GIS- Interpolated Geotechnical Zonation Maps in Surfers Paradise, Australia

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***Abstract*—Due to the escalating cost of site investigation in Australia, geotechnical data contributes substantially to the cost of engineering projects. The GIS (Geographic Information System) has been used as a vital tool in civil engineering in recent years for a variety of applications. The subsurface conditions of Surfers Paradise (as a case study) have been examined in terms of soil stiffness by using GIS. The Spatial Analyst extension in ArcMap10 has been employed to develop zonation maps for different depths in the study area. Each depth level has been interpolated as a surface to create zonation maps for the Standard Penetration Test SPT-*N* value of the soil for each depth. The Inverse Distance Weighting (IDW) method in the Spatial Analyst shows better representation for these zonation maps with certain parameters among 8 interpolation techniques.**

Keywords-soil stiffness; interpolation; Spatial Analysis, Inverse Distance Weighting (IDW); zonation maps

I. INTRODUCTION

Due to the escalating cost of site investigations in Surfers Paradise, geotechnical data are expensive and contribute substantially to the cost of the geotechnical work. Due to budgetary constraints, small projects often overlook site characterisation [1]. The GIS (Geographic Information System) has been used as a vital tool in civil engineering fields in recent years for a variety of applications. Statistical models have been developed in GIS and are widely used to evaluate landslide hazards [2][3][4]. In addition, Atkinson and Massari [5] developed a linear modelling of the susceptibility of land sliding in the central Apennines in Italy. Furthermore, GIS has been utilised to develop zonation map production and to estimate if further precaution is required for a safer area in Turkey [4]. In their study, three Standard Penetration Test (SPT) N value zonation maps have been interpolated by using GIS Spatial Analyst IDW method based on the field data [4].

In fact, geotechnical characterisation of an area was an arduous task before GIS because of complexity of soil logs and their data representation [6]. Thus, the need for the GIS which transforms all paper work (hard copies) into digital forms to make data quickly accessed and easily analysed, is inevitable. Zonation maps have been used in various disciplines providing information on slope stability, seismic microzonation, groundwater quality, watershed, vegetation, and landslide hazard assessment. In the past, zonation maps had been produced by using traditional paper maps or contour maps to show the distribution of zones within a map. Nowadays, in geotechnical engineering, for example, the zonation maps have been produced to determine the suitability of foundations in the residential area by using GIS [4]. Four case studies have been researched by Hellawell et al. [7] to verify the benefits of using GIS in geotechnical engineering in the United Kingdom. These case studies are related to small-scale geotechnical projects. The outcome of this study indicated that GIS's output enhanced the analytical and technical range of these projects in comparison with traditional techniques and the high quality maps produced are comprehensible and popular with engineers.

The Standard Penetration Test (SPT) is an in-situ test widely used because it is simple, fast conducted and low in cost [8] which had been developed around 1972 [9]. This test is used to determine soil constitutive behaviour, such as stiffness, to characterise the soil type (sand, clay, or gravel), and to provide some correlation with other properties of soil. Around 85 to 90 percent of conventional foundations are designed using SPT in North and South America [9].

In this paper, zonation maps have been developed for the soil stiffness in Surfers Paradise, Australia (see Fig.1). The purpose of this is to characterise the soil in terms of soil stiffness and to predict new SPT-N values from the existing data. This is to reduce the cost of soil investigation or at the very least to have an initial concept of the soil strength in the study area. This paper consists of, after the introduction, the methodology which has been used to achieve the results followed by presenting the results and discussion, and then, the conclusions have been drawn.

