THE INFLUENCE OF LAND USE AND THE CATCHMENT PROPERTIES ON THE TROPHIC STATUS OF SHALLOW LAKES IN TURKEY

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ABSTRACT

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Anthropogenic (human) factors can dramatically increase the nutrient concentrations of the shallow lakes which cause to cultural eutrophication. The most apparent effect of cultural eutrophication is excessive plant population and dense algal blooms that reduce the water quality. The artificial inputs of nutrients come from surface runoff such as excessive fertilize use in the agriculture, untreated wastewater effluents from the urban area trigger the eutrophication. These human activities linked with degradation of water quality lead to also dramatic consequences for drinking water sources, fisheries, and recreational water bodies.

The aim of this study was to evaluate land use and landscape characteristics influence on the trophic status of shallow lakes through rendering the statistical relations. Study area covers 38 shallow lakes from north to south in the west part of the Turkey. Catchment variables were produced by using geographic information system (GIS). Trophic status of the lakes was described by principal component analysis (PCA), using total nitrogen (TN), total phosphorous (TP), Chlorophyll a (Chl-a) and Secchi depth. In the analysis PCA result regarded as PC1 which determined the trophic state of the lake. Almost all studied lakes were eutrophic in terms of nutrient concentration, however two deep lakes (Lake Abant and Lake Büyük) were oligotrophic showed up outliers. Statistical analysis for PC1 versus catchment variables were done without these two lakes.

Firstly, catchment variables effect on lake trophic status was analyzed with 36 shallow lakes. Contrasting with the other studies, there was no significant relation in the simple linear regressions with the land use and nutrient concentrations of the lakes. There were only 3 catchment characteristics as temperature (14.41%), latitude (9.41%) and longitude (6.25%) had significant relation with the PC1. Multiple regression analysis was applied to show PC1 versus cumulative effect of catchment characteristics. There was still unexpected result that significant features for PC1 are 'slope, wetland, latitude and temperature', respectively. There was weak relationship between these variables and PC1 which explained 26.75% of the variance in PC1.

Secondly, analysis of catchment influence on PC1 was repeated with 30 lakes. Six lakes had high TN, despite their entirely forested catchment area were evaluated as outlier. The result has been changed from the first analysis that PC1 versus the significant catchment variables in the simple linear regression are catchment area (20.07%), forest and semi natural areas (19.67%), latitude (12.98%), agricultural area (12.84%) and temperature (11.04%). Multiple regression analysis was done for PC1 versus all catchment variables using 30 lake data. There was strong relationship between catchment characteristics and PC1 that PC1 explained trophic status of the lakes as 60.13%. The significant variables in the multiple regression analysis are 'slope, catchment area, latitude, wetlands, lake area and precipitation' respectively. PC1 had negative relation between the slope, latitude, wetland and lake area, while PC1 had positive relation between catchment area and precipitation.

Keywords: Catchment, Trophic Status, Land Use, Geographic Information System

ÖZ

ARAZİ KULLANIMI VE HAVZA ÖZELLİKLERİNİN TÜRKİYE'DEKİ SIĞ GÖLLERİN TROFİK DURUMUNA ETKİSİ

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Sığ göllerdeki besin tuzu miktarı antropojenik etkilerden dolayı hızla artmakta ve bu durum kültürel ötrofikasyona neden olmaktadır. Su kalitesinin azalmasına neden olan ötrofikasyonun en belirgin etkileri bitki populasyonun artması ve alg patlamalarıdır. Aşırı gübre kullanımı ile tarımdan taşınan malzeme, kentsel alanlardan taşınan evsel atık suyu ötrofikasyonu artırıcı etmenlerdir. İnsanların etkileriyle ortaya çıkan su kalitesindeki bozulma, aynı zamanda içme suyu kaynakları, balıkçılık ve rekreasyonel aktivitelerde de olumsuz sonuçlar doğurmaktadır.

Bu çalışmanın amacı arazi kullanımı ve peyzaj özelliklerinin sığ göllerin trofik durumuna olan etkisini istatistiksel ilişkilerle ortaya çıkarmaktadır. Çalışma alanı Türkiye'nin batısındaki kuzeyden güneye kadar olan 38 gölü kapsamaktadır. Havza verileri coğrafi bilgi sistemleri kullanılarak elde edilmiştir. Göllerin trofik durumu temel bileşen analizi (PCA) ile toplam azot, toplam fosfor, klorofil a ve seki derinliği ile tanımlanmıştır. Göllerin trofik durumunu tanımlayan PCA sonucu PC1 ile değerlendirilmiştir. Çalışılan tüm göller besin tuzu miktarı açısından zengin, ötrofik göllerdir, buna karşılık iki derin ve oligotrofik göl (Abant ve Büyük Göl) aykırı

göller olarak tespit edilmiştir. PC1'e karşı havza değişkenleri için yapılan istatistik analizleri bu iki göl olmadan yapılmıştır.

İlk olarak, havza değişkenlerin göllerin trofik durumu üzerindeki etkisi 36 göl ile analiz edilmiştir. Diğer çalışmalardan farklı olarak, basit doğrusal regresyonda arazi kullanımı ile besin tuzu miktarı arasında dikkate değer ilişki bulunmamıştır. PC1 ile anlamlı ilişkisi havza değişkenleri beklenmedik biçimde sıcaklık (%14.41), enlem (%9.41) ve boylam (%6.25) olarak tespit edilmiştir. Havza değişkenlerinin PC1 üzerindeki kümülatif etkisini değerlendirmek amacıyla çoklu regresyon analizi yapılmıştır. PC1 için önemli değişkenler yine beklenmedik biçimde sırasıyla 'eğim, sulak alan, enlem ve sıcaklık' olarak ortaya çıkmıştır. Bu değişkenler ile PC1 arasındaki ilişki düşük ve PC1'i %26.75 olarak açıklamaktadır.

İkinci olarak, havzaların PC1 üzerindeki etkisini görmek amacıyla yapılan analizler 30 göl ile tekrar edilmiştir. Bütünüyle orman alanında yer alan havzalardaki göllerin yüksek toplam azota sahip olmaları nedeniyle bu göller aykırı değeler olarak değerlendirilmiştir. İlk analize göre sonuç değişmiş, basit regresyon analizinde PC1'i etkileyen önemli değişkenler havza alanı (%20.07), orman ve yarı doğal alanlar (%19.67), enlem (%12.98), tarımsal alanlar (%12.84) ve sıcaklık (%11.04) olarak belirlenmiştir. PC1'i etkileyen havza değişkenlerini bulmak amacıyla çoklu regresyon analizi 30 göl verisiyle yapılmıştır. Bu analizde havza değişkenleri ve PC1 arasında en yüksek ilişki bulunmuştur, PC1 göllerin trofik durumu %60.13 olarak açıklamaktadır. Çoklu regresyon analizde önemli havza değişkenleri sırasıyla 'eğim, havza büyüklüğü, enlem, sulak alan, göl alanı ve yağış' olarak bulunmuştur. PC1 ile eğim, enlem, sulak alan ve göl alanı arasındaki negatif ilişki, PC1 ile havza büyüklüğü ve yağış arasında pozitif ilişki bulunmuştur.

