Determination and Mapping of the Bearing Capacity of Subsurface Soil: A Case Study of Moi University, Eldoret Kenya

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Abstract
Ground investigation is a prerequisite for any construction work that ultimately transfers its loads to the earth since it eliminates the uncertainties of ground conditions and can be planned for and considered accordingly during design and implementation. In Kenya, ground investigation is not given the weight it deserves since most contractors and builders use their experience and physical inspection to judge on the soil conditions. This is however very risky especially for high-rise buildings. This paper determines the soil strength parameters and mapping using four GIS methods (Kriging, IDW, spline and Natural Neighbour) to develop a continuous soil bearing capacity database of any point within the study area.
Keywords: Soil bearing capacity, Geospatial interpolation, Deterministic interpolation

1 Introduction

Uncertainties of the subsurface soil within an area or region earmarked for construction development can vary remarkably. Unfortunately, soils strength has been physically determined based on the historical structures that have been built on it in the same vicinity which is risky. Where inadequate ground investigation is carried out, unforeseen construction challenges are always stumbled upon at the excavation stage and during foundation construction or in the worst case, it can lead to total failure of the structure. If the uncertainty is so significant, it can affect the project scope and cost (Fenton et al., 2003). This study aims at improving ground investigation by applying geospatial interpolation using Geographical Information System (GIS). GIS is one of the greatest technologies of the 21st century and has found many areas of application including ground investigations. It provides powerful techniques of inputting data in a systematic and representation of data in simple and clear format. Spatial and non-spatial data can be easily analysed and retrieved when needed.

Spatial interpolation is one of GIS functionality. Spatial interpolation has been adopted widely for data analysis in such fields as hydrology, surveying, disaster management, environmental studies and planning, navigation and general mapping. For this numerical estimation many techniques of spatial interpolation are available. The methods are in two categories, namely deterministic and probabilistic interpolation methods. Deterministic methods include Inverse Distance Weighting (IDW), Global polynomial interpolation, Local interpolation, Natural Neighbour (NN) and Spline while Ordinary Kriging (OK) is a geostatistical model. The choice on the technique to employ depends largely on the nature and quality of original data, the degree of accuracy desired, and the amount of computational effort affordable (Sajid et al., 2013). However, no conventional standards are available to establish the appropriateness of a spatial interpolation technique for a particular phenomenon like soil properties but the level of accuracy of the interpolation results should be confirmed by cross-validation (Swatantra et al., 2014). The performance of spatial interpolation methods is of interest and this varies depending on the phenomenon under study as established by Metternich and Robinson (2006). Soil properties are associated with low skewness and such interpolation techniques like IDW should have their power varied in order to establish the most suitable interpolation power that gives more accurate results (Metternich & Robinson, 2006). The study also indicated that the power of two or three resulted to more accurate results for the case of spline and lognormal kriging. In the study of Sajid et al., 2013 on the suitability of using Kriging and IDW to determine the spatial values of the bulk density of soil, IDW proved to provide superior results than Kriging when optimal power value is used for bulk density. However, both Kriging and IDW had almost the same accuracy, precision and consistency with a difference of less than 1.0%, 0.5% and 2.0%, respectively. However, no significant relation was established in the variation and skewness. For each method, it is necessary to analyze its applicability, algorithm, efficiency and advantage before adopting the best approach (Kravchenko & Bullock, 1999). Optimal choice of method can only be made under the circumstances in which the study is being carried out (Yang et al., 2015). The study by Yang et al indicates that Kriging had better results compared to all other methods. Many researchers agree that Kriging produces better results than IDW in most of the phenomena (Setiento, 2013). Other interpolation techniques like thin plate smoothing splines have limited computational efficiency hence their applicability output optimization is achieved by double iteration (Hancock & Hutchinson, 2006). All these methods adopt the geographic principle 'things that are closer together tend to be more alike than those far apart' (Tobler, 1970).

1.1 Study Area

The study area covers the entire Moi University acreage, situated 32 km south east of Eldoret town, in Uasin Gishu County (UGC), Kenya. The study concentrates on the developed and proposed sites for construction as shown in figure 1. The study area is about 6.2 km2, its average location is latitude 0o 17' 19'' N and longitude 35o 17' 18'' E with an average elevation of 2221 m above sea level at the top of the surrounding plateau (Kimotho, 1996).

