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Suitability of Silt Deposits of Irrigation Tanks in Angunakolapelessa, Sri Lanka for Engineering Applications

U. P. Nawagamuwa and R. P. M. C. Senarathna

Abstract: Dry zone of Sri Lanka is the main contributor to the rice supply in the island nation. Since this zone is prone to long droughts, a large network of agricultural tanks had been built over 1500 years ago to overcome the adverse impacts of the droughts experienced in the zone. Due to poor maintenance and negligence, there is siltation in some of these tanks and as a result of this the water storage of the tanks is not at the optimum level . This study was focused mainly on ten such tanks situated in the Angunakolapelessa Divisional Secretariat Division in the Hambantota District . These tanks require dredging to be at their optimum capacities. It has therefore become necessary to investigate the possible uses of dredged material , i.e., for erosion mitigation, since ad-hoc dumping of erodible dredged materials would in turn adversely affect the capacities of the other tanks located downstream of the cascade. Thirty soil samples were collected from a depth of 300 mm and laboratory tests were conducted on them to study their soil properties. Particle size distribution and Atterberg Test results show that the samples contain mostly clay-silt sediments and according to USCS and USDA classifications, most of them can be classified as silty loam. Standard Proctor Compaction Tests conducted on the samples indicate that the soils have a low maximum dry density and a high optimum moisture content which indicate that the soils tested cannot be recommended for use in embankment/road construction. However, these soils could be reused in erosion barriers/berms erected in agricultural fields. Proper management of irrigation tanks avoiding siltation caused by erosion is recommended to ensure food security and sustainable water management.

Keywords: Silt deposits, Angunakolapelessa, soil properties, classification, erosion, mitigation

1. Introduction

For a millennium and half, the population of Sri Lanka was concentrated in the dry zone of the country which forms about 70% of the land area of the country (Figure 1). The ancient civilization of the country was rooted in the dry zone and irrigation therefore played a vital role in shaping human settlements in the area. According to history, irrigation has been considered as one of the key elements in the livelihoods of the people since the time of building the first tank by King Pandukabhaya in 4th century BC [24]. Because of the importance of water for cultivation, the then rulers of the country considered irrigation as a necessity and their efforts in this regard have blessed the dry zone of the country with thousands of agricultural tanks. However, most of these tanks were neglected during the period in which the country was under colonial rule to be subsequently abandoned. Today, the agriculture in the dry zone is mostly governed by irrigated water. Rice being the staple food of the country, detailed studies are required on those small tanks which due to siltation and negligence are not at their optimum capacities. Because of this reason it is not possible at times to utilize the tanks fully. Dharmasena [1] reported that in the tanks in the Anuradhapura District, the sediments collected amounted to 23-35% of the tank's full storage. Soil erosion resulting from forest clearing in the catchment areas of village tanks and farming without soil conservation have become major concerns in the agricultural development of the dry zone in Sri Lanka [2]. The impacts made by climate change in the Hambantota area in the dry zone had been studied and presented in the National Atlas of Sri Lanka [3] and it can be observed that there are quite noticeable fluctuations in the rainfall and temperature of the area emphasizing the need for a proper irrigation system in the area. Heavy rainfall with high intensity had been experienced with one day high rainfall events [4].

Eng.(Dr.) U. P. Nawagamuwa, *B.Sc.Eng.Hons(Moratuwa), M.Eng(AIT), Dr.Eng(YNU), C. Eng., FIE(SL), Senior Lecturer, Department of Civil Engineering, University of Moratuwa. Email:udeni@uom.lk*

Eng. R. P. M. C. Senarathna, *AMIE (SL), Civil Engineer, Department of Irrigation, Sri Lanka. Email:chandimandes@gmail.com*