Anahtar Kelimeler: Havza, Trafik durum, Arazi Kullanımı, Coğrafi Bilgi Sistemi

To my beloved parents

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LIST OF ABBREVIATIONS

TP	Total Phosphorous
TN	Total Nitrogen
Chl a	Chlorophyll a
PCA	Principal Component Analysis
PC1	First Principal Component
DEM	Digital Elevation Model
TauDEM	Terrain Analysis Using Digital Elevation Models

CHAPTER 1

INTRODUCTION

1.1 The Importance of Shallow Lakes

Freshwaters have excessively valuable resources with economic and social roles (Papastergiadou et al, 2010). Even though freshwaters constitute less than 2 % of earth’s water resources, humans heavily rely on these scarce resources in terms of drinking water supply, agriculture, industry, tourism and recreation. Besides their importance, freshwater ecosystems are exposed to human effects which are more concentrated than terrestrial ecosystems due to shortage of the resources as well as the demand on them through usage of water for energy generation, transport, flood control and dilution of chemical wastes (Vitousek et al., 1997).

Shallow lakes mostly have less than 3 m average depth and unstratified for long periods in summer (Scheffer, 2004). They are important key elements in the ecosystem by means of providing ecosystem services such as habitats for wildlife, livestock watering, fish production and recreational amenities (Jeffries, 2005; Robin, 2014). Moreover, if the shallow lakes are close to each other or connect with the ditches (Murphy, 2002; Sondergaardet al., 2005; Robin et al., 2014), biodiversity values increase in terms of both locally and regionally (Oertli et al., 2002, Robin et al.,2014).

Among freshwater ecosystems, especially shallow lakes are prone to abrupt changes, changing from clear water state with high ecological and biodiversity value to turbid water state with loss of these values (Scheffer et al., 1993). In the last 100 years, shallow lakes are in great danger due to anthropogenic processes especially through intensive land use leading to eutrophication through agriculture as well as urban sewage effluent discharge, hydrological alterations especially through over extraction of groundwater resources for agriculture, and climate change. One of the most significant problems is rapid changes of phytoplankton biomass and richness caused by nutrient loading, mostly in the form of phosphorus, nitrogen, and suspended solids carried from agricultural and urban land.

1.2 Role of Catchments for Lakes

Although the lakes are separate entities, actually one should not think a lake without its influential environment, called as catchment. Watershed or catchment is the area from which water runs into streams and rivers or through surface runoff, and hence lakes (Moss, 2010). What happens in their catchment is reflected in lake ecosystems, thus the lake is like mirror of its own catchment.

In the past, to preserve freshwater ecosystems, people mostly insisted only on the restoration of natural physical, chemical, and biological processes (Roni et al., 2008; Paukert et al., 2011). With the increasing human distribution on their catchments, landscape-level anthropogenic threats (agriculture, urbanization, dams etc) became the second component of conservation planning issue (Paukert et al., 2011).

There are numerous studies about the relationship between land use and water quality characteristics of water bodies. They reported that human activities through land use alter the ecological processes of the waters through altering the hydrology, nutrient quantity and quality. For instance, Lenat and Crawford (1994) found that the intensive agricultural land use leads to high nutrient concentrations (total nitrogen and total phosphorus) in the lakes.

U.S. Department of Agriculture (USDA) Forest Service established The Hubbard Brook Experimental Forest (HBEF) in 1955 for hydrologic research in New England. One of the aims of this experiment is to watch the effect of nutrient retention capacity of trees in catchment ecosystem (Likens et al., 1969). They studied two small stream valleys at the nearly 3000 ha experiment area. Part of the valley catchment is almost entirely deforested; the other part of the valley was kept with its natural habitat. Before deforestation, they measured that more than 90% of the nutrients was arisen from soil organic matter and 9.5% of the nutrients was comes from vegetation (Molles, 1999). After they felled trees, they showed that nutrient loss was almost 40 to 50 times higher and the other material in the catchment increased from 177% to 1558% (Molles, 1999).

Similarly, Allan et all. (1997) found that water quality, habitat and biotic integrity of the river in the U.S.A are widely influenced by land use with different spatial extent. According to them, to determine local stream condition, the best indicator is the extent of the agricultural land at the subcatchment scale. Buck et al. (2004) exposed spatial-scale effect of catchment management for impressive conservation of land and water resources.

Wagner et all. (2011) also studied TP-Chl a relationships in shallow lakes across the different landscapes. They found that land use effect can change with different landscapes. If there is an immense agricultural land use, Chl a becomes more sensitive to the changes in TP. The most studies about the relation of land use and water quality is integrated with streams, however, there are few studies about the land use influence on the lake catchments.

Papastergiadou et al. (2010) found that both agricultural land use with extensive irrigation and summer drought alter the annual water level fluctuation. Also urban development, disappearance of wet meadows and extension of reed beds cause to decrease of submerged vegetation.

Sass et al. (2010) revealed the more the influence of agricultural development on the macrophyte community species richness compared with the effect of urban land use. Beside the land use effect, latitudinal difference is an important key for the trophic status of the lakes. Northern lakes are oligo-mesotrophic with high species richness, however southern lakes are more alkaline and eutrophic. In case of comparison macrophyte communities, northern lakes include greatly isoetids and eloeids, but southern lakes have very few isoetids. This finding contradicts with the expectations, because isoetid species are able to live in nutrient poor (oligotrophic) water (Smolders et al., 2002).

Bolstad and Swank (1997) sought the land use impacts on water quality in the catchments. Land use influence has greater influence during storm conditions. According to them, even if high quality water comes from the forest sources, that cannot affect water quality positively in regards to non-point source pollution during the storm event. It can be thought landscape alterations should not exclude climatic conditions.

Fraterrigo and Downing (2008) searched the lake and catchment characteristics influence on high and low transport capacity with respect to TP and TN. They corroborated the N and P differs among the different landscapes (Heathwaite et al. 2000). For instance, near-shore agricultural lands and TP & TN density has substantial correlation with the low transport capacity; however there is no relation to the high transport capacity.

1.3 Land Use, Eutrophication and Changes in the Trophic Structure of Lakes

Intensive inputs of nitrogen and phosphorus trigger eutrophication and deteriorate the water quality and ecological unity (Vollenweider, 1968; Smith, 2003). Freshwater ecosystems comprise naturally nitrogen by plant residue, atmospheric di-nitrogen and phosphorus by bearing minerals, however these natural nutrients greatly increase due to anthropogenic sources (Newman, 1995; Rabalais, 2002; Abell et al., 2011).

