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The Zonation Mapping of Soil Allowable Bearing Capacity for Kabul City Urban Area Using Standard Penetration Test In GIS Environment

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Abstract:

In this study, it was aimed to map the corrected Standard Penetration Test (SPT) values and soil allowable bearing capacity in Kabul city area. For reach to this subject, borehole test results obtained from 90 boreholes were used to model the spatial variation of N_{55} values and allowable bearing capacity in an area of 365 (km^2). Corrections were made on reported N-values for depth, hammer energy, rod length, sampler and borehole diameter, to the data in hand. The zonation maps were prepared by Inverse Distance Weighted (IDW) geostatistical approach using power value (2) for depth 1.5 to 3m. This research considers the Bowles (1996) equation to evaluate the allowable bearing capacity of soil from the corrected SPT N-value and considering to 25mm allowable foundation settlement. The results revealed that the corrected SPT N-value (N_{55}) ranged between 3 and 34. Based on SPT N-value zonation map, Zone-2 is the predominant at the study area comprised of silt and clay soils with N_{55} ranged between 7 and 14. According to allowable bearing capacity zonation map, soil allowable bearing capacity ranged between 69 and 784 (kPa) and Zone 4 with moderate allowable bearing capacity is the predominant zone and covers around half of the study area generally at the central part and the east of Pole Charkhi. With comparison between soil type distribution and allowable bearing capacity zonation map, it is concluded that variation of allowable bearing capacity at the study area highly conforms to the soil type and shallow soil conditions.

Keywords: Geostatistical approach, zonation map, allowable bearing capacity, Kabul city, SPT

Introduction:

There are many places at Kabul City that soil was tested before to construct any important structures. But in low cost structure generally soil is not tested. So, with prepare a soil condition map peoples can get idea about the soil condition of any place under the area of the map. It will be helpful for constructing small and low-

cost structures (Humyra et al. 2012). Despite dense urbanization, conducting drilling and investigation in each desirable location will face to many restrictions. Moreover, in the current urbanization situation of Kabul city, executing engineering geological investigations need extensive cost to be allocated.

In this study, zonation maps for SPT N-value and bearing capacity are produced using collected and integrated SPT results extracted from collected geotechnical reports. This type of maps can give useful information about allowable pressure of foundation at each desired location of Kabul city area to designers and urban planners. Also, by using the generated maps, knowledge regarding geological engineering characteristics and allowable bearing capacity of soils can be achieved.

The results were mapped in UTM projection and the variation of corrected SPT values and allowable bearing capacity were contoured for 1.5 to 3.0-meter depth. Therefore, the main goal in this study was to model the variation of allowable bearing capacity of soil in a spatial manner by geostatistical approach and to present it for use in preliminary urban planning, land use policies, feasibility studies and further research projects.

There are many related studies which prepared SPT N-value zoning map and also developed soil bearing capacity zonation maps for urban areas around the world. The below are some literatures relevant to the subject of this study such as Khyberi et al (2013), Satrya et al (2014), Kamal et al (2015), Khani et al (2016), Afshar and Johnny (2017) and Maiki et al (2018).

In the light of these previous works, evaluation of geotechnical characteristics and bearing capacity of soils through zoning maps is a sufficient and acceptable method in purpose to concept designing of foundations in urban areas. Moreover, Excel software, geostatistical methods and GIS program were used to prepare geotechnical zoning maps in many scientific researches.

Materials and Methods:

Study Area:

The study area (Kabul city) has divided into 22 districts and situated nearly 1800 meter above the sea level within the Kabul province in the north eastern part of Afghanistan. The Kabul city is located within the latitude of 34°31´ to the north and longitude of 69°12´ to the east (Ahmadi and Kajita, 2017). This study covers an area of 365 km^2 which is covered the main urban area of the city.

