

Sand Gradation in Seasonal Rivers and their Suitability for Construction of Sand Dams in Kitui South, Kenya

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Abstract

This study was undertaken in Kitui South in Kitui County in the south eastern parts of Kenya. The main objective of the study was to develop a spatial model that can be used for selection of suitable sites for sand dam in Kitui South. The study also assessed the spatial variation of sand grain sizes and how these determine the suitability of sites for the sand dams. Data analysis was done using three approaches. The first approach involved the use of the Remote Sensing (RS) technique where data was preprocessed and analyzed using Erdas Imagine software and Geographical Information Systems (GIS) for spatial modelling. The distribution of sand particle-sizes was based on sieve analysis on the sand samples collected from seasonal rivers in the study area. The seasonal rivers that were investigated in this study included Mwila, Kakya, Wiitu, Nguni, Ngunyumu, Muvuko, Kanzilu, Masaa, Katiliku, Ngulungu, Nzeeu, Koma and Katitika. Statistical analysis was done to establish the relationships between the various spatial components affecting sand particle distribution. The results from the spatial model which integrated all factors shows that 16% of the studied sites along the seasonal rivers in Kitui South were fairly suitable for construction of sand dams while 79% were classified as suitable and 5% are categorized as very suitable. Several sites in the central and the entire eastern parts of Mutha Ward were found not suitable for sand dam construction due to poor conditions such as the lack of suitable sand particles, lack of bedrock exposure on the riverbeds, flat terrain, very shallow stream banks, and weak soils on the riverbanks. Suitable sites for sand dams were found on the western and central areas of Kitui South where production and high accumulation of coarse sands was observed along the seasonal rivers. The areas near Mutomo hills and the rocky areas in Ikanga wards were found to be characterized by few excellent sites for sand dams. The optimum accumulation of different grades of sand in the seasonal rivers was found on streams with slope of between 1.5 and 6% that were dominated with 0 to 40% coarse sands, 0 to 30% fine gravels, 0 to 20% fine sands, and 20 to 80% medium sands. The accumulation of fine gravels was found to be closely related to the distribution of D_{30} , D_{60} and D_{90} sand particle-sizes (0.4-4 mm) while accumulation of coarse sands showed good relationship with the distribution of the medium size sand (0.2-0.4 mm). The accumulation of medium sands was equally high when the occurrence of coarse sands was minimal. Different grades of sand were found to be strongly influenced by the changes in the elevation of the stream especially with regard to the accumulation of the medium sands ($r=0.76$) and coarse sands ($r=0.75$). Out of 80 investigated sites, 59% of them were dominated with uniform sands ($Cu<3$), 30% were intermediate sands and only 11% were well-graded sands ($Cu>5$). The study also found that 86% of the sites along the seasonal streams were dominated with medium sands while 10% were dominated with fine sands and the rest (4%) dominated by coarse and gravelly sands. From the results this study concludes that 59% of the 80 sites that were investigated in this study have a high potential for providing suitable sites for sand dams in Kitui South.

Keywords: Sand dams; Particle size distribution; Hydrology; Water management; Kitui south; Kenya

Introduction

In Kenya 80% of the land is classified as arid and semi-arid and therefore suffer from water shortage [1]. The annual rainfall (500 to 1050 mm/yr) is considerable but is limited to two rainy seasons. Most of the ASALs in Kenya experience rainfall in short high intensity events that hardly infiltrate into the ground. Between these rainy seasons, communities in the rural areas in ASALs encounter drought with severe water shortages. In Kitui County for example rain disappears as runoff into ephemeral rivers that stand dry for the rest of the year. Given the expected increase in climate variability [2,3] and the massive potential of rainwater harvesting in Africa [4], studying techniques of small scale water storage such as sand dams becomes

increasingly important. In the recent past, there has been a growing recognition of the importance of sand dams as a low cost and robust means to enhance water availability in ASALs. Determining a suitable location for a sand dam involves evaluating the favorability of both the physical and environmental conditions [5]. The physical conditions include a number of factors. One is the availability of coarse sand supplied by the runoff along the river [6]. Coarse sand is preferred in this case because it allows water infiltration into the sand which is then stored for a given period and can be abstracted for both livestock and domestic uses [7]. Medium sands are also applicable when there is minimal supply of coarse sands [8]. Fine sands are not recommended due to their limited storage capacity. The availability of accessible bedrock below the accumulated sand along the riverbed is also important [9]. The bedrock acts as the foundation and anchoring point for the sand dam. The bedrock also ensures that the water that

infiltrate into the sand matrix does not leak away from the subsurface storage [10].

The distribution of different sand particles along the streams varies from one point to the other. This is attributed to factors such as the source geology, distance from the origin, and size of the sediments [11]. Respective sand gradation denoted as D_{10} , D_{30} , D_{50} and D_{90} are commonly used to show the distribution of sand particle sizes. This represents the first decile, third decile, fifth decile and the ninth decile respectively. The median size is represented as D_{50} which means that half portion of the sand that accumulate at any given point along the river is larger than the particle size at that D_{50} and half of the sand is dominated with particles less than the value indicated at D_{50} [12]. A normal distribution curve would be attained when the dominant particle size is at D_{50} (median size). The median size varies from one point to the other along the seasonal rivers but if the size is between 0.4 to 2 mm (coarse sand), then the site would be taken as suitable for a sand dam.

The distribution of sand particle size is important but in order to maximize the storage capacity of the sand dams, assessment of uniformity and gradation of sand is also important. Uniformity of sand is defined by the Coefficient of Uniformity (C_u) and sand gradation is defined by the Coefficient of gradation (C_g). These coefficients are influenced by changes in the particle size distribution mainly D_{10} , D_{30} and D_{60} . If the ratio between the particle size D_{60} and D_{10} is less than 3 then the sand will be considered uniform and well-graded when the ratio is greater than 5 [13]. Uniform sand are preferred due to high surface area for water storage in the sand dams. Practically, rivers exhibit characteristics changes as it extends down its course. These changes show a recognizable pattern and variation in terms of the energy, discharge, velocity, channel characteristics and load on the riverbed [14]. Since the rivers are in continuous interaction with the physical environment as well as climate and human factors considerable changes in varied temporal and spatial scales are observed in both the landforms and processes of rivers [15]. The river channel becomes wider and deeper and as a result its cross-sectional area increases. In the lower course bed load can only really be found in the form of fine sediments and muds, known as alluvium [16].

The analysis of sediments involves determination of the particle-sizes, porosity and depth of the accumulated sediments. The sediments with high content of coarse sands and medium sands are deemed suitable for high storage capacity sand dams [17]. The river channels with clay sediments are not suitable due to low permeability [17]. The ideal sites should consist of consolidated rocks forming the base of the sand dam as well as the riverbanks. The river banks that consist of loose soil materials may not be suitable due to increased possibility of erosion of the banks and subsequent collapse of the sides of sand dams rendering the whole structure unstable.

