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Subsurface Visualization of Peat and Soil by using GIS in Surfers Paradise, Southeast Queensland, Australia

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ABSTRACT

The subsurface conditions of Surfers Paradise in Gold Coast, Australia have been examined in terms of soil strength by using geographic information system (GIS). Spatial Analyst extension in the GIS ArcMap10 has been utilized to develop zonation maps for different depths in the study area. Depth classification scheme has been created to easily deal with each depth layer. Each depth has been interpolated as a surface to create Standard Penetration Test SPT-*N* value GIS-based zonation maps for each depth. Inverse Distance weighing (IDW) method in Spatial Analyst extension has been used to interpolate SPT-*N* values for each depth and up to R.L. -40 m. SPT-*N* value parameters N_{60} and $(N1)_{60}$ have been calculated for each depth class and for each soil type in the study area. Friction angle values and apparent preconsolidation stress values have been estimated for all the soil types. Relationships between estimated preconsolidation stress and energy-corrected SPT-N_{60} have been also performed. Further, a comparison between clean sands in eastern US and sands in Surfers Paradise is also provided.

KEYWORDS: Geographic Information System GIS, IDW, peat, SPT-*N* values, zonation map, friction angle, apparent preconsolidation stress.

INTRODUCTION

Due to the escalating in the cost of site investigation throughout the world, geotechnical data is expensive and contributes substantially to the cost of the geotechnical work. Due to the budgetary constraints, small projects are often overlooked the site characterization (Ho and Skeel 2003). Geographic Information System (GIS) made this process possible through creating a model for different areas by using the Spatial Analyst extension in the Arc Map, by joining many GIS datasets form different data sources to be unified in the GIS environment. As an applied science, GIS has been used as a vital tool in the civil engineering fields in recent years for variety of applications. Also, GIS has been widely used to create statistical models to assess landslide hazards (Carrara et al. 1991; Xie et al. 2006; Orhan and Tosun 2010). GIS, further, have been used for engineering data management (Deaton et al. 2001; Kunapo et al. 2005). GIS can be also used to estimate if a further precaution is required for a safer area in terms of foundations failure in Turkey (Orhan and Tosun 2010). They produced three SPT-*N* value zonation maps and soil type zonation maps by using Spatial Analyst IDW technique.

In fact, geotechnical characterisation of an area was an arduous task before GIS because of the demonstration of soil boreholes and geotechnical logs data (Higashi and Dias 2003). Thus, the need to the GIS inevitable through transforming all paper works into digital forms to make data quickly accessed and easily analysed.

Study Area

Surfers Paradise is the tourist destination of the Gold Coast city in Queensland, Australia. It has been an iconic tourist destination since 1950s and one of the most famous locations in Australia. The study area is located between 27.98-28.01 *S* and between 153.41-153.43 *E* (UTM zone 56) (Figure1). Nerang River is dividing Surfers Paradise into two main parts. The right part which extends as a strip along the Coral Sea has the most high rise buildings and skyscrapers. The Q1 tower is erected on this part which considers the tallest building in Australia and the 25th tallest building in the world (GCCC 2013). Further, all the soil investigation reports studied in this paper are located within this part. However, the left part of the Nerang River is mostly consisting of residential building and does not contain skyscrapers. The subsoil profile of the study area comprises loose to medium dense sand which starts from the ground surface until depth R.L. 2.3 m. The reduced level being used in this paper is based on the Australian Height Datum (AHD). A layer of medium dense to dense sand is underlain from (R.L. 2.3 m) to (R.L. -3.2 m). After that, a very dense sand stratum is encountered from (R.L. -3.2 m) to (R.L. - 20 m). Within this very dense sand layer, a multi thickness peat layer is occurred at depth between (R.L. -10 to R.L. -19.6 m) at different locations with thickness between (0.1 – 7 m). Below this layer, an interbedded firm to very stiff clay layers are found till (R.L. -26.6 m) where a layer of firm to hard clay is occurred below it until the depth (R.L. -29 m). Underneath that, interbedded layers of medium dense sand, gravelly sand, clayey sand, sandy clay, hard silty clay are existed in different locations which overlays the bed rocks. This subsoil profile is consistent with the description given by Oh et al. (2008). The depth of the bed rock ranges from (R.L. -27.3 to -44.5 m). These rocks are slightly to moderately weathered Argillite and Greywacke (sedimentary rocks) with moderately to high strong strength. Also, very strong Schist (metamorphic rock which has been metamorphosed from clays) has been encountered as a bed rock in Surfers Paradise. The water table is approximately 3.5 m below the ground surface as an average of all the locations within the study area.