In terms of nutrient sources of lakes, land use has direct influence on the amount of nutrients, but catchment characteristics such as slope has indirect influence that affecting transfer of nutrients (Abell et al., 2011). According to Abell et al. (2011) due to awareness of the direct and indirect impact of these factors on lake trophic status, natural and anthropogenic nutrient loading can be clarified (Figure 1.1). They also revealed that among the catchment variables intensive pasture is the best predictor for TN and TP in the 101 New Zeland lakes. Contrasting with their study, Arbuckle and Downing (2001) showed that while row-cropping has high N:P, animal agriculture (pastureland) has low N:P in the catchments of 113 lakes in the United States (Iowa).

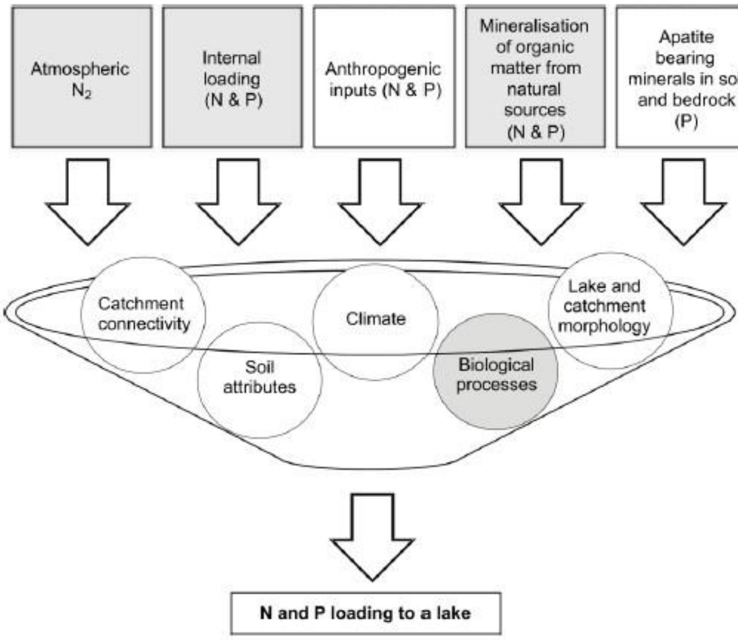

Figure 1.1 Sources of nitrogen and phosphorus to the lake

Increase in nutrient loading in particular phosphorus and nitrogen cause to eutrophication. The main resources of increasing phosphorus are waste water treatment works, discharge of raw sewage and arable lands (Moss, 2010). Nitrogen is derived both from excretal sources, mostly from cultivated land with high fertilized soil and from the atmosphere (Moss, 2010). Nowadays, due to human activities through both point and nonpoint sources to the lakes, eutrophication regarded as cultural eutrophication (Carpenter et al., 1998).

Lake eutrophication is the process of increasing primary production in response to enhanced availability of the limiting factors for photosynthesis such as light, CO2 and nutrients (Chislock et al., 2013). Eutrophication can also be seen as the deterioration of the water quality of the aquatic ecosystems by enhanced phytoplankton production namely blooms of toxic-cyanobacteria. These algal blooms can inhibit light penetration to the water column which may further inhibit the growth of the submerged macrophytes (Chislock et al., 2013). Furthermore, decreased water clarity also reduces the predation capability of piscivorous fish, since they are visual-predators. Increased photosynthesis in the water column can increase the pH value which may impair the chemosensory abilities of the organisms which is required for their survival (Turner & Chislock, 2010). Algal blooms in the lake surface can also create anoxic conditions in the water column which may initiate death of organisms and massive fish kills (Moss, 2010). Other than this bloom forming, cyanobacteria can also produce toxins which may be a threat for other organisms and public health. There are recorded events about toxicity and poisonous effects of cyanobacteria for domestic animals and for humans (Scheffer, 1997).

1.4 Aim of the Study and Hypothesis

The aim of this study is to show the influence of land use and catchment properties on the trophic status of some shallow lakes in Turkey. Basically, two questions will be addressed. First one is ‘can the catchment characteristics along with land use be the indicators for the trophic status of the shallow lakes located in Turkey?’ The second is, ‘which catchment characteristics have the most influence on the trophic status of the shallow lakes in Turkey?’

In this study the hypothesis is that the trophic properties of lakes are affected by both geographical properties and land use in the catchment (Figure 1.1). It was hypothesized that more intensive the land use e.g. agriculture, urbanization lead to higher nutrients in lakes compared to lakes with intact natural vegetation in their catchment. Geographical location, elevation, slope, catchment area, precipitation and temperature were considered to be the critical factors driving the nutrient availability in lakes.

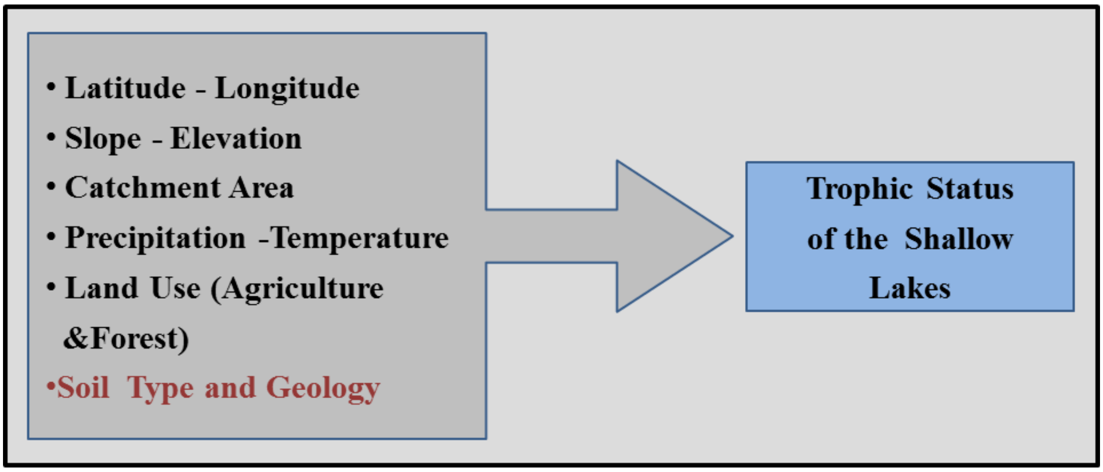

Figure 1.2 The relevant catchment properties affecting trophic status of the shallow lakes

CHAPTER 2

MATERIALS & METHODS

2.1 Study Lakes and Catchments

This study covers the western part of the Turkey from north to south (Figure 2.1). The study area includes 50 shallow lakes studied by Middle East Technical University (METU) Limnology Laboratory. The team has sampled and analyzed physical, chemical, and biological characteristics of these lakes since 2008 with different projects (TUBITAK-ÇAYDAG 105Y332 and 110Y125, EU REFRESH FP7-ENV-2009-1/244121 and ODTÜ-BAP Projects BAP.07.02.2009-2012). (Figure 2.2).

