregular shaped sand particles in comparison with rounded and smooth sand particles.

3.9. Analysis of the Correlation between Compressive Strength and Sand Impurities

In order to assess the relationship between compressive strength obtained from concrete made using sand with different levels of silt and clay content and organic impurities the compressive strength results were categories into 3 as shown in the **Table 5**. A constant water cement ratio of 0.57 was used. The samples were categorized based on similar or closely related characteristic of surface texture, particle shapes, slump level and degree of fineness obtained from percentage passing 600 microns sieve size.

The samples used for regression analysis were carefully selected to ensure that their properties are almost similar or as close as possible and that only silt and clay and organic impurities significantly varied all other factors being held constant. By use of 5 sand samples which had similar texture, particles shapes and closely linked grading curves as indicated is group (a) in the table above regression analysis was used to derive the relationship between compressive strength of concrete cubes with varying silt and clay content as illustrated in **Figure 16**.

A regression equation for predicting compressive strength of concrete made from sand containing varying level of silt and clay contents was found to be:

$$y = ax_1 + bx_2 + c \quad (1)$$

$$Fcu28 = -23.20SCI - 2.416ORG + 25.57 \quad \text{with } R^2 = 0.444 \quad (2)$$

where Fcu28 = cube compressive strength at day 28;

SCI = silt and clay content in sand;

ORG = Organic impurities content in sand.

The output from regression and correlation analysis showing the relationship between silt and clay content and organic impurities against compressive strength of concrete are shown in **Table 6** and **Table 7**.

From the R^2 value, it is deduced that the contribution of the silt and clay content and organic impurities to the overall compressive strength of concrete is a significant 44%. This implies that although there are other factors contributing to the compressive strength of concrete, presence of silt and clay content and organic impurities

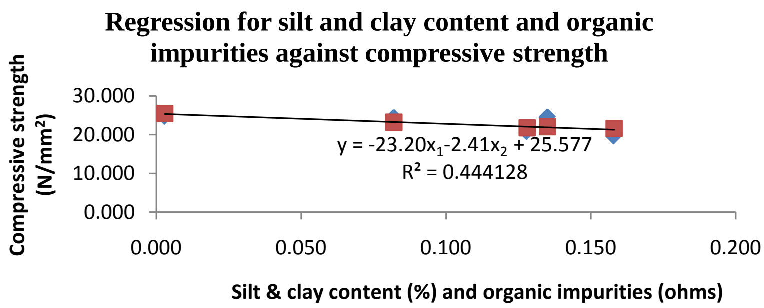

Figure 16. Regression analysis for compressive strength relationship.

Table 5. Categorization of compressive strength data for regression analysis.

	Sample	28 day strength (N/mm^2)	Silt and clay content (%) (*x*1)	Organic impurities (ohms) (*x*2)	Sand texture	Particles shape	Grading	Slump
		(a) Group of sand samples with rough surface texture, moderate grading & high workability						
1	KB2	24.403	0.082	0.202	Rough	Irregular	65%	79 mm
2	KT1	24.537	0.135	0.168	Rough	Irregular	53%	93 mm
3	KBU1	20.730	0.128	0.361	Rough	Irregular	46%	86 mm
4	CL2	24.680	0.003	0.023	Rough	Irregular	57%	58 mm
5	DC4	19.620	0.158	0.147	Rough	Irregular	69%	65 mm
		(b) Group of sand samples with rough surface texture, moderate grading & low workability						
6	KW1	24.955	0.088	0.238	Rough	Irregular	86%	4 mm
7	DC4	28.929	0.158	0.147	Rough	Irregular	69%	10 mm
8	CL2	31.858	0.003	0.023	Rough	Irregular	57%	13.5 mm
9	KBU1	37.455	0.128	0.361	Rough	Irregular	46%	9 mm
		(c) Group of sand samples with smooth surface texture, varied grading & varied workability						
10	DC2	26.979	0.161	0.738	Smooth	Rounded	72%	11 mm
11	KB3	30.393	0.17	0.513	Smooth	Rounded	58%	5 mm
12	DC1	27.188	0.189	0.415	Smooth	Rounded	70%	52 mm
13	NR1	24.937	0.428	0.594	Rough	Rounded	42%	3 mm

Note: Grading is measured in terms of percentage passing 600microns standard sieve.