Study Area

The study was carried out in Kitui South which is located in the southern parts of the Kitui County (Figure 1). The Kitui South extends roughly 200 km from north to south and 120 km from east to west with a surface area of 30,496 km². The Southern part of Kitui South which is approximately 20% of the Kitui County land cover is occupied by the Tsavo East National Park. Kitui South is divided into six administrative wards namely, Mutomo, Mutha, Ikanga, Athi, Kanziko and Ikutha.

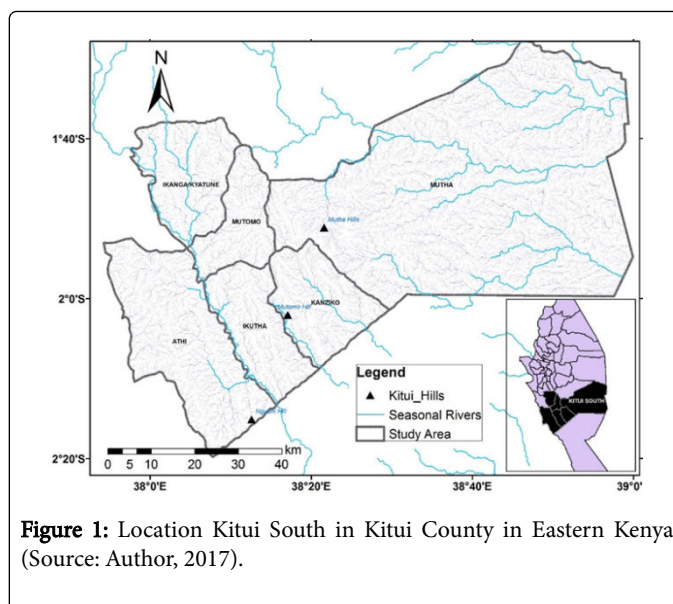


Figure 1: Location Kitui South in Kitui County in Eastern Kenya (Source: Author, 2017).

The area experiences two rainy seasons with two peaks in April-May (long rains) and November-December (short rains). The rest of the year is hot and dry. Air temperature ranges between 16°C and 34°C with mean maxima of 28°C and minima of 22°C (Borst and De Haas). The study area is well covered with seasonal rivers where the river discharge is characterized by high flows in April-May and November-December and extremely low or no discharge in the dry periods between January-March and July-October.

Methodology

Sample collection

Assessment of the stream morphology was done through measurement of the riverbank height, riverbed gradient and computation of the capacity of the reservoir to be constructed at the site. Sampling along streams was done at an interval of 500 meters to maximize comparison of sediments variation along a single river channel. Stream investigation was done from the 80 sampling sites indicated in Figure 2. The numbers indicated in Figure 2 represent the pattern used to collect 1 kg of a sample from the riverbed at a potential sand dam site. The representative samples were collected on the upstream side of the sand dam wall within the riverbed. A total of 80 samples of sand material were collected for analysis in this study form eighty (80) sampling points as indicated in Figure 2.

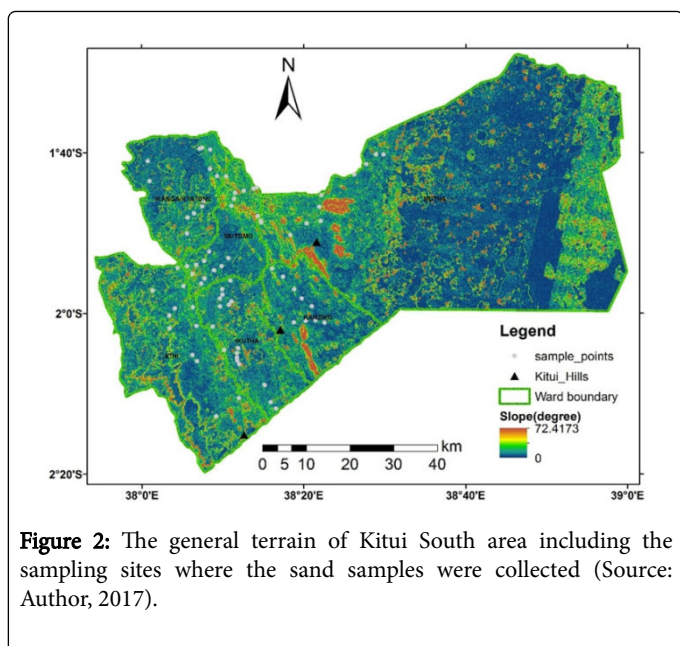


Figure 2: The general terrain of Kitui South area including the sampling sites where the sand samples were collected (Source: Author, 2017).

Particle size analysis

Dry sieving method was done to separate different grades of sand from eighty (80) samples collected from the field based on American Standard Test Method (ASTM) [18]. The samples were dried in an oven up to a temperature of 105°C for 3 hrs. At this point, each sample was spread on a tray at a thickness of about 1 cm to maximize surface areas for drying. It took eight (8) hours during the day time to dry each sample and then cooling overnight as recommended in ISO [19].

The standard sieves considered for sieve analysis based on ASTM on coarse soils were #2 (4.75 mm), #10 (2 mm), #20 (0.85 mm), #40 (0.43 mm), #60 (0.25 mm), #100 (0.15 mm), and #200 (0.075 mm). The loss observed during dry sieving was expressed as an error defined as the difference between the original sample weight and the sum of the individual retained fractions which was computed using the formula $[(Om - \Sigma MR) / Om] * 100\%$. The average error was 0.4% which was within the acceptable evaluation error that must not exceed 1% of the original sample weight [20].

Cumulative grading curves were drawn to determine sand particle-sizes distribution at any given sand dam site. The third, fifth, sixth and the ninth deciles were denoted as D_{30} , D_{50} , D_{60} , and D_{90} , respectively. These parameters were used in the determination of soil Uniformity Coefficient (Cu) and Coefficient of gradation (Ck) [12]. Cu and Ck were computed using the formulas $[Cu = D_{60} / D_{10}]$ and $[Ck = D_{30} / (D_{60} * D_{10})]$ respectively. For the single-sized (uniform) soils, Cu and Ck is equal to 1. If Cu is greater than 5 then it implies that the soil is well-graded. When Cuis less than 3, it means that the soil is uniform in size. Ck ranging between 0.5 and 2.0 indicates a well-graded soil but if less than 0.1 then the soils is possibly gap-graded [11]. The distribution of the different particle-sizes at any given sampling site was defined by the particle-sizes represented by D_{10} , D_{30} , D_{50} , and D_{90} derived from the grading curves [20].