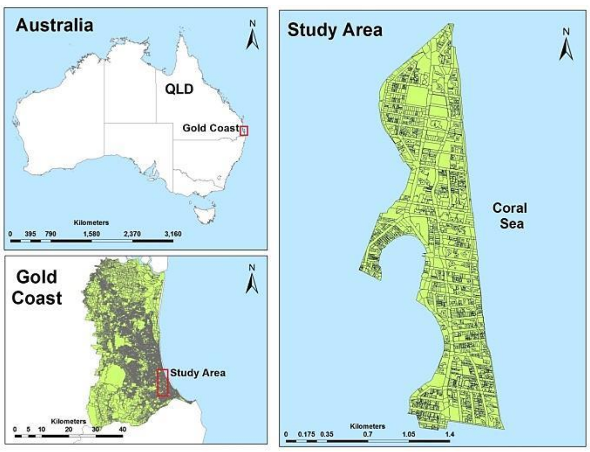

Figure 1. The study area location

II. METHODOLOGY

Data have been collected from 35 locations within the study area which extends about 1.3 by 4.0 km. Surfers Paradise is a business and tourism hub in Gold Coast city, Australia. The collected data includes 1,754 soil stiffness values which have been used as an input to the GIS. This data have been geo-referenced by obtaining the Easting and Southing coordinates from Google Earth and validated by using GPS for selected locations. In ArcMap10 and under the Spatial and Geostatistical Analyst extensions, 8 interpolation techniques have been examined in terms of their suitability to represent the SPT-N data. This has been done at the same depth which at Reduced Level (R.L. -11.6 to R.L. -13.3 m). The utilised interpolation techniques were (1) Geostatistical Analyst tools which include: Inverse Distance Weighting (IDW), Diffusion, Global Polynomial, and Kernel methods (2) Spatial Analyst tools which comprise: Ordinary Kriging, Universal Kriging, Spline, and IDW. The examination of these interpolation techniques has been done by attempting all the parameters of each method as an input to develop the SPT-N zonation maps (See Table I).

III. RESULTS AND DISCUSSION

26 zonation maps have been established from the existing Standard Penetration Test SPT-N value data by using the Spatial Analyst Inverse Distance Weighting IDW interpolation technique. Only four Standard Penetration Test SPT-N value zonation maps have been presented in this paper at depths between R.L. -1.6 m to R.L. -25 m at different depth intervals. In addition, a comparison has been done among 8 interpolation techniques to examine which technique provides better representation for the SPT-N value in the study area “see Fig. 2”. The Inverse Distance Weighting IDW interpolation technique provides better and reasonable representation for the SPT-N data among the aforementioned 8 interpolation techniques with certain parameters. These parameters are illustrated in Table II. Other interpolation techniques did not provide a correct representation. This has been discovered through matching the SPT-N values in the resulted zonation maps with the original input of the data where the resulted values was far away from the original input data. It shows that only the IDW technique provided a zonation maps with a resulted SPT-N values were very close from the original input data.

It can be seen from Table II that the power of the formula being used in the mathematical computations of the IDW technique is power 2. From the literature, Lloyd [10] utilised the power 2 of IDW to interpolate the precipitation values in the UK. In addition, Ping et al. [11] have used IDW power 2 in the exploring of spatial dependence of cotton yield in Texas.

TABLE I. THE EIGHT INTERPOLATION TECHNIQUES USED AND ITS RELEVANT PARAMETERS.

GIS Tools	Interpolation Technique	Parameters
Geostatistical Analyst	IDW	Output cell size, power, search neighbourhood, major semi axis, minor semi axis, max neighbour, min neighbour, angle
Geostatistical Analyst	Diffusion	Output cell size, number of iterations, weight field, band width
Geostatistical Analyst	Global Polynomial	Output cell size, order of polynomial, weight field.
Geostatistical Analyst	Kernel	Output cell size, Kernel function, order of polynomial, output surface type
Spatial Analyst	Ordinary Kriging	Output surface raster, semivariogram model (spherical, circular, exponential, Gaussian, linear), output cell size, search radius, number of points, maximum distance
Spatial Analyst	Universal Kriging	Output surface raster, semivariogram model (linear with linear drift, linear with quadratic drift), output cell size, search radius, number of points, maximum distance
Spatial Analyst	Spline	Output cell size, Spline type (regularized, tension), weight, number of points
Spatial Analyst	IDW	Output cell size, power, search radius (Fixed, Variable), number of points, Max distance

It has been also used for predicting and mapping of potassium soil by [12]. Other researchers have used the IDW method without mentioning to the power of this technique, such as [4]. Therefore, the value of power (2) which has been adopted in this research is considered according to [13], as a frequently used value.

Fig. 3 represents a GIS based zonation map for the SPT-N value at a depth of R.L. -1.6 to R.L. -3.2 m in Surfers Paradise. Most of the soil types at this depth have an N value of between 31 - 49 blows. This means that these soil types are dense sand, based on the soil classification given by Look [14] and based on the description provided in the soil investigation report of this location.

TABLE II. ADOPTED INVERSE DISTANCE WEIGHTING (IDW) PARAMETERS.