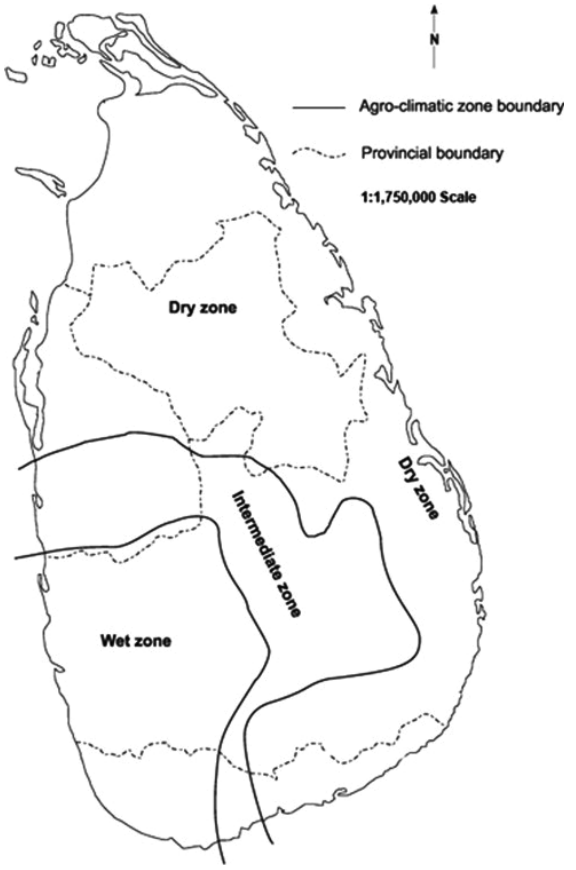

Figure1 - Main agro-climatic zones of Sri Lanka [25]

Jayawardene et al. [5] have reported that El-Niño Southern Oscillation (ENSO) has consistently lasted for 3-4 years and that Hambantota has shown a periodicity (peak events) of 3.8 years.

When the water in the soil dries up during droughts, the soil loses its cohesion and when there is rapid rainfall with high intensity during periods of heavy rain the soil becomes more vulnerable to erosion [6]. The rain drops would loosen soil particles and cause heavy damage to soil. Furthermore, when the vegetation has got depleted due to drought, the rain drops will hit the soil directly, causing more erosion [7]. This could even get worse with deforestation (when the land will lose its cover, soil biota, porosity, and moisture), intensive farming, housing development and road construction (requiring massive earthworks to landscape the area concerned without paying sufficient attention to rainwater flow and maintenance of the roadside) [8],[9]. Therefore, it is a proven fact that climate changes along with anthropogenic activities could intensify erosion which can lead to more siltation in agricultural tanks. Sustainable maintenance of the water storage of a tank at the optimum level would be directly linked to food security and the income of the farmers. Therefore, in an environment which is changing due to natural and anthropogenic circumstances, avoidance of

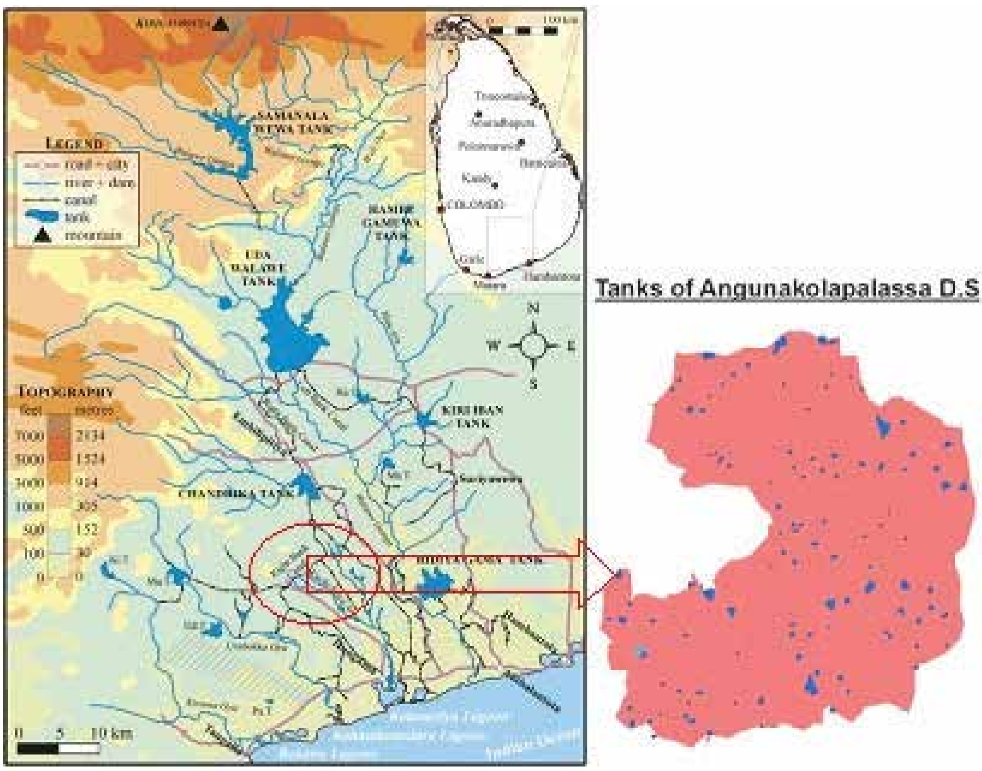

Figure 2 - Walawe basin (from [10] - area marked in a circle belongs to Angunakolapelessa divisional secretariat as shown with the arrow head

asiltation and proper maintenance of tank storage will be societal challenges.