Table 6. Regression analysis sand impurities and compressive strength.

Multiple R	0.666429		Coefficients	Standard error	t-statistic	P-value
R^2	0.444128	Intercept	25.577	2.530	10.111	0.010
Adjusted R^2	−0.11174	SCI (Variable 1)	−23.203	25.720	−0.902	0.462
Standard Error	2.556553	ORG (Variable 2)	−2.417	12.997	−0.186	0.870

Table 7. Correlation analysis between silt and clay content and organic impurities and compressive strength.

	y	x_1 (SCI)	x_2 (ORG)
y	1		
x_1 (SCI)	−0.65918	1	
x_2 (ORG)	−0.46683	0.587901	1

plays a major role. The other factors may include mode of sand formation and workability, workmanship, quality of course aggregates and quality of water among others. Therefore concrete designers must provide adequate factor of safety to guard against structural failure as a result these impurities in building sand. Frequent testing of sand for construction purposes is therefore highly recommended to ensure measures are put in place e.g. washing of sand in a bid to prevent collapse of buildings as a result of excessive levels of silt and clay content and organic impurities.

From **Table 7**, it is deduced that contribution of silt and clay content (SCI) toward the compressive strength of concrete is a significant 65%. Similarly the contribution of organic impurities (ORG) toward compressive strength of concrete is 46%.

It is observed that the contribution of silt and clay content towards compressive strength of concrete is more significant compared with the organic impurities.

From the figure above, it is clear that increase in silt and clay content and organic impurities significantly reduces the compressive strength of concrete. The 44% contribution represents a contribution of $11 N/mm^2$ for concrete with target strength of $25 N/mm^2$. Therefore present of these impurities cannot be ignored during concrete production process and they may lead to failure and collapse of structural buildings. Besides presence of silt and clay content and organic impurities having a significant contribution to buildings failure, other factors such as specific gravity, curing and workability, workmanship, adherence to structure designs, works supervision and quality of other concrete ingredients plays important role in buildings failure.

4. Conclusions and Recommendations

From the study, it is observed that building sand being supplied in Nairobi City County and its environs contained silt and clay contents, and organic impurities that exceeded the allowable limits. The level of silt and clay content ranged from 42% to 3.3% for while organic impurities ranged from 0.029 to 0.738 photometric ohms unwashed sand. An overwhelming 86.2% of the tested sand samples failed to meet silt and clay content limits set out in BS 882 while 44.4% exceeded the limit set out in ASTM limits. With regard to organic content, 77% of the sand samples studied exceeded the recommended organic content for concrete production by ASTM standard. A total of 38% of the concrete cubes made from sand with varying sand impurities failed to meet the design strength of 25 Mpa at age of 28 days. It observed that the allowable minimum level of silt and clay content and organic impurities in sand being supplied in Nairobi and its environs is 4.8% and 0.106 ohms respectively. Beyond these limits then the resultant concrete will fail to meet the expected strength at 28 days age. It is this concluded that the presence of impurities in sand significantly contributed to reduction in compressive strength of concrete strengths which may lead to collapse of buildings if not addressed in the concrete design mix.

Regression equation $\text{Fcu}28 = -23.20\text{SCI} - 2.416\text{ORG} + 25.57$ with $R^2 = 0.444$ was generated to predict the compressive strength of concrete with varying levels of silt and clay contents, and organic impurities respectively. It is noted that 44% of compressive strength is contributed by silt and clay content and organic impurities in sand used for concrete production. Since presence of these impurities significantly affect the compressive strength of concrete, they cannot be ignored hence the need to ensure sand free from these impurities is used during concrete production. This equation is applicable to concrete made using building sand with similar physical and chemical properties as the samples tested.