Method	Output cell size	Power	Search Radius	Distance
Spatial Analyst IDW	2.719E-05	2	Fixed	0.25

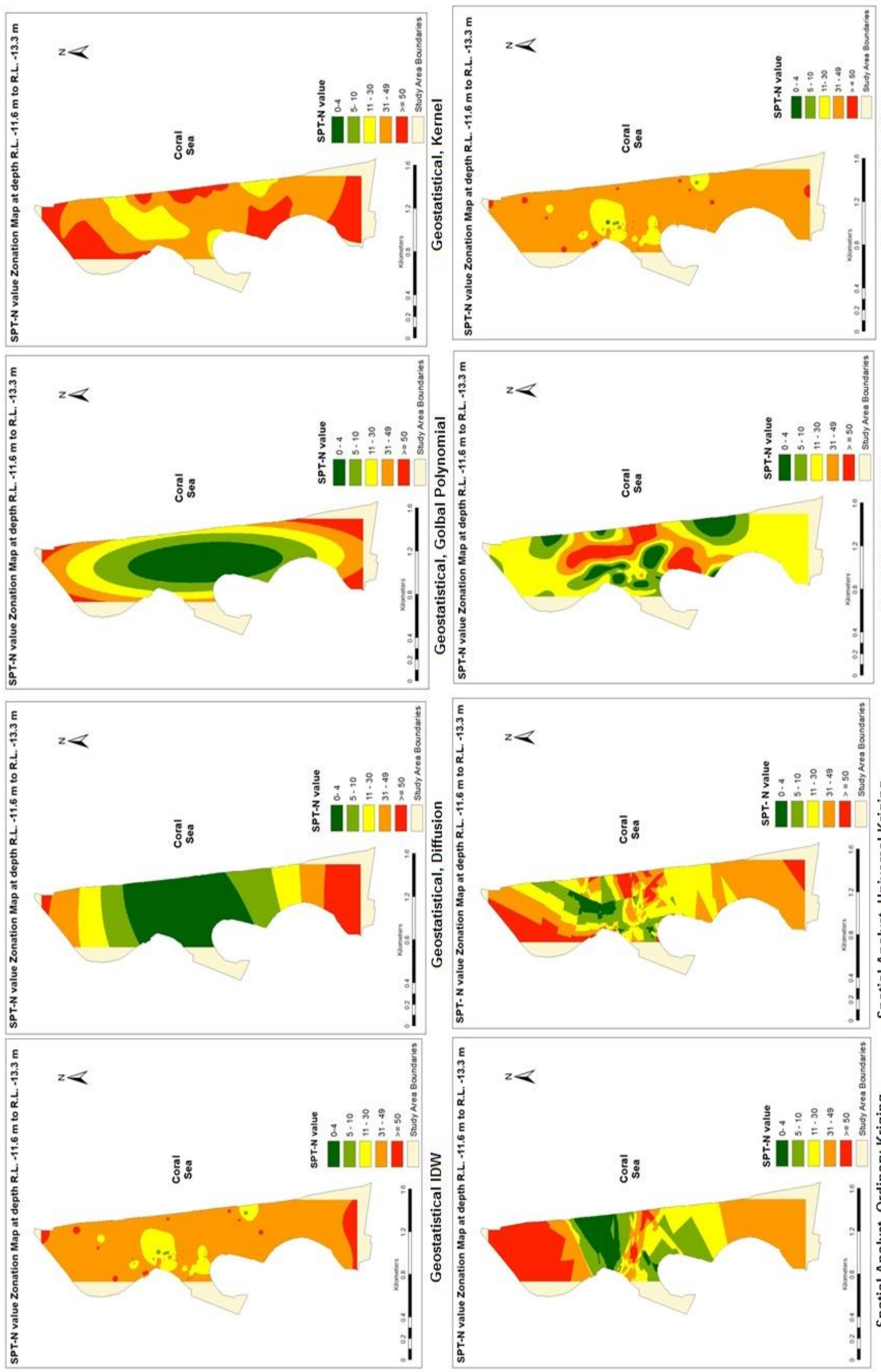

Figure 2. Comparison among eight interpolation techniques in GIS

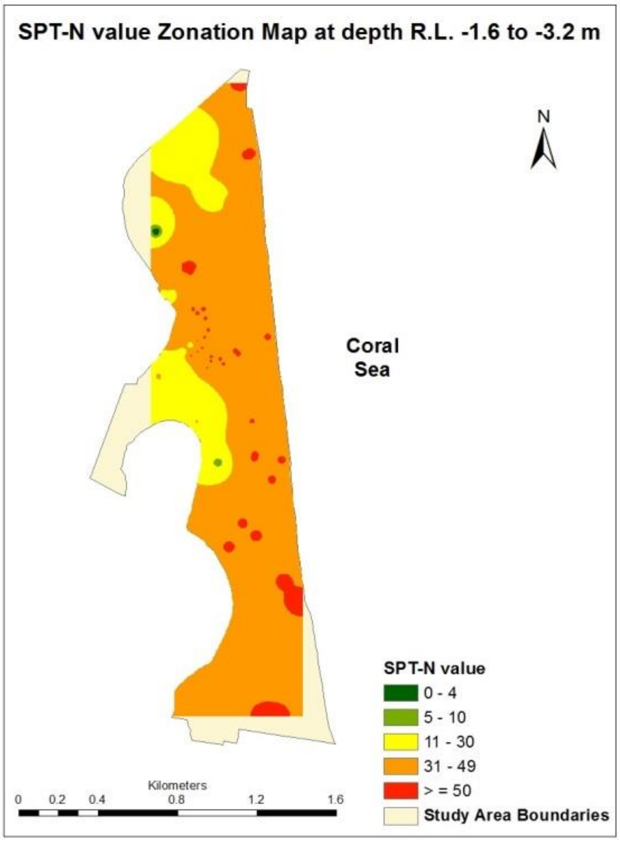

Figure 3. SPT-N zonation map at depth R.L. -1.6 to R.L. -3.2 m

However, there are some locations have an N value of between 0 to 4 and between 11 to 30 blows in the eastern parts of the study area. This reveals the occurrence of peat and medium dense sand in those locations respectively. In addition, there are well defined scattered red points throughout the map showing the occurrence of very dense sand with an SPT-N value of more than 50 blows.

Fig. 4 shows a GIS based zonation maps for the SPT-N value in Surfers Paradise at the depth of R.L. -3.2 to R.L. -5.0 m. It can be seen from this zonation map that the majority of the soil types at