With 105 tanks in its Walawe Basin, Angunakolapelessa Divisional Secretariat in the Hambanatota Distric, a district in the dry zone, is water rich (Figure 2). Most of the tanks are used for agricultural purposes. As the population in the district grows, it will become necessary to cultivate additional paddy land. However, no new irrigation tanks have been constructed in Angunakolapelessa in the recent past and even some of the existing tanks are not being utilized at their optimum levels due to siltation and the farmers are therefore suffering due to lack of water. There is thus a need to optimize tank capacities and the authorities have been dredging the tanks up to their tank beds. The dumping of the material excavated has to be planned properly as otherwise it can cause more siltation in downstream tanks because of the cascaded nature of the tank network. With the proposed extension of the southern highway, more construction work will be undertaken in the area and there will be a high demand for construction materials such as soils. Therefore, the use of these sediments in the construction of infrastructure and their reuse as erosion barriers in agricultural lands would be ideal to avoid the dumping of dredged soil. Therefore, this study discusses the need for dredging and proposes the uses that can be made of the dredged materials.

2. Methods and Materials

2.1 General Soil Morphology and Mineralogy in Angunakolapelessa

The study area generally has reddish brown earth with quartz in some locations. According to Moormann and Panabokke [11], reddish brown earth found in cultivated soils is more reddish in colour than soils under natural vegetation. Soil texture is mostly of the type sandy clay loam, sandy loam (less frequently) or clay loam. More often, and especially in cultivated soils, the 'A' horizon is structureless and hence could cause more erosion. This soil when fed into agricultural tanks will cause a reduction in their capacity. The pH values of reddish brown earth, containing dominantly the clay mineral, kaolinite, and traces of illite, usually lie between 6 and 7. Montmorillonite which is present in the lower horizons is very unlikely to contribute to the composition of sediment mineralogy.

2.2 Statistical Data

From the census data available in [28], the details of paddy production, population and the cultivated area of the Hambantota District pertaining to the period from 1978 to 2015 were extracted to verify the growth of different parameters with time which could result in a higher consumption of tank water as the population increased. However, some of the statistics required were not available year wise as the relevant information has been collected and analysed only on a decadal basis.

2.3 Collection of Soil Samples at 10 Selected Tanks and their Test Results

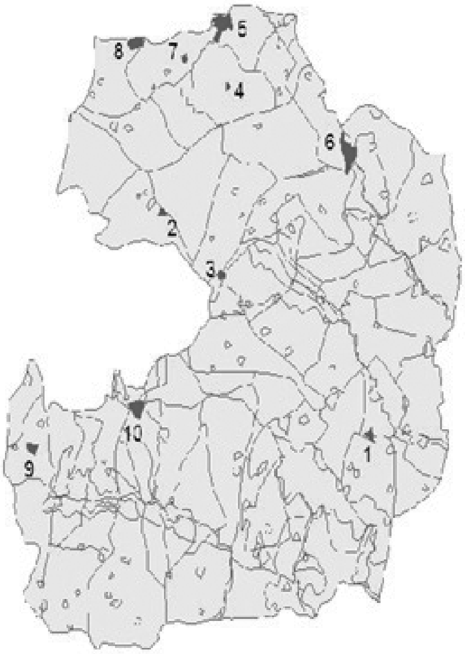

Figure 3 - Tank locations from where soil samples were collected ("Wewa" in local terminology refers to tank – local names of the tanks are provided in Table 1.)

Three disturbed samples were collected from each tank shown in Figure 3, from a depth of 300 mm. The details of the tanks are presented in Table 1. Figure 4 shows an example of a sample collection done at Mudiyanse Wewa numbered as 5 in Figure 3.

