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Augmenting in Situ Lake Level Measurements with Earth Observation Satellites

Ahmet Emre TEKELİ[1]

ABSTRACT

In this article, Ice, Cloud and Land Elevation Satellite (ICESat) altimeter data were used with Moderate Resolution Imaging Spectroradiometer (MODIS) snow cover maps to determine Akşehir Lake/wetland water levels, which dried up in 2008. Since the water level dropped below the gage in 2004, the ICESAT-MODIS (ICEM)-based lake water levels could not be compared with gage levels. Instead, combined use of Landsat satellite based lake surface area studies and Akşehir Lake bathymetry (LAB) enabled ICEM assessment. ICEM and LAB differences are between -0.09m and 0.32m and close to the standard deviations (s.d.) of pure ICESat-based studies (0.02m-0.27m). The minimum and maximum water surface elevation changes of ICEM between consecutive winter and spring are 0.30m and 1.35m and are in the historical range. ICEM showed highest s.d. during October 2005, when the wind velocities were highest.

Keywords: ICESat, GLA14, laser altimeter, Akșehir Lake, water level, MODIS, landsat, drying lake.

1. INTRODUCTION

Wetlands, in addition to the water they hold, have been considered important ecosystems due to the ecological and biological diversity that inhabit them. The diminishing fresh water resources in addition to the rising population have increased the importance of protection and sustainable management of wetlands. Turkey is considered an important nation in the Middle East and Europe, having wetlands with different ecological characteristics and being on two out of four important bird migration routes in the West Palearctic Region [1]. As wetlands are sensitive areas from ecological and biological perspectives, monitoring and sustainable management of wetlands have been topics of many environmental studies. The Lakes Region, located in southwestern Turkey, includes a number of lakes and wetlands that have been included in the Wetlands Treaty -also known as the Ramsar Treaty [2]. Unfortunately, water levels of lakes in the Lakes Region have been declining due to the changing climate. Akșehir Lake/Wetland (AL/w), being among the five biggest lakes in the region, has

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experienced reduction of water levels [3-5]. Water levels in AL/w had been measured by gage level readings that were made during on-site visits performed monthly since 1975. However, in 2004 AL/w's water level had fallen below the gage's level. Since then, no water level reading has been obtained. AL/w totally dried up in 2008.

In-situ gage measurements form the backbone of main data collection for environmental studies and provide ground truth observations for accuracy assessment of Earth observation satellites. However as in AL/w case, gage(s) can be obsolete for various reasons such as climate change and/or human intervention. Moreover, owing to initial investment and operational costs, installing gages everywhere is not possible. Besides, in-situ observations may not provide the high temporal and spatial data required, such as when monitoring lakes and wetlands. Remote sensing (RS), especially with high temporal and spatial data availability spaceborne RS, have long been used in wetland area and lake water level monitoring [6-8]. Remotely-sensed images obtained from different regions of electromagnetic spectrum optic [9,10] and radar [11-13] have long been used primarily in the detection and monitoring of changes in lakes and wetlands. Besides, water levels in these sensitive areas have also been investigated as a secondary mission.

With its long history, Landsat provides a large remotely-sensed image database that can be used in different studies focusing on change detection such as forestry, urban growth, water resource management [14-19]. There are studies demonstrating successful applications of Landsat imagery in water resource management [3, 4, 5, 20, 21]. The aforementioned studies investigated either lake surface variations or coastline changes of Turkish lakes using Landsat images.

Geoscience Laser Altimeter System (GLAS) is the first spaceborne laser altimeter that enabled water level measurements from space [22] between February 2003 and February 2010. To the best of author's knowledge, no accuracy assessment of GLAS-derived water surface elevations over Turkish Lakes have yet been performed.

In this study, the usability of GLAS-derived water surface elevations (WSE) over AL/w, Turkey is tested. What makes this study distinct from previous GLAS studies is that AL/w completely dried in 2008. During the recession, water surface elevations of AL/w are derived from GLAS measurements. Since WSE fell below the gage's level in 2004, GLAS-derived WSE could not be compared with in-situ observations. Instead, GLAS-derived WSE are compared using WSE obtained from the combined use of lake bathymetry and lake surface area information obtained from Landsat satellite images. The general concept of in-situ measurements is to provide ground truth observations to remote sensing. However, as indicated in this study, the combined use of various satellite-based Earth observations can provide WSE of a drying lake during its recession and supply additional information to environmental studies even in cases where in-situ observations may be inadequate or unavailable.

2. THE STUDY AREA

Akşehir Lake/wetland (AL/w), located in the Akarçay Basin between 38^{0} 24' - 38^{0} 37' N latitudes and longitudes 31^{0} 18 '- 31^{0} 35' E (Figure 1a), is an important lake among the seven other lakes in the Lakes Region (LR) of Turkey [23] and is known to be the fifth biggest lake in Turkey [24].

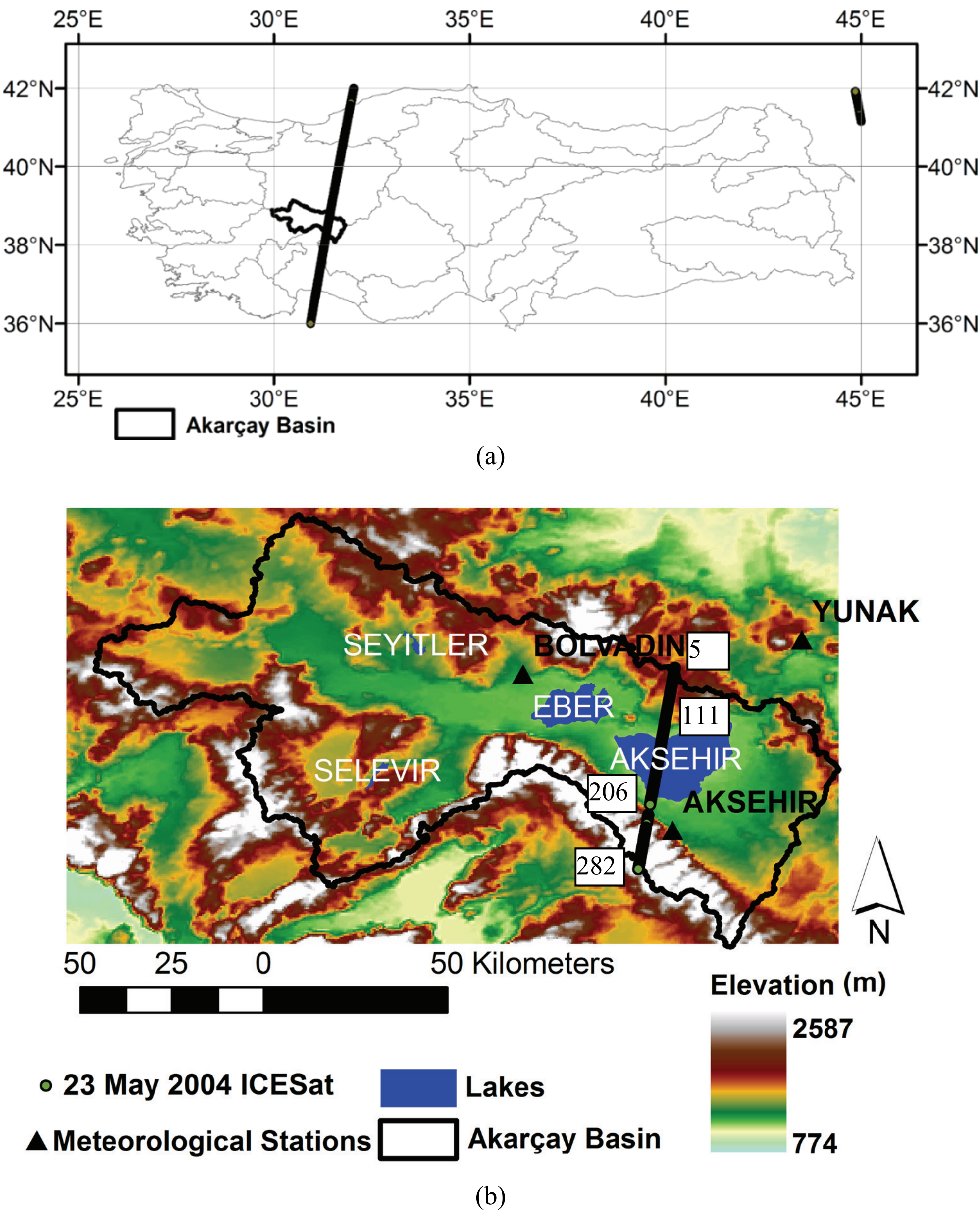


Figure 1. Location of Akarçay Basin in Turkey and ICESat data over Turkey for 23 May 2004 (a) Lakes on Digital Elevation Model of Akarçay Basin with meteorological stations and ICESat data over Akarçay Basin for 23 May 2004 (b).

Located on the migration route of Palearctic birds between Africa and Europe, LR, is also a suitable nesting place for various endemic birds [4]. Some of those birds are under protection [25]. Unfortunately, water levels in most of the lakes in the region are declining [3-5, 21, 26]. AL/w is located in a tectonic depression zone at the lowest region (Figure 1b) of Akarçay Basin (7500km^2) [4, 5]. AL/w has a circular shape and is a shallow lake, as a result, small reductions in water levels result in large areal shrinkage [1]. Water from rainfall and surface runoff replenishes AL/w, whereas, evaporation and water extraction are the major sources of water losses [5]. Water surface elevations have been recorded during site visits performed once a month since 1975. Şener [3], Yıldırım [4] and Bahadır [5] have indicated water level reductions in AL/w in their studies. As a consequence of these reductions, WSE fell below lakes gage level in 2004 since when on site measurements have been abandoned and AL/w totally dried in 2008 [3-5].

3. DATA SETS

3.1. ICESat GLA14

Ice, Cloud and Land Elevation Satellite (ICESat) is the first satellite-based laser altimeter [27]. ICESat was the benchmark for measuring ice sheet mass balance, cloud and aerosol heights, besides land topography and vegetation characteristics [28]. Geoscience Laser Altimeter System (GLAS) onboard ICESat, makes measurements in 70 m diameter footprints spaced 172 m apart. To perform these measurements, for surface altimetry and dense cloud top heights, 1064 nm laser pulses and 532 nm laser pulses for vertical distribution of thin clouds and aerosols are utilized [29]. GLAS, measures the duration between the shooting of laser from satellite and return of the related pulse to the satellite following the reflection from Earth's surface and then calculates the range vector. Surface heights are then calculated by subtracting the range vector from GLAS path parameters. If calculated heights pass quality controls and cloud effect checks, they are presented to the end users. Further physical and mathematical details of surface height calculations can be reached from algorithm and theoretical documents [30].

High accuracy (2~ 10 cm) of GLAS derived surface heights over flat regions are already mentioned in scientific literature [31-33]. Among various GLAS data sets, GLAS / ICESat L2 Global Land Surface Altimetry Data (GLA14) which provides surface heights over land, Version 33 is used. Successful applications of GLA14 data sets are shown in literature [22, 34-36]. GLA14 V33 [37] data are obtained from the National Snow and Ice Data Center (NSIDC).

ICESat GLA14 V33 data over Turkey, Akarçay Basin and AL/w from the 23rd of May 2004 are presented in Figures 1a and 1b. Land surface height profile obtained from ICESat data for 23rd of May 2004 (Figure 1b) is shown in Figure 2. Numbers 5, 111, 206 and 282 presented in text boxes in Figure 1b correspond to values over the x axis in Figure 2 and indicate ICESat data starting from entrance of Akarçay Basin at the upper right and going towards the bottom left, passing from the entrance and exit boundary of static vector layer of Akşehir Lake and ending point of Akarçay Basin.

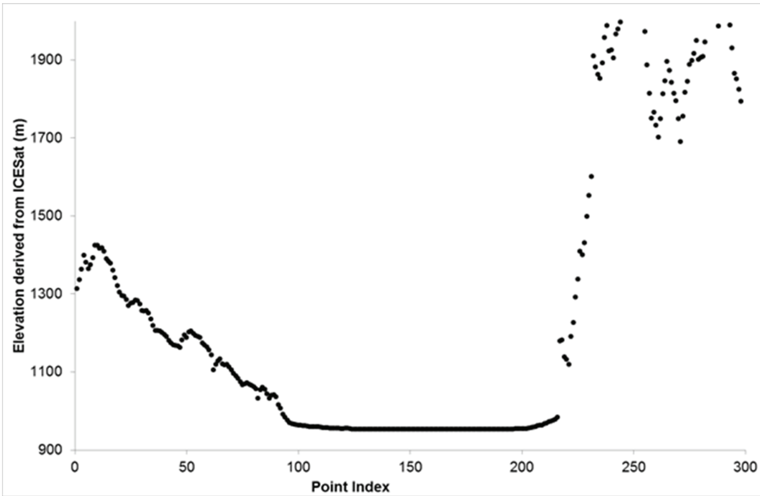


Figure 2. Elevation profile obtained from ICESat GLA14 for 23 May 2004 over Akarçay Basin presented in Figure 1b.

3.2. MODIS Daily Snow Cover Maps

Terra satellite has Moderate Resolution Imaging Spectroradiometer (MODIS), a sensor performing Earth observations through 36 narrow spectrum bands at varying spatial resolutions ranging from 250 to 1000m. The algorithm developed by Hall et al [38] uses MODIS calibrated radiance data (MOD02HKM), geolocation product (MOD03) and cloud mask product (MOD35_L2) as input [39] to produce MODIS snow-covered area (SCA) maps. MOD10A1, MODIS Snow Cover Daily L3 Global 500m Grid, data from various MODIS snow products was used in this study. In the daily SCA maps, the pixel is assigned to one of the following classes: missing data, no decision, night, no snow, lake, ocean, cloud, lake ice, snow, saturated detector and fill [39]. The high accuracy of MODIS snow-covered area maps has been reported in several studies [39-43]. In addition to those, the usability of MODIS snow-covered area maps of Turkey is shown by [40, 44]. In this study version 5 [45] of MOD10A1 are used.

4. METHODOLOGY

Using the Akşehir Lake's static vector file (Figure 3a), the dates of ICESat GLA34 V33 data passing over AL/w were determined. Table 1 summarizes the 14 days that ICESat laser operation coincided with AL/w. The relevant ICESat data was downloaded from NSIDC. A similar approach to Zhang et al. [34]'s work has been applied to downloaded binary files to derive the land surface heights.

Similar to Zhang et al. [22], MODIS SCA maps were used to determine the ICESat footprints that fall on the water surface. However, since water levels in AL/w were declining, daily actual water surfaces which necessitated daily land cover classification were needed. Due to that, each of the MOD10A1 SCA maps for the dates listed in Table 1 was downloaded from the NSIDC and processed.