Based on the available data, all the existed buildings in the Surfers Paradise are supported by rafted pile and pile foundations as a measure to avoid the peat layer underneath those buildings. Peat layer is an organic layer contains unconsolidated organic material consisting mainly of organic residues accumulated as a result of incomplete decomposition of dead plant remains under conditions of excessive moisture (Landva 2007). Construction over peat tends to be considered by many engineers as a 'Black Art'. Consequently, a great number of engineers try to avoid the adventure of construction over peat layers especially if they are without peat experience (Munro and MacCulloch 2006). Peat has an adverse effect on the settlement of foundations and the raft foundations in particular, where the highly compressive peat can bring about exorbitant settlements for buildings erected above it (Oh et al. 2008). It is generally accepted that the organic matter presence in soils causes a detriment of their geotechnical and engineering qualities (Malkawi et al. 1998).

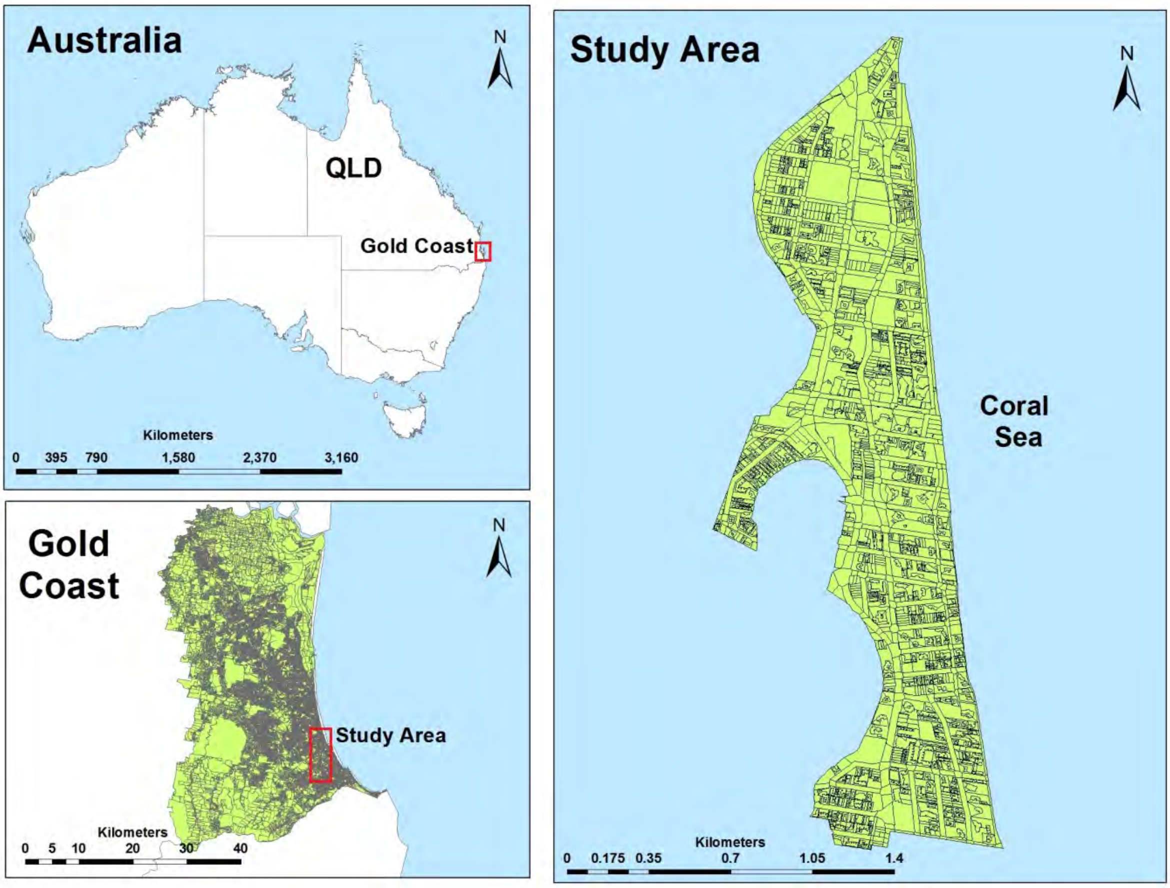

Figure 1: The location of the study area

Data Collection

Data was available in many different forms and locations. Data has been collected from 51 soil investigation reports related to the already existed high rise buildings, multi-story buildings, and other engineering structures in the study area. The total borehole numbers used in this paper is 117 boreholes and the total length of these boreholes was 4,096.5 m in depth. The study types used in this study are given in Table 1. The SPT-*N* values have been used to develop the GIS-based zonation maps to examine the soil stiffness and to determine the occurrence of peat layer in the study area.

Table 1: Summary of study types

Study Type	Unit	Value
Soil Investigation Reports	Amount	51
Number of Boreholes	Amount	117
Deepest Borehole Depth	Metres	46.45
Total SPT-N Tests	Amount	1,754
Interpolation Method	Amount	7
Depth Class	Amount	9
Depth Subclass	Amount	26
Interpolated Surfaces	Amount	26

METHODOLOGY

Two approaches have been performed in this study to extract the geotechnical data. First, the manual approach which is characterized by collecting data directly from bore logs in the soil investigation reports. The second approach was by using GETDATA software to obtain data from graphs and charts. Considerable time and effort went to the data tabulation by using Microsoft Excel to make this data familiar with the GIS environment.