Table 1 – Names of the selected tanks

Tank no	Name of the tank
1	Aluth Wewa
2	Pahala Wewa
3	Koragahawala Wewa
4	Kandeketiya Wewa
5	Mudiyanse Wewa
6	Matigathwala Wewa
7	Dabarella Wewa
8	Morakanuwa Wewa
9	Ampitiya Wewa
10	Bogamuwa Wewa

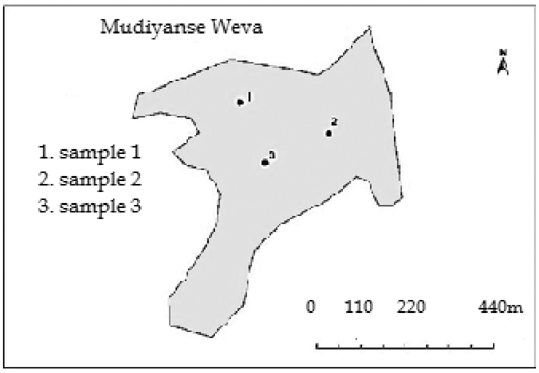

Figure 4 - Locations from where three samples were collected from Mudiyanse Wewa

Basic soil tests were carried out on the thirty samples collected based on the ASTM Standards given in Table 2.

Table 2 - Standards followed in the laboratory experimental studies

Test	ASTM reference
Standard test method for particle size analysis of soils	ASTM D 6913 [12]
Standard test method for moisture-density relations of soils	ASTM D 698 [13]
Standard test method for specific gravity of soils	ASTM D 854 [14]
Standard test method for liquid limit, plastic limit and plasticity index of soils	ASTM D 4318 [15]

3. Results and Discussion

3.1 Statistical Data

Figure 5 shows the parameters that were inter-linked to paddy cultivation in the last four decades. As can be seen, there has been an increasing trend in paddy production over the years, and a very good correlation exists between paddy production and population / cultivated area ($R^2 = 0.94$) .

$$Pp = 0.0048A+0.000184P-125.7 \quad ...(1)$$

where Pp- Paddy production (MT), A – Area (ha) and P – population

Dharmasena [1] reported that 23-35 % of the storage capacity of the tanks in Anuradhapura had been filled with sediments. There must be a proper dredging management programme to regularize the storage capacity. By regularly maintaining the tanks, water storage can be increased and erosion in the upstream catchments mitigated. This will subsequently help to increase the cultivated area. According to Equation (1), if the cultivated area in the Hambantota District is increased by another 20%, there will be a corresponding increase in the paddy production which would help to address issues relating to food security in the country and the increasing population in the Hambantota District.

3.2 Particle Size Distribution

Figure 6 shows the particle size distribution of the 30 samples which are numbered according to the number of the tank and number of the location of the tank from where they were obtained. For example, Mudiyanse Wewa is numbered as Number 5 and its second location is numbered as 5-2. Compared to other samples Sample 10-1 containing more sand has a distinct variation in the particle size distribution. Since Bogamuwa Wewa (Figure 3) from where the sample was obtained is located farther downstream of the cascade network in the Walawe Basin (Figure 2), this high sand content could be due to the accumulation of sand in the downstream of the basin. The graphs marked as upper and lower limits are the gradation envelopes specified by ICTAD [16] for soils used in the upper sub base layers of roads. However, it was noticed that none of the 30 samples except 10-1 lies within the envelopes confirming that these soils are not suitable for road construction.