It was observed that 3, 1 and 5 samples failed on compressive strength at 7, 14 and 28 days. This study recommends monitoring of strength at 56 days and beyond to establish any trend beyond 28 day. Sand samples were sourced from supply points in Nairobi County and its environs. It is appreciated that some suppliers do adulterate sand by mixing it with soils for unjustified economic gains. This was evident during samples collection where it was observed that some suppliers received sand from different sources and mixed it up to dilute the negative color, texture and silt and clay content levels. This study recommends further study to establish the quality of sand collected directly from the source (river, pit or sea) in comparison to the quality of sand sourced at the supply points (market places) in order to establish the extent of adulteration within the supply chain.

In regard to construction management practices, construction professional are to enhance inspection of the quality of building materials to ensure that quality, cost, time and customer expectations for concrete structures is not compromised and to avoid the collapse of buildings as observed in Nairobi in the recent years. It is noted that investors lose up to 40% of their investment through purchase of sand with impurities. Kenya and other developing countries need to formulate policies to govern allowable limits of silt and clay and organic impurities in sand and ensure that materials are inspected and approved by an authorized construction professional before use.

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Appendices

Appendix 1

Appendix 1. Reported cases of collapsed buildings in Kenya (2003-2013).

	Location	Building description	Date	No. reported deaths	No. of injured	Suspected causes from print media
1	Ronald Ngara Street, Nairobi CBD, Nyamakima	Five storey commercial building	24th June 2006	20	35	Inadequate curing
2	Kiambu town	Three storey commercial building	19th October 2009	11	14	Structural failure and materials
3	Kiambu town	Rental residential building	January 2010	3	4	Heavy down pour
4	Mulolongo, Nairobi	Six storey building	9th June 2012	4	15	Substandard material, lack of proper supervision, inappropriate foundation design for water logged area
5	Langata, southern bypass, Nairobi	Langata Southern Bypass building	20th June 2011	None	6	Use of poor quality sand for beams and columns
6	Mosocho in Kisii County	One-storey building	7th May 2012	None	3	Heavy rains, cheap and poor quality materials
7	Ngara, Nairobi City	One storey building under construction	30th July 2011	None	5	Poor workmanship, Owner ignored construction standards
8	Makupa, Mombasa County	Four storey building	April 09, 2009	3	7	Cracks and weak building
9	Luanda, Vihiga, Western Kenya	Three storey building	September 2011	3	5	Heavy rains. Lack of involvement of Structural engineer and poor concrete mix
10	Westlands, Nairobi	Seven storey building	May 2012	Unknown	2	Increase of number of floors from approved 3 to 5. Structurally unsound.
11	Kasarani, Nairobi	Residential buildings	5th February 2012	None	6	Large spans between the beams and columns, weakening the structure, weak materials
12	Embakasi, Pipeline estate	Six storey building	June 2011	2	6	Poor workmanship and use of substandard materials
13	Matigari Building along Thika Road near Mathare North	Not reported	9th Sept 2011	Not reported	Not reported	Poor workmanship and poor materials
14	Kisumu	Six storey building	16th Jan 2013	7	35	Poor workmanship, lack of columns on the side adjacent to existing building

Source: Print and electronic media in Kenya.

Appendix 2

Appendix 2. Chemical analysis of the contents of the sand samples.