Depth classification scheme has been designed to facilitate the production of the SPT-N value zonation maps (Figure 2). This scheme has an interval of every 5 m except for the first class. The first class represents the depth from the ground surface until depth R.L. 0 (AHD). Each class has three subclasses except the last class which has two classes due to the lack of data below the depth of R.L. -40 m.

Geographic coordinates have been obtained for each borehole from Google Earth based on each project's site plan. This borehole coordinate's designation has been done through accurate measurements based on each project's site plan. The distance between boreholes, the distance between the borehole itself and the adjacent streets or buildings, and the site dimensions have been used to determine the actual boreholes locations (Figure 3). Randomly selected boreholes have been checked by using GPS to validate the coordinates obtained from Google Earth.

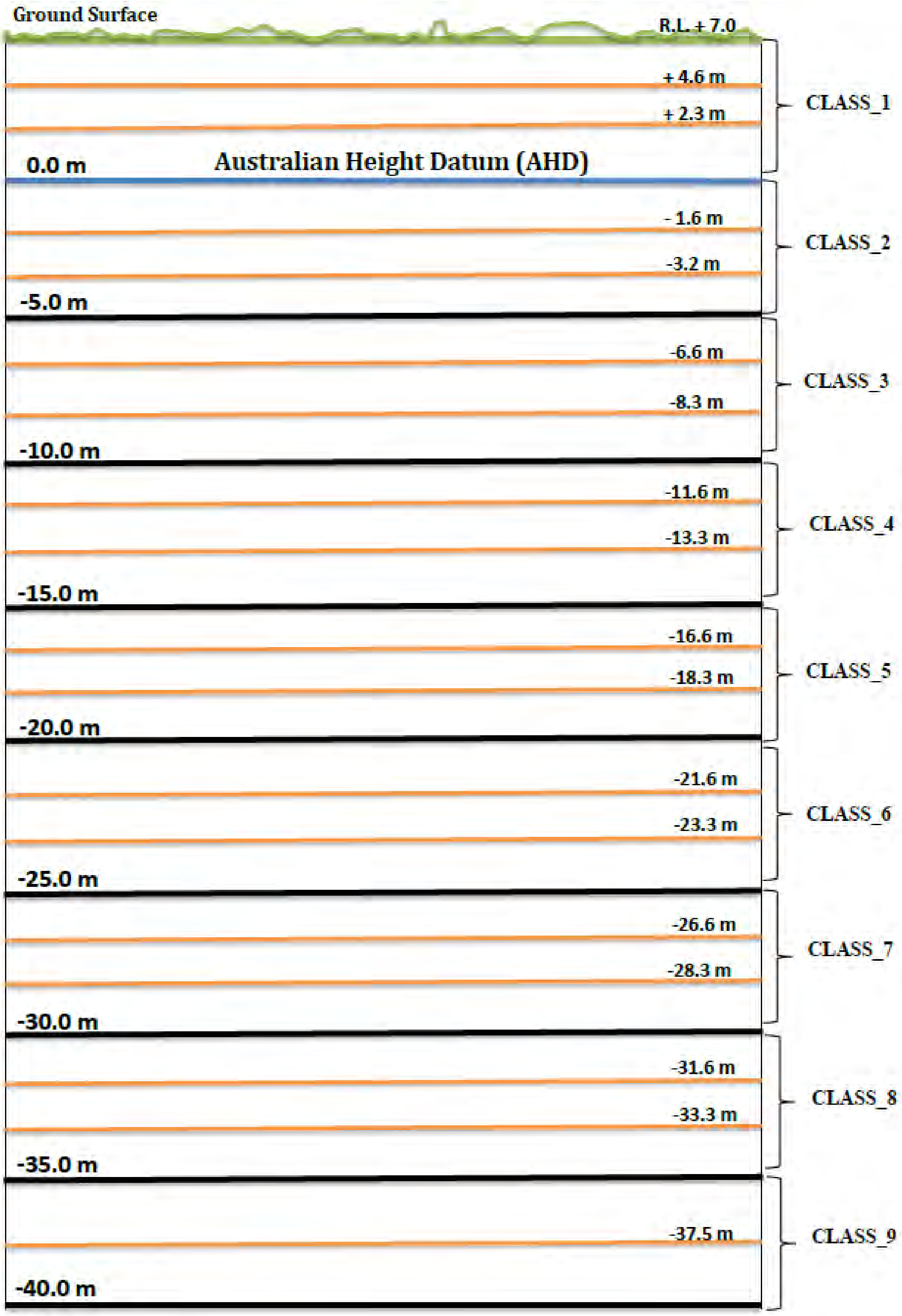

Figure 2: Depth classification scheme.