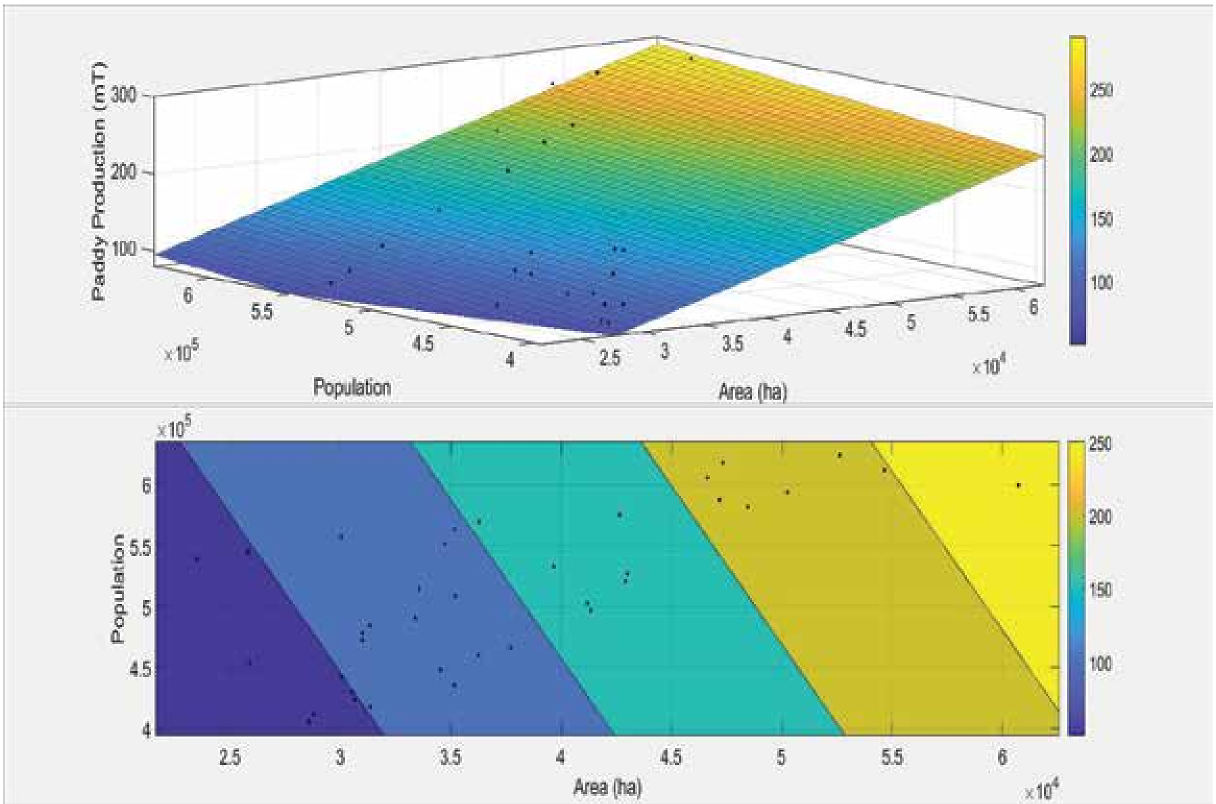

Figure 5 - Growth of interlinked parameters related to paddy production in the Hambantota District over the last 4 decades