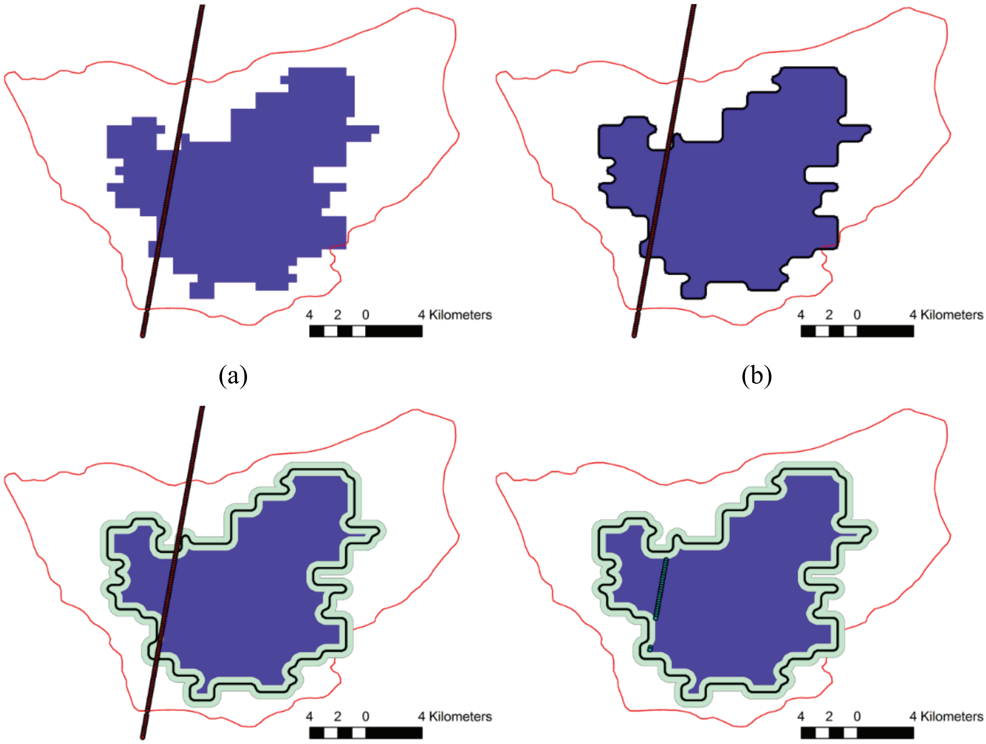
Table 1. Dates of ICESat laser periods that overlap Akşehir Lake/Wetland and availability of MODIS snow cover maps.

Laser Operation	**Start**	**End**	**Overlap AL/w**	**MODIS SCA** MOD
1AB	2003-02-20	2003-03-29	NA	NA
2A	2003-09-25	2003-11-19	10/21/2003	A[1]
2B	2004-02-17	2004-03-21	2/22/2004	A
2C	2004-05-18	2004-06-21	5/23/2004	A
3A	2004-10-03	2004-11-08	NA	NA
3B	2005-02-17	2005-03-24	2/23/2005	C
3C	2005-05-20	2005-06-23	5/25/2005	A
3D	2005-10-21	2005-11-24	10/26/2005	A
3E	2006-02-22	2006-03-28	2/27/2006	A
3F	2006-05-24	2006-06-26	5/29/2006	A
3G	2006-10-25	2006-11-27	10/29/2006	C
3H	2007-03-12	2007-04-14	3/16/2007	A
3I	2007-10-02	2007-11-05	10/7/2007	A
3J	2008-02-17	2008-03-21	2/22/2008	C
3K	2008-10-04	2008-10-19	10/8/2008	A
2D	2008-11-25	2008-12-17	NA	NA
2E	2009-03-09	2009-04-11	NA	NA
2F	2009-09-30	2009-10-11	10/5/2009	A

C: Cloud covered A: Available NA: Not Applicable
[1] No ICESat data available over AL/w water surface

Based on the MOD10A1 images, water surface of AL/w were extracted daily (Figure 3a). The water surfaces were transformed into vector files (Figure 3b). To remove the mixed pixels which may be encountered in MODIS [44], 500 m buffers are applied to water surface vectors (Figure 3c).

ICESat footprints that are actually on the water surfaces (Figure 3a) and outside the 500 m buffer (Figure 3c) are used to obtain AL/w water surface heights (Figure 3d). Figure 3 shows the static AL/w vector file used for ICESat overlapping dates (Table 1), ICESat foot prints for 23 May 2004 (red dots), AL/w water surface based on MOD10A1 for 23 May 2004 (a), vector of AL/w water surface (b), 500 m buffer applied to water surface vector (c) and ICESat footprints over the actual water surface that are outside the 500m buffer (d). Figure 4 presents the flowchart of the methodology.



(a) (b)

(c) (d)

Figure 3. Static AL/w vector file used in ICESat overlapping dates, ICESat foot prints for 23 May 2004 (red points), AL/w from MOD10A1 (a), vector of AL/w (b), 500 meter buffer applied to Al/w lake vector (c) and ICESat footprints over the actual water surface that are outside the 500m buffer (green points)(d).

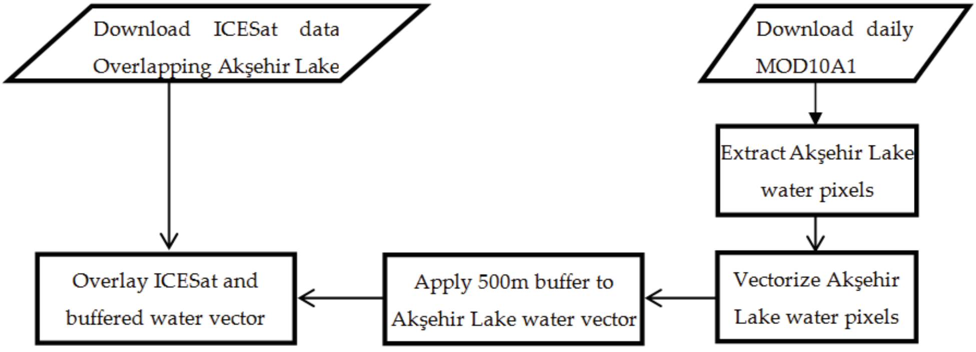


Figure 4. Flowchart of the proposed methodology

5. RESULTS

GLA14 V33 data belonging to 23 May 2004 is clipped for Akarçay Basin and presented in Figure 2. The data set (Figure 2) starts from the medium height mountains (1200m) in the north of the AL/w, decreases as it approaches AL/w, remains constant over the lake surface and reaches 1900m in the mountains forming the southwest boundary of the watershed. These are in agreement with the topography presented as DEM in Figure 1b.

Following the flowchart given in Figure 4 and based on the methodology mentioned in section four, the calculated water surface elevations of AL/w is given in Table 2. The data date, elevation (m), standard deviation (sd) (m) under the ICEM column are derived using the ICESat- MODIS based data sets. As the water level in the AL/w fell below the gage level in 2004, in-situ water level measurements performed once a month were totally abandoned. Therefore, it was not possible to make direct comparisons between ICESAT-based water levels with in-situ gage observations. However, findings in [3-5] were used to obtain water levels in AL/w. Above mentioned studies ([3-5]) investigated the changes in water surface area (WSA) of AL/w using different remote sensing approaches and provided WSAs on different dates. LAB header in Table 2, includes data set which indicates the first author of the group that performed the study among ([3-5]) and data date indicating the date

Table 2. Akşehir Lake/Wetland's water surface elevations obtained from ICESat data and literature surveys.

LAB				ICEM			Difference
Data Set	Data date	Area (km^2)	Elevation (m)	Data Date	Elevation (m)	sd (m)	(m)
Yıldırım	16 Jun 2002	205.133	*953.71*				
				22 Feb 2004	952.01	0.34	
				23 May 2004	953.36	0.04	
Sener	!		953.5				0.14
Yıldırım	!		953.35				-0.01
				25 May 2005	952.81	0.06	
Bahadır	19 Jun 2005	113	*952.72*				-0.09
				26 Oct 2005	951.65	0.87	
				27 Feb 2006	952.08	0.08	
				29 May 2006	952.38	0.04	
Yıldırım	19 Jun 2006	110.76	*952.7*				0.32
Sener	6 Agu2006	84.94	*952.48*				0.10
				16 Mar 2007*	952.28	0.15	
Yıldırım	13 May 2007	123.560	*952.81*				
				7 Oct 2007	951.85	0.28	
				8 Oct 2008	951.69	0.20	
				5 Oct 2009	950.96	0.39	

! Exact date could not be found *ICESat data could not satisfy 500m buffer criteria of the Landsat satellite image acquisition used in analysis. Area column shows the WSA of Akşehir Lake determined by the respective group for the particular day. Using AL/w bathymetry data with the lake WSA information obtained from [3-5], respective water surface elevations (WSE) are obtained and these are written in italics in the "Elevation" column in Table 2. The last column in Table 2, Difference, represents the difference in WSE between the LAB and ICEM based methodologies. Elevations and standard deviations obtained by ICEM methodology and AL/w water surface elevations obtained from literature are shown in Figure 5.

The minimum and maximum differences in water surface elevations between LAB and ICEM are -0.09m and 0.32m, respectively. These values are close to the standard deviations of 0.27 m and 0.25 m of the ICESat measurements stated in [22, 34]. Moreover, they show agreement with the 0.21 m difference between ICESat measurement and in-situ lake observations made on the 27th of February 2008 mentioned in [34].

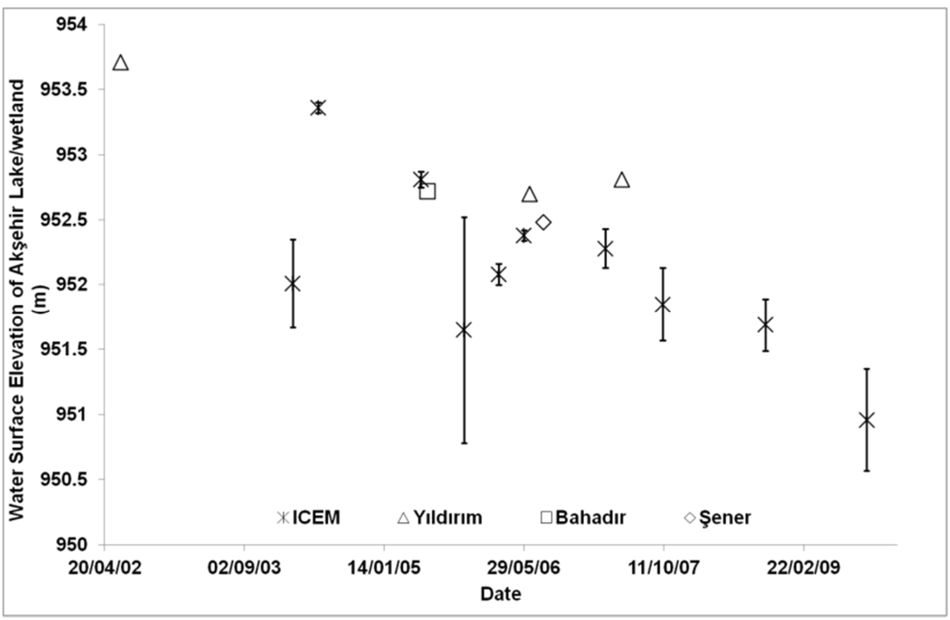


Figure 5. Akşehir Lake/Wetland's water surface elevations obtained from literature surveys and ICEM methodology and its standard deviations.

Bahadır [5] indicated the minimum and maximum water elevation changes between successive winter and spring seasons as 0.4 and 1.78m. These values were calculated to be 0.30m from the 27th of February 2006 to the 29th of May 2006 and 1.35 m from the 22nd of February 2004 to the 23rd of May 2004 based on ICEM measurements. The values found are within the range specified by [5]. Changes in water levels in successive winter and spring months can be explained by high precipitation [4] and snowmelt runoff [5, 46].

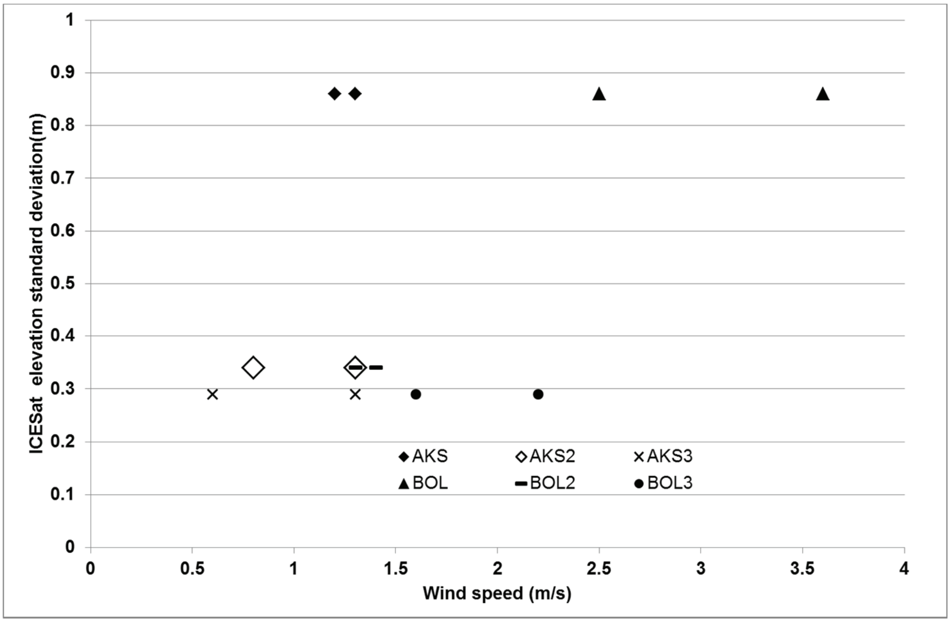


Figure 6. Standard deviation of ICESat derived water surface elevations and wind speeds (m/s) recorded in Akșehir and Bolvadin meteorological station at the start and end hours of ICESat observations.

Standard deviations (SD) of elevation data obtained by ICEM methodology showed high values in October with the maximum SD calculated as 0.87m on 26 October 2005. This finding is in agreement with the relatively higher wind speeds recorded at Akșehir (AKS) and Bolvadin (BOL) meteorological stations in Akarçay Basin. In both meteorological stations wind speeds are recorded hourly. Figure 6 shows variation of ICESat derived elevation SD and the wind speeds at the AKS and BOL meteorological stations recorded at the start and end hours of ICESat observations, being close to 1.5 m/s and greater than 2.5 m/s for AKS and BOL stations respectively. For the smaller SD values, wind speeds in AKS and BOL are less than 1.5 m/s and 2.5 m/s. The maximum standard deviation calculated as 0.87m on 26 October 2005 fits in the historical observations mentioning about waves reaching up to 1m over Akşehir Lake [1]. The high standard deviations observed at ICESat water levels in October are similar to the findings of Zhang et al. [22, 34] and these high standard deviations can be attributed to the wind speeds that play important role in wave heights [47].