The purpose of this process is to visualize the subsurface conditions in terms of soil strength. The soil strength values of sand and clay in this paper have been classified based on the classification given by Look (2007).

Eight interpolation techniques in ArcMap10 have been used to examine which technique gives better representation for the SPT data in the study area. Inverse Distance Weighting IDW, Kriging (Ordinary and Universal), Spline, Diffusion, Global Polynomial, Kernel, and Geostatistical interpolation IDW techniques have been examined with different setting parameters to assess these methods' suitability for a better SPT data representation. The Spatial Analyst IDW technique shows a better representation for the SPT data in the study area with specific parameters.

The IDW method simply means that the attribute value of an unsampled point is the weighted average of known values within the neighbourhood. The weights are inversely related to the distances between the sampled locations and the predicted locations (Lu and Wong 2008).

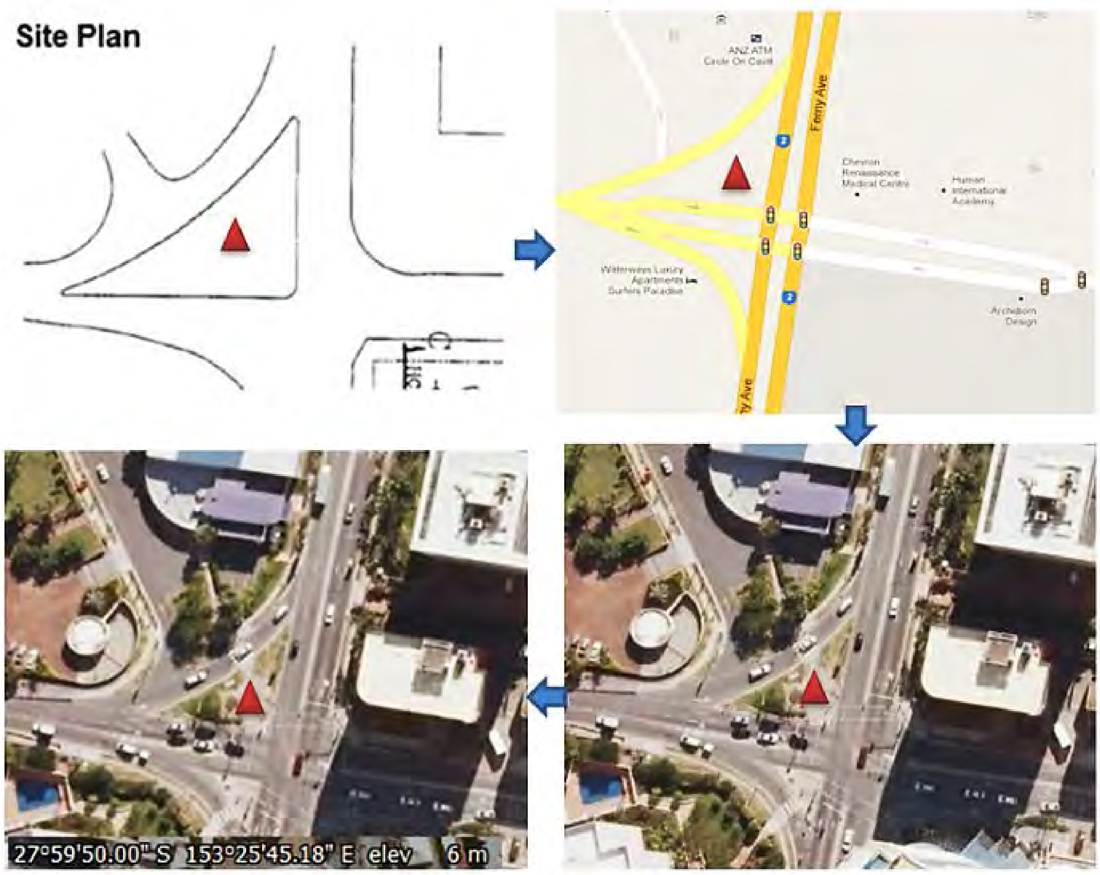

Figure 3: The steps of obtaining boreholes cordinates from a project site plan.

RESULT AND DISCUSSION

GIS –based zonation maps

Based on the depth classification scheme given in Fig 2, 26 interpolated surfaces (zonation maps) have been performed for all the depth categories within the study area. In this paper four different interpolated surfaces are provided at four different depth levels.

The first interpolated surface is located at depth between R.L. 4.6 to R.L. 2.3 m (Fig 4A) which is situated within class 1 subclass 2 based on the depth classification scheme given in Fig 2. In this zonation map, the soil type was between very loose sand to medium dense sand and the *N* values generally ranged between 1-18 blow except in two locations in the middle and north-east the study area were between 31-50 due to the occurrence of dense and very dense sand respectively.