	Chemical elements	1	2	3	4	5	6	7	8	9	10	11	12
	Sample	Na	Mg	Al	P	S	Cl	K	Ca	Sc	Ti	V	Cr
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
1	KT1	24117.23	4559.00	32325.89	43.60	38.31	20.53	24329.09	12708.67	3.89	1625.29	11.40	14.84
2	KT2	16068.99	4559.00	25357.91	43.60	38.31	75.43	20701.97	16370.29	3.89	1468.44	5.23	4.90
3	KT3	17684.86	4559.00	23539.89	43.60	38.31	77.24	19718.96	6863.32	3.89	1351.82	5.56	4.66
4	ML1	21499.61	4559.00	28624.87	43.60	38.31	20.53	40495.42	2317.12	3.89	541.92	5.69	5.00
5	ML2	23672.27	4559.00	27479.42	43.60	38.31	20.53	20440.30	10851.96	3.89	2097.36	12.02	7.68

Continued

6	ML3	17049.90	4559.00	26421.98	43.60	38.31	35.02	21769.11	7905.12	3.89	754.17	9.69	3.77
7	ML4	25937.39	4559.00	16767.54	43.60	38.31	63.69	11093.58	11177.48	5.43	543.71	9.89	3.63
8	KW1	22136.41	4559.00	33345.14	43.60	38.31	42.81	21778.66	10158.71	3.89	2068.49	13.44	5.94
9	KW2	18704.62	4559.00	26377.91	43.60	38.31	52.50	19957.29	11204.45	8.69	743.37	17.51	5.54
10	KW3	24480.57	4559.00	37901.76	43.60	38.31	1090.19	42265.19	7357.23	3.89	2231.46	1.02	23.71
11	DC1	24766.34	4559.00	12448.34	43.60	38.31	47.34	8545.13	1536.49	3.89	885.74	5.38	2.17
12	DC2	24239.91	4559.00	16275.43	43.60	38.31	28.99	13235.36	2046.55	3.89	1028.91	8.56	2.66
13	DC3	32027.40	4559.00	29712.56	43.60	38.31	32.46	19501.24	8506.99	6.58	667.48	11.63	5.00
14	DC4	21732.83	4559.00	29746.52	43.60	38.31	49.32	26497.87	8809.70	3.89	1069.66	20.16	8.46
15	KB1	23551.18	4559.00	28668.30	43.60	38.31	30.28	19656.16	8628.65	7.97	1104.45	15.52	2.86
16	KB2	23518.09	4559.00	23900.63	43.60	38.31	68.82	15917.09	16442.32	3.89	1275.99	21.79	3.05
17	KB3	33867.94	4559.00	47246.99	43.60	38.31	1490.24	47032.00	8632.33	3.89	2474.11	1.02	18.31
18	NR1	23925.71	4559.00	23582.46	43.60	38.31	67.78	24398.09	3460.91	3.89	1101.27	11.99	2.01
19	NR2	17404.08	4559.00	19479.90	43.60	38.31	20.53	14514.57	1999.66	3.89	1000.17	12.87	23.87
20	NR3	16335.16	4559.00	26667.99	43.60	38.31	20.53	22558.61	3774.96	3.89	1168.15	11.41	20.72
21	NB4	23448.08	4559.00	22424.25	43.60	38.31	20.53	31678.27	2251.45	3.89	559.53	11.42	2.85
22	KBU 1	25203.49	4559.00	41223.45	43.60	38.31	1648.31	44796.68	8069.88	3.89	2325.34	1.02	19.03
23	TK1	19462.37	4559.00	25499.55	43.60	38.31	65.47	20470.06	6758.26	3.89	4814.00	24.82	10.31
24	TK2	20950.30	4559.00	18586.38	43.60	38.31	154.99	29506.24	671.06	3.89	330.67	9.39	1.82
25	TK3	25094.91	4559.00	23234.07	43.60	38.31	97.98	21705.91	5433.51	3.89	1960.19	27.47	14.03
26	CL1	28173.27	4559.00	28233.28	43.60	38.31	20.53	24048.26	8687.93	3.89	625.71	12.60	5.49