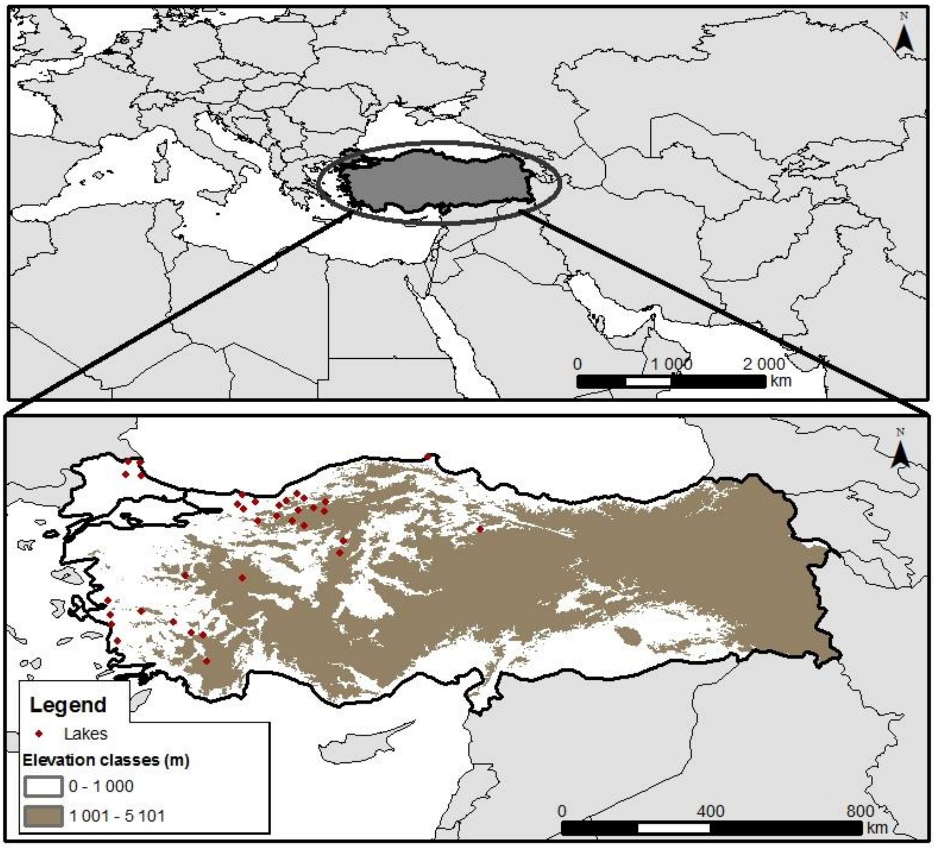

Figure 2.1 Study area

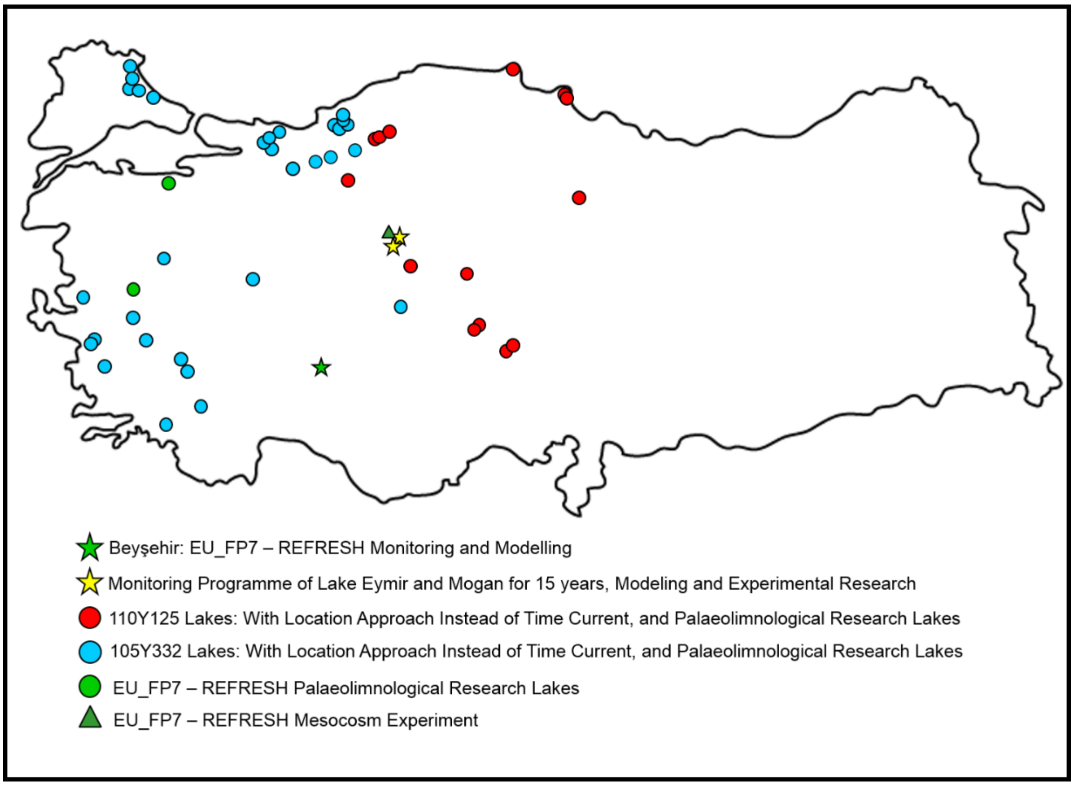

Figure 2.2 Fifty shallow lakes (Beklioğlu et al., unpublished data)

2.1.1 Lake Sampling

The studied lakes were visited during summer months sometime between 2006 and 2012. Although the values are based on a single visit to each lake, they represent the great amount of variation in the variables that determine their trophic state. For this study selected lake variables characterizing the chemical and biological features of shallow lakes are "lake area, dissolved oxygen, Chlorophyll a, Secchi depth, maximum depth, Secchi depth/maximum depth, total phosphorus, total nitrogen, average submerged plant volume inhabited, Average submerged plant volume inhabited, alkalinity and conductivity".

2.1.2 Catchment Delineation

Out of the available 50 lakes, 38 were chosen due to various reasons, mainly catchment delineation problems. The following were left out: Lake Tatlı, Lake Gıcı and Lake Gizli near the Black Sea Region have been exposed to sea water, thus they cannot be accepted as freshwater. Lake Bağınaltı, Lake Eğri and Lake Sarp are small openings in the much larger Sultansazlığı Wetland (319.000 ha catchment area) and are not proper lakes. Lake Seyfe is a Central Anatolian salt lake, however the Limnology Team sampled only a small man-made pond behind an impoundment to the west of the lake. Automatic catchment delineation of this man made and very small pond is difficult with the varied topography. Lake Kaya and Lake Balıklı small shallow lakes are in a quite flat area, thus a very big catchment area was created for each with the catchment delineation software. Similarly, Lake Gökgöl situated in a plain has a very big catchment area and also the catchment somehow spills over a mountain ridge when checked with the three dimensional view in Google Earth. Lake Uyuz is largely fed by groundwater (KOP, 2012), for this reason evaluation the nutrient status of this lake using its catchment area will be not be realistic. Lake Kalp had dried out when the Limnology Team was there for sampling and they could not get enough data for the trophic status of this lake; therefore this lake catchment also was not been studied.