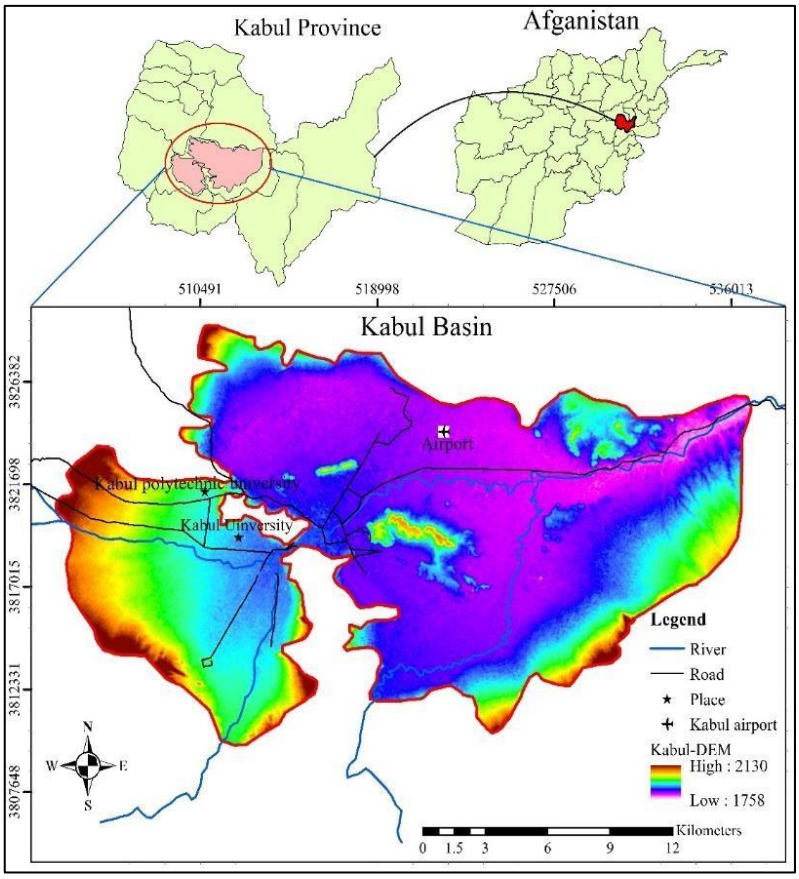


Figure 1: Geographical location of Kabul city (produced by authors)

Data:

Geotechnical data from 90 sites at scattered locations throughout the Kabul city was collected. The collected data from those locations contained standard penetration test N values, soil classification, soil stratigraphy, sub-soil characteristics. For the purpose of this study, SPT N values of 1.5 meter and 3-meter depth were extracted from the collected data and average N value from 1.5 and 3 meter was calculated to be corrected and used in bearing capacity calculation.

The distribution of the subsurface investigation locations in the study area is given in Figure 2.

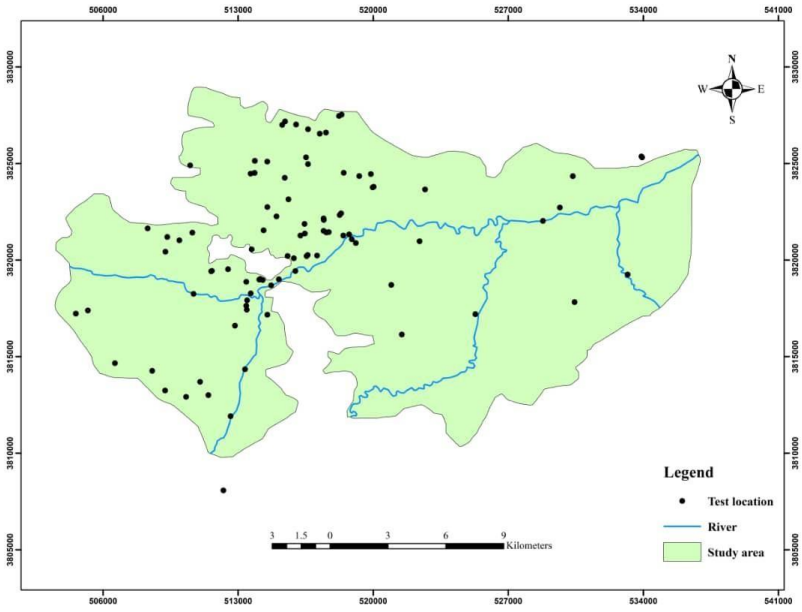


Figure 2: Distribution of soil investigation locations

Method:

The Standard Penetration Test (SPT) is one of the most popular tools for geotechnical characterization of a site primarily due to its simplicity and economy. The SPT was first standardized by the American Society for Testing Materials (ASTM) in 1958 (designation D1586-58) (Humyra et al. 2012). The process is used in many countries around the world, and is included in their testing standard, such as the ASTM D1586, BS 1377, and the JIS 1219 (Hayat, 2003), as well as the Australian Standard AS1289. Standard penetration tests are conducted by driving a standard split spoon sampler into soil at a standardized energy. Here, the standardized energy is obtained by a free-fall hammer of 63.5 kg weight falling from a height of 76 cm. By counting the number of falls, the sampler is initially driven 15 cm to the soil for passing through the disturbed part. The sum of blow counts belonging to the next two 15 cm driving is recorded as the SPT number (N-value). If the number of blows exceeds 50 for any 15 cm driving or 10 successive blows cause no penetration, „refusal" is entered into boring log (Altun et al 2013). The results are affected from many factors and discrepancies in test results are noted in the literature due to use of equipment from different manufacturers, drive hammer configurations, hammering system, use of liner inside the split barrel

sampler, overburden pressure, length of drill rod and other problems in application (Altun et al 2013).

The study focuses on the prediction of foundation soil bearing capacity based on Standard Penetration Test (SPT) N-values using empirical model in the Kabul city area. The research made use of standard penetration test (SPT) data collected from 90 soil investigation reports distributed over the study area. Computations were done based on the average that reliably represents each investigation location. The correction factors used in the study are those proposed by Bowles (1996) to standardize the field penetration number as a function of the input driving energy and its dissipation around the sampler into the surrounding soil (Salahudeen and Sadeeq 2016).

Skempton (1986) suggested that a correction factor for the energy of the drop hammer in the drill rod, as it affects the SPT-N value. In practice, the average energy ratio is about 55 to 60% of the theoretical free fall energy for the SPT.

For the calculation of allowable bearing capacity of soil, the corrected N-value "N_{55}" (SPT number at 55% of the hammer energy) was used according to Bowles (1996) recommendation. The below equation is used for the correction of SPT N-values.

$$N_{55} = E_m C_B C_S C_R N/0.55 \qquad \text{Equation (1)}$$

Where:

N_{55} = The SPT- N value corrected for field procedures to average energy ratio of 55%

E_m = the hammer efficiency

C_B = the borehole diameter correction

C_S = the sample correction

C_R = the rod length correction

N = the measured SPT- N value

The bearing capacity is a criterion for structural stability. Any structure, unless it floats, must eventually be founded on soil. The failure criterion for foundation soil is known as the ultimate bearing capacity or simply the bearing capacity of soil and is considered as one of the corner stones of soil mechanics. For such a purpose, scientists from about many decades ago tried to establish sound bearing capacity equations, which take into account the most variables encountered (AbdulRazzaq et al. 2011). For the allowable bearing pressures of shallow foundations, footing plan dimensions of 1.5m by 1.5m by 1.5m for length, breadth and depth, was respectively assumed with a safety factor of 3 in this study.

The extensive researches have been made to find out the allowable bearing capacity of shallow foundation in cohesionless soil from SPT N-value. Among them, Terzaghi and Peck (1948, 1967), Meyerhof (1956, 1965, 1974), Bowles (1968, 1977, 1982, 1988, 1997), Teng (1962), D"Allolonia et al. (1968) Parry (1977), Peck and Bazarra (1969), Peck (1974), Mohan et al. (1971), Burland and Burbridge (1985) are extensively used all over the world. Some are in graphical form and others are in equations.