Second, Fig 4B shows a zonation map for the depth between R.L. -11.6 to -13.3 m which is located within class 4 subclass 2 (Fig 2). Peat layer existence is distinct and obvious in the core of the study area where most of the high buildings are situated there. The SPT-*N* value ranged between 1-11 blows and the thickness of the peat layer within this depth is between 0.6-3.25 m.

In addition, the third zonation map is allocated for the depth between R.L. – 15 to -16.6 m which is located within the class 5 and subclass 1 (Fig 4C). This zonation map has also an occurrence of peat layer in five different locations and the SPT-*N* values ranged between 7 -50 blows. The lowest value was for the peat layer and the highest value for the very dense sand layer. The thickness of peat in this zonation map is between 0.45-4.5 m.

Further, the fourth zonation map is for the depth between R.L. -21.6 to -23.3 m (Fig 4D) which is located within the class 6 subclass2. The dominant soil type in this depth is firm – stiff clay and dense sand where the SPT-*N* value for the clay and sand ranged between 8-21 blows and between 13-49 blows respectively. Pockets of very loose sand, very loose clayey sand and very soft sandy clay are encountered in the core of the study area where the SPT-*N* values ranged between 0-1 blows.

It can be seen from those zonation maps that map A and B have quite similar map extent. However, map C and D have different extent from Maps A and B. The reason of that is related to the data availability in different locations at different depths within the study area.

Eight interpolation techniques have been examined to assess which technique provides the better representation in GIS. The result of examining these techniques showed that the most suitable interpolation technique that gives better representation for the SPT-*N* value data in that study area was the spatial analyst interpolation IDW with certain parameters. These parameters are: output cell size is (2.719E-05), power is (2), search radius is (fixed) and distance is (0.25). This finding is consistent with the method used by Orhan and Tosun (2010) in Turkey. The IDW method is one of the most repeatedly used deterministic model in spatial interpolation by geoscientists (Lu and Wong 2008).