Watershed or catchment is the area from which water gathers or runs into streams and rivers and hence lakes (Moss, 2010). “Watersheds, also known as basins or catchments, are physically delineated by the area upstream from a specified outlet point” (Maps, Data and Government Information Centre, Trent University Library, 2012). Catchment boundary can be generated both manually on topographic maps and automatically using geographic information system (GIS) techniques. There are no available catchment data directly to this studied 38 shallow lakes, despite the some catchment databases can be acquired by different agencies and the institutes. For instance, there is catchment data produced by the Ministry of Forestry and Water Affairs of a small scale and is not useful for very small lakes. Besides, the Joint Research Centre, Institute for Environment and Sustainability (IES) Catchment Characterisation and Modeling (CCM) activity developed a European database of river networks and catchments including Turkey. This database is slightly larger scale than others, however, still not utilizable for the selected 38 shallow lakes.

In place of manual catchment delineation on a topographic map, automatic catchment delineation is preferable for this thesis because of its easiness and convenience. Manual delineation is difficult, since hard to get a topographic map from the different parts of the Turkey as vector data and even if obtained this data it would take a long time.

There are several methods for automatic catchment delineation. The common programs used in conjunction with geographic information systems (GIS) and digital elevation models (DEM) are Better Assessment Science Integrating Point and Nonpoint Sources (BASINS), Hydrological Simulation Program - Fortran (HSPF), Soil and Water Assessment Tool (SWAT), Multi-Watershed Delineation (MWD), ArcGIS Hydrology Tool and Terrain Analysis Using Digital Elevation Models (TauDEM).

In this study, TauDEM 5.1.2 was used within ArcGIS 10.1 to generate catchment boundary of 38 shallow lakes. TauDEM is a hydrologic analysis and catchment delineation tool for digital elevation model based development at Utah State University (USU) (Tarboton, 2011). This free software is the oldest one developed in 1991. Since all other software use the same method, TauDEM was chosen.

Delineation of Catchment with TauDEM

Several steps were performed for delineation of the catchment boundary with the TauDEM tools. To acquire catchment area, Digital Elevation Model (DEM) is used as a major material. DEM is a representation of terrain or relief that obtains continuous elevation values over a topographic surface by a regular array of z-values, referenced to a common datum. There is a variety of DEM source data available produced by Light Detection and Ranging (LIDAR), Photogrammetry, topographic maps, etc. In this study The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM was used that obtained by LIDAR. ASTER DEM has 30 m resolution/pixel (1 arc second) was taken United States Geological Survey (USGS).

DEM is used while working with TauDEM, because DEM can be used as identification of individual grid values that define elevation values. Hydrological flow can be represented from DEM by flow from each grid cell in one or more of its neighbors (Tribe, 1992).

Generation of catchment includes some steps in TauDEM as 'Pit Remove, D8 Flow Direction, D8 Contributing Area. Stream Definition by Threshold, D8 Contributing Area and Stream Reach and Watershed'. The same phases have been performed for all lakes to acquire catchment boundary. Lake Abant has been chosen as an example that catchment delineation will be clarified incrementally below.

The first step of catchment boundary is **'Pit Removal'**, because DEM data do not contain pits (Figure 2.3.ii). Pits or depressions are lower areas in the DEM data that entirely surrounded by higher elevation areas. With the pit remove, their elevation becomes higher that they drain off the edge of the domain. If real DEM is used, there is no need to run pit remove tool.

The second step of catchment boundary is **'D8 Flow Direction'**. This tool generates two outputs as D8 Flow Direction Grid and D8 Slope Grid. Tribe (1992) developed eight flow directions (D8) approach for drainage pattern. Because of the limitation of this method as lack of actual drainage data and depression and flat data, the improvement methods from Garbrecht and Martz (1997) was being used. According to them "the approach is based on the recognition that in natural landscapes drainage is generally away from higher and towards lower terrain".

D8 Flow Direction Grid includes direction encoding (east, northeast, north, northwest, west, south west, south, south east) are to the steepest downwards slope from each grid in neighbor grid (Figure 2.3.iii). D8 Slope Grid is the evaluation of steepest descent as drop/distance (Figure 2.3.iv).

The third step is **'D8 Contributing Area'**. In this part, an outlet can be used optionally, but the outlet will have been understood in the following steps. Using only D8 Flow Direction grid data, contributing area can be created (Figure 2.3.v). It calculates the number of draining grid cells based on D8 Flow Direction.

The fourth step is '**Stream Definition by Threshold**'. In this tool DB Contributing Area is used as input, the result depicts the preliminary stream network by threshold (Figure 2.3.vi). The threshold value does not have the effect on the delineation catchment boundary, it is important for demonstration subcatchments.