The study also used the median values (D_{50} in mm) which represented the corresponding sand particle-size in millimeters that divided the cumulative curve into two where one half is above and the other half is below this particle sizes. The particle diameter at D_{50} as

well as at D_{10} , D_{30} , D_{60} , and D_{90} were very important values in the analysis as they show how particle-sizes are distributed in a sand dam site and the uniformity of sand can also be determined [19]. These values provided more meaningful and representative statistics in terms of particle-size distributions unlike when using simple 'mode' and 'mean' to show the same. The significance of using the median sand grain size (D_{50} in mm) was also upheld in other related studies [12,21].

Results

Variations of sand gradation along the riverbeds

Several seasonal rivers were found to be suitable sites for sand dam with uniform grade and appropriate particle sizes accumulated on the riverbeds (Figure 3) namely river Nzeeu, Katiliku, Memboo, Kanzilu, Kavuti, Muvuko, Tiva, Mwila, Mitanda, Nguuni, Ndiliu and Ngunyumu. River Nzeeu in Ikanga Ward at an elevation of 848 m had 23% fine gravel, 42% coarse sand, 30% medium sand and 4% of fine sand. At a lower elevation of 841 m, Memboo River in Mutomo Ward had 0.7% of fine gravel, 8.1% coarse sand, 80.3% of medium sand and 10.5% of fine sand which shows a great impact of the change in elevation along the seasonal river. River Kanzilu in Mutha Ward showed high accumulation of fine gravel (28%) at an elevation of 580 m near Makutano Kivili, 41% of coarse sand, and 28% of medium sand. Along the same river were other suitable sites for example Kwa Kikuyu at an elevation of 498 m with 2.6% fine gravel, 8.6% coarse sand, and 75% medium sand. At Kwa Musyimi site along Kanzilu river had 14% fine gravel, 42% coarse sand, and 41% medium sands. At an elevation of 468 m, another site at Kwa Katu Kilonzo had least fine gravel of 0.7%, 8.9% of coarse sand but showed high accumulation of medium sand (85%) hence suitable for a sand dam.

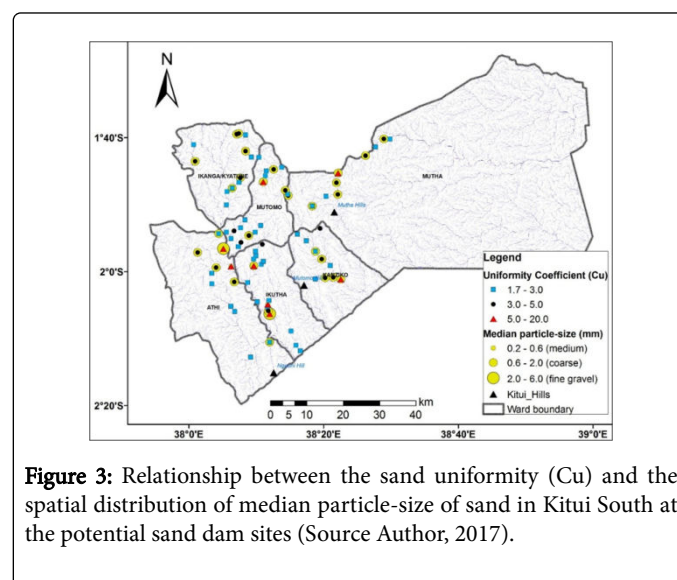


Figure 3: Relationship between the sand uniformity (Cu) and the spatial distribution of median particle-size of sand in Kitui South at the potential sand dam sites (Source Author, 2017).

The particle-size distribution along the seasonal rivers in Kitui South ranged from 8% fine sands (0.08 mm-0.15 mm), 66% medium sands (0.25 mm-0.43 mm), 21% coarse sands (0.85 mm), and 5% fine gravel (2 mm-4.75 mm). 13.8% of the sands available along the seasonal rivers in Kitui South were found to be 'uniform graded medium sands', 3.8% were 'gap graded fine sands', 1.3% were 'uniform graded fine sand', 10% were 'uniform graded medium sand', 26.3% were found to be 'well-graded coarse sands', 6.3% were 'well-graded fine sand', and 48.8% were 'well graded medium sands'. The results show

that most of the investigated sites were dominated with medium sands and coarse sands in that order.

Uniform coarse sands are deemed the best for sand dam [10]. The parameters C_u and C_k were used to assess uniformity and gradation of the sands along the seasonal rivers in Kitui South. $C_u < 3$ indicates uniform soils while $C_u > 5$ indicates well-graded soils. Out of the 80 samples that were analyzed, 47 (59%) of them were categorized as uniform sands ($C_u < 3$), 24 (30%) were intermediate and only 9 (11%) were well graded ($C_u > 5$). Out of the 47 sites observed with uniform sands, 86% were dominated with the medium sands and the rest 14% were coarse sands. The Coefficient of Uniformity (C_u) varied between a maximum of 16.67 and a minimum of 1.74 resulting to a range of 14.93 and a mean of 3.42 (Figure 3). The results also showed that the coefficient of gradation, C_k varied between 2.55 and 0.33, a range of 2.22 and a mean of 0.94. These results imply that 47 (59%) of the 80 sites are highly potential and suitable for sand dams.

Sand accumulation and the dominant particle-sizes

The distribution of different grades of sand namely; D_{10} , D_{30} , D_{50} , and D_{90} were used to explain the relationship between the accumulation of fine gravels and the distribution of different grades of sands Figures 4a-4d). The particles represented as D_{10} show a moderate relationship with a coefficient of determination, R^2 of 0.27 and a correlation coefficient of 0.52. The distribution of particle size represented as D_{10} ranges between 0.1 and 0.4 mm (fine to medium sands). In Figure 4b, the distribution of the particle-sizes represented as D_{30} ranges between 0.2 to 0.6 mm which simply indicate the occurrence of medium size sands. The relationship between the occurrence of medium sands and accumulation of fine gravel is significant with a coefficient of determination, R^2 of 0.58 and a correlation coefficient, r of 0.76.

Figure 4c shows that an increase in the accumulation of fine gravels was strongly influenced by the distribution of the median particle-sizes (D_{50}) along the riverbeds. This relationship was significant with the coefficient of determination, R^2 of 0.73, and a correlation coefficient, r of 0.85. The distribution of the median size (D_{50}) sand ranges between 0.2 to about 1.4 mm which imply presence of medium to coarse sands. The distribution of the particle-sizes represented at D_{90} also shows a strong influence in the accumulation of fine gravels along the riverbeds. This relationship was significant with a coefficient of determination, R^2 of 0.66 and a correlation coefficient, r of 0.81. The distribution of particle sizes at D_{90} varies from 0.1 to 5 mm in diameter. These imply that the accumulation of fine gravel is associated with a wide range of particle sizes from fine sand to very coarse sands.