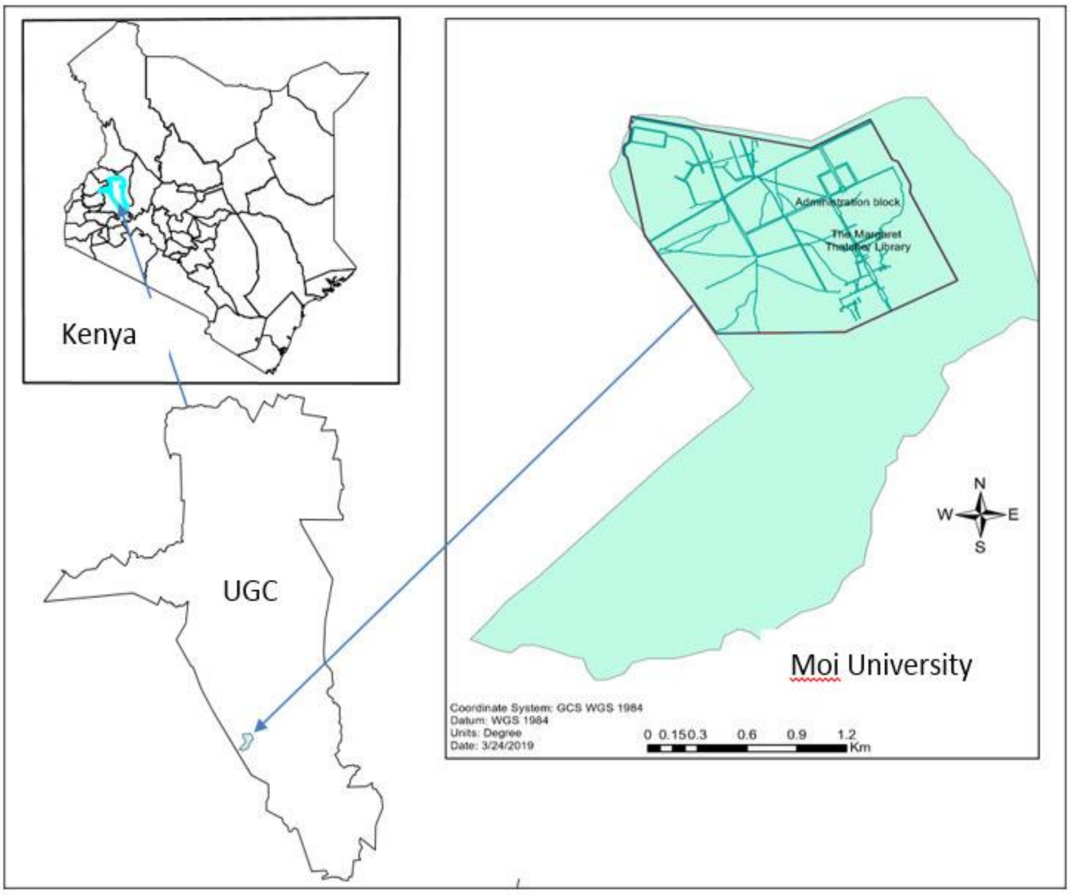


Figure 1. Study Area

2 Methods

Triangulation method was adopted to establish the sampling points on the study area shape file this was followed by subdivision of the area using gridlines into triangles and the nodes taken as initial data points. The grid system resulted in points approximately 1.5 km apart. It is worth noting that the distribution of data points affects surface interpolation significantly but with the application of triangulation a representative sample of the population is obtained which enhances accuracy during geospatial interpolation. However, 1.5 km is seemingly large enough and possibilities of different soils existing within this radial distance are eminent. Geostatistical approach of interpolation significantly arrests this possibility since the soil property has more strength on the point of analysis and its strength reduces in a radial distance. This infers that two points adjacent to each other will actually share the 1.5 km and each will have an influence of 0.75km. Visits were made to the site to carry out ground survey and GPS locations to establish feasibility and accessibility of trial pit location and excavation. The survey was conducted in the entire area of study to obtain the general topography and notable land forms guiding the types of soils in the study area. The variability of surface soil validated the hypothesis that the study area is covered with a variety of soils ranging from stiff to weak soils. The points were distributed as shown in figure 2. The northern part of the study area is a built-up area hence has more data points than the southern part which is mainly composed of extensive weak clayey soils.