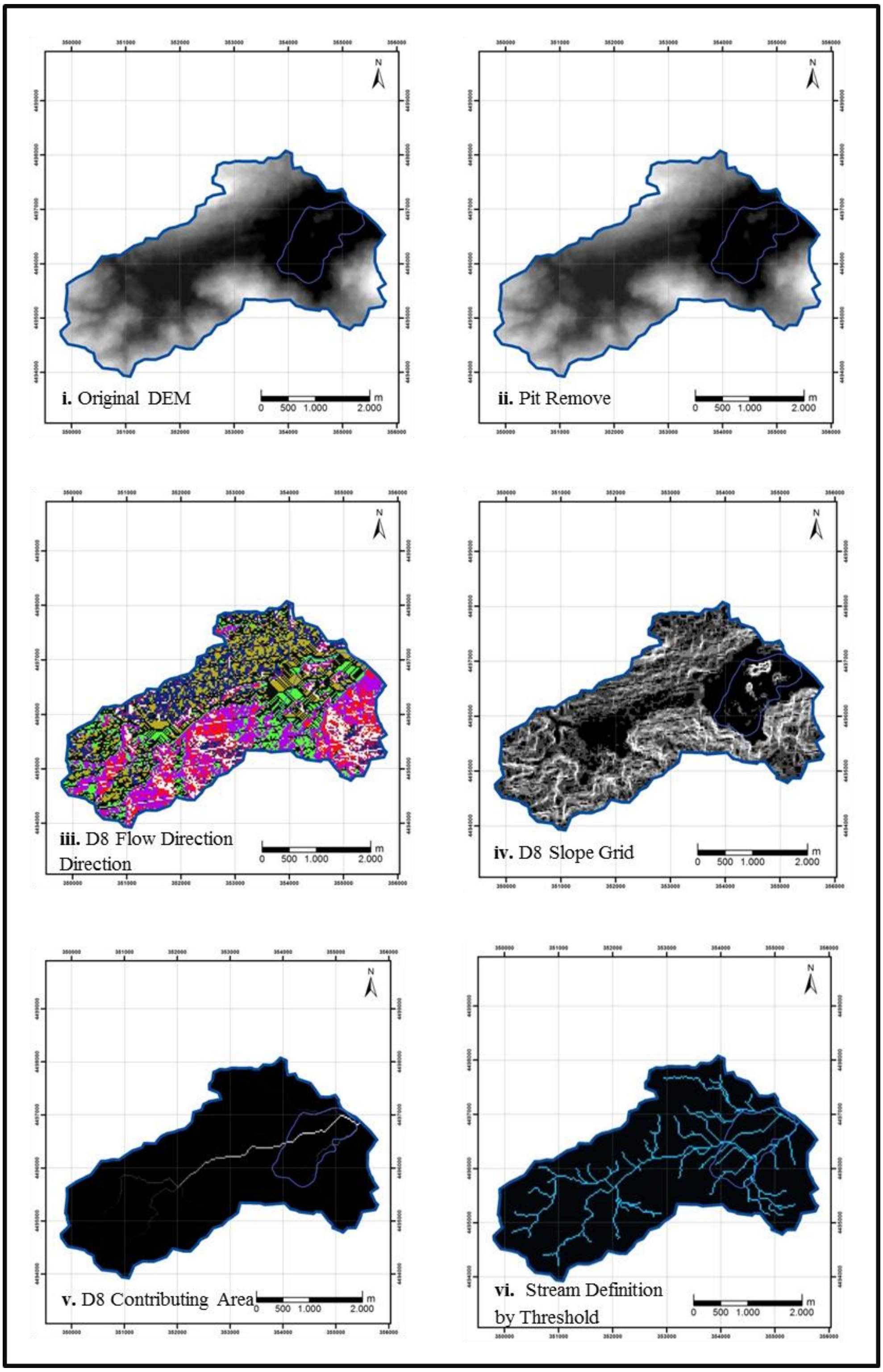

Figure 2.3 Six phases of the catchment delineation

The fifth step is '**Stream Reach and Watershed**'. The previous files such as 'Pit Filled Elevation Grid, D8 Flow Direction Grid, D8 Drainage Area, Stream Raster

Grid 'are inputs for this tool. After running the program with all these files, spatial and non-spatial data can be created. Non-spatial data are 'Output Network Connectivity Tree' that shows grid values of stream network and 'Output Network Coordinates' includes x, y coordinates of the stream network. Spatial data are 'Output Watershed Grid' (Figure 2.4) and 'Output Stream Order Grid' (Figure 2.5). These are suitable indicator to determine outlet or pour point of the lake.

