Teknik Dergi, 2018 8731-8751, Paper 521

A Moisture Index Map of Turkey for Design of Slabs Resting on Expansive Soils by the GIS Approach

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ABSTRACT

Expansive soils commonly exist in the arid and semi-arid regions of the world. Climate change causes large volume changes in these soils depending on variation of the soil moisture content. Several design procedures are available for upper structures built on expansive soils in order to prevent the damages due to volume changes of expansive soil. Although there are some methods developed for use in design of slabs resting on expansive soils, project planning information is needed locally in regions where this type of soil exists. The most important parameter of this knowledge is moisture index. For this purpose, many moisture index calculations are given in literature. In this study, Thornthwaite Moisture Index (TMI) described by Thornthwaite (1948) was calculated by using rainfall and temperature records for an average period of sixty-three years of 81 stations of Turkey. The data were received from General Directorate of Meteorology. Later TMI values belonging to each station are arranged in tables. As a result of this comprehensive study, the values of TMI determined for each station were used to prepare a TMI map of Turkey by using Geostatistical Analyst Module of ArcGIS 10.0 software and Kriging interpolation method. The study provides climate of region and the parameters related to structure and soil to be taken into account in design of slabs resting on expansive soils. It is believed that this map would be used intensively for the design of slabs resting on expansive soils in Turkey.

Keywords: Expansive soil, thornthwaite moisture index, slab design, geographic information system, Turkey.

1. INTRODUCTION

Soils, changing volume due to variance in their water content, are called expansive soils. Expansive soils tend to swell up as their water contents increase and are encountered in many places on earth. In Turkey, expansive soils exist in many cities such as Ankara, Artvin, Çankırı, Çorum-Sungurlu, Edirne-Enez, Giresun, İstanbul, Konya, Ordu-Fatsa-Ünye, Tokat-Resadiye and Trabzon. When designing slabs which are in direct contact with expansive soils, interaction between the soil and the slabs is usually not taken into consideration and

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Note:

- This paper has been received on March 22, 2018 and accepted for publication by the Editorial Board on September 04, 2018.
- Discussions on this paper will be accepted by January 31, 2019.

- DOI: 10.18400/tekderg.408814

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slab designs are achieved by assuming soils as elastic mediums. It is possible to accept this approach to some degree for soils which do not change their volume with seasonal change. But in projects where airports and especially highways that pass thorough expansive soils are in question, this volume changing feature of the soil should be taken into consideration (Mitchell and Soga 2005). Usually coatings and buildings are built in a time when the top of the soil is dry. In this way, evaporation is prevented by coating and the soil swells up due to water that is kept within the soil. Swelling of soil with high plasticity causes heavy damages in light weight construction (houses, warehouses, small industry buildings and coatings). In 1973, a research showed that 60% of foundations which are on expansive soils are subjected to different foundation movements (Brown 1987). As a result, it is stated by researchers that the cost of damages caused by volume change of the soil is more than twice the cost of cumulative damages caused by floods, hurricanes and earthquakes (Rao 1988; Holtz 1984). It is obvious that if swelling behavior of soil is not taken into consideration before construction, damages will increase in years to come (Aytekin 1992).

It is possible to consider pavements, airport or parking lot coverings, thick mats or similar structures as slabs which are built on the soil. There are many suggested methods for slab designs which are placed directly on soils. These methods (Winkler method, Vlasov method, Modified Vlasov method etc.) usually assume soils as semi-infinite elastic mediums. However these approaches yield unreliable results for slabs resting on expansive soils. There are several realistic methods in literature for designing slabs which have direct contact with expansive soils (Alonso et al. 1999; BRAB 1968; Lytton and Ramesh 1970; Walsh 1974; Fraser and Wardle 1975; Wray 1978; Holland and Lawrance 1980; Sanchez et al. 2005; Sanchez et al. 2012; Wray and Lytton 1980; Wire Reinforcement Institute 1981). The common feature of suggested methods is to take into consideration climate of the area, soil parameters and parameters related to the structure. The most important parameter of these is the moisture index. The importance of moisture index is that the climate factor can be represented within the design. There are many moisture index calculation methods in the literature for this purpose. Moisture calculation methods in the literature firstly consider climate classification. Even though the first formula called moisture factor for climate classification was given by Linsser (1869), the climate classification system of Köppen (1900) is the most widely used classification system all around the world. Then it was followed by Transeau (1905), Walter (1910), Penck (1910), Oldekop (1911), Lang (1915), Köppen (1918), Meyer (1926), De Martonne (1926), Emberger (1930), Crowther (1930), Angström (1936), Wilson (1936), Trumble (1937), Giacobbe (1938), Gardner (1942), Gorczynski (1943), Thornthwaite (1948), Budyko (1948), Prescott (1949), Lauer (1952), Bagnouls and Gaussen (1957), Crowe (1957), Erinç (1965) and Aydeniz (1988).