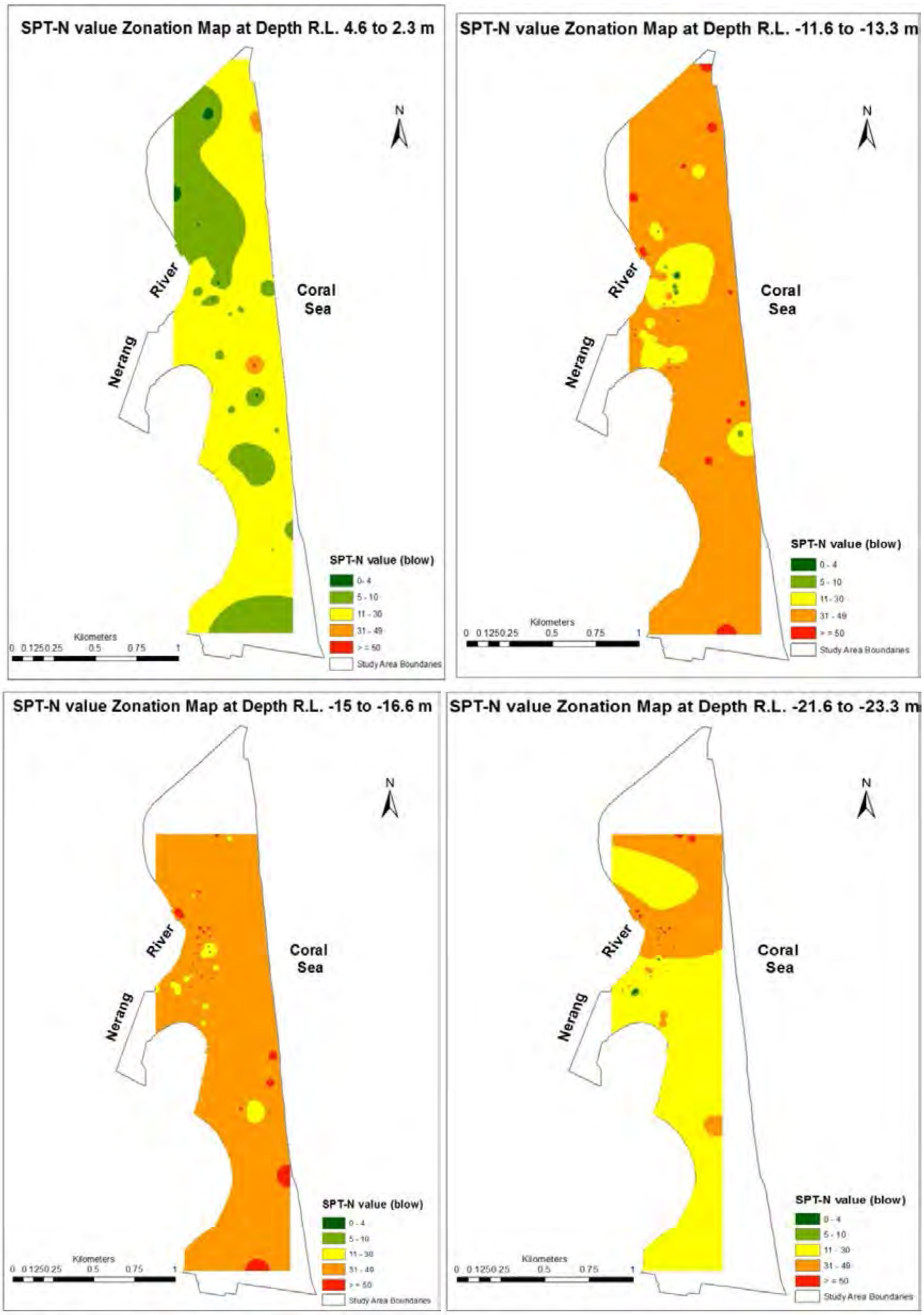

Figure 4: IDW Zonation maps for different depths within the study area.

SPT-N values parameters

Skempton (1986) suggested a correction factor based on the standard practices and the value is called N_{60} which is the corrected SPT value at 60% hammer energy. Also, he recommended an overburden correction factor to compensate for the effects of the effective stress and to adjust the measured *N* value to the corrected value to provide a consistent point of reference. This correction factor called $(N_1)_{60}$. These two factors provide better design parameters when it correlated with other geotechnical properties of soil.

These two correction factors have been applied on 1,754 SPT-*N* values to obtain the N_{60} and the $(N_1)_{60}$ values in the study area. These corrected values have been acquired as an average for all the depth classes as shown in Table 2. In addition, SPT-*N* corrected values have also been obtained for all soil types within the Surfers Paradise soil profile (Table 3). It has been accomplished as an average values as well as minimum and maximum values.

Table 2: SPT-N value parameters based on reduced level depth

Depth R.L. (m)	SPT-N Average	N_{60} Average	$(N_1)_{60}$ Average
7 - 0	17.25	17.84	21.77
0 – (-5)	38.97	40.30	36.15
(-5) – (-10)	48.89	50.55	35.09
(-10) – (-15)	35.32	36.52	16.56
(-15) – (-20)	42.39	43.83	20.04
(-20) – (-25)	29.39	30.57	20.95
(-25) – (-30)	22.4	23.16	9.43
(-30)–(-40)	27.64	28.58	10.28

Table 3: SPT-N value parameters based on soil type

Soil Type	SPT-N Average	SPT-N Range		N_{60} Average	N_{60} Range		$(N_1)_{60}$ Average	$(N_1)_{60}$ Range	
		Min	Max		Min	Max		Min	Max
Very Loose Sand	1.74	0	4	1.8	0	4.13	2.29	0	5.81
Loose Sand	7.30	4	10	7.55	4.13	10.34	11.49	5.07	18.01
Medium Dense Sand	18.7	11	29	19.34	11.37	32.05	15.7	2.88	48.63
Dense Sand	38	31	49	39.28	31.02	50.6	22.9	7.1	53.66
Very Dense Sand	50	50	>50	51.70	51.7	>51.7	31.77	11.72	87.8
Clay	13.68	0	36	14.14	0	37.2	5.39	0	32.81
Peat	8	0	22	8.27	0	22.7	4.53	0	14.22

Friction angle and apparent preconsolidation stress

Hatanaka & Uchida (1996) and Mayne et al. (2002) stated that the effective stress friction angle (φ') can be obtained from the energy-corrected *N* value of clean sands to assess the strength and stress history of sand. Based on their empirical formula which is given in Equation (1), estimated friction angle values have been obtained from the 1,754 SPT-*N* values for different types of sand (in terms of its strength) as presented in Table 5.

Also, Mayne (1992) has provided an empirical formula to estimate the apparent preconsolidation stress from the energy-corrected SPT (N_{60}) for the clean sands in eastern US (Equation 2). Thus, by applying this formula on the values of SPT N_{60} in this study, an apparent preconsolidation stress (σ_p') can be predicted for the sand in Surfers Paradise.

$$\varphi' = 20^\circ + \sqrt{15.4 * (N_1)_{60}} \quad (1)$$

$$\sigma_p' \approx 0.47(N_{60})^m * \sigma_{atm} \quad (2)$$

Where the m = 0.6 for clean quartzitic sand, m = 0.8 for silty sand to sandy silts, and m =1 for clay.

In this study m value has been calculated as 0.6 and 1 for the sand and clay respectively to obtain the apparent preconsolidation stress in Surfers Paradise (Table 4).

Table 4: Estimated friction angle and apparent preconsolidation stress in Surfers Paradise.