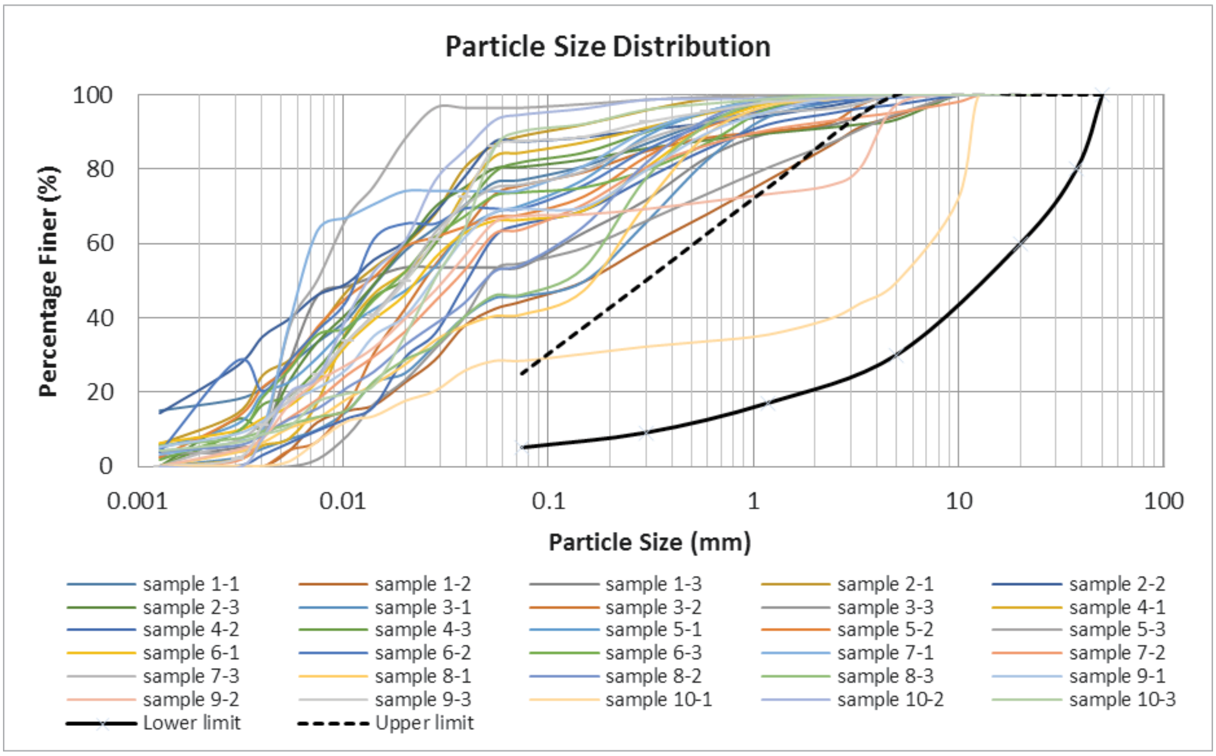

Figure 6 - Particle size distribution of the 30 samples

3.3 Atterberg Limits and Plasticity Chart

The results of Atterberg Limit Tests are presented in Figure 7. Test results of Sample 2-1 obtained from Location One of Pahala Wewa are at a point slightly beyond the U-line and as this is unrealistic for natural soils ([17], [18]), the results of that point were considered as erroneous and excluded from the analyses. ICTAD [16] specifications for soils to be used in the upper sub base layer in road constructions require them to have a liquid limit (LL) less than 45% and a plasticity index (PI) less than 15% although majority of the soils do not meet these requirements.

3.4 Activity and Swell Potential

According to the results shown in Figure 7, clay and silt representations in the samples are almost similar and the results of about 15% of the samples show that the corresponding soils have high plasticity (i.e. LL is more than 50). Casagrande [17] and Bain [19] stated that soils that lie closer to the A-line must contain kaolinite and illite. Figure 6 shows more kaolinite and illite minerals than montmorillonite. Swell potential was investigated using the method proposed by van der Merwe [20] which defines Gross Plasticity Index as the product of the plasticity index and the fraction passing the 0.425 mm sieve. According to that definition, most of these soils have a low swell potential (Figure 8). The conclusions that can be made about the presence of minerals in the surface erodible soils in the area, based on the findings of Casagrande [17], Bain [19] and van der Merwe [20], are in agreement with the findings of Moormann and Panabokke [11] .