With the total area of about 6.2 km2, the largest radial area for the sampling points was 2.0108 km2 which is 31. 97 % while the smallest was 0.3849 km2, representing 6.1% of the total area. There is no standard method of determining the optimum number of data points and its distribution for a given area (Gouri et al., 2018), however, careful selection of sampling points which adequately represented the study area so as to improve on the accuracy was carried out. Out of the nine datasets obtained from trial pits, six were used for spatial interpolation while the remaining three were used to correct and validated the interpolated results for OK, IDW, Spline and NN. The estimated results from the map is compared with the actual results obtained from the tests. The mapped results were checked for errors and compared to find out which method has minimum errors during interpolation of surface bearing capacity.

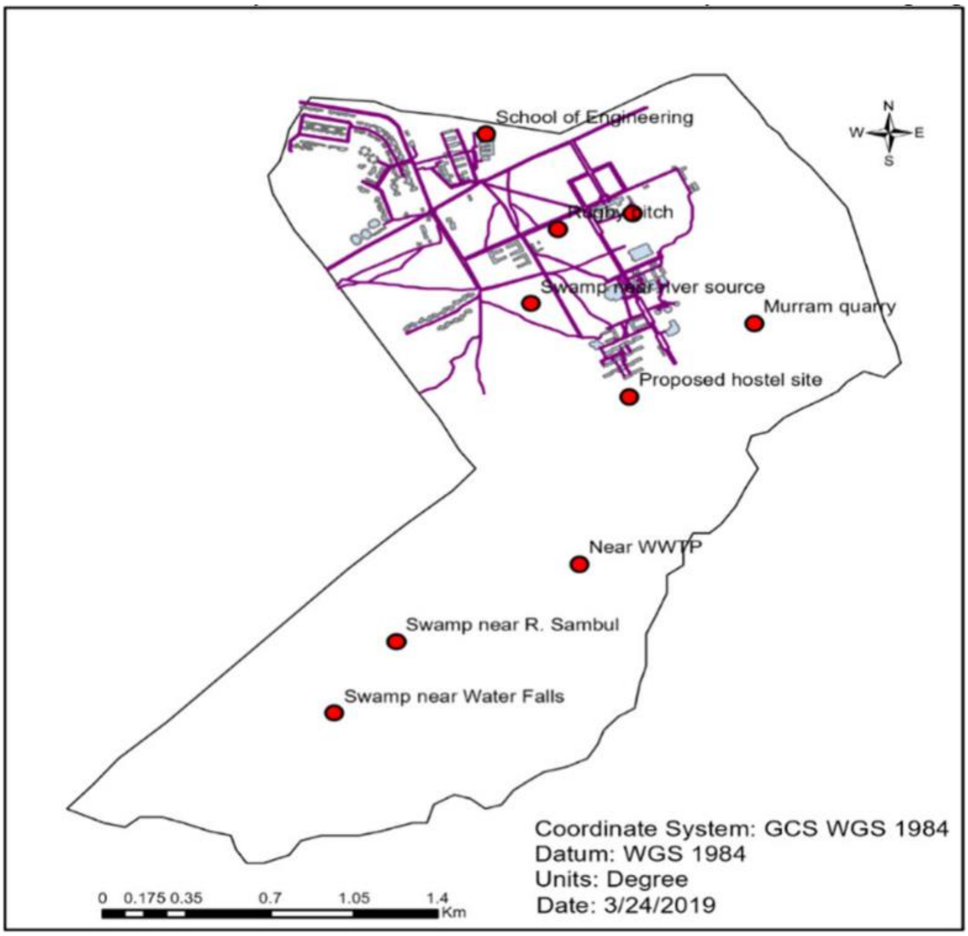


Figure 2. Trial pits marking

3 Results

3.1 Soil Bearing Capacity

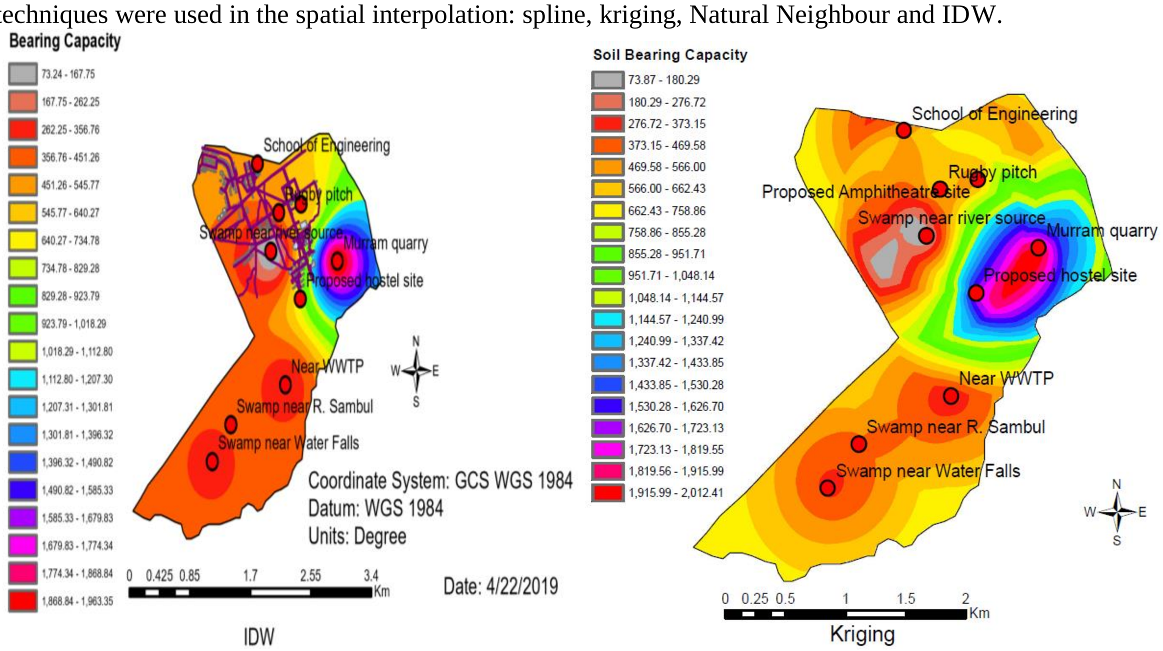
A typical graph of normal stress against shear stress was plotted for the determination of the shear parameters namely internal angle of friction and cohesion strength as shown in figure 3. Soaked samples produced lower shear stresses