When methods suggested for slab design on expansive soils are examined, it is seen that the Post Tensioning Institute (PTI) method presented by Wray and Lytton (1980) is the most widely used method. In most of these methods, soil swelling under slabs is examined for two situations. One situation is the center lift in internal parts under the slab and the second one is swellings near slab edges. These are called “center lift” and “edge lift” in sequence. PTI design method is based on slabs resting on semi-infinite elastic mediums. When obtaining design data inputs, Thornthwaite Moisture Index (TMI) of the construction area should be determined first. Then edge moisture variation distance should be determined by using the TMI value. After this, “center lift” and “edge lift” values can be calculated with these two values by using the relationship between TMI value given by Wray (1989) and the edge moisture variation distance.

There are many factors affecting swelling capacities of soil. Soil features and environmental factors are on the top of the list. Soil properties are the content of clay, mineralogy, soil–water chemistry, soil suction property, plasticity, soil structure and dry density. Initial moisture conditions and moisture variations are considered as common environmental conditions, which influence swelling potential of soils. For this purpose, many researchers tried to develop their own countries' moisture index maps in order to include the climate and soil parameters of the areas subject to projects while designing light structures on expansive soils. Isozaki (1933) made the moisture map of Japan by using annual rainfall and evaporation values of 99 stations in Japan. Later on, Wilson and Savage (1936) made Ohio's, and Thornthwaite (1931) made North America's moisture index maps. Angström (1936) published northwest Europe's moisture index map. Following this, Church and Gueffroy (1939) made a similar map for America using Angström's formula. Setzer (1946) made the moisture index map of Sao Paulo state of Brazil by using Setzer index which is identical to Angström's index.

The formulas and methods used to calculate moisture index are usually based on relationship among meteorological factors like rainfall and temperature. But Thornthwaite method added water storing capacity as a third factor to these two factors. When results are examined, it is seen that this method gives more detailed and accurate results.

Maps showing TMI change from area to area are prepared by researchers in both the state scale maps and those for whole of the USA (Thornthwaite 1948; Aitchison and Richards 1965; McManus et al. 2003) and other countries, then center and edge lift values are tried to be estimated by using TMI values (Aitchison and Richards 1965; McManus 2003; Aitchison and Richards 1969; Nelson and Miller 1992; Fityus et al. 1998; Evans et al. 1998; Fox 2000; McManus et al. 2004; El-Garhy and Wray 2004; Osman et al. 2005; Osman and McManus 2005; Osman et al. 2005; Osman et al. 2007; Osman 2007).

Despite the fact that these maps are prepared in almost every developed country, we feel the absence of these maps which are very helpful in the design stage. In this study, Average monthly rainfall and temperature records for 63 years were taken from Turkey's Meteorology Head Office in order to calculate the Thornthwaite Moisture Index. Since manual processing of excessive meteorological data is an overwhelming and demanding process, a computer code in MATLAB has been developed in order to calculate TMI values. It is obvious that a computer code designed for this subject would shorten the time for computations and increase reliability of the results obtained. "Kriging" interpolation method located in Geostatical Analyst module of ArcGIS 10.0 software was applied in order to enter TMI values to the project correctly without recalculating for settled areas located in intermediate zones. For this reason TMI values of 81 stations for chosen areas are entered into the Turkey Database by using the self-developed computer code and by applying Kriging interpolation method, TMI distribution map for 81 stations in Turkey was obtained. With this study, a reference was developed that avoids long calculations and makes it easy for designers to take into consideration climate of the area, soil and structure parameters in slab design. This map is expected to be a helpful tool for geotechnical engineers to obtain better land usage planning and to take precautions for damages caused by expansive soils.

2. STUDY AREA

Turkey is located between Western Asia (the Anatolian peninsula) and South-eastern Europe (the Balkans) (approximately between 36°-42° north latitude and 26°-45° east longitude) and covers 783.602 km² of land. With semiarid climate features, it lies between mild climate and subtropical climate of the North hemisphere. Being surrounded by seas in 3 sides, it has range of mountains along the northern and southern shores, subject to sudden height changes and their proximity to the shores change the climate in short distances. Rainfall amount changes as well according to climatic features. Southern parts of the country are affected by Mediterranean climate which is similar to subtropical climate and northern parts are affected by Black Sea climate which is rainy throghout the year. Internal parts are affected by dry steppe climate which is mostly dry. Cold weather masses in north (pole) and hot weather masses in south (tropics) affects the country seasonally. Turkey has land forms belonging to every age and type geologically. Being a high and mountainous country, it is even higher than the highest continent Asia (1.010 m) with 1.132 m. North and East are surrounded by high mountains. Turkey's height feature is identified by Northern Anatolian Mountains in the North and Taurus Mountains in the East.

For this study, information for 81 stations in Turkey, which represent Turkey, is taken from the Meteorology Head Office. Data about these 81 stations include monthly average climate and rainfall amount for 63 years which are evaluated. 1950-2012 periods are used for climate and rainfall data. A detailed research was carried out in order to determine Turkey's TMI distribution through chosen stations.