Figure 4 showed that accumulation of fine gravel varied between 0% and 40% of the total volume of sediments that accumulated on the riverbeds in Kitui South seasonal rivers. The median size particle seems to have more influence in the variation of the amount of fine gravels that accumulate on the riverbed. For example along river Ngulungu in Mutomo, this relationship was observed at Kwa Musingila site where the fine gravel was 9% while the median sand particle-size (D_{50}) was 0.45 mm and at Kwa Joseph Mulatya, the accumulation of fine gravel was 1.8% while the median sand particle-size was 0.38 mm. Along Memboo river at Kwa Nyamai, the fine gravel accumulation was at 0.8% while the median sand particle-size was 0.47 mm and at Kwa Nguute the median size sand was 0.28 mm when fine gravel

accumulation was 0.3%. Another example that showed significant relationship between the median sand particle-size and the accumulation of fine gravel was at Kwa Mwendwa along Muvuko seasonal river in Kanziko ward. Fine gravel accumulation at this site was at 11.6% while the median particle-size was 0.69 mm. At Kwa Mula along the same seasonal river, the accumulation of fine gravel was 2% while the median sand particle-size (D_{50}) was 0.32 mm. The trend showed that as the accumulation of fine gravel increased, the median particle-size also increased.

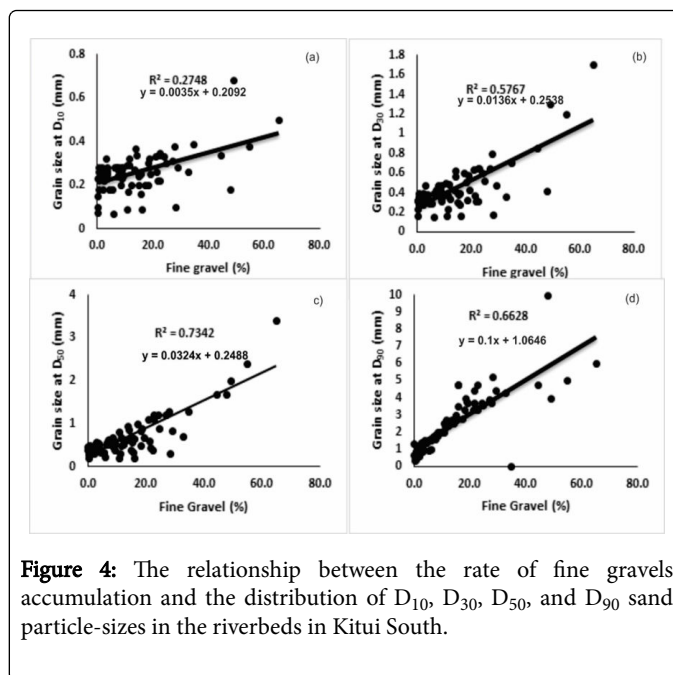


Figure 4: The relationship between the rate of fine gravels accumulation and the distribution of D_{10} , D_{30} , D_{50} , and D_{90} sand particle-sizes in the riverbeds in Kitui South.

In order to determine the relationships established in Figure 4, a regression analysis was done to establish the contribution of different grades of sand in the accumulation of fine gravels. Table 1 shows that the distribution of medium to coarse sands (D_{30} , D_{60} and D_{90}) have a significance influence in the accumulation of fine gravels which is evident with a coefficient of determination, R^2 of 0.911, and a correlation coefficient, r of 0.95. This relationship is statistically significant since the F-value is less than 0.05 and the P-Values for D_{30} , D_{60} and D_{90} is 0.04, 0.00 and 0.00, respectively (Table 1).

ANOVA	Df	SS	MS	F	Significance F
	5	12736.60	2547.32	151.04	2.3E-37
	74	1248.02	16.87		
	79	13984.62			
R ² =0.911					
	Coefficients	Standard Error	t Stat	P-value	Lower 95%
Intercept	-7.58	1.83	-4.14	0.00	-11.23
Median (D50) (mm)	-15.36	10.16	-1.51	0.13	-35.62
D10 (mm)	-6.77	11.25	-0.60	0.55	-29.18
D30 (mm)	25.77	12.24	2.10	0.04	1.38
D60 (mm)	15.19	5.18	2.93	0.00	4.87
D90 (mm)	3.58	0.47	7.64	0.00	2.65

Table 1: Sand characteristics that influence the occurrence of gravelly sands.

The results also shows that there is no significant influence of the distribution of the medium sands (0.2-0.4 mm) represented by the particle size D₁₀ in the accumulation of fine gravels along the riverbeds (Figure 4). In conclusion the accumulation of fine gravels is well associated with the distribution of sand particles ranging between 0.4 mm and 4 mm (coarse sands). The median sand particles do not seem to have any relationship with the changes observed in the accumulation of fine gravels as the P-value is 0.13 (Table 1).

Figure 5a shows that sand particles ranging between 0.1 and 0.3 mm (fine to medium sands), denoted by D₁₀, have a moderately influence in the accumulation of coarse sand along the riverbeds. This is reflected with a coefficient of determination, R² of 0.296 and a correlation coefficient, r of 0.54 (Figure 5a). Results also showed that sand particles ranging between 0.1 and 0.5 mm also had a moderate influence in the accumulation of coarse sand along the riverbeds. This is evident with a coefficient of determination, R² of 0.269, and a correlation coefficient, r of 0.52 in the particle of sand denoted with D₃₀ (Figure 5b).

The accumulation of coarse sand was fairly influenced by the occurrence of median particles of sand. Figure 5c shows that upto 40% accumulation of coarse sand is partly influenced by the occurrence of median sand (D₅₀ mm) with a coefficient of determination, R² of 0.23 and a correlation coefficient, r of 0.48. However the occurrence of sand particles ranging between 0.2 and 4 mm shows no significant influence in the accumulation of coarse sands (Figure 5d). The coefficient of determination, R² of 0.08 and correlation coefficient, r of 0.27 were generally low indicating weak relationship.

The analysis of variance in Table 2 shows similar observations where the particle diameter at D₁₀ indicates a significant influence in the variation of accumulation of coarse sands with a significance F-value less than 0.05 and a P-value of 0.04. The other particles represented as D₃₀ D₅₀ D₆₀ and D₉₀ do not show any significant influence in the accumulation of coarse sands as indicated with P-value 0.73, 0.91, 0.70 and 0.13, respectively (Table 2). The 34% of the variation in the accumulation of coarse sands is explained by the changes in the distribution of D₁₀ particle sizes along the riverbeds. This shows that

the medium sands (0.2-0.4 mm) have a great influence in the accumulation of coarse sands on the riverbeds (Figure 5a). The occurrence of the median sand particle-size did not show any significant relationship with the accumulation of coarse sands in seasonal rivers found in Kitui South.