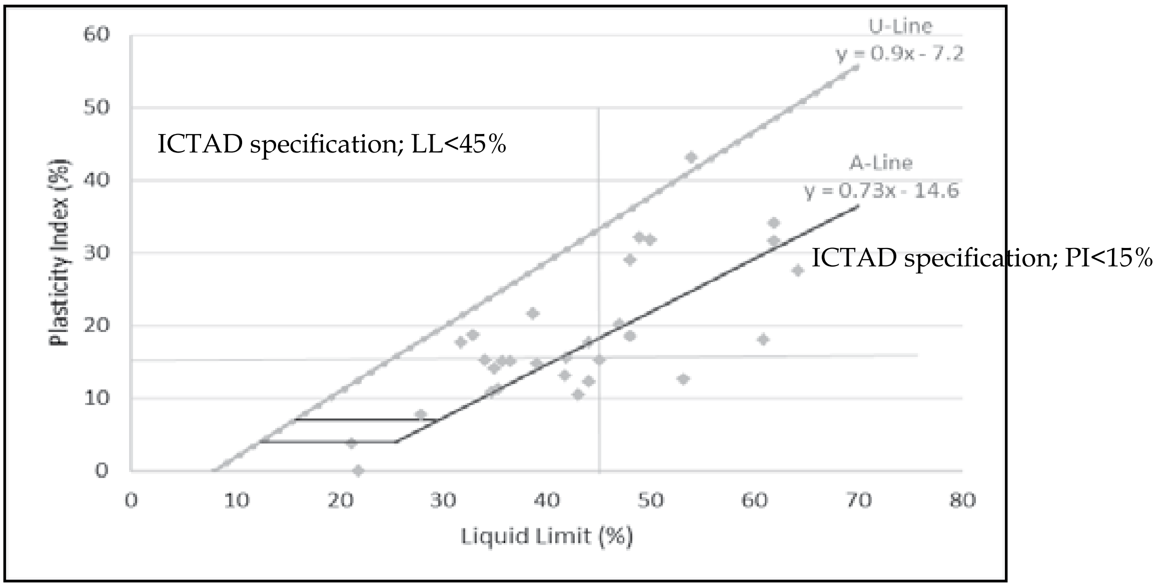

Figure 7 - Particle size distribution of 30 samples collected from 10 tanks

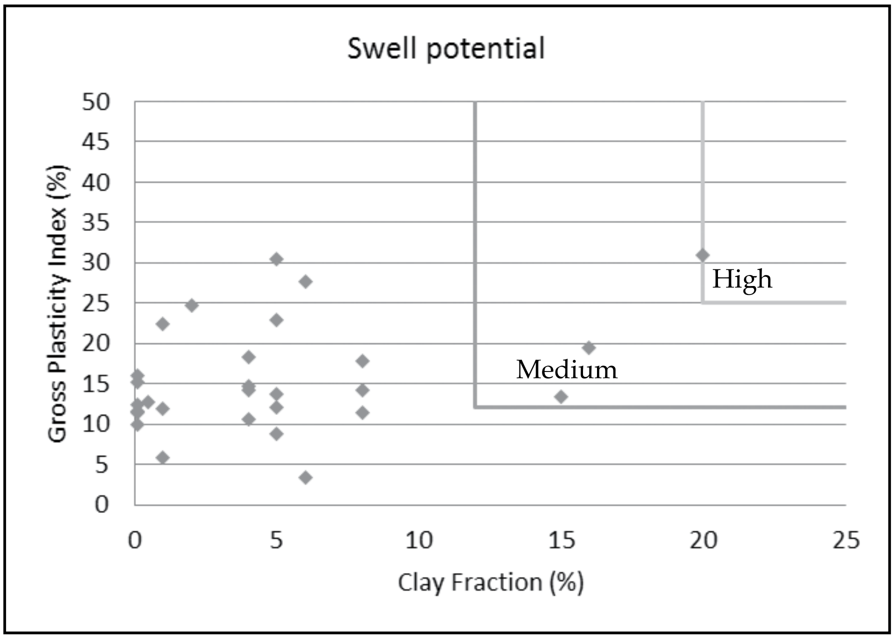

Figure 8 - Swell potential of soil after van der Merwe (1964)

3.5 Compaction, Optimum Moisture Content and Specific Gravity

Figure 9 prepared using the results of the Standard Proctor Compaction Test shows a linear variation between the optimum moisture content (OMC) and maximum dry density (MDD). This relationship has a Pearson Correlation of 0.925 and a R2 of 0.855. However, it is observed that the majority of the MDD values are well below the ICTAD [16] specification of 1.75 g/cm3 for road constructions (Figure 8). Veeraraghavan [21] concluded that soils with low dry density would cause more erosion and that since most of the soils have low dry density they are vulnerable to erosion.

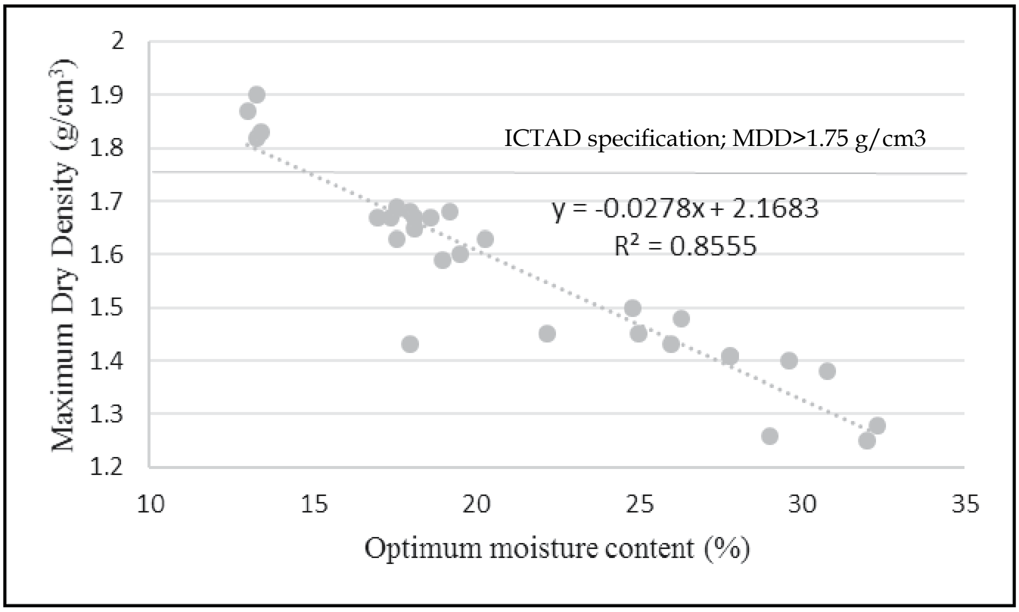

Figure 9 - MDD and OMC relationship plotted using Standard Proctor Compaction Test results

Table 3 - Summary of classifications

Sample location	1-1	1-2	1-3	2-13	2-2	2-3	3-1	3-2	3-3	4-1
USCS[1]	CL	SC	CL	CH	CH	CH	SC	MH	CL	MH
ASTM[2]	Lean clay with sand	Clayey sand	Sandy silt	Fat clay	Fat clay	Fat clay with sand	Clayey sand	Elastic silt with sand	Sandy lean clay	Elastic silt with sand
USDA	Silt loam	Silt loam	Silt loam	Silt loam	Silt loam	Silt	Sandy loam	Silt	Silt loam	Silt