3. METHODOLOGY

3.1. Determination of Thornthwaite Moisture Index

Soil moisture is important in many hydrological processes and also a key factor for plant growth, land degradation, flood generation and drought mitigation. It has an important effect on the partitioning of precipitation in surface runoff, infiltration and groundwater recharge (Tavakoli 2012; Tavakoli and Smedt 2013). Scientists have tried in various ways to determine moisture index. Some of these are taking soil samples and Time Domain Reflectometry (TDR). But because having limited time and lacking equipment and labor force, measurements can only be made in certain areas and in certain times. For this reason, researchers tried indirect methods to determine land moisture. For this purpose, formulas and methods used to calculate moisture index are based on the relations between meteorological factors such as rainfall and temperature. In addition to this, several hydrological data are needed to estimate moisture index of a region such as temperature, precipitation, evapotranspiration and potential evapotranspiration. In addition, the index is used in areas like climate clasification, hydrological characterization for water management, environmental studies, and agricultural planning to define land use and agricultural practices (Dourado-Neto et al. 2010).

There are many moisture index calculations in literature. One of these is the Thornthwaite Moisture Index Method proposed in 1948 by Thornthwaite. The most important advantage of the method over other methods is that it takes water storing capacity of soil as an additional parameter in addition to rainfall and temperature data of the chosen area.

In this study, the Thornthwaite Moisture Index (TMI) has been determined for Turkey as the index for potential evapotranspiration. TMI is defined as the amount of water, which would be returned to the atmosphere by evaporation from the ground surface and transpiration, by plants if there was an unlimited supply of water to the plants and soil.

It is impossible to estimate condition of soil that is dry or wet, it must be known that whether the rainfall is more or less than the amount of water needed for evaporation and transpiration. When there is a water surplus and no water deficiency (D), the relation between water surplus (S) and water need constitutes an index of humidity, I_h, Eq. (1). Similarly, when there is a water deficiency and no surplus, the ratio between water deficiency and water need constitutes an index of aridity, I_a, Eq. (2).

$$I_h=100S/PE \tag{1}$$

$$I_a=100D/PE \tag{2}$$

Where; PE: Potential evapotranspiration. When there is no rainfall and water deficiency is equal to water that is needed, aridity index is equal to 100%. The ratio of aridity index to humidity index is about 6/10. Thus, moisture index that is called the Thornthwaite Moisture Index can be expressed as in Eq. (3) and Eq. (4).

$$TMI = I_h - 0.6I_a \tag{3}$$

$$TMI = \frac{100S - 60D}{PE} \tag{4}$$

Table 1. Thornthwaite Moisture Index Values of Climatic Types (Thornthwaite 1948).

Climatic Type	**Moisture Index (TMI)**
A - Perhumid	100 and above
B_4- Humid	80 to 100
B_3 - Humid	60 to 80
B_2- Humid	40 to 60
B_1- Humid	20 to 40
C_2- Moist Subhumid	0 to 20
C_1- Dry Subhumid	(-20) to 0
D - Semiarid	(-40) to (-20)
E – Arid	(-60) to (-40)

The Thornthwaite Moisture Index is used on an annual basis to provide an indication of the overall potential evaporation and rainfall balance. A positive index value indicates a net surplus of soil moisture characteristic of a wet climate while a negative index value shows net soil moisture characteristic of dry climate. Regions with a Thornthwaite Moisture Index between –20 and –40 are classified as semiarid areas, and a Thornthwaite Moisture Index of less than –40 indicates arid areas (Table 1).

In order to calculate the TMI value, monthly average temperature and rainfall height data belonging to long years for each station, should be evaluated, potential evapotranspiration, water deficiency and water surplus values should be calculated and a water balance-sheet chart should be drawn up.

3.1.1. Working out Water Balance

In arid regions, potential evapotranspiration may exceed the free water evaporation rate, when the amount of necessary water is increased, the value of evapotranspiration is maximum that is described as potential evapotranspiration. Potential evapotranspiration cannot be measured directly but estimated experimentally. In order to estimate the evapotranspiration for a region, a variety of approaches are available as seen in Table 2 (Schulz 1976).

In the relation of potential evapotranspiration and average temperature of a ceertain month, a month is taken as 30-day, and each day is assumed to have 12-hour exposure to sunlight. Potential evapotranspiration is estimated by Eq. (5).

$$PE=cta \tag{5}$$

In Eq. (5), t is monthly average temperature (ºC). Constants a and c vary from a location to location. Thus, estimated a and c constants could be used for warm climates but cannot be used for cold climates. In general, a and c in the formula are smaller for cold climates, and larger for hot climates. To this end Eq. (6) is given as follows;

$$i=(t/5)1.514 \tag{6}$$

Temperature index can be calculated by summation of 12 months’ temperatures Eq. (7). Temperature index can vary between 0 and 160.

$$I=\sum i=\text{temperature index} \tag{7}$$

Where; i: temperature index and I: total temperature index. In eq. 5, constant a can vary between 0 and 4.25. The relationship between I and a is given in Eq. (8).