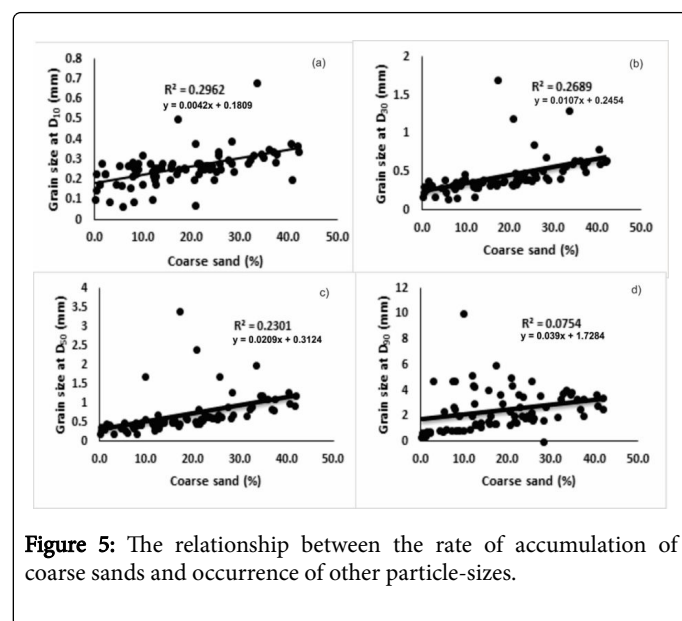


Figure 5: The relationship between the rate of accumulation of coarse sands and occurrence of other particle-sizes.

The results also showed that the accumulation of medium sands increased as the overall sand particle sizes decreased (Figure 6). There is no significant relation between an increase in the accumulation of medium sand and the overall decrease in size of the sand particles occurring on the riverbed. This relationship had a low coefficient of determination, R² of 0.02 and a correlation coefficient, r of 0.15 (Figure 6a). A weak relationship was observed between the increase in the amount of medium sands and the decrease in the distributed median-size sands denoted as (D₅₀) with coefficient of determination, R² of 0.3087 and correlation coefficient, r of -0.56 (Figure 6b). The median

size sand particles in this case ranged between 0.2 and 1 mm which slightly indicate coarse sands.

ANOVA	Df	SS	MS	F	Significance F
Regression	5	3506.21	701.24	7.45	1.05E-05
Residual	74	6969.20	94.18		
Total	79	10475.41			
R ² =0.34					
	Coefficients	Standard Error	t Stat	P-value	Lower 95%
Intercept	-2.45	4.33	-0.57	0.57	-11.08
Median (D50) (mm)	2.71	24.02	0.11	0.91	-45.15
D10 (mm)	55.97	26.57	2.11	0.04	3.02
D30 (mm)	10.20	28.93	0.35	0.73	-47.45
D60 (mm)	-4.80	12.24	-0.39	0.70	-29.18
D90 (mm)	1.71	1.11	1.54	0.13	-0.50

Table 2: Site characteristics that influence the occurrence of coarse sands.

The distribution of particle size represented as D₆₀ showed a moderate relationship with the accumulation of medium sands in Figure 6c. This study found that as the volume of medium sand increased the occurrence of sand particles between 0.2 and 1.5 mm which is also represented as D₆₀ (medium to coarse sands) decreased with a coefficient of determination, R² of 0.37 and correlation coefficient, r of -0.61. A decrease in the size of coarse sand particles (0.5 to 4 mm) which was represented as D₉₀ (Figure 6d) significantly contributed to the increase in the accumulation of medium sands on the riverbed with a coefficient of determination, R² of 0.48 and correlation coefficient, r of -0.69.

medium sands (Figures 6b-6d). Similar observations were made on the correlation analysis where variation in the accumulation of medium sands was strongly attributed to the changes in the distribution of sand particles above the average sizes (D₉₀ mm). A significant variation was attributed to the changes in the coarse sands (D₉₀) as the P-value was 0.001. Although D₁₀ and D₃₀ particle-sizes (less than 0.5 mm) showed a weak relationship, the results showed that to some extent, the distribution of these particles also contributed in the overall accumulation of medium sands as the P-values was in the range of 0.00 and 0.01 respectively.

Eighty-six percent of sand accumulated along the seasonal rivers in Kitui South showed 0% to 20% composed of fine sand (Figure 7). Results showed that the occurrence of fine sands was strongly related to the decrease in the corresponding finer grades of sand (D₁₀). This relationship existed with a coefficient of determination, R² of 0.51 and a correlation coefficient, r of 0.71. The accumulation of fine sands was moderately influenced by the decrease in particles less than 0.5 mm (Figures 7a and 7b). It was concluded that the accumulation of fine sand was probably attributed to the decrease in the sand particle-size ranging between 0.2 and 0.4 mm (medium sands). This implies that more accumulation of fine sands would occur where the accumulation of medium sediments is minimal.

Figure 7c showed a weak relationship between the decreases in the median size particles (D₅₀) and the increase in fine sand accumulation with a coefficient of determination, R² of 0.19 and correlation coefficient of 0.43. There was no significant relationship established between accumulation of fine sands and the decrease in size of coarse sands (Figure 7d). The influence of the low grade particle-sizes in the accumulation of fine sands is evident from the results shown in Figure 7 where the particles represented as D₁₀ and D₃₀ showed a significant contribution (56%) in the observed variation. The significance of these low grade particle sizes was reflected with P-value of 0.001 and 0.04 for D₁₀ and D₃₀, respectively. This implies that the accumulation of fine

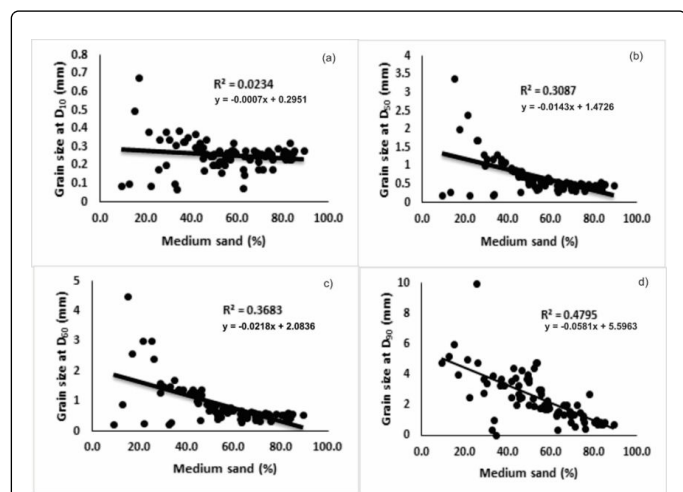


Figure 6: The relationship between the accumulation of medium sands and occurrence of other particle-sizes.

In conclusion the results show that a decrease in coarse sand particle sizes (0.6-4 mm) results to an increase in the accumulation of

sands is well associated with the accumulation of low grade particle-sizes as compared to the coarse sands.