This research considers the most famous method to evaluate the allowable bearing capacity of soil from the SPT N value which is Bowles (1996) equation. Authors applied the Bowles (1996) method slightly for 55% energy correction. Since water table correction is already reflected in N-value hence no need for water table correction factor. Also overburden pressure correction was not considered in this study because allowable bearing capacity is calculated in a shallow depth and effect of overburden pressure is negligible in shallow depths.

The allowable bearing capacity calculated by Bowles (1996) formula is suggested as following.

$$q_a(\text{kPa}) = 11.98(N_{55})\left(\frac{3.28B+1}{3.28B}\right)^2 F_d\left(\frac{s}{25.4}\right) \quad \text{for } B > 1.2\text{ m} \qquad \text{Equation (2)}$$

Where:

$$F_d = \text{Depth factor} = 1 + 0.33\frac{D_f}{B} \leq 1.33$$

D_f = depth of footing

B= width of footing

$$s = \text{Torable sattlement (mm)}$$

N_{55} = Statistical average of corrected N value (55% energy correction) for the footing influence zone of about 0.5B above footing base to at least 2B below.

Evaluating the allowable bearing capacities for foundations of lightly loaded structures was based on no shear failure of the supporting soil using a factor of safety 3 for an allowable settlement of 25 mm for square footings.

After calculation of allowable bearing capacity for each site, obtained data were digitized, and then they were converted into accessible format by GIS via coordinates for each location. The required steps for geographic information system (GIS) application to the geotechnical data included: (1) the creation of borehole coordinates; (2) the GIS-form borehole data preparation; (3) the spatial analysis of the geotechnical data; and (4) investigations and comparisons among different interpolation techniques. The data were tabulated so that it would be acceptable for use later in the GIS environment. ArcMap10 was designed to manage different

amounts and types of information. Importantly, the software allows the data to be represented spatially by referencing the data to its own geographical reference. For example, even though the geotechnical data are not easily represented, especially if there are many boreholes, this technique can produce zonation maps which can categorize the allowable bearing capacity of soil in the study area.

The geostatistical analyst extension in the Arc Map 10 software was utilized to interpolate the geotechnical data and generate new values for each geotechnical property. Several types of interpolation techniques exist for geostatistical and spatial analysis in ArcMap. One is Inverse Distance Weighting (IDW), which was used to characterize the Standard Penetration Test SPT-N values and allowable bearing capacity to produce the zonation maps in this study. The interpolation, in turn, predicted the values of the cells at specific locations that lacked sampled points. The main aim of this process was to provide new geotechnical properties in locations where there no data existed (Al-Ani 2015).

The mandatory fields in the process include the input point features, the z value (e.g., SPT-N value, allowable bearing capacity), and the output raster name. The optional fields in the process include the output cell size, the power, search radius, and distance, which all have specific purposes.

Each zone has its own value (or range of values) representative of this zone, which differs from other zones on the same map. To produce a zonation map in the conventional method, at least two sets of data (groups of related and organized information) are required to present a map with two different zones. These parameters were output cell size, power, search radius, and distance. These parameters show that the power of the formula used in the mathematical computations of the IDW technique was power (2).

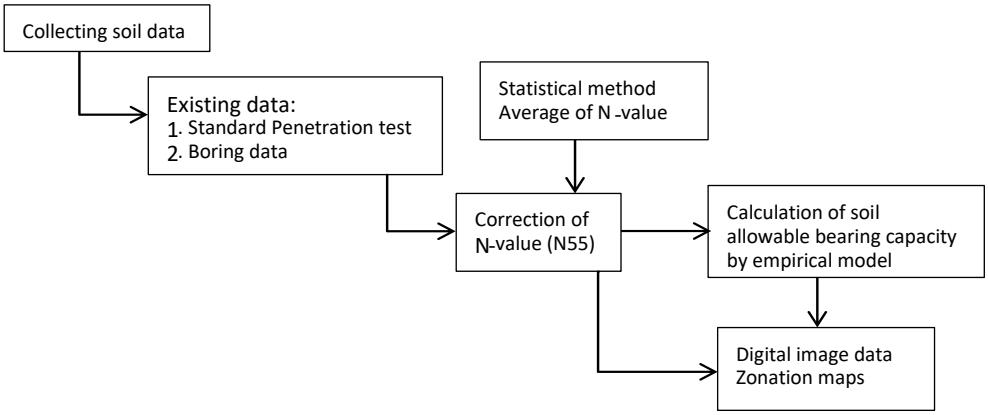


Figure 3: Flowchart of research process

Results and Discussion:

Zoning of Kabul city has been proposed on the basis of corrected SPT–N values for 3- meter overburden soils. The area was divided into five zones based on N_{55}-values that have shown in Table 1. The minimum N_{55} is found 3 and maximum is found 34 at the study area.

Table 1: Dividing N_{55}-values in five zones

Zone	N_{55} value interval	% from total 90 values
1	1 – 7	23
2	7 – 14	42
3	14 – 21	12
4	21 – 28	7
5	28 – 34	16

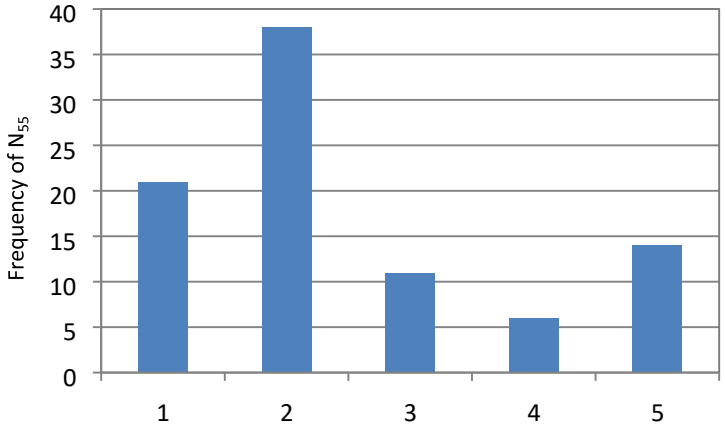


Figure 4: Frequency of N_{55} value in the study area

A histogram as well as the basic statistical analysis of the N_{55} values is given in Figure 4, which can form an opinion about the frequency of the SPT N-values in the area. It is understood that the highest histogram of the corrected SPT values is for 7 – 14, forms 42 percent of total values and lowest histogram is for 21 – 28 values, forms 7 percent of total values. The mean value of N_{55} is calculated 14. Based on N_{55} values and location of each test, zonation map was produced as shown in Figure 5.

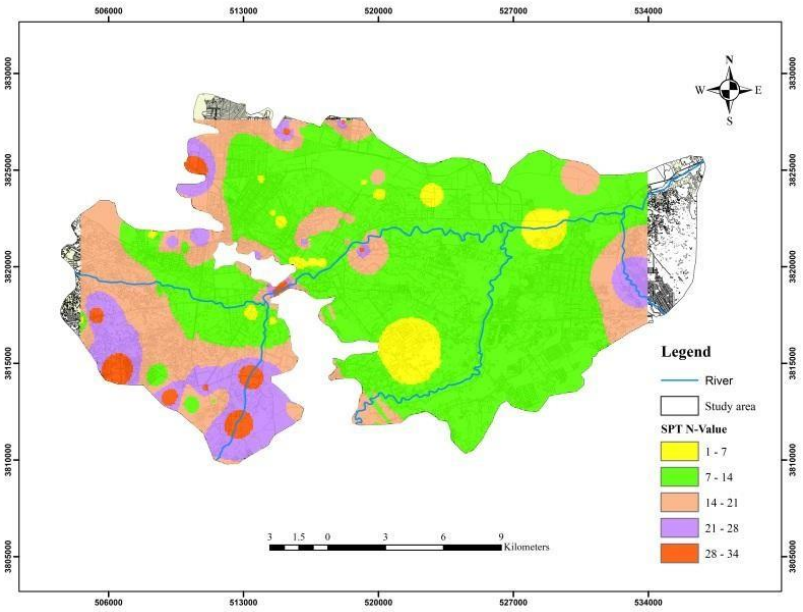


Figure 5: Zonation map of Kabul city based on corrected SPT N-values (N_{55})