$$a=0.000000675\,I^3 - 0.0000771\,I^2 + 0.01792\,I+0.49239 \tag{8}$$

Therefore, potential evapotranspiration can be found by Eq. (9).

$$PE=1.6(10t/I)^a \tag{9}$$

Table 2. Equations for Computation of Evapotranspiration (Schulz 1976)

Equations	Required Climate Data
Averaging Daily Temperature Equations	
Lowry-Johnson	Temperatures of different seasons
Thornthwaite	**Temperature**
Blaney-Criddle	Temperature, sunlight %, crop coefficient
Averaging Daily Temperature and Sunlight Equations	
Jensen-Haise	Temperature, light spreading
Turc	Temperature, light spreading
Grassi	Temperature, light spreading, crop coefficient
Stephens-Stewart	Temperature, light spreading
Averaging Daily Temperature and Moisture Equations	
Blaney-Morin	Temperature, sunlight %, crop coefficient, relative moisture
Hamon	Temperature, absolutely moisture, sun light %
Hargreaves	Temperature, sunlight %, crop coefficient, relative moisture
Papadakis	Temperature, saturated vapor pressure
Complex Equations	
Penman	Temperature, light spreading, wind moisture
Chritiansen	Temperature, relative moisture, spread, wind, sunlight %, crop coefficient, altitude
Van Bavel	Temperature, light spreading, wind, moisture

Some corrections must be made on the value of PE found by Eq. (9) due to the number of days in a month in a year vary from 28-day to 31-day. Also, sunlight is not available 12-hours in a day throughout a year. Corrected PE values are given in Table 3.

In order to determine potential evapotranspiration, average monthly temperature must be realistic and the location of the region must be known. Potential evapotranspiration can be estimated from a chart that is shown in Fig. 1. In Fig. 1, the vertical axis shows logarithm of temperature, and the horizontal axis shows logarithm of non-corrected values of potential evapotranspiration. There is a linear relation between the vertical axis and the horizontal axis. In Fig. 1, all lines pass through from point Y at which t=26.5°C and PE=13.5 cm. Slope of this line is described as temperature index of the station. Thus, i values in Eq. (6) are calculated for average monthly temperature. Then, temperature index can be found from value of Σi, which is equal to I. Once, value of I is known, a straight line from I to point Y is drawn in Fig. 1. Then, the potential evapotranspiration is determined by drawing a vertical line from the intersection of the straight line and the horizontal line of average monthly temperature. Fig. 1 can only be used for the temperature value of 26.5°C and below it. For other temperatures greater than 26.5°C, the potential evapotranspiration values can be taken from Table 4.

Table 3. Potential Evapotranspiration Correction Rates for Turkey (Kızılkaya 1998)

Nor. Lat.	Jan.	Feb.	Mar	Apr	May	June	July	Aug.	Sept	Oct.	Nov	Dec.
0°	1.04	0.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
5°	1.02	0.93	1.03	1.02	1.06	1.03	1.06	1.05	1.01	1.03	0.99	1.02
10°	1.00	0.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99
15°	0.97	0.91	1.03	1.04	1.11	1.08	1.12	1.08	1.02	1.01	0.95	0.97
20°	0.85	0.80	1.03	1.05	1.13	1.11	1.14	1.11	1.02	1.00	0.93	0.94
25°	0.93	0.89	1.03	1.06	1.15	1.14	1.17	1.12	1.02	0.99	0.91	0.91
26°	0.92	0.88	1.03	1.06	1.15	1.15	1.17	1.12	1.02	0.99	0.91	0.91
27°	0.92	0.88	1.03	1.07	1.16	1.15	1.18	1.13	1.02	0.99	0.90	0.90
28°	0.91	0.88	1.03	1.07	1.16	1.16	1.18	1.13	1.02	0.98	0.90	0.90
29°	0.91	0.87	1.03	1.07	1.17	1.16	1.19	1.13	1.03	0.98	0.90	0.89
30°	0.90	0.87	1.03	1.08	1.18	1.17	1.20	1.14	1.03	0.98	0.89	0.88
31°	0.90	0.87	1.03	1.08	1.18	1.18	1.20	1.14	1.03	0.98	0.89	0.88
32°	0.89	0.86	1.03	1.08	1.19	1.19	1.21	1.15	1.03	0.98	0.88	0.87
33°	0.88	0.86	1.03	1.09	1.19	1.20	1.22	1.15	1.03	0.97	0.88	0.86
34°	0.88	0.85	1.04	1.07	1.20	1.20	1.22	1.16	1.03	0.97	0.87	0.86
35°	0.87	0.85	1.03	1.09	1.21	1.21	1.23	1.16	1.03	0.97	0.86	0.85
36°	0.87	0.85	1.03	1.10	1.21	1.22	1.24	1.16	1.03	0.97	0.86	0.84
37°	0.86	0.84	1.03	1.10	1.22	1.23	1.25	1.17	1.03	0.97	0.85	0.83
38°	0.85	0.84	1.03	1.10	1.23	1.24	1.25	1.17	1.04	0.96	0.84	0.83
39°	0.85	0.84	1.03	1.11	1.23	1.24	1.26	1.18	1.04	0.96	0.84	0.82
40°	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81
41°	0.83	0.83	1.03	1.11	1.25	1.26	1.27	1.19	1.04	0.95	0.82	0.80
42°	0.82	0.83	1.03	1.12	1.25	1.27	1.28	1.19	1.04	0.95	0.82	0.79
43°	0.81	0.82	1.02	1.12	1.26	1.28	1.29	1.20	1.04	0.95	0.81	0.77
44°	0.81	0.82	1.02	1.13	1.27	1.29	1.30	1.20	1.04	0.95	0.80	0.76
45°	0.80	0.81	1.02	1.13	1.28	1.29	1.31	1.21	1.04	0.94	0.79	0.75
46°	0.79	0.81	1.02	1.13	1.29	1.31	1.32	1.22	1.04	0.94	0.79	0.74
47°	0.74	0.80	1.02	1.14	1.30	1.32	1.33	1.22	1.04	0.93	0.78	0.73
48°	0.76	0.80	1.02	1.14	1.31	1.33	1.34	1.23	1.05	0.93	0.77	0.72
49°	0.75	0.79	1.02	1.14	1.32	1.34	1.35	1.24	1.05	0.93	0.76	0.71
50°	0.74	0.78	1.02	1.15	1.32	1.36	1.37	1.25	1.06	0.92	0.76	0.70