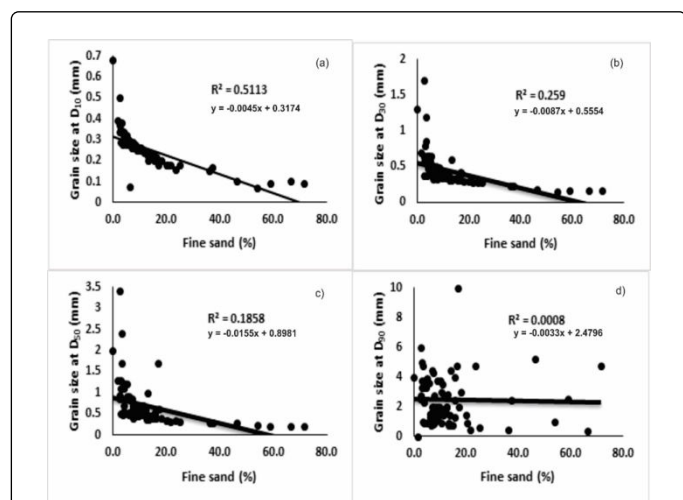


Figure 7: The relationship between the accumulation of fine sands and the occurrence of other particle-sizes.

Relations between sand gradation and stream elevation

Sites located upstream from the potential sand dam sites were dominated with larger particle-sizes as compared to the sites located downstream where sediments due to the impact of erosion. Figure 8a shows that the overall changes in the sand particles-size ranging between 0.2 to 0.8 mm (D_{30}) was significantly influence by the changes in the elevation along the seasonal streams in Kitui South.

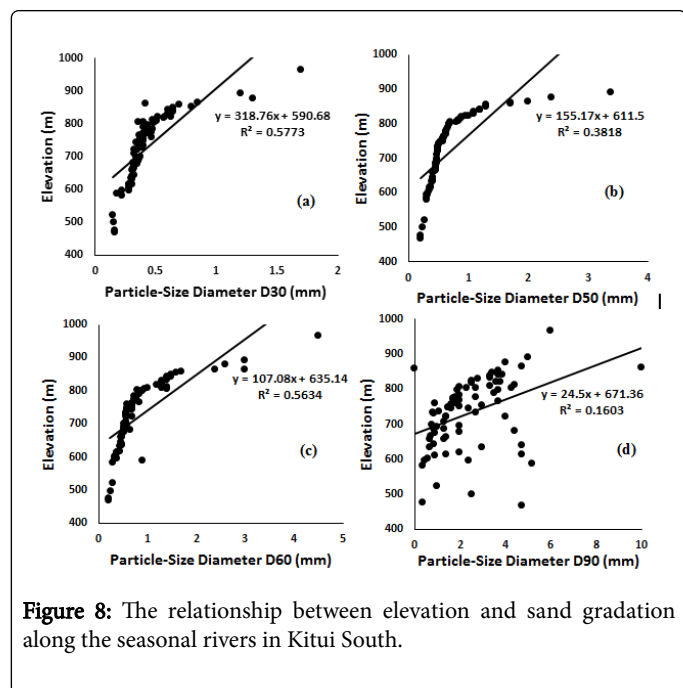


Figure 8: The relationship between elevation and sand gradation along the seasonal rivers in Kitui South.

Sand particle-sizes increased from 0.2 mm at an elevation of 600 m to 0.8 mm at an elevation of 860 m. This shows a strong relationship between elevation and sand gradation especially for the medium and coarse sands (0.2-0.8 mm) (Figure 8a) with a coefficient of

determination, R^2 of 0.58 and correlation coefficient, r of 0.76 at D_{30} particle size distribution Figure 8b showed similar trend where the median size (D_{50}) also increased from about 0.2 mm to 1.5 mm at an elevation between 470 m and 850 m. The influence of elevation was significant in this case with a coefficient of determination, R^2 of 0.38 and a correlation coefficient, r of 0.61.

Figure 8 showed that sand particles which were slightly larger than the average size (i.e., medium to coarse sand (0.2-2 mm)) showed a decreased particle diameter along the seasonal rivers in Kitui South (Figures 8a and 8c). A similar trend was observed on coarse sands (0.2-2 mm) represented as D_{60} , where R^2 is 0.56 and r is 0.75 between an elevation of 450 m and 900 m. Sand particles sizes larger than 2 mm (gravels) represented as D_{90} did not show any significant influence by the changes in the elevation along the seasonal streams in Kitui South ($R^2=0.1603$, $r=0.40$) (Figure 8d).

The influence of riverbank depth and stream width

According to Sasol and Acacia (n.d.), very wide streams (more than 25 m) are not recommended for sand dams. Reinforcing very wide riverbed is not cost effective. The minimum and the maximum stream widths observed in the study area were 8 m and 48 m, respectively (Figure 9).

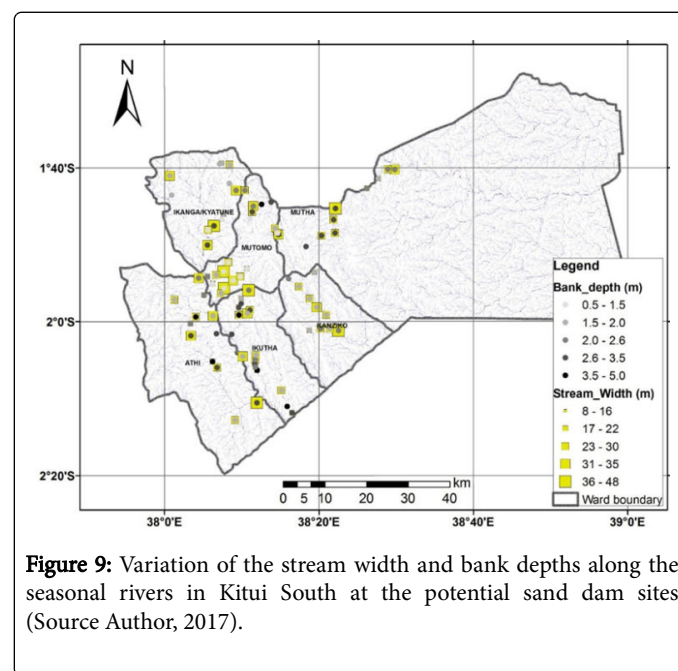


Figure 9: Variation of the stream width and bank depths along the seasonal rivers in Kitui South at the potential sand dam sites (Source Author, 2017).

55% of the streams were less than 25 m wide while 45% had a width ranging from 28 m to 48 m (Figure 9). Suitable sites on the seasonal rivers with stream width less than 25 m were observed on the hilly areas in Kitui South. Some of the site were observed in Ikanga Ward for example at Kwa Mbithi, Kiangwa along Manzee river, and and Kwa Ngombai along Nzeu river. Other sites were distributed in the hilly areas of Mutomo and Ikutha wards. There were few sites on the eastern hilly areas of Athi ward for example at Kwa matheka along Nguni river and MukueNdiliu and northern parts of Kanziko Ward. Mutha Ward were least dominated with sites having streams width of less than 25 m.