6. CONCLUSIONS

In this article, it is shown that how satellite onboard sensors working on different regions of electromagnetic spectrum can be combined to augment environmental studies. In this sense, optical sensor MODIS on board Terra satellite and first satellite laser altimetry instrument GLAS on board ICESat data are used in combination (ICEM) to get the water surface elevations (WSE) of Akşehir Lake/wetland (AL/w) during its shrinkage and complete dry up in 2008. What makes this study distinct from available ICESat studies is that Akşehir Lake totally dried up in 2008. Thus ICESat data are evaluated during the recession of the lake.

Due to non-existence of ground lake level measurements following the lakes level falling below gage in 2004, WSE had to be calculated using LAB in which; AL/w bathymetry is used with Landsat satellite image based water surface areas provided in literature. LAB derived WSE enabled evaluation of ICEM based WSE.

Minimum and maximum differences in WSEs between LAB based studies and ICEM are found to be -0.09m and 0.32m, respectively. These differences are acceptable considering that data are compiled from various sensors each having various spatial and temporal resolutions and working on different regions of electromagnetic spectrum. Moreover, water surface elevation differences are close to published studies where ICESat-derived water surface elevations are compared with on-site observations.

When ICESat observations over AL/w are investigated, it is seen that water levels start to increase during the year from February to May. This is in line with the hydrological characteristics of the basin, as it is inevitable that the snowmelt runoff coming to the lake will cause increases in the water levels. This finding matches with snowmelt runoff importance in AL/w indicated by [46]. Water surface elevation increments between consecutive fall and spring seasons were calculated as 0.30-1.35m and these are in the historical range indicated by [5].

The primary mission of ICESat was monitoring sea ice [28], which reduced data availability over the study area, AL/w. Still, many valuable applications can be made using existing ICESat data in combination with other satellite-based Earth observations. The methodology presented here can easily be applied to different regions of the world and can be implemented for ICESat follow-up missions. This study is a solid application of the scientific goal and mission of ICESat2 "Enhancing the utility of other Earth-observation systems through supporting measurements." [48].

Acknowledgements

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Construction Site Layout Planning: Application of Multi-Objective Particle Swarm Optimization

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ABSTRACT

Construction Site Layout Planning (CSLP) comprises determining, sizing and placing of the temporary facilities within the boundaries of a construction site by considering many factors. Traveling distance between facilities and safety risks are two essential factors that need to be minimized while planning site layout of a construction project. Many studies treated CSLP as a single objective optimization problem. They have mainly focused on either diminishing the travel cost of resources on site without considering the safety aspect or vice versa. While a few of the studies have treated the problem as a multi-objective optimization problem, none of them included a risk assessment approach including crane-related constraints. Hence, a user-friendly CSLP model that includes a risk assessment approach for safety constraints is proposed by using a Multi-Objective Particle Swarm Optimization algorithm based on Pareto dominance approach to minimize both the construction safety risks of crane operated projects and the total traveling distance of the resources between temporary facilities.

Keywords: Construction site layout planning, crane, multi-objective optimization, particle swarm optimization, safety.

1. INTRODUCTION

Site layout planning is one of the significant tasks of site management. In the absence of an effective and a systematic approach to site layout planning, construction projects involving a high number of manpower, subcontractors, and equipment may face time loss, cost overruns and jeopardized construction site safety [1,2,3] .

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Construction Site Layout Planning (CSLP) comprises determining, sizing and placing of temporary facilities within the boundaries of a construction site by considering many factors such as; location/design features of the permanent structures to be build, project type/scale, the location of the site, machinery used during construction and organization of the construction works. Presence of tower crane(s) on site is in itself one of the major factors that should be considered during the placement of temporary facilities as cranes are associated with nearly one-third of deaths on construction sites [4].

While practitioners in the industry still rely on individual experience and subjective judgment, significant research advancements have been accomplished in the area of optimizing construction site layout plans. Researchers used a variety of approaches comprising Genetic Algorithms (GA), Ant Colony Optimization (ACO), Multi-Objective Particle Swarm Optimization (MOPSO) and knowledge-based systems. Although these models had great contributions (discussed in the following section), very few of them focused on optimization of both traveling distance between facilities and crane-related site safety risks. Thus, the aim of the current study has been to develop a user-friendly site layout planning model which would both minimize construction safety risks of crane operated projects and the total traveling distance of resources between temporary facilities for quadrilateral construction sites with one tower crane. Unlike previous studies, a risk assessment approach has also been integrated into the model.

2. LITERATURE REVIEW

Table 1 summarizes optimization models developed for CSLP problems.

Table 1. Optimization models developed for CSLP problem

Reference	Optimization Objective(s)	# of Objectives	Method(s) Used	Validation
1. Li and Love (1998) [3] Li and Love (2000) [5]	Minimize total traveling distance between facilities on site	Single	GA	Based on a hypothetical case study. Analyses effect of population sizes on the optimal solution.
2. Zouein and Tommelein (1999) [1]	Minimize total traveling distance between facilities on site	Single	The Constraint Satisfaction and Propagation Algorithm	Based on a hypothetical case study.
3. Harmanani et al. (2000) [6]	Minimize total traveling distance between facilities on site	Single	GA	Based on a hypothetical case study. Analyses effect of facility/site area ratio on the optimal solution.
4. Tawfik and Fernando (2001) [7]	Minimize safety risk, maximize space use, minimize the total traveling distance between facilities on site individually.	Single	GIS, GA, Simulated Annealing	Based on a hypothetical case study. Analyses effect of number of generations on cost values.
5. Mawdesley et al.(2002) [8]	Minimize total traveling distance between facilities on site	Single	GA	Based on two case studies; one hypothetical and one real-life project.

Table 1. Optimization models developed for CSLP problem (continued)

6.El-Rayes and Khalafallah (2005) [9]	Maximize safety (including the crane) and minimize traveling costs, simultaneously	Multiple	GA	Based on a real-life case study; a multi-story garage building. Analyses effect of population sizes and number of generations on the optimal solution.
7.Sanad et al. (2008) [10]	Maximize safety and minimize traveling costs, simultaneously	Multiple	GA	Based on a real-life case study. Analyses effect of population sizes and number of generations on the optimal solution.
8. Zhang and Wang (2008) [11]	Minimize total traveling distance between facilities on site	Single	PSO	Compares results with the results (based on number of iterations) obtained by using GA model by Li and Love [5].
9. Khalafallah and El-Rayes (2011) [12]	Minimize construction safety, construction-related aviation safety construction-related security level, and overall site layout costs separately (including crane as a typical facility).	Multiple	GA	Based on a real-life case study (Airport construction project) Observes the changes in number of population and generation on the optimal solution. Compares optimal solution for each objective graphically.
10.Xu and Li (2012) [13]	Maximize safety and minimize traveling costs, simultaneously	Multiple	PSO with permutation-based representation	Based on a real-life case study. Analyses solutions obtained from fuzzy random type, fuzzy type and standard type of MOPSO.
11.Ning et al. (2010) [14] Ning and Lam (2013) [15]	Maximize safety and minimize traveling costs, simultaneously.	Multiple	ACO	Based on a real-life case study. Analyses effect of the quality site layout alternatives generated in the initial solution set to the final solution.
12.Adrian et al.(2015) [16]	Minimize total traveling distance between facilities on site	Single	GA, PSO, and ACO	Uses a hypothetical case study to compare the results obtained from three methods.
13.Yahya and Saka (2014) [17]	Maximize safety (including the crane) and minimize traveling costs, simultaneously	Multiple	Multi-objective ABC (MOABC) via Levy flights	Compares real-life site layout, Basic-MOABC model, and MOABC via Levy flights solution for a hospital project.
14.Zhao and Li (2014) [18]	Minimize total traveling distance of resources and security risks, simultaneously	Multiple	Multi-objective GA	Uses a hypothetical case study.

It is seen that earlier studies have focused on single objective -minimizing the total traveling distance of resources between site facilities- by using GA. Validations of the models have been based on case studies which were mostly hypothetical. Quality of obtained solutions was generally discussed by considering the effect of population sizes and number of generations. Later studies have generally focused on solving CSLP as a multi-objective problem by using methods like GA, PSO, and ACO. Optimal trade-offs between construction safety and total traveling cost of resources have been selected by the model developers from various solutions provided by the existing models. For example, Khalafallah and El-Rayes (2011) [9] provided four trade-off curves (which were site layout cost vs. construction safety, debris control, wildlife management and airport security) from which the airport planners were expected to choose the most suitable one. They maximized construction safety only by placing most vulnerable facilities from the crane as far as possible. Sanad et al. (2008) [7], on the other hand included constraints like; prohibited areas (in order to prevent some facilities that have harmful effects such as noise, air pollution, etc. from being positioned adjacent or near to sensitive entities like hospitals), minimum distance requirements between temporary facilities, and safety zones (in order to protect workers from falling materials, tools or equipment). Use of cranes was not considered as a separate risk factor. Meanwhile, Ning et al. (2010) [14] and Ning and Lam (2013) [15] used ACO, and Xu and Li (2012) [10] used PSO to solve the multi-objective dynamic construction site layout planning to minimize the cost for each single facility, the interaction cost between different facilities and the possibility of safety or environmental accidents. All focused on safety optimization which was based on the logic that 'high-risk' facilities would be placed far from 'highly protected' facilities. Crane related risks were not formulated separately. Among all of these studies, only El Rayes and Khalafallah (2005) [9] and Yahya and Saka (2014) [17] considered crane operations as part of safety constraints. While El Rayes and Khalafallah (2005) considered safety criteria based on risk sensitivities of the temporary facilities only due to falling objects from cranes [9]; Yahya and Saka (2014) included a constraint only for the facilities that should be placed within the reachable radius of cranes [17]. However, considering the risks of only the falling objects (like El Rayes and Khalafallah (2005) [9]) or, only the radius of crane operations (like Yahya and Saka (2014) [17]) is not sufficient for safe placement of the facilities on site because crane operations create different risk zones which house varying degrees of risk magnitudes and probabilities which change according to the tower height and the jib length [19], [20]. Thus, the current study takes crane-related risks into account by considering the sensitivity of different areas on site related to possible load struck, object falls, crane collapses and object scatters during crane operations.

3. PROPOSED MODEL

Site layout planning is unique for each project and depends on a large number of variables requiring human experience for the assessment of risks involved. Designing a site layout plan involves; identification of the required temporary facilities, determination of the sizes and other features of the facilities, the establishment of the inter-relationships between the facilities, and placement of the facilities on the site plan. Sites with cranes additionally require the definition of risk relationships between facilities and crane(s), that are not globally quantified. Thus, a risk assessment based on experts' knowledge and experience is crucial for any model which tries to solve the site layout planning problem considering minimization of crane-related safety risks. Hence, in addition to the aforementioned models, a risk assessment approach has been adopted to the safety constraints in the current model.

Tower crane-related constraints for quadrilateral construction sites with one tower crane were constructed in the form that both the risk magnitudes and the probabilities of possible accidents were expressed together with the risk perceptions/approaches of the experts. To achieve this, the proposed model utilizes Equation 1 to calculate safety risk (SR_i) of a temporary facility *i*.

$$SR_i = RM_i * P_i \tag{1}$$

where;

RM_i: Risk magnitude of temporary facility *i*, which is the estimated magnitude of the risk for the provisional facility owing to the position of the tower crane (see Equations 2-3, 5 and 8).

P_i: The probability of an accident that is influenced by the distance between facility *i* and the tower crane (see Equations 4, 6, 7 and 9).

Assuming that the crane operating on the construction site has tower height H and jib length J, the construction site is divided into three zones that house varying degrees of risk magnitudes, as shown in Fig.1.

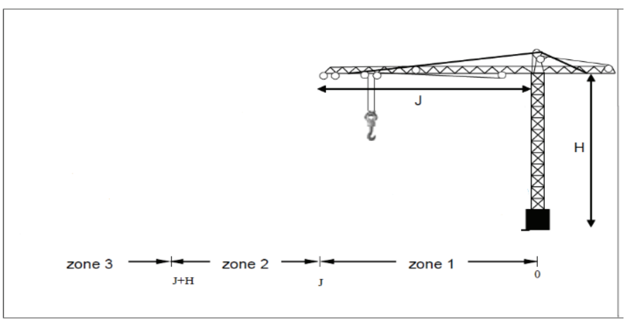

Figure 1. Tower crane dimensions and risk zones

Zone 1: The area that covers the crane operating angles (0 < distance ≤ J); represents the highest sensitivity due to its vulnerability to striking loads and/or falling objects and/or collapse of the crane during its operations. The risk magnitude for facility *i* in Zone 1 is given in Equation 2.

$$RM_i = (RM_{Si} + RM_{Fi} + RM_{Ci}) \tag{2}$$

RM_{Si}, RM_{Fi}, and RM_{Ci} represent the fatality and injury risks related to possible strikes, load falls, and crane collapses, respectively, on the temporary facility *i* by the tower crane. Three types of risk magnitudes can be calculated from Equations 3 as follows.

$$RM_{Xi} = \sum_{e=1}^{5} \sum_{j=1}^{m} (RS_{Xiej} * W_e) \tag{3}$$

where;

m is the number of risk experts varying in each expertise type *e*, W_e is the weight of the risk expert *e* (please note: As setting W_e values would require a comprehensive field survey which would be out of the scope of the current research, these are adapted from Zeng et al. (2007) [19]. The validity of the values were confirmed by Zeng et al. (2007) [19] during the application of their risk assessment approach.), X is the event symbolized with S for load **(S)**truck, F for load **(F)**all and C for **(C)**ollapse, RS_{Xiej} is the generalized form of risk severity due to possible X event on the temporary facility *i* by the use of the tower crane, expressed by the expert j who has an expertise type *e*. (that is converted to a constant depending [18])

Temporary facility *i* has the highest probability of an accident (P_i) if it is allocated in Zone 1. It is constant (Equation 4) and its value is calculated by considering the P_i values in all zones and their sub-zones as discussed below.

$$P_i = \frac{29}{33} \qquad (4)$$

Zone 2: It is the area located between zones 1 and 3 (J < distance ≤ J+H); represents an intermediate level of sensitivity due to its vulnerability to the collapse of the tower crane. The risk magnitude for facility *i* in Zone 2 is given in Equation 5.

$$RM_i = RM_{Ci} \qquad (5)$$

Zone 2 is divided into two equal sub-zones to calculate the probability of an accident, P_i. It is linearly decaying and has different slopes within each sub-zone. In sub-zone 1 ($J < distance \leq J + \frac{H}{2}$), and sub-zone 2 ($J + \frac{H}{2} < distance \leq J$ +H), the probability is governed by Equations 6 and 7, respectively.

$$P_i = \frac{52*(J-distance)}{33*H} + \frac{29}{33} \qquad (6)$$

$$P_i = \frac{4*(J-distance)}{33*H} + \frac{5}{33} \qquad (7)$$

As for the location of a facility afar from the reach of the tower crane, the probability of an accident rapidly decreases. This is reflected on the Equations 6 and 7 with different slope values.