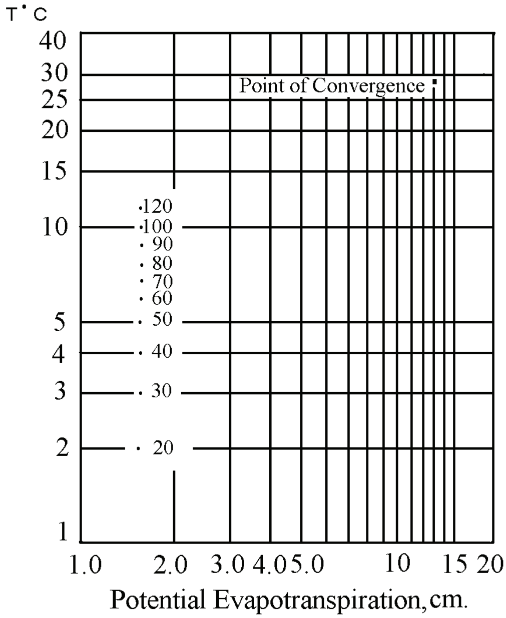

Figure 1. Nomogram for Determining Potential Evapotranspiration (Thornthwaite 1948)

Table 4. Potential Evapotranspiration Values for Using at Higher Temperatures (Thornthwaite 1948)

TEMPERATURE (C°)	POT. EVAPOTR. (cm)	TEMPERATURE (C°)	POT. EVAPOTR. (cm)
26.5	13.5	32.5	17.53
27.0	13.95	33.0	17.72
27.5	14.37	33.5	17.90
28.0	14.78	34.0	18.05
28.5	15.17	34.5	18.18
29.0	15.54	35.0	18.29
29.5	15.89	35.5	18.37
30.0	16.21	36.0	18.43
30.5	16.52	36.5	18.47
31.0	16.80	37.0	18.49
31.5	17.07	37.5	18.50
32.0	17.31	38.0	18.50

In calculations, useful water reserve is taken 100 in first months (This reserve will decrease in the following months). According to this, two alternatives are possible for calculations. These are:

- Initially, if height of rainfall, P_i, for a month is greater than corrected potential evapotranspiration, actual evapotranspiration is taken to be equal to the potential evapotranspiration. In this case, the difference between rainfall and potential evapotranspiration would increase soil moisture. Then, excess water in soil pores would start to flow after the soil moisture reaches its maximum value.
- Finally, if height of rainfall for a month is less than potential evapotranspiration, corrected evapotranspiration is equal to the difference between corrected potential evapotranspiration and water that is needed.

At last, Thornthwaite Moisture Index is calculated by entering water deficiency, water surplus and potential evapotranspiration values as in Eq. (4).

In order to prepare Thornthwaite Moisture Index map for Turkey; monthly average rainfall and temperature values of long years for each station are taken from the Meteorology Head Office, these values are entered into the water balance-sheet table, and by using calculations explained above TMI values are calculated for each station. Entering these values one by one, doing long calculations to find TMI values, and especially using charts and tables extensively may cause mistakes. Therefore, a computer software in the MATLAB language is developed and TMI values of 81 stations were calculated with the help of this program. The flow chart of this program is given in Fig. 2.

As an example, calculation for the water balance-sheet table of the Adana station is given in Table 5.