Kitui South is well distributed with deep riverbank streams. About 80% of the seasonal streams have riverbank depth ranging between 2 to 5 m. Suitable sites were observed with deep riverbanks for example

in Mutha ward at Kwa Katu Kilonzo where the riverbank depth was upto 2.6 m, Kwa Mwendwa Kilatya in Kanziko ward the riverbank depth was 2 m and Nzeveni in Ikutha the riverbank depth was 3 m. Deep riverbanks ranging between 4 to 5 m were common in the seasonal streams in Athi and Ikutha wards namely Makue Ndiliu and Kwa Meshack Mutua in Athi and Kwa Kiluu, Kwa Kisangau and Kwa Kinene in Ikutha ward.

Suitable sites for sand dams in Kitui south

Suitable sites were concentrated at the north eastern parts of Ikanga ward (especially along Thua-Syotwii river, Manzee-Ngunga, Nzeeu and Koma-kwa Mbithi (Figure 10).

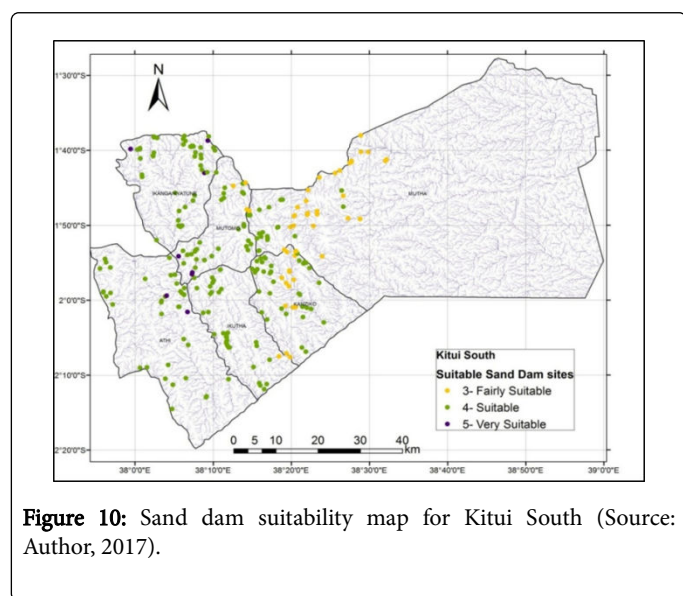


Figure 10: Sand dam suitability map for Kitui South (Source: Author, 2017).

The southern parts of Mutomo ward was also dominated with suitable sites for sand dam construction especially along Ngulungu and Memboo seasonal rivers. There were few sites on the western parts of Mutha ward that were found suitable for sand dam construction especially along Katuluvi-Kanzilu and Kavuti seasonal rivers. In Kanziko ward, suitable sites for sand dam were also well distributed especially at the northern parts for example along Ikungute-Muvuko, Ikutanzale-Muvuko and Muliluni seasonal rivers at the southern parts of the ward. Ikutha ward was found with suitable sites along Mwila-Tiva, Masoma-Tiva, and Ke Mwaa-Muliluni seasonal rivers. Suitable sites for sand dams in Athi Ward were established along Mitanda-Nguni seasonal river which is found near the border to Ikutha Ward and Ndiliu-Ngunyumu seasonal river at the south eastern parts of Athi Ward.

Discussion

According to Maddrell and Neal [22], high sediment load in the seasonal rivers promotes and dams fill with sand and mature more quickly where seasonal rivers have the greatest sediment load. Sand gradation along the seasonal rivers in Kitui South is spatially varied. Majority of the streams in Kitui South are dominated by medium sand (66%) and coarse sands (21%). The uniformity coefficient (Cu) and coefficient of gradation (Ck) were applied in the classification of sands based on their particle size distribution. 26.3% of the sites were found to be 'well-graded coarse sands' distributed in Athi 3, 3 in Ikutha, 2 in Kanziko, 3 in Mutomo, 6 in Mutha and 4 in Ikanga Ward, 6.3% were

'well-graded fine sand' distributed in small quantities along the streams on the hilly areas of Athi and Ikutha wards. 48.8% of the sites were dominated by 'well graded medium sands' which were equally distributed in Ikanga, Mutomo, Ikutha and Kanziko wards and few sites in Athi and Mutha. The study also found that 59% of the potential sand dam sites are dominated with uniform sands while 30% are intermediate. The sites accumulated by the uniform sands were categorized as suitable for sand dam's construction in Kitui South. These sites were 6 sites in Athi at Kwa Mutunga, Kwa Matheka, Kwa Nyamai, Mukue, Kwa Kasuku, and Kwa Sila Mutiso, 12 sites in Ikutha ward along KeMwaa, Nzeveni and Masoma-Tiva seasonal rivers, 5 sites in Kanziko ward one on Ikutanzale seasonal river and the rest along Ikungute-Muvuko river, 5 in Mutha along Katuluvi-Musila-Kanzilu seasonal river, 12 in Mutomo ward distributed in three streams name Memboo, Ngulungu and Katiliku-Masaa seasonal river, and 8 sites were found in Ikanga Ward along Koma-Kwa Mbithi, Manzee-Katitika, and Nzeeu seasonal streams.

Other parameters which were found significant in the determination of sand gradation along the seasonal streams included the particle sizes represented as D_{10} , D_{30} , D_{60} and D_{90} (expressed in millimeter). The advantage of using these parameters is that they give a more representative statistic derived from the sieve analysis results as also observed in Petersen N [10]. These parameter were found significant in the determination of the distribution of sand particle sizes along the riverbeds unlike when only the median grain size as a parameter is applied [10,19]. Kitui South is widely spread with uniform medium and coarse sands distributed in Athi, Ikanga, Mutomo, Kanziko, and Ikutha wards Mutha wards. Well-graded sands are observed in Ikutha and Athi wards.

Dominant particle-sizes

Limited studies have been undertaken to explain if there is any spatial relationships that exist on the characteristics of the potential sand dam sites. However, several studies confirm that the occurrence of coarse and uniform medium sands is critical for high performance of sand dams [22,23]. It is therefore important to make sure that any sites selected for sand dam construction has a considerable accumulation of the appropriate sands for a sustainable good performing of sand dam. The higher the percentage of uniform coarse sands, the greater the storage capacity of that dam [10,24]. Coarse sands are deemed the best for sand dams [25]. Unlike the fine gravels which give an average drainable porosity of 25%, uniform and unconsolidated coarse sand gives an average drainable porosity of 27% for the accumulation and storage of subsurface water [26]. Most of the investigated sites in Kitui South dominated with coarse and medium sands. The accumulation of medium sands also corresponded with the accumulation of coarse sands which concur with other findings [21]. Areas with limited accumulation of coarse sands were observed with significant accumulation of medium sand which is also considered suitable for sand dam [22]. Accumulation of medium sands in the seasonal rivers in Kitui South is relatively higher than the other grades of sand occurring along the riverbeds. The results show that accumulation of medium sand ranged between 20% and 80%. This represents 62% of the sites which were observed to have accumulated medium sand. Although the median sizes (D_{50}) was found important in a previous study [21] in the determination of sand particle-size distribution on the sand dam sites, in this study, (D_{50}) as well as D_{60} did not show any significant influence in the accumulation of medium sands along the riverbed (P-value=0.17 and 0.27 respectively). However, the occurrence of fine sands showed a strong relationship

with the decrease in the medium size particles of sand ranging between 0.2 and 0.4 mm.