Zone 3: the area that is outside the crane risk areas (J+H < distance); represents a low level of sensitivity due to its minor vulnerability to the scattered objects during the crane collapse [19]. Therefore, the risk magnitude is quite low and is as given as in Equation 8.

$$RM_i = 1/33 \qquad (8)$$

The probability of an accident P_i is treated as in Zone 2. Once again, the Zone is divided into two sub-zones. In the first sub-zone ($J + H < distance \leq J + \frac{3*H}{2}$), the distance dependent probability is calculated as;

$$P_i = \frac{2*(J-distance)}{33*H} + \frac{1}{11} \quad (9)$$

In the second sub- zone($J + \frac{3*H}{2} < distance$), however, tower crane related accident probability becomes extinct.

3.1. Objective Functions

The problem of satisfying two different objectives at the same time is expressed by formulating two separate objective functions, which in our case are;

$$Min\,\{SR = \sum_{i=1}^{n} RM_i * Pi\} \quad (10)$$

$$Min\{TD = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} w_{ij} d_{ij}\} \quad (11)$$

The objective function for the minimization of the safety risk (SR) is expressed as in Equation 10 and can be calculated by using Equations 1 to 9. The objective function for the minimization of the total traveling distance (TD) is formulated by considering the proximity weights w_{ij} which depends on the desired closeness between the facilities [10]. Proximity weights are originally verbal statements expressed by the site management and need to be quantified. The conversion metrics, used by Hegazy and Elbeltagi (1999) [2] and Sanad et al. (2008) [10], given in Table 2, is used to determine quantified proximity weights [20][10].

Table 2. The six-value scale used for desired closeness between facilities

Desired closeness between facilities	Proximity weights for relationships between facilities (w_{ij})
Undesirable (X)	6^0=1
Unimportant (U)	6^1=6
Ordinary closeness(O)	6^2=36
Important (I)	6^3=216
Especially important (E)	6^4=1296
Absolutely necessary (A)	6^5=7776

d_{ij} is, on the other hand, the distance between facilities *i* and *j,* and can be calculated from Equation 12.

$$d_{ij} = \sqrt{(C_{xi} - C_{xj})^2 + (C_{yi} - C_{yj})^2} \quad (12)$$

where;

C_{xi}, C_{yi}, and C_{xj}, C_{yj} are the coordinates of the center of gravity of facilities *i* and *j*, respectively.

3.2. Optimization Constraints

To assure the improvement of initial site layout plans, two types of constraints; boundary and overlap, are imposed on the generated solutions. These constraints are required to ensure that temporary facilities are located within the construction site boundaries while avoiding the overlapping of the facilities.

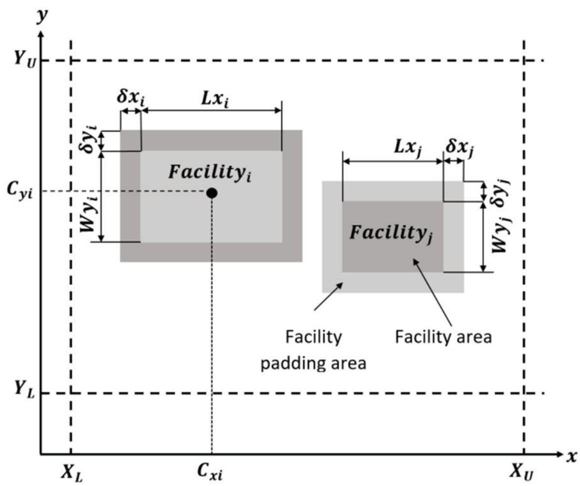

Figure 2. Boundary and overlap constraints

3.2.1. Boundary Constraints

Boundary constraints are investigated using the following steps to provide that each facility is located within the boundaries of the site (provided by the site management and initial site layout drawings).

Boundary constraints for the facility *i* are satisfied for all k-directions –which in turn satisfies the area requirement of the facility- (see Fig. 2) if:

$$C_{ki} + \frac{LWk_i}{2} + \delta k_i \quad \leq k_U \tag{13}$$

$$C_{ki} - \left(\frac{LWk_i}{2} + \delta k_i\right) \leq k_L \tag{14}$$

where;

C_{ki}: k (x or y in 2D space) component of the center of gravity of facility *i*.

LW_{ki}: Length or width of the facility i in the k-direction. If k is x-direction then LW is the length of facility i; otherwise, it is the width.

δk_i: Minimum distance required between the facilities i and j, or facility i and the site boundary in the k-direction.

k_U: Upper boundary of the site area in the k-direction.

k_L: Lower boundary of the site area in the k-direction.

3.2.2. Overlap Constraints

To ensure that no overlap occurs between the facilities on site, overlap constraints are examined using Equation 15. (see Fig. 2).

In k direction overlap constraint between facilities i and j are satisfied if:

$$|C_{ki} - C_{kj}| \geq \left(\frac{LWk_i}{2} + \frac{LW_{kj}}{2}\right) + \max\{\delta k_i, \delta k_j\} \quad (15)$$

3.3. Multi-Objective Optimization

As stated in the above sections, site layout optimization problem considering safety risks and traveling distances between facilities is multi-objective in nature as it incorporates more than one objective function to be optimized concurrently. There is not a single solution that simultaneously satisfies each objective [21]. In fact, trade-offs between the objectives of minimizing safety risks and traveling distances between facilities force the decision maker to select an optimal solution from a set of Pareto optimal solutions that are considered equally good if there is not any additional subjective preference. A solution is called Pareto optimal or non-dominated if none of the objective functions can be improved without degrading one or more objective functions.

Given an N-dimensional decision variable vector $\mathbf{x}=(x_1, x_2, \ldots., x_N)$ a minimization multi-objective decision problem with Ω objectives can be formally defined as follows:

$$\min\{\mathcal{F}(\mathbf{x}) = [f_1(\mathbf{x}), f_2(\mathbf{x}), \ldots \ldots, f_\Omega(\mathbf{x})]\} \quad (16)$$

$$\mathbf{x} \in X \quad (17)$$

$$\mathcal{G}(\mathbf{x}) = [g_1(\mathbf{x}), g_2(\mathbf{x}), \ldots \ldots, g_\lambda(\mathbf{x})] \geq 0 \quad (18)$$

$$\mathcal{H}(\mathbf{x}) = [h_1(\mathbf{x}), h_2(\mathbf{x}), \ldots \ldots, h_\varphi(\mathbf{x})] = 0 \quad (19)$$

$$x_i^{(Lower)} \leq x_i \quad \leq x_i^{(Upper)}, \; i = 1, \ldots \ldots, N \quad (20)$$

where, Ω≥2, set X is the solution space, $\mathcal{G}(\mathbf{x})$ and $\mathcal{H}(\mathbf{x})$ are λ inequality and φ equality constraints of the problem. $x_i^{(Lower)}$ and $x_i^{(Upper)}$ are lower and upper boundary of each decision variable x_i , respectively. A solution vector $\mathbf{x}^{fsbl} \in X$ is called Pareto optimal or non-dominated solution, if no other solution dominates $\mathbf{x}^{fsbl}$. Formally, a feasible solution $\mathbf{x}^1 \in X$ *dominates* another solution $\mathbf{x}^2 \in X$, if;

$$f_i(\mathbf{x}^1) \le f_i(\mathbf{x}^2) \tag{21}$$

for all indices $i \in \{1, 2, \ldots, \Omega\}$ and,

$$f_j(\mathbf{x}^1) < f_j(\mathbf{x}^2) \tag{22}$$

for at least one index $j \in \{1, 2, \ldots, \Omega\}$

The set of all non-dominated solutions is called Pareto front, and if there are no preference criteria, the outcome can be any element of the Pareto front set. The concept of dominated and non-dominated solutions is exemplified in Fig. 3.

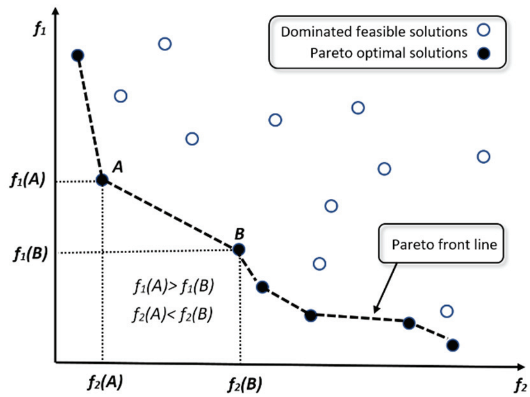

Figure 3. Feasible solutions of a multi-objective problem with two conflicting objective functions

3.4. Methodology

The literature review showed that GA, PSO, and ACO have been the most adopted algorithms in solving CSLP problems. Meanwhile, PSO has been reported to outperform the other two algorithms with its superior search performance with faster and more stable convergence rates (Zhang and Wang (2008) [11], Brutto et al. (2016) [22]).

Particle Swarm Optimization (PSO) is a stochastic optimization algorithm based on the social behavior of birds in a flock or fish in a school. A simple mathematical model which describes the behavior of an individual in such a swarm has been developed by Kennedy and Eberhart in 1995 [23].

The model is based on the main principles of self-organization that is utilized to define the dynamics of complex systems. Self-organized systems display emergent behavior that is decentralized and more complex than the individual's own actions in a flock. This emergent behavior is the result of individuals' triggered actions that present random fluctuations by amplified positive feedback. Therefore, they achieve a higher level of intelligence. However, members of a flock create complex patterns by accomplishing simple and recurring tasks. A simplified model of this social behavior is used by PSO to solve many optimization problems in a cooperative and smart framework.

In basic PSO, any suggested solution to the problem at hand is called a particle. The problem domain is called problem space where all particles fly through. Each particle has its own position and velocity vector, that is regularly updated relative to either the leader of the flock (best solution in the swarm) and/or dominating solution within a neighborhood as well as the best personal solution experienced so far. The position and the velocity vectors are fluctuated by a degree of randomness to avoid getting trapped in local optima.

Multi-Objective Particle Swarm Optimization or MOPSO algorithm is a multi-objective version of PSO by embodying the Pareto Envelope and Grid Making Technique [24][25]. The particles in MOPSO behave similarly to those of PSO. Common actions of particles in both algorithms are to share information and moving towards the resultant vector that is formed by global best particle and individual's personal (local) best memory. However, a multi-objective optimization problem with conflicting objectives has a set of optimal solutions that are known as non-dominated (Pareto optimal) solutions. Therefore, a sub-swarm that is called "Repository" is formed by gathering all non-dominated optimal solutions. The global best particle of PSO is replaced with the repository. Therefore, the global best solution is randomly selected from the repository for each particle in MOPSO.

MOPSO algorithm can be summarized as follows [25]:

1. Create a set of feasible solution vectors (*POP*) in search space. $\mathbf{POP}_i$ is called i^{th} particle (vector) in problem space that is bounded by the constraints of the problem.
2. Assign a velocity vector (**V**) to each particle in *POP*. $\mathbf{V}_i$ is the flying speed of i^{th} particle in solution space.
3. Evaluate each particle's fitness $f(\mathbf{POP}_i)$
4. Create a Repository (*REP*) from non-dominated optimal solutions (particles). $\mathbf{REP}_i$ is the i^{th} Pareto optimal solution in *POP*.
5. Generate hypercubes of the search space explored by the particles so far. Use these hypercubes to locate a particle.
6. Create a memory (*PB*) to keep track of each particle's personal best position in the search space. Initially, *PB* is same as *POP* since there has been no previous experience of any particle.
7. Repeat;

   7.1. Update each particle's velocity $\mathbf{V}_i$ by using the following expression.

   $$\mathbf{V}_i' = w\mathbf{V}_i + R_1(\mathbf{PB}_i - \mathbf{POP}_i) + R_2(\mathbf{REP}_h - \mathbf{POP}_i)$$

   where, w is inertia coefficient, R_1 and R_2 random numbers in the range of [0-1], and $\mathbf{REP}_h$ is a non-dominated solution randomly selected from Repository as a flock leader.

   7.2. Calculate new position of each particle as;

   $$\mathbf{POP}_i' = \mathbf{POP}_i + \mathbf{V}_i'$$

7.3. Update Repository by discarding all dominated solutions and by adding new non-dominated solutions.

7.4. Update personal best positions if particles discover better solutions than previous ones.

7.5. Increase cycle counter.

7.6. If a maximum number of cycles are reached, then break the loop.

8. Randomly pick one (or more) Pareto optimal solution(s) from REP as an outcome.

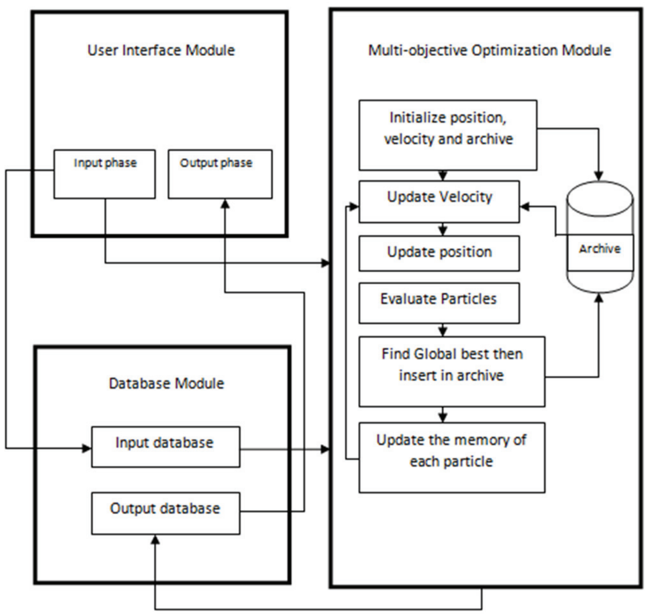

Figure 4. Structure of the proposed model

The presented MOPSO model is implemented with MATLAB to achieve the generation of near-optimal site layout plans that minimize both the safety risks and the traveling distances between facilities by satisfying all layout constraints explained earlier. Computational steps are illustrated in Fig. 4.