Soil Type	Estimated φ' Average (degree)	Estimated φ' (degree)		Estimated σ_p' Average (kPa)	Estimated σ_p' (kPa)	
		Min	Max		Min	Max
Very Loose Sand	24.81	20	29.47	59	49	113
Loose Sand	33.21	28.84	37.09	162	95	197
Medium Dense Sand	34.72	26.61	47.37	284	197	389
Dense Sand	38.09	30.47	48.75	438	382	512
Very Dense Sand	41.7	33.44	56.77	518	518	518
Clay	—	—	—	687	50	1809

Three relationships between the estimated apparent preconsolidation stress and the energy corrected SPT N_{60} have been also performed on three different types of sands in Surfers Paradise (Figure 5). Loose (Figure 5A), medium dense (Figure 5B) and dense sand (Figure 5C) relationships showed that, the highest apparent preconsolidation stress values the highest SPT N_{60} required.

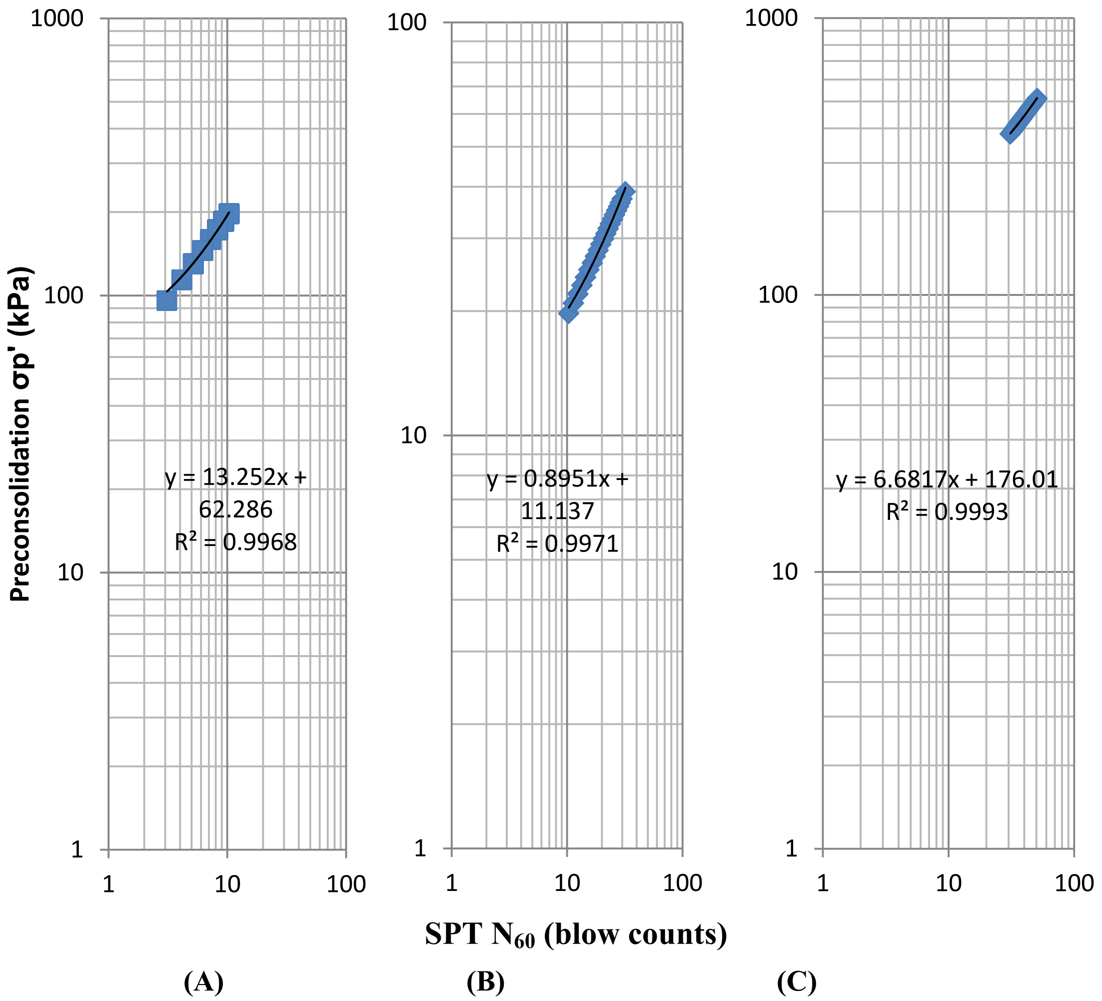

Figure 5: Estimated apparent preconsolidation stress versus N_{60} for sands in Surfers Paradise A. loose sand B. medium dense sand C. dense sand.

Three empirical formulas have been performed to determine the relationship between the apparent preconsolidation stress and the corrected-energy N_{60} value. Equation 1 shows this relationship for the loose sand in Surfers Paradise with R^2 value of 0.9968:

$$\sigma_p' = 13.252(N_{60}) + 62.286 \quad (3)$$

Where σ_p' is the apparent preconsolidation stress and N_{60} is the corrected-energy of standard penetration test (SPT) *N* value.