Riverbed gradient and sand accumulation rate

The river bed gradient determines the rate at which sands accumulate at a given site [22]. Grounds located on gentle slope (0-10 degrees) along the riverbed are recommended for sand dam because they provide maximum potential for water storage. Previous studies show that steep gradient accelerates the movement of riverbed sediments down the stream due to high influence of gravity and high energy of the river [27,28]. The results show that 86% of the investigated sites in Kitui South were suitable for the sand dam with a river bed gradient ranging from 0% to 8% which fall within the recommended range for the slope of a potential suitable site for sand dam [22]. High riverbed gradient will decrease water infiltration. High volumes of fine grained sands were observed at the lowlands far from the erosional plains.

Influence of elevation on the sand accumulation rate

The accumulation of sands along the riverbed is influenced by several factors along the river which include both physical and human related factors [6]. This study confirmed that there is no significant relationship between the change in elevation and the rate at which sand accumulate on the riverbeds. Substantial accumulation of sand accumulates up to an average of 50% medium sand at an elevation between 600 and 900 m above sea level. This study concluded that sand accumulation along the seasonal rivers depended more on the stream gradient than the elevation of a site located along the stream. The favourable stream gradient was between 0.5 and 4%. This imply that even if the elevation is high, other attributes such as favourable slope would encourage sand accumulation at the site located in such site and therefore considered suitable for sand dam.

The influence of elevation on sand gradation

Sand gradation along stream channels is associated with changes in the river morphology [22]. More erosion occurs upstream while the deposition occurs at the floodplains where the river energy and erosional activities are minimal. Vertical soil erosion occurs at the upstream when the river energy is still high while lateral erosion occurs at the depositional plains due reduced energy of the river under the influence of low terrain [25]. The findings show that changes in the elevation has a strong influence on the dominant sand particles-sizes found on the riverbed. This is attributed to the distance travelled by the sediments down the stream whereby smaller particles imply that they have been transported over a longer distance to the point of deposition than the coarse sediments which occur at the higher elevation near the river head [12].

Uniformity of sands and suitability for sand dam

The coefficient of uniformity was applied to show how uniformity of the sands varied across the study area. High accumulations of coarse uniform sediments increase the storage capacity and the abstraction potential from a sand dam [22]. In order to maximize the extractable water from a sand dams it is important to construct sand dams at the sites with uniform-sands [10,22,25]. Results show that Uniformity Coefficient (C_u) varied between 16.67 and 1.74 with a mean of 3.42. The coefficient of gradation (C_k) varied between 2.55 and 0.33 and a mean of 0.94. Most of the sites located along the seasonal streams in

Kitui South (86%) were accumulated by uniform medium sands ($C_u < 3$). The rest of the sites (14%) were dominated with coarse and gravelly sands. This means that 86% of the investigated sites in Kitui South are suitable for sand dams. Other studies found that medium sand is also applicable in sand dams [10]. This study established that uniform medium sand have higher storage capacity than well graded sands.

Excellent sites were concentrated in places where the supply of coarse sands was sufficient. This is the case observed especially on the western parts of the study area where the basement rocks are dominant unlike in the regions covered with sedimentary rocks in the east. The riverbanks in this region are firm and rocky hence good for anchoring the sand dam wall. This is contrary to the eastern region (flood plains) especially in the larger parts of Mutha where the geology does not favor siting of sand dams. Most parts in the western region of the study area are also characterized with occurrence of relatively coarse sand which is recommended for excellent sand dams. The lowlands in Mutha is covered with relatively finer particles which originate from the erosional plains in the west and are deposited after long distance hence the reduction in grain size. The eastern region of the study area shows unfavorable and unsuitable sites for sand dam due to weak riverbanks, minimal exposure of bedrock where the sand dam wall can be constructed and common occurrence of shallow riverbanks. Very suitable sites were observed in sparsely different distributed areas Makutano Kivili, Kwa Ngombai in Ikanga Ward, Kwa Beth Mutinda in Ikutha Ward, Kwa Kasilu in Mutomo and Itumba B in Mutha. However this ward can be supplemented with underground water. Shallow wells can also be dug in this area since there is possible enough recharge.

Conclusions

Suitability of sites for sand dams varies throughout the study area. The analysis on particle-size distribution played major role in determining the relationships between the suitability of sites and sands gradation for seasonal rivers found in Kitui South. Sands available along the riverbed in most of the seasonal rivers in Kitui South were well-graded. 86% of the sites considered suitable for sand dam are dominated with uniform medium size sands which imply that majority of the sites capable of having high capacity for water storage. The rate at which sands accumulate on the riverbed did not show any relationship with several factors namely; the riverbed gradient, sand particle-size, and elevation. On the other hand the difference in the dominant grade size of sand varied significantly with changes in the elevation.

Coarse sands occurred at high elevation riverbeds while fine sands accumulated in the depositional areas with low gradient. However, majority of the suitable sites for sand dams are in Kitui South were found in the transitional zones where the medium sand were dominant. 59% of the investigated sites in Kitui South were found to have uniform sands, 30% had intermediate and only 11% had well-graded sands. Out of the 47 sites, 59% had uniform sands; 86% were dominated with uniform medium size sands and hence are suitable for sand dam. Only 10% of the sites were dominated with fine sands while the rest, 4% of the visited sites were dominated with coarse and gravelly sands. These findings imply that 59% of the sites located along the seasonal rivers in Kitui South are highly potential and are suitable for sand dams. The distribution of different grades of sands along the riverbed showed a significant association with the distribution of different grades of sands. Suitable sites were concentrated on the western parts of Kitui South where the basement rocks are dominant

unlike in the western parts of the area where the dominant bedrock are sedimentary. The suitable sites identified in Kanziko, Ikutha, Mutomo Ikanga, and some parts in Athi are located on firm and none fractured bedrock hence good for anchoring the sand dam wall. This is contrary to the eastern region (flood plains) especially in the larger parts of Mutha where the geology does not favor siting of sand dams. Most parts in the western region of the study area are characterized with medium and coarse sands which are favorable for excellent sand dams.

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