3.5. Case Study

To validate the practicability and capability of the developed model, real-life site layout planning data were obtained from a site management team working on a residential building project. The project consists of seven permanent buildings and a tower crane. Input data of the application example are summarized in Tables 5 to 11. Table 3 presents the project site and tower crane dimensions.

Table 3. Project site and tower crane dimensions

	Length (m)	Width (m)	Height (m)	Jib Length (m)
Site	189.28	159.59		
Crane			40	50

Table 4. Permanent facilities

Symbol	Facility Name	Length (m)	Width (m)	Location in site
F1	Tower crane	6	6	(94.44,64.83)
F2	Building 1	25.7	20.65	(106.88,24.50)
F3	Building 2	25.7	20.65	(65.95,32.05)
F4	Building 3	25.7	20.65	(25.30,27.70)
F5	Building 4	25.7	20.65	(27.30,74.20)
F6	Building 5	25.7	20.65	(59,117.94)
F7	Building 6	25.7	20.65	(111.93,87.30)
F8	Building 7	25.7	20.65	(138.98,50.8)

Table 5. Temporary facilities

Symbol	Facility Name	Length (m)	Width (m)
F9	Welding workshop	10	18
F10	Contractor office	10	8
F11	Rest room	10	10
F12	Parking	17	17
F13	WC	6	6
F14	Fuel stock	6	5
F15	Tool stock	10	12
F16	Generator	2	2

Table 4 and 5 present characteristics of the permanent and the temporary facilities that need to be located on the site. Location of the permanent facilities are presented in the form of (x,y) coordinates in Table 4.

The proximity weights between the facilities are summarized in Table 6 in accordance with the site management input.

Table 6. Proximity weights between facilities

	Facility (i)															
Facility (j)	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16
F1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F2	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F3	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-
F4	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-
F5	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-
F6	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-
F7	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-
F8	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-
F9	1296	1	1	1	1	1	1	1	0	-	-	-	-	-	-	-
F10	1	36	36	36	36	36	36	36	36	0	-	-	-	-	-	-
F11	1	36	36	6	6	6	6	6	6	6	0	-	-	-	-	-
F12	1	6	6	6	36	6	6	6	6	36	6	0	-	-	-	-
F13	1	1	1	1	1	1	1	1	6	6	6	6	0	-	-	-
F14	1296	1	1	1	1	1	1	1	1	1	1	1	1	0	-	-
F15	1296	1	1	1	1	1	1	1	1	1	1	1	1	1	0	-
F16	1	6	6	36	36	6	6	6	6	6	6	6	6	6	6	0

Note: — = equivalent values in this symmetric matrix.

Tables 7, 8 and 9 demonstrate assessments of the risk experts related to the possibilities of the fatalities and injuries based on the risks of crane accidents. E1 to E5 are the project manager, construction manager, senior engineer and two site engineers, respectively Experts' assessments are evaluated in accordance with the weights of the experts.

Table 7. Experts' assessments related to the possibilities of the safety risks due to load strucks by the tower crane on the temporary facilities

	E1	E2	E3	E4	E5
F9	0.4	0.8	0.4	0.6	0.6
F10	0.6	0.4	0.2	0.8	0.8
F11	1.0	0.4	0.2	0.4	0.4
F12	0.2	0.4	0.4	0.4	0.6
F13	0.2	0.4	0.2	0.4	0.4
F14	0.2	0.2	0.2	0.2	0.4
F15	0.2	0.4	0.4	0.2	0.4
F16	0.6	0.2	0.2	0.2	0.6

All the data related to the site layout plan and information provided by the experts are fed into the developed software by using the interface shown in Fig.5. The developed software allows the user to design the site layout plan by considering; only the distance, only the safety, or both objectives at the same time.

Table 8. Experts' assessments related to the possibilities of the safety risks due to the load falls from the tower crane on the temporary facilities

	E1	E2	E3	E4	E5
F9	0.4	0.8	0.6	0.6	0.8
F10	0.2	0.4	0.2	0.4	0.8
F11	0.2	0.4	0.2	0.4	0.8
F12	0.4	0.4	0.4	0.2	0.8
F13	0.2	0.4	0.2	0.4	0.4
F14	0.4	0.2	0.2	0.4	0.8
F15	0.4	0.2	0.4	0.2	0.8
F16	0.2	0.2	0.2	0.2	0.6

Table 9. Experts' assessments related to the possibilities of the safety risks due to the crane collapses on the temporary facilities

	E1	E2	E3	E4	E5
F9	0.4	0.8	0.6	0.6	0.8
F10	0.2	0.4	0.2	0.4	0.8
F11	0.2	0.4	0.2	0.4	0.8
F12	0.4	0.4	0.4	0.2	0.8
F13	0.2	0.4	0.2	0.4	0.4
F14	0.4	0.2	0.2	0.4	0.8
F15	0.4	0.2	0.4	0.2	0.8
F16	0.2	0.2	0.2	0.2	0.6

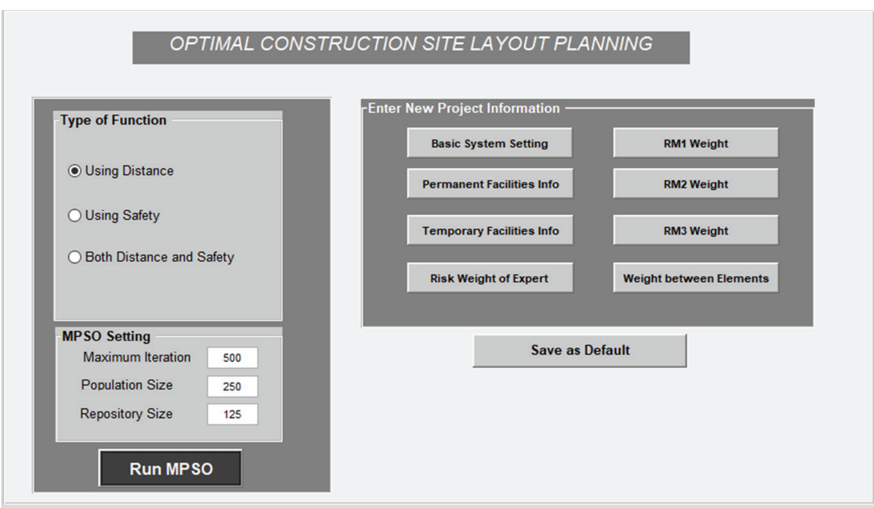

Figure 5. User input interface of the proposed model

4. RESULTS AND DISCUSSION

To achieve the best optimization performance, a grid search has been applied for the parameter selection of MOPSO algorithm. The grid is formed by five different population sizes (PSs); 50, 100, 150, 200 and 250, and six different repository sizes (RSs); 25%, 30%, 35%, 40%, 45% and 50%. That allows to build thirty different MOPSO models for CSLP and to select the best performing model. Each model has been run for 500 iterations. One can argue that number of iterations may not necessarily ensure finding the global best solution. However, it should be underlined that there is no strict or clear rule for determining the total number of iterations to get an optimal or near-optimal solution. Not only number of iterations, but many parameters (or algorithm's characteristic components) affect the quality of the final solution. To minimize the effects of MOPSO's random nature, each model has been tested five times, and the reported results are the mean values of these tests.

The graphs of mean trade-off values for five different PSs with six RSs are presented in Fig. 6 to Fig. 10. Figure 6 shows that RS 50% yields the optimum value of $3.5*10^5$ after 250 iterations for PS 50. For PS 100, the optimum value is obtained by RS 45% after around 50 iterations (Fig. 7). The behavior of RS 50% for this population is similar to 45%, but not as good. For PS 150 (Fig. 8), the optimum value is obtained by 40% RS after 400 iterations. RS 50% reaches the same value but after 500 iterations. Meanwhile while Fig. 9 indicates RS 40% that reaches the optimum value before RS 50% for PS 200, Fig. 10 indicates RS 50% that reaches the value of $3.2 *10^5$ after 250 iterations and stays stable for another 250 iterations for PS 250. The detailed analysis of the Figures indicates that the results obtained by RS50% are more stable than the other RSs and the best value among the optimum values obtained by RS 50% is for PS 250. Thus PS250 with RS 50% has been chosen as the best optimization performance and is used for further analysis.

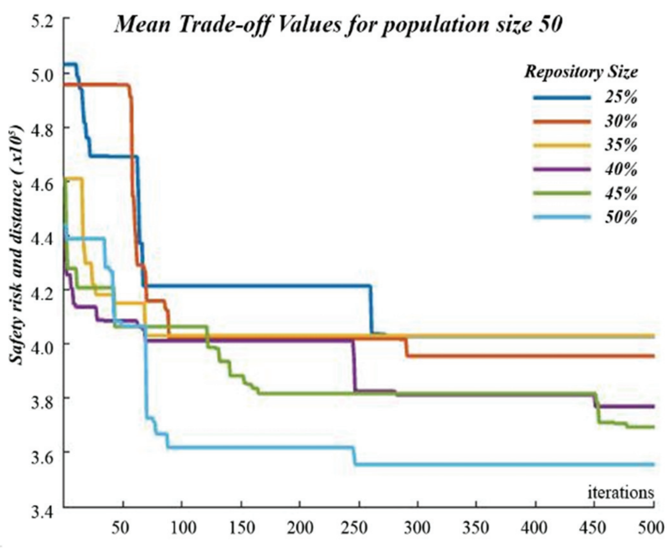

Figure 6. Mean trade-off values for population size 50

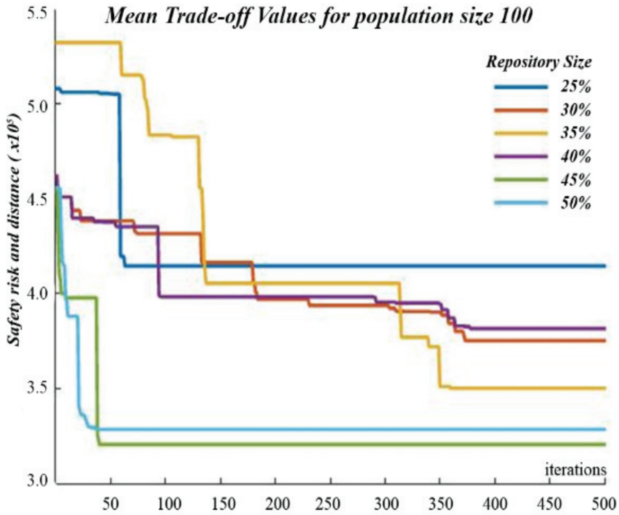

Figure 7. Mean trade-off values for population size 100

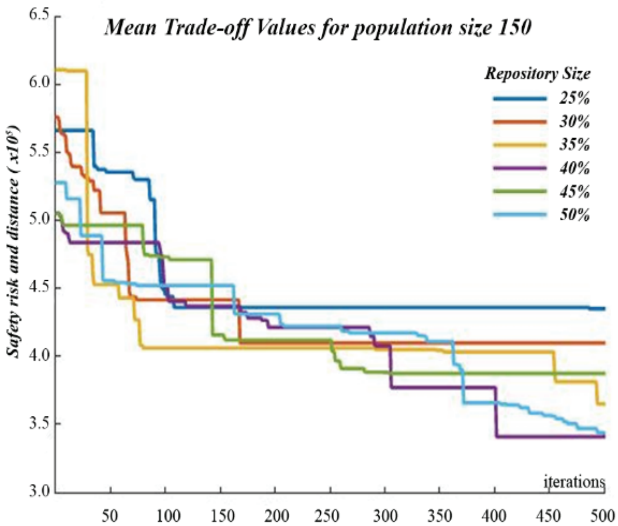

Figure 8. Mean trade-off values for population size 150

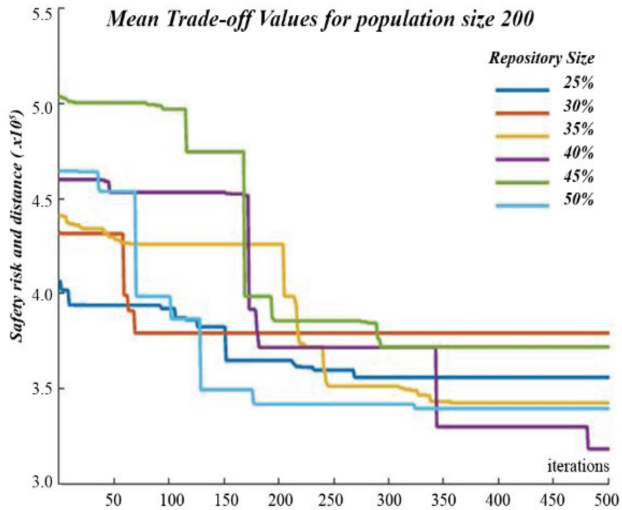

Figure 9. Mean trade-off values for population size 200

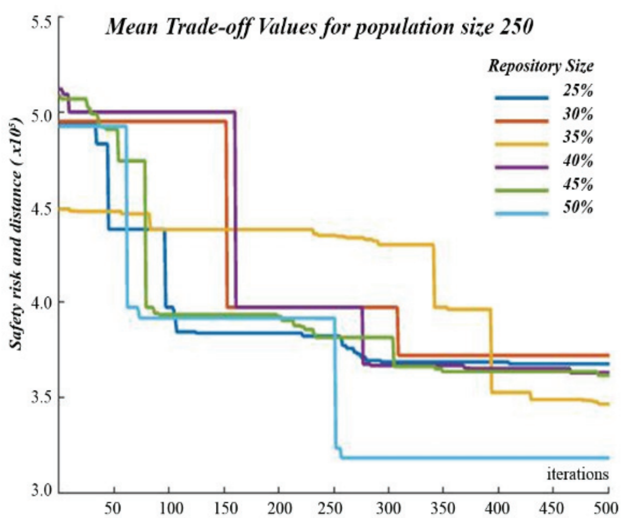

Figure 10. Mean trade-off values for population size 250

After deciding the MOPSO parameters (i.e., PS 250, RS 50%), the algorithm has been run for 500 iterations, and the final population is obtained. The scatter diagram is drawn according to both objectives (the first objective is the distance, and the second objective is the safety) and given in Fig. 11. Any solution from the Pareto front line, marked with red circles in Fig. 11, can be chosen and implemented as CSLP. For the current case study, the Pareto front line consists of 38 solutions. Solution A, for example, has the minimum total traveling distance among the Pareto set. On the other hand, it has the worst safety objective score. Similarly, solution B has the best safety score; unfortunately, it has the worst distance objective score. Therefore, a decision must be made to select the most satisfactory plan from the Pareto set.