compared to dry samples. Water particles lubricate the soil particles hence lowering the internal angle of friction. It further loosens the soil conglomerations which makes them disintegrate and easily collapsible. All the other samples were tested and their respective graphs of normal stress against shear stresses plotted. The shear parameters were explicated for direct shear test (DST) and tri-axial test (TAT) as shown in table 1.

Table 1. Safe bearing capacity for DST and TAT

TP ID	Safe Bearing Capacity (kN/m^2)			
	Direct Shear box	Tri- axial test	Critical SBC	Critical Method
1	640.873	551.42	551.42	Tri-axial Test
2	511.03	483.51	483.51	Tri-axial Test
3	713.05	694.53	694.53	Tri-axial Test
4	73.14	92.55	73.14	Direct Shear box
5	338.88	295.23	295.23	Tri-axial Test
6	1891.06	1862.68	1862.68	Tri-axial Test
7	469.95	432.02	432.02	Tri-axial Test
8	336.87	409.94	336.87	Direct Shear box
9	1963.49	2437.13	1963.49	Direct Shear box

3.2 Geospatial Interpolation

This forms the main objective of the project. Six data points of the nine points obtained was used to carry out the spatial interpolation. The other three points were used to validate the interpolation output. Four interpolation techniques were used in the spatial interpolation: spline, kriging, Natural Neighbour and IDW.