3.2. Preparation of Moisture Index Map by Using GIS

GIS software is used efficiently to store geological, geotechnical and hydraulic data and to determine prospective disaster areas (Wikle 1991; Dai et al. 2001; Türkoz and Tosun, 2011). At this point of the study, "Kriging" interpolation method located in Geostatical Analyst module of ArcGIS 10.0 software was applied in order to enter TMI values to the Project correctly without recalculating for residential areas located in intermediate zones. Kriging interpolation method is an interpolation method which predicts optimum values of data by using data obtained from close locations. The basis of the Kriging method depends on regional variables theory. Positional changes in events presented by heights are homogeneous statistically along the surface. Surface is described as sum of these 3 main components; a structural component which consists of a constant average or a trend, a random but locational correlated component, and a locational noncorrelated mistake term (Martensson 2002). Kriging method uses a weight model which helps obtaining figures affected by closer points (Krige, 1966). This method is similar to the predominantly average method.

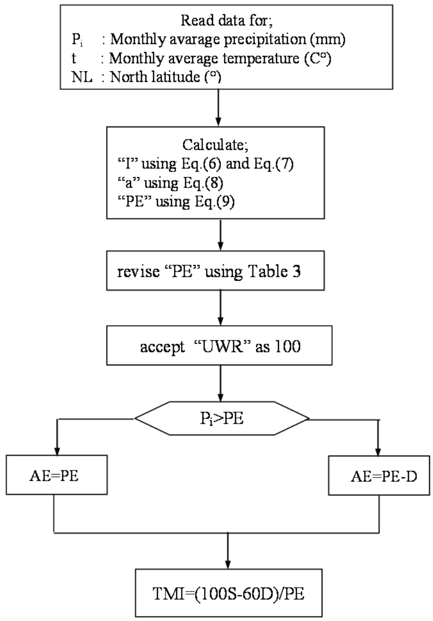

Figure 2. The flowchart for calculation of TMI

General equation of the Kriging Method is;

$$Z_P = \sum_{i=1}^{n} W_i \, Z_i \tag{10}$$

Where;

Z_P : Searched undulation value of point P;

W_i: Weight values equivalent to each;

Z_i value in the account of Z_P; Z_i: Undulation values used in the account of Z_P;

N: Number of points used in the account of Z_P.

The most important feature of the Kriging method which separates it from other interpolation methods is that it calculates variance value for each predicted point or area. This shows the reliability degree of predicted value. It is proved that Kriging method is a geostatistical interpolation method which could be used in many areas and it is very popular (Golden Software 1999). Data were needed in order to apply "Kriging" interpolation method which is situated in Geostatical Analyst module in ArcGIS 10.0 software. For this reason, calculated TMI values of 81 stations in chosen areas were entered into the Turkey database separately. Later the Kriging interpolation method was applied and the TMI distribution map was prepared as in Figure 3.

Table 5. Water balance-sheet table for the Adana Station

Months	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Temper.	9.2	10.4	13.1	17.0	21.3	25.1	27.6	28.0	25.3	20.9	15.7	11.1
Precipit. (mm)	112.4	95.4	68.6	53.9	48.3	19.9	4.4	4.5	15.3	38.3	66.6	119.1
i	2.5	3.0	4.3	6.4	9.0	11.5	13.3	13.6	11.6	8.7	5.7	3.3
Potans. Evapotr (cm)	1.6	2.0	3.2	5.5	8.6	12.1	14.6	15.1	12.3	8.3	4.6	2.3
Correct. Coeffic.	0.9	0.8	1	1.1	1.2	1.2	1.2	1.2	1	1	0.8	0.8
Correct. Pot. Evp. (mm)	13.5	16.9	33.1	60.1	105.4	148.4	183.0	176.4	126.3	80.7	39.5	19.1
Storage Change	0	0	0	-6.2	-57.1	-36.6	0	0	0	0	27.1	72.9
Storage	100.0	100.0	100.0	93.8	36.6	0.0	0.0	0.0	0.0	0.0	27.1	100.0
Actual Evapotr. (mm)	13.5	16.9	33.1	60.1	105.4	56.5	4.4	4.5	15.3	38.3	39.5	19.1
Water Defic.	0	0	0	0	0	91.9	178.6	171.9	111.0	42.4	0	0
Water Surplus	98.9	78.5	35.5	0	0	0	0	0	0	0	0	27.1

Total Surplus= 240.0 Total Deficiency= 595.7
Total Corrected Potential Evapotranspiration = 1002.4
Thornthwaite Moisture Index= (100*240-60*595.7) / 1002.4 = -11.7