this depth has an N value of between 31 and 49 blows. This represents dense sand with an embedded peat and loose sand pocket in 5 different locations to the east of the study area. Also, many places have an N value of more than 50 blows which represent very dense sand.

It can be seen from Fig. 5 that the dense sand is dominant at this depth level with an N value of between 31 and 49 blows. There are some areas that have not been interpolated due to the lack of data in these locations. Further, other areas which have an N value of between 11 to 30 blows represent stiff clay to medium dense sand with few very dense sand locations in the south and north east of Surfers Paradise.

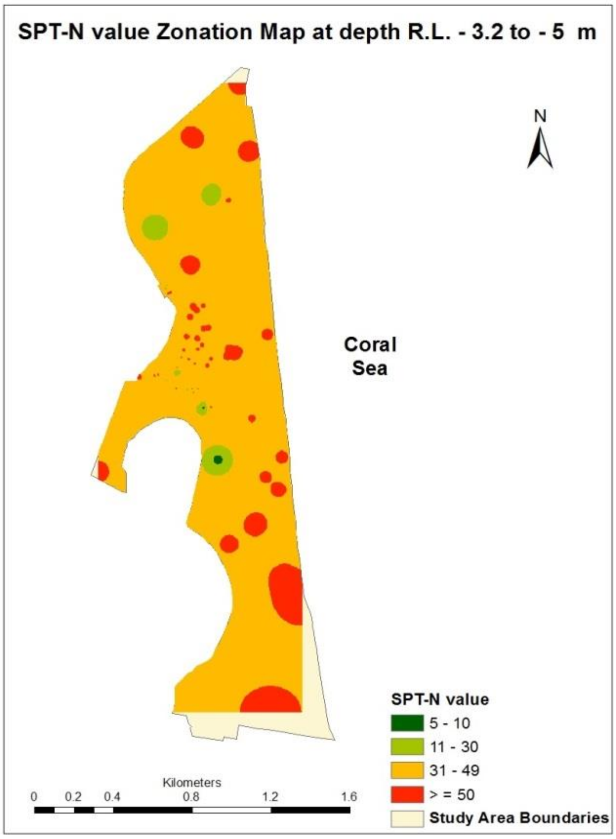

Figure 4. SPT-N zonation map at depth R.L. -3.2 to R.L. -5.0 m

Fig. 6 shows a GIS based zonation map at a depth of between R.L. -23.3 to R.L. -25.0 m in Surfers paradise.