Also, a relationship between apparent preconsolidation stress and N_{60} has been achieved for the medium dense sand of Surfers Paradise and the R^2 value was 0.9971:

$$\sigma_p' = 0.8951(N_{60}) + 11.137 \quad (4)$$

Further, a relationship for the dense sand in Surfers Paradise has been accomplished between the apparent preconsolidation stress and N_{60} with R^2 value of 0.9993:

$$\sigma_p' = 6.6817\ (N_{60}) + 176.01 \quad (5)$$

Moreover, a comparison between the clean sands of eastern US form Mayne (1992) and the sands of the Surfers Paradise has been performed. This comparison shows that the sand behaviour of the study area is consistent with the clean sands of the Mayne's study and the R^2 was 0.986 as shown in Figure 6.

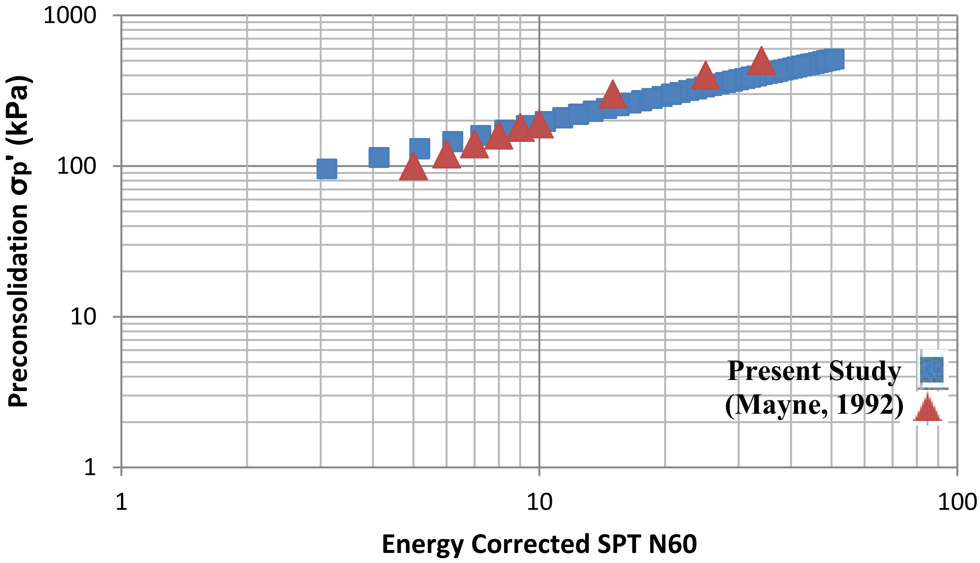

Figure 6: Comparison between clean sands in eastern US (Mayne 1992) with the Surfers Paradise sands.

CONCLUSIONS

To sum up, the following conclusions have been made:

1. The most suitable GIS interpolation technique to develop the SPT- N zonation map for the study area was spatial analyst interpolation Inverse Distance Weighting IDW method with certain parameters.
2. The Surfers Paradise soil profile is consisting of very loose sand as a top layer appears in some locations within the study area whereas; loose sand appears to be the top layer in other locations underlain by medium dense sand then very dense sand. Within the very dense sand layer, a varying thickness of peat layer is occurred at depth between (R.L. -10 to R.L. -19.6 m) at different locations with thickness ranges from 0.1 – 7 m. After that, a layer of clay is located underneath the very dense sand layer and above the bed rocks.
3. SPT-N value parameters N_{60} and $(N1)_{60}$ have been produced based on Skempton (1986) formulas from 1,754 N values for all the soil types in the study area and also for all the depth classes given in Fig 2, these parameters can be seen in Table 4 as it varies in accordance with soil type and the depth of it.
4. Friction angle values have been estimated based on empirical formulas of Hatanaka & Uchida (1996) and Mayne et al. (2002) formulas and the results showed that the average estimated friction angle very loose sand, loose sand, medium dense sand, dense sand, and very dense sand were 24.8°, 33.2°, 34.7°, 38.1°, and 41.7° respectively.
5. Apparent preconsolidation stress values have also been estimated based on Mayne (1992) formula and the results showed that the average estimated values of very loose sand, loose sand, medium dense sand, dense sand, and very dense sand are 0.5, 1.6, 2.8, 4.3,

and 5.18 bar respectively. Also, the average estimated apparent preconsolidation stress of clay in the study area was 6.87 bars.

6. Relationships between estimated apparent preconsolidation stress and energy-corrected SPT-N_{60} values for loose sand, medium dense sand, and dense sand have been performed and indicated that the more apparent preconsolidation stress the high SPT-N_{60} required.

7. Three empirical formulas have been performed between apparent preconsolidation stress and N_{60} for loose, medium dense and dense sands in Surfers Paradise. The R^2 values were between 0.996-0.993.

8. A comparison between clean sands in eastern US and sands in Surfers Paradise (in terms of the relationship between apparent preconsolidation stress and energy-corrected SPT-N_{60}) shows that the sands in Surfers Paradise fall within the same range of clean sands of eastern US.

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