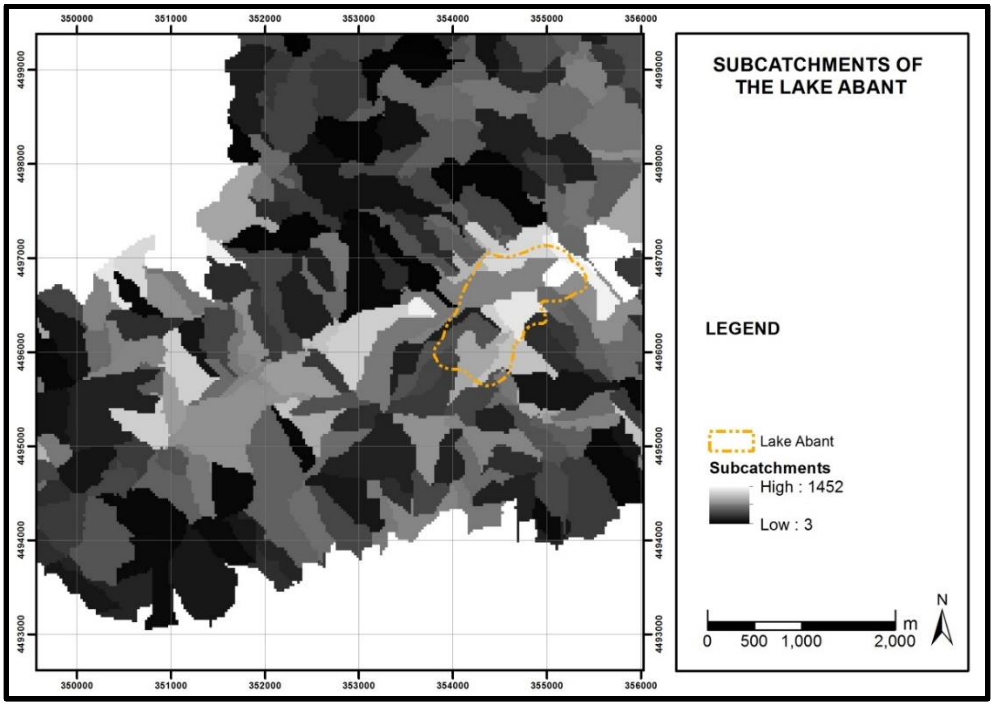

Figure 2.4 Subcatchments of the Lake Abant and environment

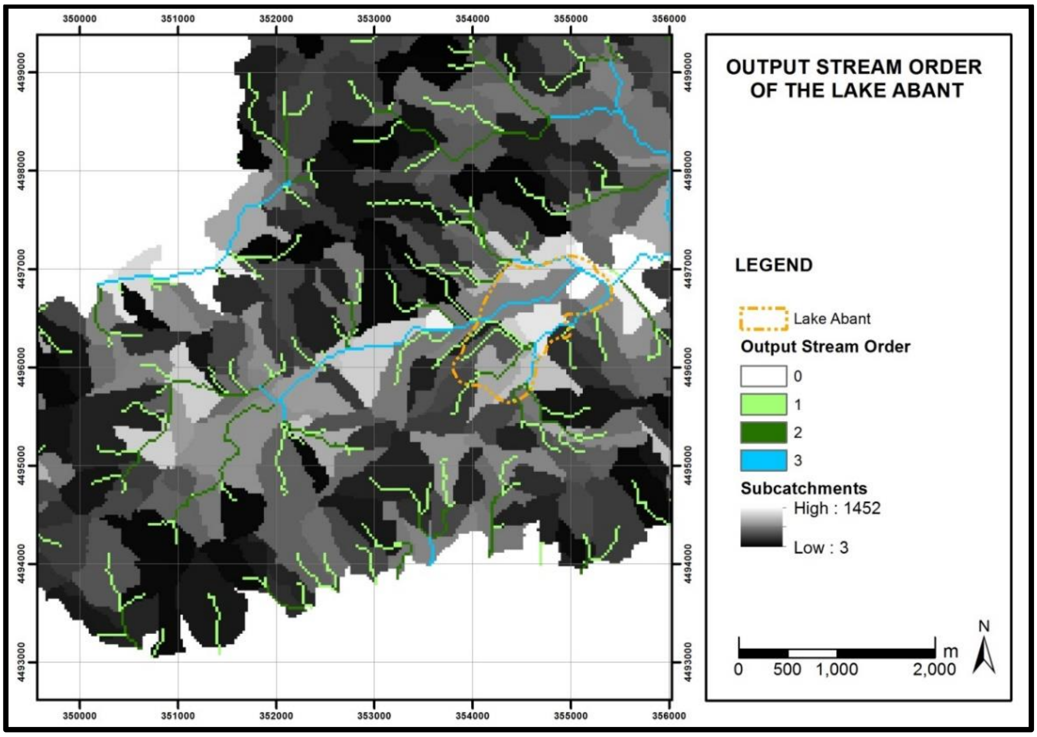

Figure 2.5 Output stream order of the Lake Abant and environment

The final step is catchment delineation. '**D8 Contributing Area**' tool is used with the outlet point different from the third step. If there are no lake outlet data, it can be found from the Output Stream Order that gives information about the stream flow direction. In the Figure 2.6, water flow direction is from southeast to northwest. Water accumulation is respectively from light green, dark green and blue line. Thus the outlet point where the water goes out can be defined in the blue line easily without field survey.

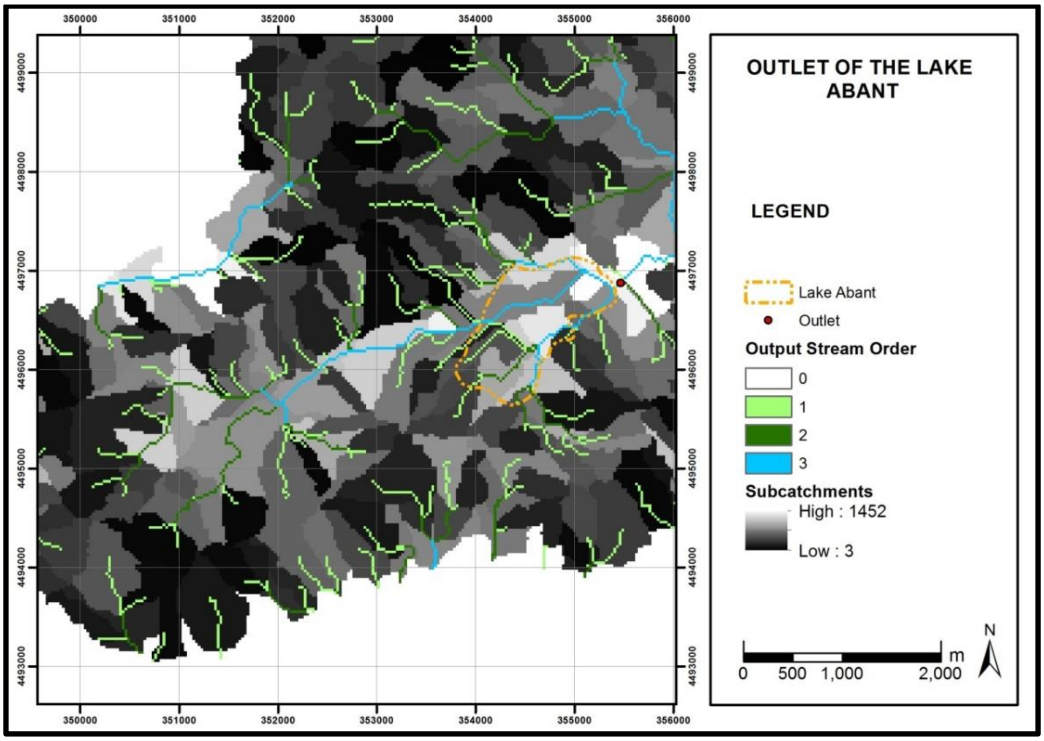

Figure 2.6 Outlet of the Lake Abant

After determination of the lake outlet, with both Pit Filled Elevation Grid and outlet, D8 Flow Direction tool is performed. The result shows the catchment area (Figure 2.7).

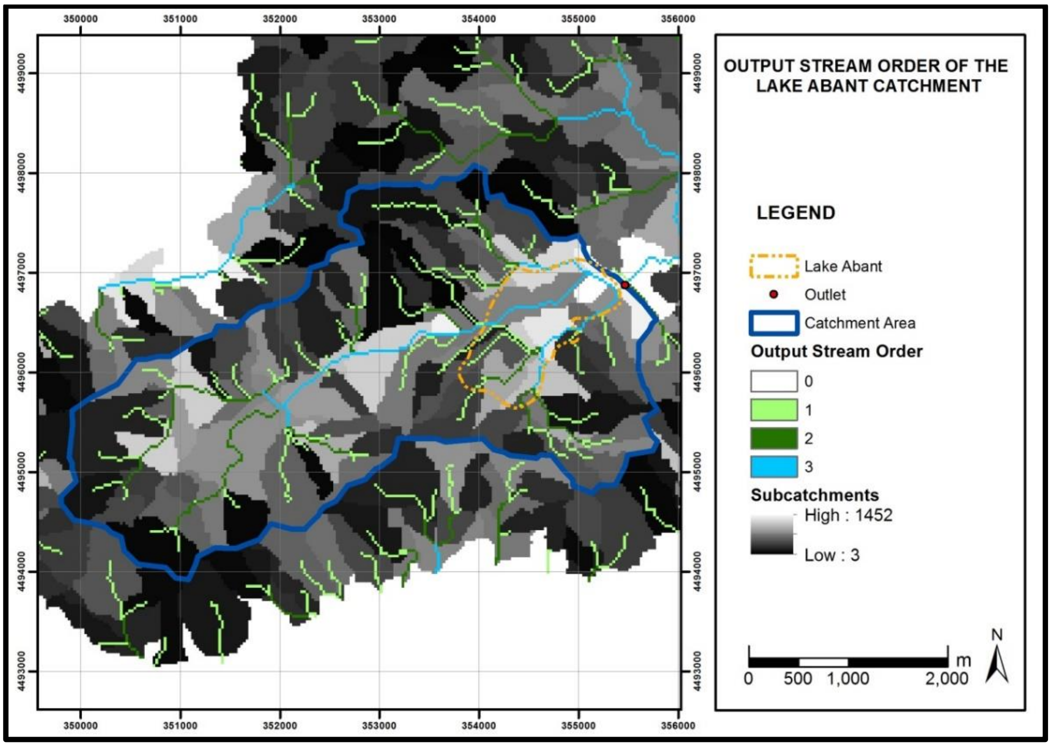

Figure 2.7 Catchment area of the Lake Abant

2.1.3 Elevation, Slope, Catchment Area, Climate and Land Cover/Use

Instead of traditional field survey or topographical map based method, 30-m advanced spaceborne thermal emission and reflection radiometer global DEM (ASTER DEM) was used for elevation of the catchment. DEM based analysis is the practical and least cost method for the clarification of landscape morphometry nowadays.