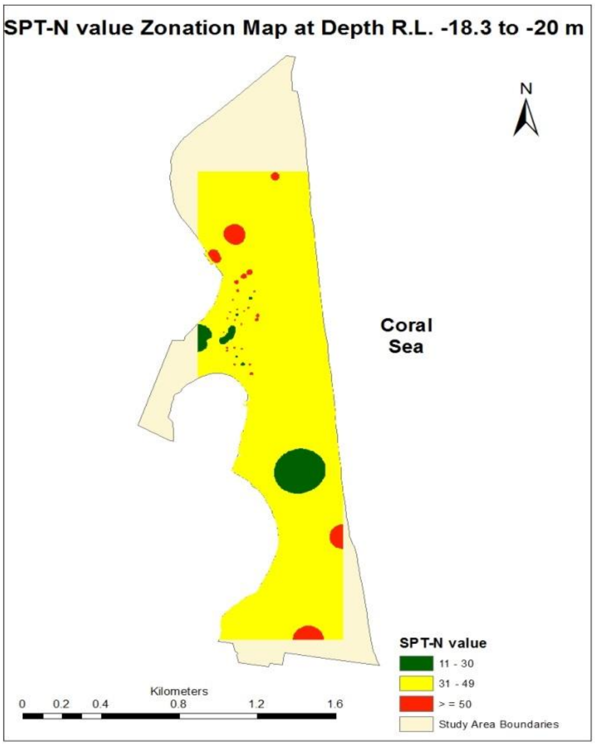

Figure 5. SPT-N zonation map at depth R.L. -18.3 to R.L. -20.0 m

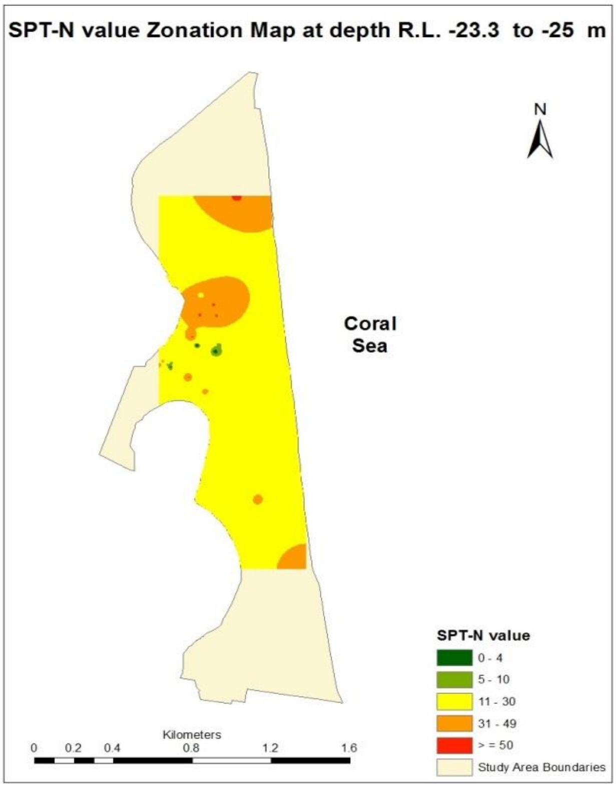

Figure 6. SPT-N zonation map at depth R.L. -23.3 to R.L. -25.0 m

It can be observed from this zonation map (see Fig. 6) that due to the lack of data in some locations at this depth level, only the centre of the Surfers Paradise area has been interpolated. It shows that the medium dense sand and stiff to very stiff clays are dominant with an N value of between 11 - 30 blows. Areas of very soft clays and very loose sand and peat have also been observed.

These zonation maps have shown a representation for the SPT-N value data for all the soil types (sand, clay, peat, and organic clay) in the Surfers Paradise area by using the IDW interpolation technique in Spatial Analyst extension of the ArcMap. This is consistent with what has been reported by Al-Ani et al. [15] and Al-Ani et al. [16]. Similarly, 16 zonation maps have been developed in a densely settled area in Turkey by Orhan and Tosun [4] to determine the suitability of foundation soils. These zonation maps showed three geotechnical properties as follows: 6 zonating the soil class, 6 zonating the SPT-N value, and 4 for the uniaxial compressive strength at 1 m depth intervals from the depth of 1 m and up to the depths of 6.5 m. They also used the IDW technique to accomplish these zonation maps.