As it can be seen in above zonation map, zone 5 and 4 generally are extended at southwest of Kabul city in district 6 and 13 and one small area in northwest of the area. The extension of these zones is locally and limited and complied with soil type distribution where generally gravely soils are encountered. Therefore, high N values of these two zones are related to extension of granular soils at these areas. Zone 3 with N value between 14 and 21 is encountered at several places of the study area. The larger area of Zone 3 extent at the west of Kabul city and smaller areas are encountered at northwest and east parts of study area. According to the soil type map, sandy soils are covered the area mostly where Zone 3 is extended. Zone 1 and 2 with corrected N-values between 1-7 and 7-14 cover the central and east parts of the study area where generally silt and clay soils are encountered. Based on zonation map of SPT N-value, zone 2 is the predominant zone comprised of silt and clay soils and covers more than half of the study area. On the other hand, zone 5 is the smallest zone which encountered at a few places comprised of gravely soils.

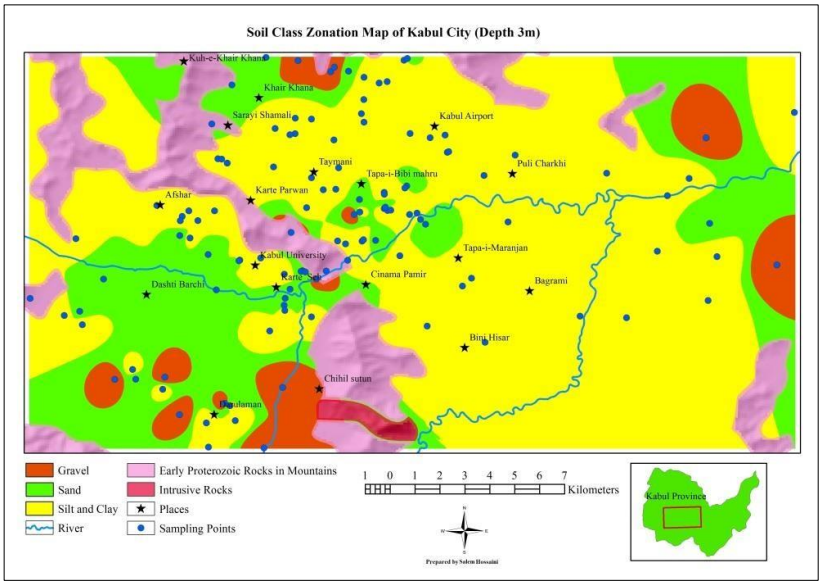


Figure 6: Zonation map of Kabul city based on soil type distribution

Evaluating the allowable bearing capacities for foundations of lightly loaded structures was based on allowable settlement of 25 mm for square footings. Allowable bearing capacities in overburden soils have been evaluated for 1.5 m wide square footings and the depth of foundation is taken as 1.5 m from natural ground level. The zonation map of allowable bearing capacity is prepared and shown in Figure 7. The basis of zonation is value of allowable bearing capacity which calculated from corrected SPT N-values (N_{55}) at the different location of study area. The study area is divided in seven zones according to Table 2.

Table 2: Classification of soil allowable bearing capacity (Ladeira and Gomes, 1994)

Zone	Qa (kPa)	Description
1	0 – 50	Extremely low
2	50 – 100	Very low
3	100 – 200	Low
4	200 - 300	Moderate
5	300 – 500	High
6	500 – 800	Very high
7	>800	Extremely high

According to the zonation map, Zone 2 and 3 with low allowable soil pressures are extended at the north part (Taymani and Kabul airport), south (Bagrami and around Logar river) and east part (intersect between Logar and Kabul river and Pole Charkhi) where the soil is weak at shallow depth and generally comprised of silt and clay. Therefore, to have increased bearing capacity proper compaction and other improvement methods of shallow layers up to the structure influence zone has been suggested for these areas.