The solution C has been chosen as the most satisfactory plan (visualized form in Fig.12, which is drawn by the model as an output when requested by the user) since it is the "knee point" [25] of Pareto front line. "Knee point" is the solution which satisfies the least distance from the utopia point U and it is determined by using the minimum distance selection method (TMDSM). It should be noted that both objective scores have to be normalized to eliminate the effects of any overpowering magnitudes.

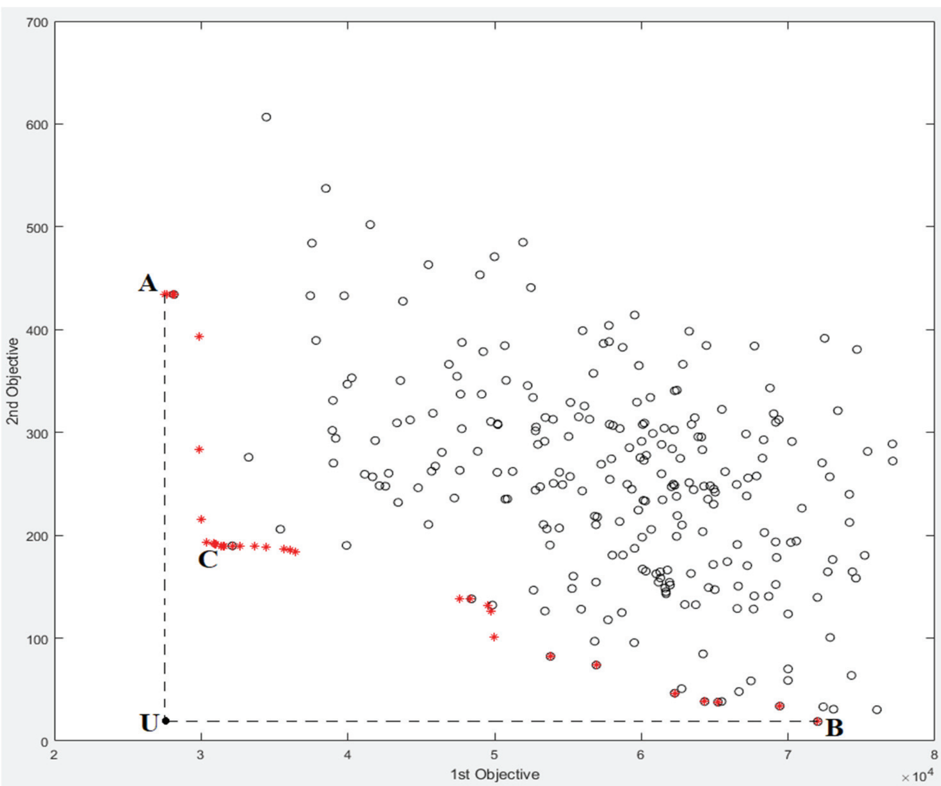

Figure 11. Pareto optimal solutions (Results of the case study)

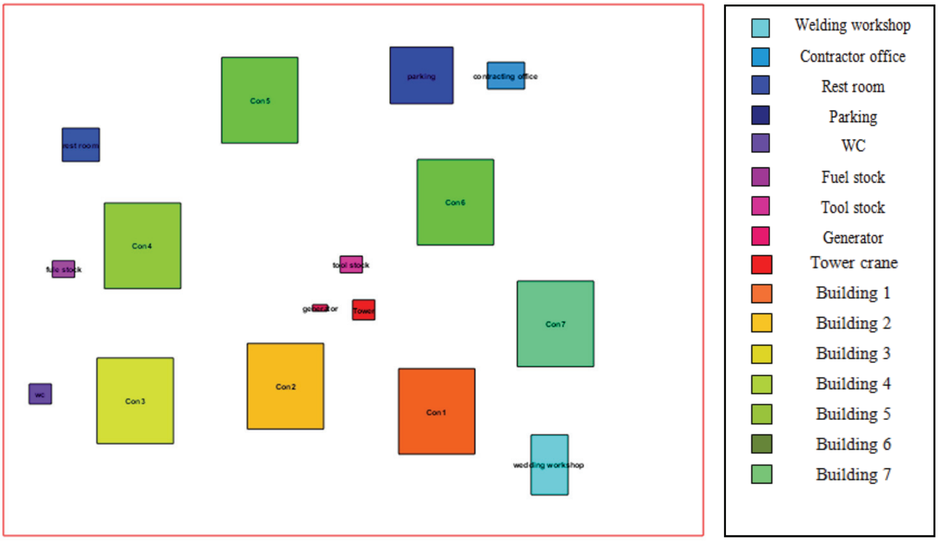

Figure 12. Optimal site layout plan (Results of the case study)

5. CONCLUSIONS

Current research focused on the multi-objective problem of minimization of both safety risks of crane operated construction sites and total traveling distance between temporary facilities. A model to generate site layout plans that provide optimal trade-offs between these two important objectives while satisfying all related constraints on site was designed.

Earlier studies on CSLP optimization have mostly focused on minimizing the total traveling distance of resources between site facilities, and the evaluation of the quality of the models was generally based on the parameters like the population sizes and the number of generations. Later studies have generally focused on solving CSLP as a multi-objective problem but few included tower crane operations within safety constraints. Even these had limited approach to the problem as they did not include varying degrees of risk magnitudes and probabilities that change according to the dimensions and the location of the tower cranes. Unlike previous studies, safety risk between tower crane and temporary facilities were presented by considering both the risk magnitude and the probability of a possible accident. Risk assessment approaches of construction safety experts were also reflected in the constraints depending on their experiences and management positions. MOPSO was utilized to solve the optimization problem, and a real-life construction project was used as an application example to illustrate its use and its capabilities. The application example with seven permanent buildings, a tower crane and eight temporary facilities to be located was also unique with respect to its size. Grid search method was used to optimize model parameters.They were performed to create the optimal trade-offs between the safety risks and the total distance between facilities as well as to study the efficacy of the diversifying iteration sizes, population sizes, and repository sizes, on the quality of the attained solutions. Results showed that the system is capable of providing a variety of different solutions as well as site layout plans that can be practically utilized by construction planners. The system provides a user-friendly environment which allows if required, the user input related to MOPSO settings, project, and expert information.

The limitation of the model is that it produces solutions only for quadrilateral construction sites with one tower crane. Development of a model that covers any site shape with multiple tower cranes is recommended for further research. Developments which include security and environmental requirements as optimization objectives are also recommended.

Acknowledgments

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An Investigation of Litigation Process in Construction Industry in Turkey

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ABSTRACT

Projects are laden with variety of uncertainties depending on their respective characteristics. Construction projects also have their own distinctive characteristics, such as technologies applied and numerous uncertainties. Thereby, it is highly probable that disputes could be encountered between concerned parties. While resolving these disputes, unspecialized legal professionals conducting construction related cases would increase the number of unsatisfactory judicial results. In this study, it is aimed to classify the most frequent dispute sources concerning the construction sector and to identify the qualifications and competency levels of concerned judicial actors. Correspondingly, 282 cases between 2007 and 2017 in Turkey are classified regarding relevant contents and analyzed. These cases are extracted from legal websites. While elaborating the cases, content analysis is performed in order to categorize the sources of disputes. Moreover, by inspecting the judgments of Court of Cassation for each case, qualifications and competency levels of judicial actors are questioned. In conclusion, the main dispute sources are classified under 5 headings along with some associated subheadings. Among the subheadings, construction works, construction contracts, debits and credits are detected as the most frequent dispute sources. Secondly, in majority of the cases, reassessment decisions were given by Court of Cassation due to inadequate competency levels of Court of First Instance and expert reports.

Keywords: Disputes in construction, competency levels of legal actors, legal process in construction, content analysis.

1. INTRODUCTION

A project is a systematic process requiring finite resources to achieve stakeholders' objectives which are defined in a contract. A stakeholder can be a person or an organization affected by the project outcomes positively or negatively [1], [2]. Level of responsibility, power and expectation of stakeholders may vary from project to project [2]. Tendency to maximize the

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benefit of each stakeholder may cause conflicts of interest and may result in disputes. Therefore, the construction sector is also identified as a dispute ridden industry as well. Litigation is the most formal way and the final destination in terms of settling disputes in Turkey, and it is time and cost consuming in addition to several other disadvantages [3]. According to Oxford Business Group [4], economy of Turkey is driven by the construction sector. Although there is widespread dissatisfaction among parties leading to the litigation process [5] along with its concomitant cost and time overrun and adversarial relationships [6], [7], unfortunately, Turkish construction industry mostly applies to litigation before trying other dispute resolution methods.

Understanding the factors influencing the occurrence of disputes determines the performance of a construction project [8], [9]. Although the subject of dispute resolution is widely discussed in literature, there are limited studies related to inspecting the efficiency of the litigation process in construction industry. Apanoğlu [10] initiated a study to determinine the frequency of dispute types according to only Contract of Work in "Turkish Code of Obligations". He investigated the cases until 2007. However, in addition to Contract of Work, other significant classifications and their cross-tabulations are needed in order to provide an in-depth analysis. Additionally, while these cases conducted by Court of Cassation are overviewed, judgments of Court of Cassation are to be analysed in order to determine the weaknesses of the concerned actors. To do this, extensive literature review is conducted, and construction related lawsuits from 2007 to 2017 are reviewed and analyzed as a quantitative method through SPSS in this research. To analyse the data, content analysis is used. The main purpose of content analysis is to transform the qualitative data to quantitative data through classification. Thus, dispute categories including the main dispute reasons are generated and competency levels of judicial actors are questioned. Content analysis is generally utilized in social science aiming to systematically examine the data obtained from different sources such as documents, archives, newspapers, television series, cinemas, etc. [11]. According to Yıldırım A. and Şimşek H. [12], content analysis allows the researcher to investigate the summarised and interpreted data through an in-depth descriptive approach in order to figure out the hidden themes. Additionally, Yıldırım and Şimşek [12] underline the importance of content analysis as gathering similar data as per defined themes through an inductive approach. In this study, contents of the cases are classified according to following categories; articles in Contract of Work in Code of Obligations, dispute types, project types, scope of construction project contract, and decisions by Court of Cassation. After the cases are grouped as per type of the disputes, frequency analysis is made in order to figure out the occurrence rates of the categories statistically. Hence, contract related cases conducted by Court of Cassation between 2007 and 2017 are categorized to determine the sources of the disputes and bottlenecks of the participating actors in order to be able to take crucial precautions concerning construction projects in advance. The reasons behind limiting the cases with only the ones having construction project contracts and judged by Court of Cassation are given below;

- Construction project contract is one of the most vital tools hindering disputes,
- Decisions of Court of Cassation set a precedent for future cases,
- Decisions of Court of Cassation are disclosed for public use through legal websites,

As in industries related to Medicine and Information Technology (IT), construction industry has its own characteristic elements and requires specific knowledge to resolve the disputes between the parties; still, in current judicial process in Turkey, judicial actors mostly have bachelor's degree without specializing in a specific subject. Thus, projects' parties in the construction sector encounter numerous problems during the resolution of disputes through litigation. In order to settle these problems, this study intends to achieve the following goals;

1. To detect the problem areas in the content of the cases concerning construction industry along with their occurrence rates through classifications of disputes.
2. To identify the competency levels and qualifications of judicial actors who participated in construction related disputes in Turkey.

2. THE LITIGATION PROCESS

Litigation is one of the most effective and common methods used to resolve a dispute. İlter [13, p. 589] expresses in her study that "*In most disputes, parties try negotiation and if this is not successful, dispute is taken to arbitration or litigation right away.*" This process is managed by a judge in order to release a binding decision. However, there are some disadvantages such as the case being relatively slow and being an expensive process along with the potential of damaging the business relationship.

Court of First Instance (Trial Court) is the first level of courts handling any type of disputes. It contains two main organizations namely, civil and criminal divisions in order to conduct civil and criminal issues respectively. Civil Courts consist of Civil Courts of Peace, Civil Courts of General Jurisdiction and Specialized Courts. Criminal Courts contain divisions as General Criminal Courts and Specialized Criminal Courts. If a Specialized Court doesn't exist in a district, concerned Civil Courts or General Criminal Courts have the authority to judge on behalf of Specialized Courts. Generally, construction cases are conducted by Civil Courts of General Jurisdiction.

Following the verdict for the case by the Court of First Instance, should one of the parties is not satisfied, the parties of the dispute have the right to apply to the Regional Courts of Justice. Then, the process extends again. With respect to application to Regional Courts of Justice for appeal, the deposited amount for the lawsuit shall be higher than 3.110 TL as of January 01, 2017 excluding libel suits which don't require a limit according to Article 341/2 in the Law of Civil Procedure [14]. If the claimant or defendant is not satisfied with the decision of the Regional Court of Justice than the amount for the lawsuit would be higher than 41.530 TL as of January 01, 2017, claimer can thus apply to the Court of Cassation.

Before the establishment of Regional Courts of Justice, Court of Cassation was responsible for appeal. Regional Court of Justice was established on September 26, 2004 with the law number 5235 and came into force in July 2016. Above the Regional Courts of Justice, Judicial Justice is conducted by Court of Cassation in Turkey. This organization constitutes 23 Civil Chambers and 20 Criminal Chambers which have their own individual roles. Civil Chambers in the Court of Cassation are charged to deal one of the following decisions [14];

- If a Civil Chamber in the Court of Cassation agrees with the award dealt by the Courts of First Instance, the award is accepted.

- If the Civil Chamber disagrees with the award dealt by the Courts of First Instance and asks reassessment, the Court of First Instance either accepts the reassessment or rejects the decision of reassessment. If the Court of First Instance agrees with the award of the Civil Chamber, the case is opened again and the decision is changed as per law. If the decision of reassessment is rejected by the Court of First Instance, the case is reviewed by the General Assembly of Civil Chamber in the Court of Cassation instead of the Civil Chamber.

Structure of Judicial Justice is illustrated in Organizational Figure 1 below.