Sample location	4-2	4-3	5-1	5-2	5-3	6-1	6-2	6-3	7-1	7-2
USCS	CL	CL	CL	CL	CL	ML	ML	MH	CL	CL
ASTM	Sandy lean clay	Lean clay with sand	Sandy lean clay	Sandy silt	Lean clay	Sandy silt	Sandy silt	Elastic silt with sand	Lean clay with sand	Sandy lean clay
USDA	Silt loam	Silt loam	Silt loam	Silt loam	Silt	Silt loam	Silt loam	Silt loam	Silt loam	Silt loam

Sample location	7-3	8-1	8-2	8-3	9-1	9-2	9-3	10-1	10-2	10-3
USCS	ML	SC	CL	SC	CL	CL	CL	SM	ML	ML
ASTM	Sandy lean clay	Clayey sand	Sandy lean clay	Clayey sand	Sandy lean clay	Sandy lean clay	Lean clay	Silty sand with clay	Lean clay	Lean clay
USDA	Silt loam	Sandy loam	Sandy loam	Sandy loam	Silt loam	Silt	Silt	Silt loam	Silt	Silt

1- USCS group symbol

2-ASTM group name [21]

3-This being above the U-line was not considered in the analyses

3.6 Classification (USCS/ASTM and USDA)

Classifications of the soils done based on the Unified Soil Classification System [22] and the classification proposed by the United States Department of Agriculture (USDA) [23] are summarized and presented in Table 3. Out of the 30 samples, 14 have been categorized as CL (low plastic clay) in accordance with USCS classification. According to USDA classification, 18 samples fall into silty loam category. Veeraraghavan [21] too confirmed that silty loam and sandy loam soils are highly vulnerable to erosion due to their low dry density and high clay content.

3.7 Possible Uses of Sediments in Mitigating Soil Erosion

Dumping of the materials dredged from the tanks without utilizing them properly would pose a serious threat to the environment. Dredged material itself could cause more siltation in downstream tanks. The maximum dry density of most of the samples lie below 1.75 g/cm3 and most of these samples have been classified as low plastic clay/lean clay or silty loam. Hence, the use of this soil for rural road construction will not be acceptable according to ICTAD [16] specifications and will not be economically feasible even with soil improvement. However, these soils could be used in agricultural lands for erosion control that have been observed to be prone to hazardous erosion. Therefore, it is recommended to utilize the excavated material in earth berms which can act as barriers against soil erosion and subsequent siltation in tanks. Soil/sand bags could also be made from these dredged materials and used in places where severe erosion takes place. It has to be noted that design procedures with retention criteria have to be followed along with proposals for the use of dredged material in erosion barriers and sand bags.

3.8 Way Forward

It is necessary to conduct a detailed analysis by carrying out borehole investigations and contour surveys to determine the quantities of sediments that have to be removed by dredging based on the depth of the tank. A vulnerable situation could arise in some of the tanks if they are over excavated during dredging as there is a possibility of removing the natural impermeable clayey liners within which water can be kept without seepage in to the downstream. Therefore, a proper analysis of borehole data has to be done before executing any dredging.

4. Conclusions

The capacities of the tanks considered in this study are alarmingly low due to sediments. This has been a serious issue in the past few years in the dry zone when water storage was found to be insufficient during times of long droughts. Insufficient storage has had a negative impact on the food security in the area and the financial status of the residents. Therefore, dredging could be considered as one of the solutions for this problem, although there is a serious concern about the dumping of dredged material which could cause more siltation in the downstream tanks in the catchment.

In this study, thirty sediment samples were collected from ten tanks in Angunakolapelessa DS Division to study the possible applications of dredged material. It was found that most sediments can be classified into fine particles (with a high concentration of silt and clay). According to ASTM Soil Classification, the soil types of the ten tanks different from one another. However, the soils of most of the samples fall into the category of lean clay. Application of the type of soils contained in those samples without any improvement, in general construction work such as embankment fills is not encouraged. However, their reuse in agricultural fields in erosion barriers/berms could be considered as a sustainable way forward. Furthermore, the use of soil (sand) bags made of dredged material to mitigate severe erosion could also be considered .

This study was carried out at ten tanks in Angunakolapelessa DS Division and a detailed study must be carried out in other tanks as well. Analysis could be enhanced with a total analysis on quantity calculation done after driving boreholes at suitable locations along with bathymetric/contour surveys. This could provide additional information on time dependent siltation if proper borehole investigations could be done.

Acknowledgement

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