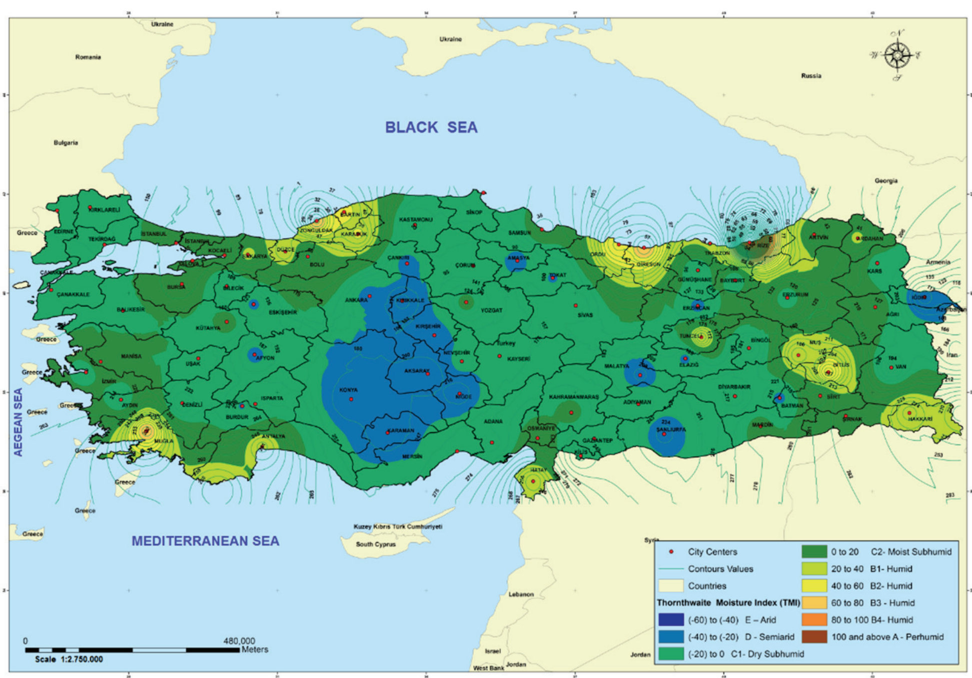

Figure 3. Thornthwaite Moisture Index Distribution of Turkey

4. RECOMMENDATIONS FOR DESIGN OF SLABS RESTING ON EXPANSIVE SOILS

Clayey soils having the potential to shrink or swell are widely encountered throughout the world but this potential is only realized in climates that have periods of adequate rainfall followed by extended periods without sufficient rainfall. These semi-arid conditions are particularly evident in the central and eastern parts of Turkey. The danger of potentially high swelling soils in a region of wet climate is less from swelling and more from soil shrinkage during periods of little or no rainfall. Conversely, if the site is in an area that has low rainfall and the climate remains relatively dry throughout the year, there is more opportunity for large differential swelling to occur. Therefore, the engineer needs some environmental indicator or knowledge of the climate at the site in consideration in order to estimate the potential severity of the shrink-swell activity of the soil on which the foundation would reside.

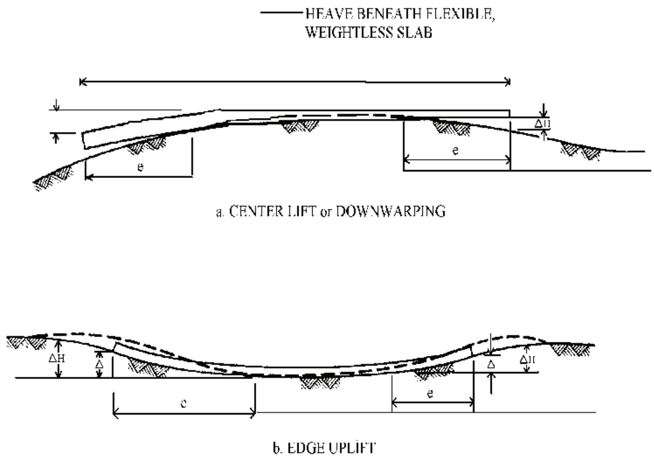

Figure 4. Soil Slab Displacements on Heaving Soil (Wray 1989)

If slabs or mat foundations rest on expansive soils, some damages are expected to occur on the superstructures as well. Therefore, climatic conditions for a region must be taken into account during the design of these types of structures. Eight design parameters should be known for designing of slabs which have direct contact with expansive soils. These eight parameters include three soil and five structural quantities. When slab is to be constructed over expansive soils, climate has to be considered as a ninth parameter. For this purpose, maximum differential heave (ΔH) and edge moisture variation index (e_m) has to be known. Vertical swelling or heave of expansive soils under a covered area such as mat foundations or slabs on ground could occur as edge lift or center lift. The center lift occurs when trees around the structure grow up and take water from the underlying soil. Another reason for the center lift could be the construction season. When the surface of an expansive soil is covered during a wet season, and a long period of an arid season would follow, soil moisture content is decreased along the edge of the covered area so that contraction occurs around the edge of the covered area. Thus bending of the structure begins around its edges (Fig. 4a.). Edge lift or dish-shaped heaving may be observed relatively soon after the construction. The removal of vegetation leads to incremental variance in the soil moisture. The removal of vegetation leads to incremental variance in the soil moisture (Fig. 4b).

The study which explains slab design in expansive soils, the appropriate designs for Turkey, and its details after modifications on proposed method is carried out by İkizler and Aytekin (2009).