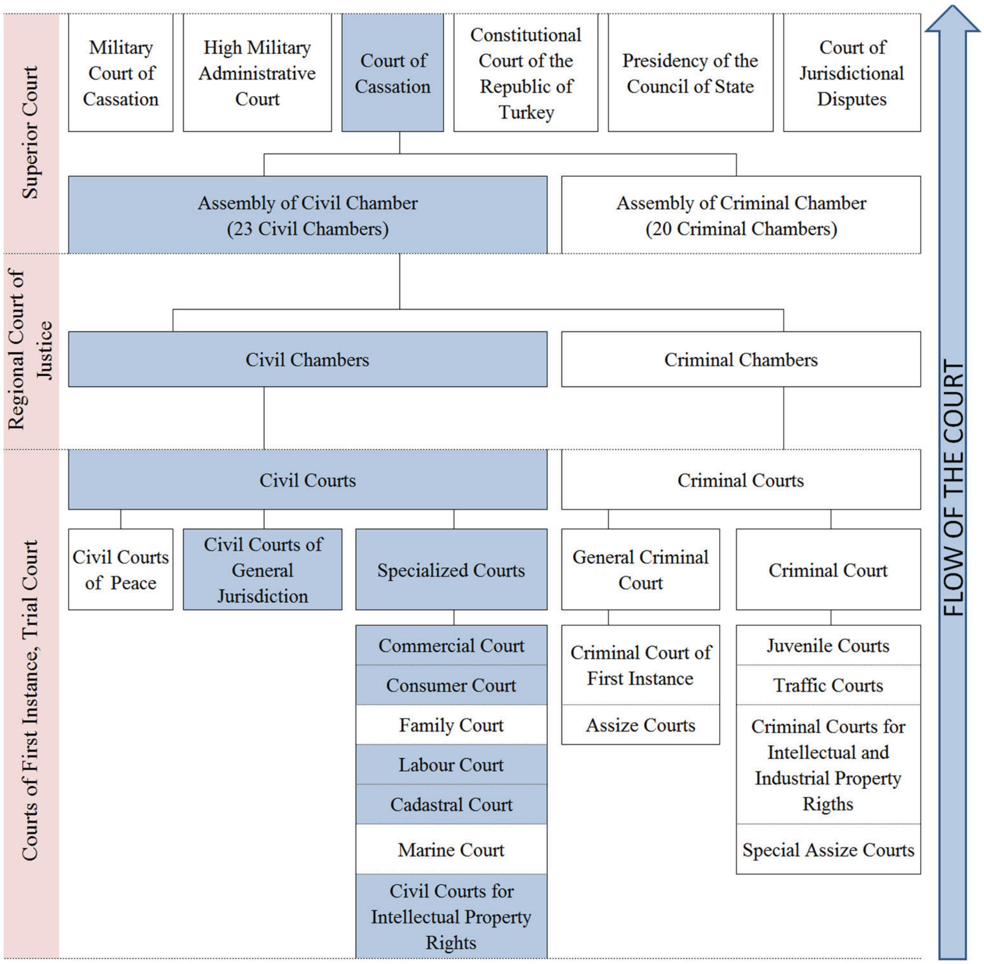

Figure 1. Organization of judicial justice in Turkey [15], [16]

In Figure 1, cases related to construction industry are mostly conducted by the courts shaded in blue above.

General Law consists of Public and Private Law. Disputes in Turkish private construction industry are ruled by Private Law. In this study, cases resulting from private projects with contracts are focused. Contract related cases are conducted as per Contract of Work which is part of Code of Obligations. Code of Obligations was transferred from Swiss Code of Civil Law and was established on April 22, 1926 with a law number 818. Then, the final update entered into force on January 01, 2011 with the law number 6098 and started to be used on July 1, 2012 [15]. Code of Obligations # 6098 contains 18 parts and mainly defines the relationship between debtor and creditor through related articles from 1 to 649. Part 7 in the Code of Obligations allocates Contract of Work which defines statements in a contract in terms of scope, liabilities, payment and termination [17]. Contract of Work covers the articles from 470 to 486, which correspond to the articles from 355 to 371 in the Code of Obligations # 818. In this study, article numbers in both Code of Obligations 818 and 6098 are utilized during the reviewing phase of the cases as the study covers the cases from 2007 to 2017.

3. METHODOLOGY AND RESULTS

In order to achieve the objectives of the study, 420 cases examined by the Court of Cassation between 2007 and 2017 are reviewed, and 282 cases are found to be related to the construction industry. The cases are elaborated and content analysis is applied in order to categorize the main dispute sources and define the qualifications and competency levels of judicial actors. By doing this, concerned cases are classified as per articles in Contract of Work, dispute types, project types, scope of construction project contract, and decisions made by Court of Cassation in order to define the most sensitive dispute areas and to define the qualifications and competency levels of judicial actors. After the cases are categorized as per concerned contents, frequency analysis is made in order to determine the occurrence rate of each dispute content.

To serve the goals mentioned above, a summary of the classifications of elements related to the content and their objectives are tabulated in Table 1 below.

Table 1. Summary of the classifications and their objectives

CLASIFICATION	PURPOSE
Articles in Contract of Work	To reveal the crucial articles in Contract of Work in terms of dispute
Dispute Types	To identify the major sources of the disputes
Project Types	To determine the most frequent project types leading to disputes
Scope of Construction Project Contracts	To determine the most frequent Articles of Construction Project Contracts leading to disputes
Decisions made by the Court of Cassation	To define the qualifications and competency levels of judicial actors

The obtained data is analysed through SPSS. According to the outcome of the analysis, tables from 2 to 7 are developed. To begin with, the frequency of article numbers is defined in Table 2 below.

Table 2. Frequency of Articles in Contract of Work

Articles #	**Description**	**# of Cases**	**Percent (%)**
470/355	Contract	197	69.9
471/356	General responsibilities of contractor	7	2.5
472/357	Material	6	2.1
473/358	Commencement of work and defect in execution	5	1.8
474/359	Indication of defect of work by Client after handing over	12	4.3
475/360	Client rights resulted from defects of work	10	3.5
476/361	Defects caused by client and warned by contractor	2	0.7
477/362	Acceptance of work	9	3.2
478/363	Time limit of opening a case due to defects of work	1	0.4
479/364	Due date of payment	2	0.7
480/365	Lump sum price	11	3.9
481/366	Price as per value (Unit measure and Cost plus fee)	17	6.0
483/368	Destruction of work before completion	1	0.4
484/369	Cancelling the contract through paying completed work	2	0.7
Total		**282**	**100.0**

It should be noted that there are some changes in law and in codes of law during the period of 2007-2017. In year 2012, a new Code of Obligations was released, and article numbers for the law 818, which refers to the previous law, and law number 6098, which refers to the final Code of Obligations, are introduced in Table 2 above in order to refrain from confusion. In the first column of Table 1, while the first number in each row refers to the final release of Code of Obligations # 6098, the following number refers to the previous Code of Obligations # 818.

Each article shown in Table 2 defines the frequency of dispute areas as per Contract of Work. Since each construction related dispute in this study pertains to a contract, the contract becomes the most sensitive issue. This also correlates with Bvumbwe C. and Thwala D. W.

[18]'s study in which poor contracts are identified as one of the major causes of disputes in construction industry. Detailing each article concerning the parties' expectations and eliminating the ambiguities in construction project contracts are believed to prevent disputes in projects.

As depicted in Table 2, the main definition of Contact of Work namely, Article 470/355 (Contract) constitutes the biggest part of the examined cases by almost 70%. The term of Contract as an article expresses all the general contract related disputes. In other words, it is a definition term of 'Contract of Work'. Therefore, categorising the cases as per only Contract of Work provides missing information. In order to deeply investigate the main dispute areas, dispute types are essential to be grouped and elaborated as per defined contents, namely 'Dispute Types', 'Project Types', 'Scope of Construction Project Contract', 'Decisions by Court of Cassation' and their relevant cross tabulation between each other in this study. Therefore, the next assessments shown in the following tables namely, Table 3, 4 and 5 intend to serve this purpose.

After all the cases are reviewed in terms of their subjects, firstly, dispute types are aggregated as 'Debit and Credit', 'Cancellation of Contract', 'Defective Products', 'Delay', 'Occupational Accident' and 'Registration and Nullification for Deed and Title'. Frequencies of concerned dispute types are tabulated in Table 3 below.

Table 3. Frequency of Dispute Types

Dispute Type	**# of Cases**	**Percent (%)**
Debit and Credit	142	50.4
Defective Products	63	22.3
Delay	32	11.3
Termination of Contract	22	7.8
Registration and Nullification for Deed and Title	21	7.4
Occupational Accident	2	0.7
Total	282	100.0

It is derived from Tables 3 that debit and credit related cases constitute almost half of the disputed cases. While 142 over 282 cases are related to 'Debit and Credit', 63 over 282 cases are related to 'Defective Products'. These are followed by 'Delay' with 32 cases, 'Termination of Contract' with 22 cases, 'Registration and Nullification for Deed and Title' with 21 cases and 'Occupational Accident' with 2 cases. The study of İlter and Bakioğlu [9] also support this finding by stating that debit and credit related dispute types such as price adjustment requests, additional payment requests, unit price determination and owner cash flow problems appear as the most frequent dispute types in construction projects.

Secondly, all the 282 cases are reviewed in terms of project types of concerned cases; then, project types are grouped as per 'Civil', 'Mechanical', 'Electrical', 'Infrastructure', 'Design', 'Finishing Works', 'Electrical/Mechanical' and 'Auditing'. Frequency of aforementioned project types is illustrated in Table 4 below.

Table 4. Frequency of Project Type

Project Type	# of Cases	Percent (%)
Construction Works	169	59.9
Finishing Works	36	12.8
Mechanical	26	9.2
Infrastructure	26	9.2
Electrical	12	4.3
Electrical/Mechanical	5	1.8
Design	4	1.4
Auditing	4	1.4
Total	**282**	**100.0**

Construction works define the projects such as housing, hospital etc. which contain other related disciplines provided in Table 4 above as well as civil works. According to the table, projects related to construction works are detected as the main problematic areas with the number of 169 over 282 cases and while this corresponds to approximately 60% of the overall cases, finishing works ranks as the second by almost 13%. Since projects concerning construction works mostly contain many divisions such as civil works, finishing works, mechanical works, electrical works, design etc., coordination between the disciplines carries many risks in terms of dispute. This fact clarifies the high occurrence rate of construction works. Thus, attention to the projects containing multi-disciplinary works is to be closely paid during the project life cycle.

Considering the disputes arising from both project types and dispute types, cross tabulation is needed to deeply investigate the main dispute sources. Therefore, Table 5 is generated for this matter.

It is derived from Table 5 that disputes mostly occur in Construction Works with the issues concerning debit and credit by 25%, defective product by 12%, Delay by 10%. Each of other correlations constitutes less than 10%.

Thirdly, 282 cases are reviewed in terms of Scope of Construction Project Contract and they are grouped as per ‘Contract between Employer and Contractor’, ‘Contract of Flat in Return for Land’, ‘Design Contract’ and ‘Building Audit Contract’. Frequency of given Scope of Construction Project Contract is demonstrated in Table 6 below.

With respect to Scope of Construction Project Contract, while ‘Construction Contract excluding Contract of Flat in Return for Land’ corresponds to 71.6% of the total cases, ‘Contract of Flat in Return for Land’ constitutes 25.9% of the cases, which covers approximately a fourth of the total types. Cases associated with the issue of ‘Contract of Flat in Return for Land’ accelerated after the Urban Transformation legislation released on December 15, 2012 was established. 62 over 73 cases concerning ‘Contract of Flat Return

Table 5. Cross Tabulation between Dispute Types and Project Types

		Project Type																Total
		Construction Works		Mechanical		Electrical		Infrastructure		Design		Finishing Works		Electrical/ Mechanical		Auditing		
		# of Cases	%	# of Cases	%	# of Cases	%	# of Cases	%	# of Cases	%	# of Cases	%	# of Cases	%	# of Cases	%	
Dispute Types	Debit and Credit	70	25%	15	5%	7	2%	18	6%	4	1%	22	8%	2	1%	4	1%	142
	Cancellation of Contract	18	6%	1	0%	0	0%	1	0%	0	0%	2	1%	0	0%	0	0%	22
	Defective Products	33	12%	10	4%	4	1%	7	2%	0	0%	6	2%	3	1%	0	0%	63
	Delay	29	10%	0	0%	1	0%	0	0%	0	0%	2	1%	0	0%	0	0%	32
	Occupational Accident	0	0%	0	0%	0	0%	0	0%	0	0%	2	1%	0	0%	0	0%	2
	Registration and Nullification for Deed and Title	19	7%	0	0%	0	0%	0	0%	0	0%	2	1%	0	0%	0	0%	21
Total		169		26		12		26		4		36		5		4		282

for Land' were conducted after December 15, 2012. Annual construction amounts have increased due to some privileges. This legislation provides the contractors and house owners to renew the existing buildings, and the number of cases related to 'Contract of Flat Return for Land' has increased accordingly.

So far, as stated in the purpose of this study the main problem areas in the content of the cases concerning construction industry along with their occurrence rates of disputes are classified. Next, 282 cases are reviewed in terms of decisions of Court of Cassation and it is categorized as per Reassessment decisions with 'Needs for Expert Judgment', 'Unsuitable Case Condition', 'Missing Review and Wrong Assessment', 'Defective Expert Report', 'Decision of Rejection of Venue', 'Not Offering Taking an Oath', and approving the 'Judgment' and 'Judgment with a Correction'. Frequency of given decisions by Court of Cassation is demonstrated in Table 7 below.

Table 6. Frequency of Scope of Construction Project Contract

Scope of Construction Project Contract	**# of Cases**	**Percent (%)**
Construction Contract excluding Contract of Flat in Return for Land	202	71.6
Contract of Flat in Return for Land	73	25.9
Building Audit Contract	4	1.4
Design Contract	3	1.1
Total	**282**	**100.0**

Table 7. Frequency of Determination by Court of Cassation

Decision by Court of Cassation	**# of Cases**	**Percent (%)**
Reassessment - Missing Review and Wrong Assessment	123	43.6
Reassessment - Needs for Expert Judgment	83	29.4
Reassessment - Defective Expert Judgment Report	33	11.7
Reassessment - Decision of Rejection of Venue	21	7.4
Reassessment - Unsuitable Case Condition	7	2.5
Approving Verdict with a Correction	6	2.1
Approving the Verdict	5	1.8
Reassessment - Not Offering Taking an Oath	4	1.4
Total	**282**	**100.0**

While Court of Cassation approves the verdicts of Courts of First Instance by only 3.9%, Court of Cassation decides to reassess the cases conducted by Courts of First Instance by 96.1%. Of all the reassessment reasons, 'Missing Review and Wrong Assessment' made by

Courts of First Instance constitutes the biggest part of the decisions of reassessment with the number of 123 cases. The reason for second reassessment decisions due to lack of expert judgment in the cases, cover approximately 30% of all the cases.