Lu and Wong [13] stated that the IDW is one of the most frequently used deterministic models in spatial interpolation. The reason behind this is because it is easy to compute, relatively fast, and straightforward to interpret. In addition, Mueller et al. [17] stated that IDW has been used because it is simple and fast, in contrast to Kriging technique, which is time consuming and more complex than the IDW.

In the literature, there no comparison has been reported among the interpolation methods with the purpose of selecting the suitable method to represent the geotechnical properties of soil in geotechnical engineering. However, a comparison between Ordinary Kriging and the IDW has been performed by [17] to assess soil fertility management in the UK. They showed that there are many opinions regarding the most suitable method in their discipline. Some of them stated that the Ordinary Kriging is better and some stated the IDW is the better option. They suggested doing a cross validation to verify which one is the better method. However, researchers have cautioned using cross validation in the selecting of interpolation methods for mapping purposes [18] and [19]. Further, Mueller et al. [17] stated that cross validation should not be used as the sole criteria for deciding whether or not the specific interpolation method must be used over another.

The Spatial Analyst extension in GIS employs interpolation techniques to create a zonation map. The interpolation, in turn, is a procedure used to predict the values of cells at locations that lack sampled points [20]. As such, the input SPT-N value data have been used to predict SPT-N value in locations that lack sampled points. Therefore, regarding the validation of the results, the resulting zonation maps will be validated with a new data extracted from new engineering projects in the study area. However, from a geotechnical engineering point of view, the interpolated (predicted) values appear sensible as the resulted SPT-N values of the soil in certain selected locations are consistent and comparable with other engineering laboratory tests, such as dry density, moisture content, void ratio, shear strength, and compression index. These physical and engineering properties primarily indicate that there is a valid relationship between, for example, the interpolated high value of the SPT-N value (>50 blows for the very dense sand) and its related soil properties, such as high density (1.92 Mg/m^3), low moisture content (1.5 %), low void ratio (0.23%), low compression index (0.11), and high shear strength (>200 kPa). On the contrary, the resulting SPT-N values which have low SPT-N values (between 0 to 4 blows for the loose sand or organic soil), have magnitudes of low density (0.31 Mg/m^3), high moisture content (239%), high void ratio (4.7 %), high compression index (1.23), and low shear strength (25 kPa). These results are also consistent with what has been reported by Look [14] and Day [21].

Miles and Ho [22] stated that the production of cartographic quality maps or representations can certainly provide support in many pertinent decision making processes. Therefore, this paper provides GIS based zonation maps for the Standard Penetration Test SPT-N value with an aim to facilitate the recognition of the soil stiffness in the study area. In addition, it is type of subsurface visualisation of soil in terms of soil strength at different depth levels. As such, Miles and Ho [22] emphasised that the visualisation can be supplemented by spatial queries of the model results where these queries can help in identifying possible correlations between input parameters and model predictions. Therefore, this paper provides a correlation between the SPT-N values and many geotechnical properties, such as dry density, moisture content, void ratio, compression index, and shear strength.

Further, Player [23] pointed out that GIS can aid geotechnical engineers, as long as the geotechnical data has spatial attributes. Thus, the resulting GIS-based SPT-N value zonation maps can help geotechnical decision makers through providing information on soil stiffness and the occurrence of problematic peat layer in the study area.

IV. CONCLUSION AND FUTURE WORK

Based on the findings, the IDW interpolation technique showed a better representation for Standard Penetration Test N value to characterise the soil in Surfers Paradise. The IDW method has been identified as a better technique based on fixing the predicted points and comparing it with the original input points. It gives an actual representation for each input data compared with other interpolation techniques. Further, the zonation maps showed that the zonation maps developed by the IDW technique exhibited a homogenous distribution for the SPT-N value. Furthermore, the predicted points in the lack sampled areas showed a consistency in terms of the correlation with other geotechnical properties of soil.

Four SPT-N value zonation maps have been developed at various depths. As such, the subsurface profile of the Surfers Paradise area has been examined and showed the occurrence of sands, clays, and peat with various ranges of stiffness magnitudes. This paper is a part of ongoing research to characterise physical and engineering properties of soil in Surfers Paradise, Australia. The next step of this research will be a cross validation for the resulting zonation maps and expand the study area to include the entire city of the Gold Coast, Australia.

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