In İkizler and Aytekin (2009)'s study as described in detail, in the design of a slab on ground or a mat foundation, Thornthwaite Moisture Index (TMI) is taken from Fig. 3. Then, the edge moisture variation distance (e_m), one of the design parameters in the design of slab on expansive soil, could be taken as a function of TMI from Fig. 5.

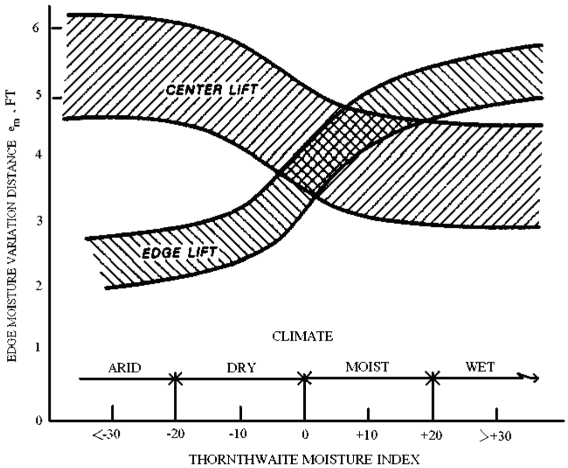

Figure 5. Approximate Relationship Between the Thornthwaite Moisture Index and the Edge Lift-off Distance (Wray 1989)

5. CONCLUSIONS

Design of slabs on expansive soils is different than it is for regular soils. Despite the fact that there are many methods in literature for this design, it is seen that the Post Tensioning Institute (PTI) method is used most widely. In order to use the method, Thornthwaite Moisture Index (TMI) values of the construction area are needed. For this reason, TMI maps are prepared in most countries and they are made use of in design work. In Turkey, while preparing designs, TMI maps of other countries which have a similar climate to Turkey are used. In order to eliminate this deficiency and determine TMI values for Turkey in general, meteorological values such as monthly average temperature and rainfall for 63 years (1950-2012) of 81 stations in Turkey are obtained from the Meteorology Head Office. Then, using these two values for each station, water balance-sheet table is prepared by entering the values of monthly stored water, water deficiency, water surplus and corrected and non-corrected monthly evapotranspiration. Preparing this water balance-sheet table is the most important part of the methodology. After preparing water balance-sheet table, using related formulas, TMI values are calculated. Even though values of stations are taken from the table, values of intermediate areas can be different than the chosen station. In order for the engineers to achieve designs in a fast and reliable way and to enter values to the design effort without dealing with long calculations, TMI values are entered into the Turkey database through the ArcGIS 10.0 software and by applying Kriging interpolation method located in software's Geostatical Analyst module, TMI distribution map of Turkey's 81 stations is prepared.

When the map created for Turkey by applying Thornthwaite moisture index is examined, it is seen that northeast of Turkey is perhumid, North is humid, Northwest and West is moist subhumid. If we split the Southern regions into 6 equal parts, it can be classified as humid-moist subhumid, dry subhumid, humid, dry subhumid and moist subhumid-humid. East is usually dry subhumid and semiarid. West of internal parts is dry subhumid, and east of internal parts is humid-moist subhumid. According to the map prepared in this study, 50% of Turkey is dry subhumid, 30% is moist subhumid and 20% is humid. Having dry soils in high amounts shows how important it is considering the climate of the construction area, parameters of soil and structure carefully evaluated while working out the TMI values while designing slabs. By taking this value quickly and accurately from every point on the map prepared in this study for Turkey, state of the climate could be reflected to the Project at hand accurately. With this study, a very useful source is provided to designing engineers which avoids long calculations and makes it easy with this work to take climate of the area, soil and construction parameters into consideration in the design.

Symbols

The following symbols are used in this paper:

ΔH : maximum differential heave;

AE : actual evapotranspiration (mm);Fa

a : constant depending on temperature;

c : constant depending on temperature;

D : water deficiency;

e : lift-off distance;

e_m : edge moisture variation distance;

GIS : Geographic Information System;

i : temperature index;

I : total temperature index;

I_a : index of aridity;

I_h : index of humidity;

N : number of points used in the account of Z_P

PTI : Post Tensioning Institute

P_i : monthly avarage precipitation (mm),

PE : potential evapotranspiration (cm);

S : water surplus;

t : monthly average temperature (ºC);

T : temperature (ºC);

TDR : Time Domain Reflectometry

TMI : Thornthwaite moisture index.

UWR : Useful water reserve

W_i : weight values equivalent to each Z_i value in the account of Z_P

Z_i : undulation values used in the account of Z_P

Z_P : searched undulation value of P point

Acknowledgments

The Office for Scientific Researches Projects of Karadeniz Technical University has financially supported this study (Project No:112.001.2). Used in the study the average 68-year meteorological records for all the provinces are provided by the General Directorate of State Meteorological Service (DMI). The author wishes to express gratitude to Karadeniz Technical University and the authorities of the General Directorate of State Meteorological Service for their support and provision of data.

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