Considering the overall 282 cases, Court of Cassation accepts 11 verdicts dealt by the Courts of First Instance, whereas remaining 271 cases are decided to be reassessed. In other words, around 96.1% of the cases carried to Court of Cassation are found incorrect and required to be reassessed. It can be derived from these findings that most decisions of Courts of First Instance are found unsatisfying. Considering the actors contributing to the wrong decisions given by the Court of First Instance, the associated errors namely, 'Missing Review and Wrong Assessment', 'Need for Expert Judgment', 'Decision of Rejection of Venue', 'Unsuitable Case Conditions' and 'Not Offering Taking an Oath' which are provided in Table 7 are related to the qualifications and competency levels of the judicial parties. The reassessed cases due to inadequate qualifications and competency levels of judicial parties correspond to approximately 85%. Aside from judicial knowledge, technical and process related knowledge in construction would decrease wrong decisions and considerably shorten a lengthy process of litigation. The assessments of the cases also indicate that the qualification of chosen experts is another problematic area that needs to be focused. Around 12% of the reassessed cases have resulted from the experts' defective reports.

According to the legal process, if Court of First Instance insists on its decision and refuses the reassessment decision of the Court of Cassation, the case is evaluated again by the General Assembly of Civil Chamber which takes place under Court of Cassation [14]. It has been found that 6 cases over 282 cases were dealt with the General Assembly of Civil Chambers. It means that Courts of First Instance conducting these 6 cases disagreed with the reassessment decision given by the Court of Cassation. Still, reassessment decisions were given for 5 of the cases again.

In this study as the final step, relations between types of disputes and determinations made by Court of Cassation are presented in Table 8 below.

Considering the dispute types and determinations made by the Court of Cassation, the most notable findings are given as follows; debit and credit related cases are associated with 64 reassessment decisions due to missing reviews and wrong assessments made by Court of First Instance and 41 reassessment decisions are made due to needs for experts. The most remarkable findings derived from Table 8 are that the 'Needs for expert judgment' constitute almost 30% of the total cases. Almost half of the cases (41 cases) in this category are related to debit and credit issues between the project stakeholders mainly the general contractors and the owners. That is followed by the determination of the defective products by 27 cases, delay in projects by 8 cases, registration and nullification for deed and title by 7 cases. Each issue in this process needs knowledge of construction process by the judicial actors in order to determine the conditions of cases. The findings indicate that unqualified expert reports cause courts to make inappropriate decisions. Encouraging the utilization of qualified experts in the courts with regard to these areas is believed to improve the success of the litigation process. In Table 8, 'Missing Review and Wrong Assessment' constitute 44% of the cases. Half of the cases in this category and 23% of the total cases constitute 'Debit and credit' issue. These outcomes indicate the lack of construction specific knowledge during the decision making process.

Table 8. Cross Tabulation between Dispute Type and Determination by Court of Cassation

Dispute Types	**Determination by Civil Chambers of Court of Cassation**																**Total**	
	Reassessment - Needs for Expert		**Reassessment - Unsuitable Case Condition**		**Reassessment - Missing Review and Wrong Assessment**		**Reassessment - Defective Expert Report**		**Reassessment - Decision of Rejection of Venue**		**Reassessment - Not Offering Taking an Oath**		**Approving the Judgement**		**Approving the Judgement with a Correction**			
	# of Cases	**%**	**# of Cases**	**%**	**# of Cases**	**%**	**# of Cases**	**%**	**# of Cases**	**%**	**# of Cases**	**%**	**# of Cases**	**%**	**# of Cases**	**%**	**# of Cases**	**%**
Debit and Credit	41	15	5	2	64	23	17	6	7	2	4	1	1	0	3	1	142	50
Termination of Contract	0	0	1	0	9	3	5	2	4	1	0	0	3	1	0	0	22	8
Defective Products	27	10	1	0	25	9	5	2	3	1	0	0	0	0	2	1	63	22
Delay	8	3	0	0	14	5	6	2	3	1	0	0	0	0	1	0	32	11
Occupational Accident	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	2	1
Registration and Nullification for Deed and Title	7	2	0	0	11	4	0	0	2	1	0	0	1	0	0	0	21	7
Total	83	29	7	2	123	44	33	12	21	7	4	1	5	2	6	2	282	100

4. CONCLUSION

In this study, initially, 282 cases conducted by Court of Cassation between the years 2007 and 2017 in Turkey are reviewed and the content of the cases along with their occurrence rates are classified as per articles in Contract of Work, dispute types, project types, Scopes of Construction Project Contracts in order to detect the problematic areas in the contents of the cases. Secondly, it is aimed to identify the competency levels and qualifications of actors in the judicial system for construction related cases in Turkey. In order to achieve this goal, the classification of determinations made by the Court of Cassation is utilized. Following the in-depth review of the cases and the classification, the data is analysed via SPSS as a quantitative study. As a consequence, it is derived from the analysis that contract is the most common dispute reason in construction. Because, the majority of contracts are not focused to an analytical approach for dispute resolution, which is also identified by İlter [13]. Additionally, of the contracts drawn up in the construction sector in Turkey, 70% of them were drafted without considering any type of existing standard contacts [19] Thus, concerning contractual problems, it is highly beneficial for construction projects to deeply investigate the contents of the contracts made to be able to take significant precautions against negative impacts of potential disputes. In conclusion, the amount of disputes related to contracts would be reduced. With respect to disputes resulting from contract, it is found that civil projects such as buildings or any other related turnkey projects containing more than one discipline carry higher probability of risks; therefore, close attention is to be paid to these kinds of projects during the contract stages of the projects in order to prevent the amount of potential disputes by eliminating ambiguities.

Contents of ‘Construction Contract excluding Contract of Flat in Return for Land’ and ‘Contracts of Flat in Return for Land’ are presented as the biggest sensitive areas in dispute. When the contents of contracts are investigated, monetary issues under the title of debit and credit rank as the most frequent dispute source related to contracts. This is followed by defective products. Therefore, while initiating the construction project contract, these subjects are to be taken into consideration highly to eliminate disputes during the course of the projects.

‘Missing Review and Wrong Assessment’ is detected as the major factor contributing to wrong determinations of Courts of First Instance by 43.6%. It is followed by ‘Needs for Expert Judgment’ by 29.4%, ‘Defective Expert Report’ by 11.7%, ‘Decision of Rejection of Venue’ by 7.4%, ‘Unsuitable Case Condition’ by 2.5% and ‘Not Offering Taking an Oath’ by 1.4%. It is claimed that the success of judgment would definitely increase by assigning the correct expert to the cases considering technical issues. Additionally, qualifications of experts also need to be reconsidered by the legislators, judicial actors, and trade chambers. Excluding ‘Defective Expert Judgment’ Reports’, all the reasons concerning reassessment decisions by Courts of First Instance stem from inadequate qualifications and competency levels of the other judicial actors namely, judges and lawyers. This corresponds to approximately 85% of the total cases. This outcome indicates the qualifications of judges and lawyers as another problematic area affecting dispute resolution process. Construction industry has its own characteristics like industries of Medicine and Information Technology (IT) and requires specific knowledge in order to resolve any dispute concerning construction. Therefore, improving technical knowledge of construction of these judicial actors is believed to improve the success of the judicial process.

According to the final legislation related to experts, which was released on November 3, 2016 with the law number 5754, people graduating from faculties of law cannot be enrolled in the expert registry unless they have specialist expertise outside the legal field. This new legislation is believed to reinforce the qualifications and competency levels of experts and it is thought to reduce the experts' defective reports in the upcoming cases. It can be concluded that litigation processes are mostly prolonged due to inadequate qualifications and competency levels of judicial actors; thus, not only the judicial process but also the parties in construction projects are exposed to inconvenient prolongation of works.

Since this study is limited with investigating the cases conducted only by the Court of Cassation in Turkey between 2007 and 2017 to identify solely the sources of disputes and current qualifications and competency levels of judicial actors, further studies can be conducted beyond the limitations of this worek. This study can be enhanced through contributions of other actors participating in judicial processes concerning construction like contractors, claimants, defendants etc. This study is believed to highlight the bottlenecks of the construction projects and judicial process concerning construction industry, and guide the judicial actors and parties participating in construction related cases. Finally, this study is believed to contribute to future studies concerning development of standard construction project contracts and the improvement of litigation process as one of the dispute resolution methods.

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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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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).

$$I_h=100S/PE \quad (1)$$

$$I_a=100D/PE \quad (2)$$

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).

$$TMI = I_h-0.6I_a \quad (3)$$

$$TMI = \frac{100S - 60D}{PE} \quad (4)$$

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

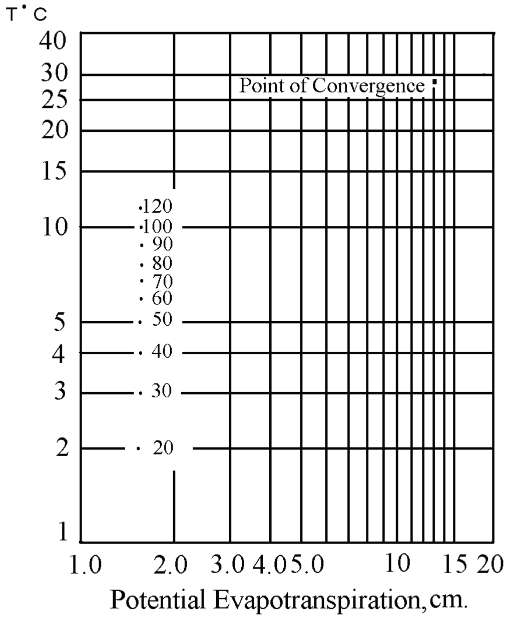

Figure 1. Nomogram for Determining Potential Evapotranspiration (Thornthwaite 1948)

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.

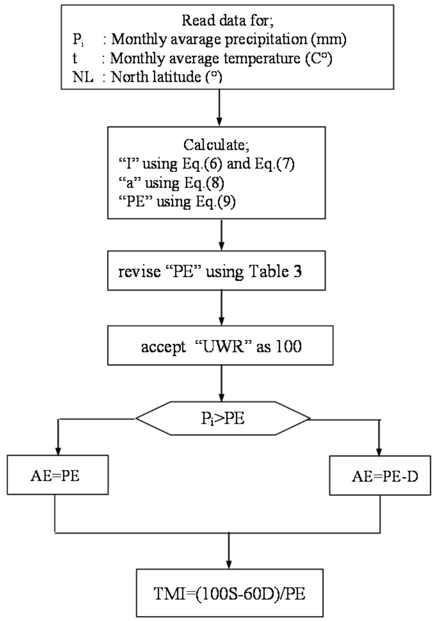

Figure 2. The flowchart for calculation of TMI

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

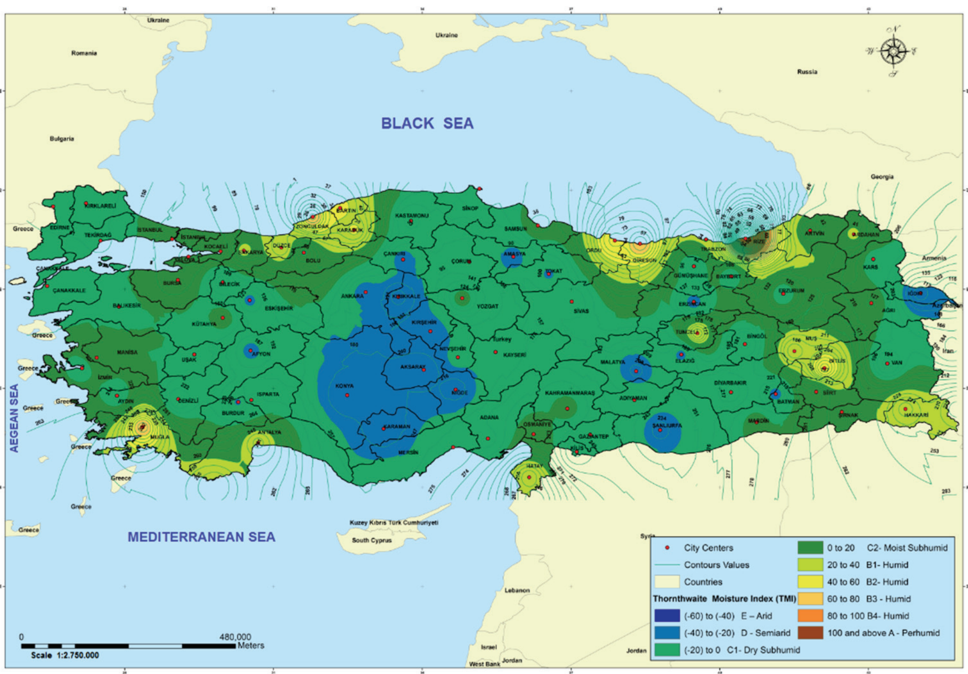

Figure 3. Thornthwaite Moisture Index Distribution of Turkey

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.

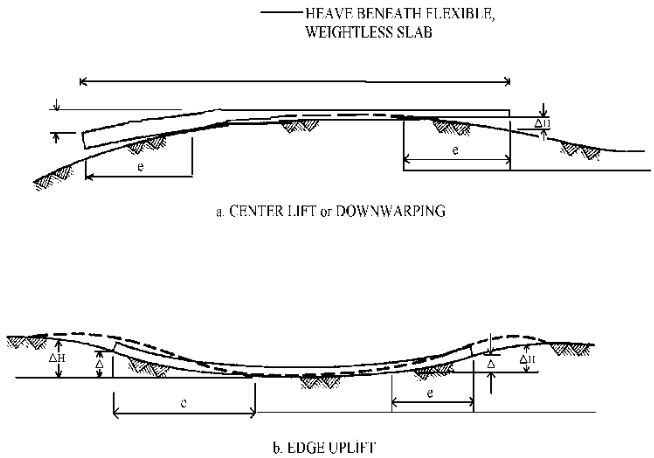

Figure 4. Soil Slab Displacements on Heaving Soil (Wray 1989)

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.

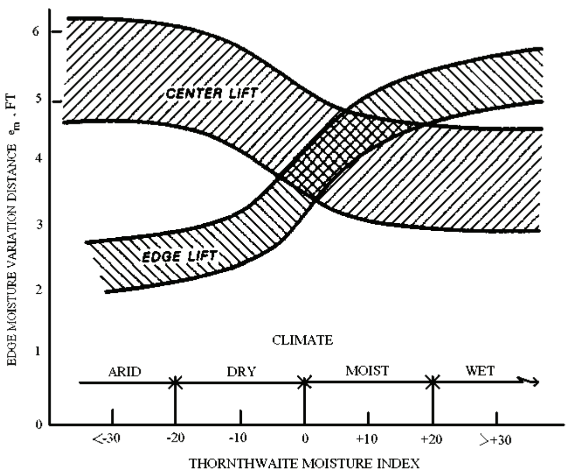

Figure 5. Approximate Relationship Between the Thornthwaite Moisture Index and the Edge Lift-off Distance (Wray 1989)

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

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