Zone 4 with moderate allowable bearing capacity is the predominant zone which covers around half of the study area generally at the central part and the east of Pole Charkhi. Zone 5 is extended at the southwest and west of the study area and at the a few small areas around Kabul city where generally sandy soils are encountered. Zone 6 is generally encountered at three places; south part (Dogh Abad and Darulaman), southwest (Omid Sabz township) and northwest (Khair Khana) of the study area. According to the soil type map, Zone 6 is extended where generally gravelly soils are encountered. The allowable capacities for Zone 5 and 6 are fairly good at shallow depth. According to the obtained allowable bearing capacity at the study area, there is no location has allowable bearing capacity less than 60 (kPa) and more than 800 (kPa), so Zone 1 and 7 are not application in this study.

With comparison between soil type distribution and allowable bearing capacity zonation, it can be concluded that distribution of allowable bearing capacity highly conforms to the soil type and shallow soil condition at the study area.

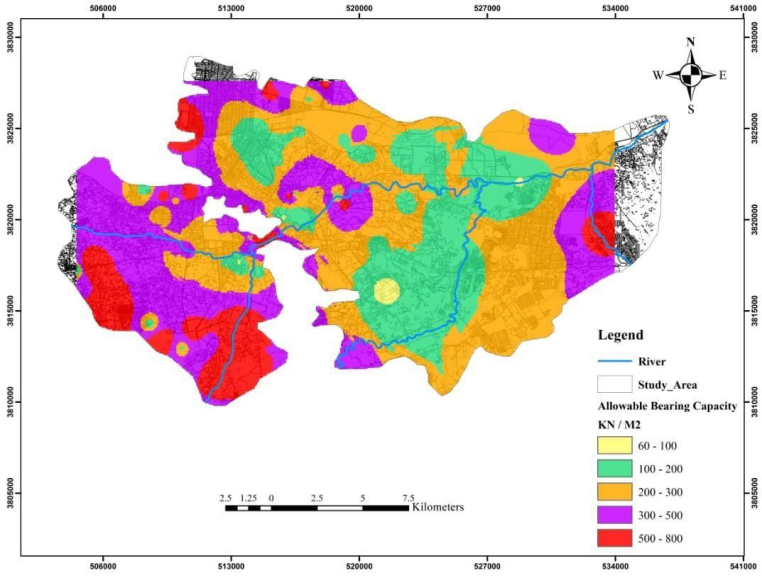


Figure 7: Zonation map of Kabul city based on soil allowable bearing capacity

Conclusions:

In this research, zonation map of soil allowable bearing capacity was prepared for square footing size 1.5m, depth 1.5m and allowable settlement 25 mm. According to soil type map, mainly area of Kabul city is located on sandy and Silt-Clay soils. At the northwest of the study area, fine-grain sediment consist of silty-clayey soils are encountered and sandy soils are encountered at small parts of the area. With respect to the soil allowable bearing capacity zonation map, some places of southwest and west of Kabul city are identified as Zone 6 with very high allowable bearing capacity value (between 500 and 800 kPa). At these locations, generally soil material consists of sands and gravels.

In direction toward east and mountain areas, thickness of alluvium deposits is being decreased and at the some parts of northwest area, soil allowable bearing capacity is high and located in Zone 5. Then toward the central parts of Kabu city, soils have a moderate allowable bearing capacity as Zone 4. In continue at the central parts toward east, Zone 2 and 3 extend with allowable bearing capacity between 50-100 and 100-200 (kPa). These eastern areas consist of fine-grain soils such as silt and clay.

It can be concluded that soil allowable bearing capacity at the study area from southwest and west toward north and central parts have a reduction trend and then toward northeast and east values of allowable bearing capacity are increased. The zonation of soil allowable baring capacity is related to soil texture at the study area.

With respect to the change in soil texture and fine-grain soil types in the central parts of Kabul city and weakness of soils with low bearing capacity in this part, soil improvement methods are recommended to be considered in the foundation design and construction planning.

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