	Chemical elements	13	14	15	16	17	18	19	20	21	22	23	24	25
	Sample	Mn	Fe	Co	Ni	Cu	Zn	Ga	As	Br	Rb	Sr	Y	Zr
	Sample	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
1	KT1	197.74	8691.70	0.61	4.91	3.67	8.72	7.70	0.30	0.17	25.40	307.22	6.03	21.98
2	KT2	604.83	7771.89	0.61	1.44	2.41	19.18	6.62	0.30	0.17	29.79	182.06	10.83	21.98
3	KT3	577.85	9482.62	0.61	1.16	2.21	14.92	5.88	0.30	0.17	29.46	121.61	15.00	21.98
4	ML1	247.78	5527.80	0.61	0.72	2.39	9.57	8.21	0.30	0.17	67.04	95.90	5.23	21.98
5	ML2	164.28	8331.24	0.61	1.26	2.69	7.88	6.70	0.30	0.17	20.23	262.11	5.30	21.98
6	ML3	127.52	5039.14	0.61	1.62	3.39	5.03	5.96	0.30	0.17	29.49	177.53	6.32	21.98
7	ML4	302.67	4735.27	0.61	2.75	2.44	7.32	3.24	0.30	0.17	13.83	133.26	5.88	21.98
8	KW1	308.57	15668.52	0.61	2.20	3.58	18.64	8.01	0.30	0.17	29.73	201.55	12.92	21.98
9	KW2	385.14	6410.27	0.61	4.86	4.24	7.31	4.90	0.30	0.17	28.27	215.88	3.98	21.98
10	KW3	1231.63	37653.85	0.61	0.30	2.04	134.11	21.99	0.30	0.21	101.29	10.18	41.00	47.30
11	DC1	56.60	2138.10	0.61	0.71	1.52	3.41	2.94	0.30	0.17	8.30	110.47	2.68	21.98
12	DC2	74.61	2900.87	0.61	0.66	2.44	5.77	4.52	0.30	0.17	12.02	181.68	4.62	21.98

Continued

13	DC3	113.12	5445.12	0.61	2.26	2.81	21.00	7.02	0.30	0.17	23.67	134.89	3.60	21.98
14	DC4	268.45	9852.99	0.61	3.34	5.58	10.93	6.07	0.30	0.17	38.78	149.81	6.06	21.98
15	KB1	206.99	6291.31	0.61	2.45	3.53	7.72	7.04	0.30	0.17	20.59	197.05	5.27	21.98
16	KB2	258.38	7033.01	0.61	6.24	3.15	8.50	5.36	0.30	0.17	17.65	223.76	5.21	21.98
17	KB3	1370.05	42768.33	0.61	0.30	3.04	158.43	24.57	0.30	0.60	128.00	16.51	51.46	69.73
18	NR1	1504.86	14386.80	0.61	2.37	2.84	33.75	6.71	0.30	0.17	59.36	95.62	10.65	21.98
19	NR2	1127.61	17136.29	0.61	7.26	10.67	38.17	4.51	258.61	0.42	40.43	50.22	6.67	21.98
20	NR3	1103.73	16029.41	0.61	3.85	7.60	34.54	6.15	87.46	0.77	39.88	119.54	8.96	21.98
21	NB4	313.69	5583.33	0.61	1.16	1.78	9.22	6.27	0.30	0.17	50.37	78.20	4.74	21.98
22	KBU 1	1364.69	41938.05	0.61	0.30	2.75	158.45	23.82	0.30	0.69	122.30	9.99	50.31	66.88
23	TK1	497.95	19183.49	0.61	5.46	6.12	216.37	5.78	0.30	0.17	31.90	238.84	8.70	21.98
24	TK2	240.59	2447.36	0.61	0.30	1.18	3.44	3.66	0.30	0.17	48.92	34.63	1.47	21.98
25	TK3	171.28	17424.05	0.61	2.95	9.58	11.79	4.74	0.30	0.17	22.36	416.57	2.32	21.98
26	CL1	145.78	5280.18	0.61	1.31	2.03	4.59	6.39	0.30	0.17	23.07	276.65	2.36	21.98