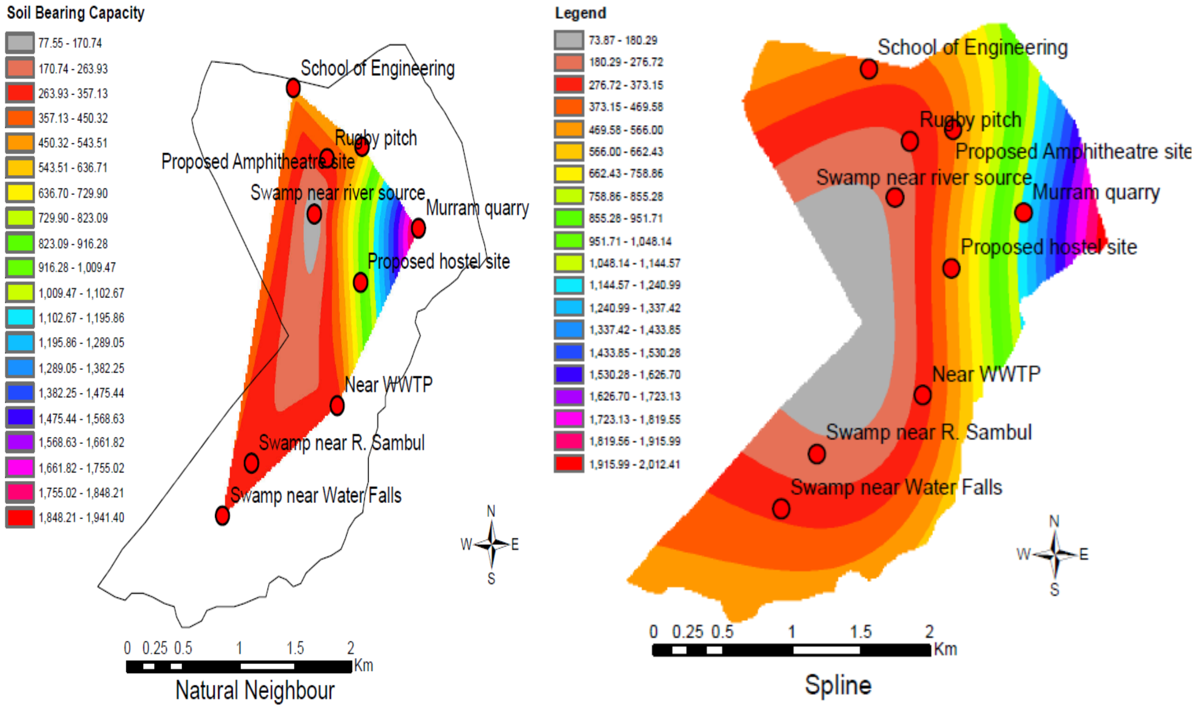


Figure 3. Safe bearing capacity distribution within study area for the four methods

4 Discussion

Of the 9 trial pits sampled and tested, 6-point results were used to obtain the surface interpolation. The other three points were used to validate the interpolated results. The interpolated bearing capacity surface is shown in figures 3. The DEM provides the elevations of the study area and therefore indicates the highest and the lowest points. Similarly, table 4.11 shows the interpolated results with their corresponding measured value. The errors associated with each method are also given.

Table 2. Cross-Validation

TP		Predicted SBC (kN/m2)			
ID	Actual	Kriging	IDW	Spline	NN
3	694.53	710	593.02	421.365	403.725
6	1712.07	1674.5	1065.55	614.215	1056.07
7	432.02	421	404.01	228.505	310.58
Root Mean Square Error (RMSE)		10.93894	71.77841	193.1568	205.6302
Mean Absolute Error (MAE)		15.47	-101.51	-273.165	-290.805
Mean Relative Error (MRE)		15.47	101.51	273.165	290.805
% Mean Relative Error		2.227406	14.61564	39.33091	41.87076
R2		0.9993	0.9927	0.8961	0.9935

5 Conclusions

Kriging interpolation method gave more suitable soil bearing capacity spatial interpolation results compared with IDW, spline and Natural Neighbour methods. Kriging had a relatively smaller error margin of 2.2274 % and R^2 of 0.9993. However, both methods cannot correctly demarcate instantaneous change of soil properties. A good example is where there is a spring and the soil tends to have a high-water content and low bearing capacity; a common phenomenon in soil mapping. GIS can therefore be used in the interpolation of soil bearing capacity.

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