		26	27	28	29	30	31	32	33	34	35	36	37
	Chemical element	Ba	La	Ce	Pr	Nd	Sm	Hf	Ta	W	Pb	Bi	Th
	Sample	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
1	KT1	4728.43	407.65	16.12	0.73	6.58	8.45	0.95	0.12	0.18	11.33	0.11	0.26
2	KT2	2821.84	416.36	34.67	0.57	3.47	8.95	0.19	0.33	0.18	11.59	0.11	0.26
3	KT3	2683.78	439.80	33.61	0.57	5.08	13.73	0.43	0.32	0.18	10.02	0.11	0.26
4	ML1	3049.13	216.54	18.20	0.86	5.00	6.99	1.08	0.28	0.18	18.07	0.14	0.33
5	ML2	3846.45	510.25	24.42	0.57	5.57	8.73	0.93	0.16	0.18	8.44	0.11	0.35
6	ML3	2562.56	213.23	14.63	0.90	2.61	4.92	0.19	0.18	0.18	8.31	0.11	0.31
7	ML4	2855.11	236.88	21.98	1.04	6.69	3.87	0.19	0.12	0.18	2.96	0.19	0.26
8	KW1	3491.81	694.41	39.79	0.57	6.68	7.13	0.43	0.86	0.18	16.26	0.11	0.26
9	KW2	3319.49	272.62	22.96	1.24	4.87	6.72	0.19	0.12	0.18	11.18	0.11	0.26
10	KW3	462.82	1664.53	132.72	0.88	36.23	4.99	4.50	3.85	1.31	9.43	0.11	8.46
11	DC1	1623.13	164.09	7.17	0.57	1.39	1.06	2.30	0.12	0.18	10.86	0.11	0.26
12	DC2	2501.49	244.02	13.13	0.57	2.73	2.35	2.40	0.18	0.18	3.63	0.11	0.26
13	DC3	2615.61	235.26	15.98	0.75	5.81	5.08	0.19	0.31	0.18	6.88	0.11	0.26
14	DC4	3273.35	386.38	27.95	0.71	4.12	11.05	0.19	0.71	0.18	10.21	0.11	0.26
15	KB1	2996.27	353.70	33.51	1.01	4.61	7.20	0.60	0.41	0.18	6.39	0.15	0.26
16	KB2	2694.56	434.11	34.36	0.73	3.94	6.53	0.27	0.49	0.18	6.19	0.11	0.26
17	KB3	526.53	1995.29	146.83	1.05	46.07	6.63	5.47	4.27	1.10	29.03	0.11	10.06
18	NR1	2867.06	756.29	109.42	1.15	8.70	8.27	0.49	1.50	0.18	22.56	0.11	0.90
19	NR2	1551.61	721.44	96.77	0.57	7.03	8.29	0.25	1.36	0.18	427.61	0.20	0.39

Continued

20	NR3	2557.11	739.96	97.24	0.81	14.14	0.78	0.37	1.35	0.18	387.18	0.11	0.26
21	NB4	2437.70	248.80	49.54	1.05	3.11	6.72	0.89	0.42	0.18	31.98	0.19	0.26
22	KBU 1	250.47	2008.32	158.27	1.20	61.82	5.02	5.00	3.99	0.44	16.25	0.11	8.68
23	TK1	2972.45	1454.78	85.45	1.71	5.19	13.53	0.19	2.04	0.18	17.29	0.11	0.79
24	TK2	2646.51	148.72	18.04	0.82	2.90	2.53	0.19	0.22	0.18	8.24	0.24	0.26
25	TK3	5709.47	767.78	32.72	1.24	6.40	0.78	0.19	0.87	0.18	11.32	0.11	0.26
26	CL1	5030.75	216.63	13.67	1.46	6.40	5.41	1.17	0.12	0.18	13.54	0.11	0.26

Note: Chemical tests carried out using Total X-ray fluorescence (TXRF) and Laser Diffraction and Particle Size Analysis (LDPSA) methods.

Note: Significant chemical elements in the sand samples included Na, Al, CL, K, Ti, Mn, Fe, Pb while minimum elements included Mg, P, S, Sc, Co and Ni.