For delamination of catchment boundary, ASTER DEM was extracted with respect to this boundary (Figure 2.8). From the attribute table of DEM, minimum (m), maximum (m), mean (m) and standard deviation was provided by histogram (Table 2.1).

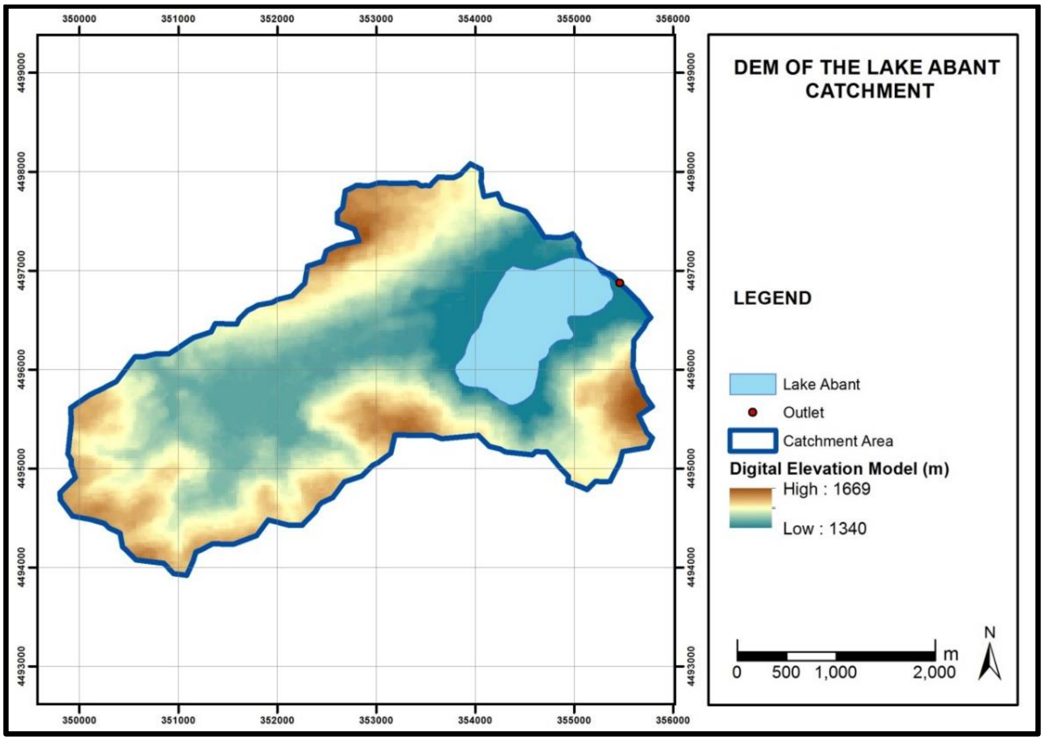

Figure 2.8 Digital Elevation Model of the Lake Abant Catchment

Table 2.1 Digital Elevation Model Attributes of the Lake Abant Catchment

Variables	Minimum	Maximum	Mean	Standard deviation
Elevation	1340.00	1658.00	1449.48	80.00

Slope data of the catchment was derived by DEM (Figure 2.9). All the catchment slope data classified to five groups and unit of measurement was chosen degree. Slope attributes from the classification statistics were shown in (Table 2.2)

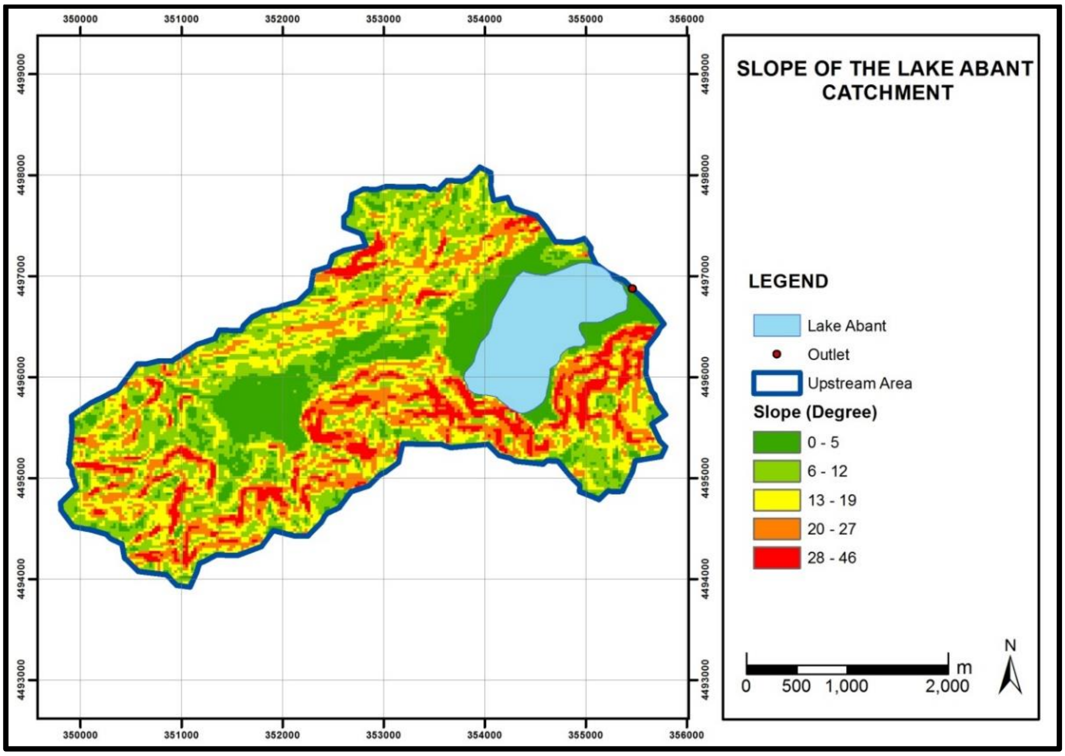

Figure 2.9 Slope of the Lake Abant Catchment

Table 2.2 Slope Attributes of Lake Abant Catchment

Variables	Minimum	Maximum	Sum	Mean	Standard deviation
Slope	0.00	53.88	394007.67	13.47	10.53

Catchment area was calculated by using ‘calculate geometry’ in the geographical information analysis. Unit of measurement was chosen as square kilometer and field type was chosen as double which refers to a decimal number. Lake Abant catchment area was calculated to be 13.05 km^2.

Land cover and land use are sometimes used interchangeably, despite their distinction from each other. Land cover is the biophysical state of the earth’s surface (Turner et al., 1995); however land use is characterized and changed by the human activities. Land cover or land use data (referred to land use after here) can be produced by field survey or remotely sensed imagery. Land use data acquired by remote sensing varies greatly around the world. Global Land Cover Facility (GLCF), European Environment Agency (EEA) Corine Land Cover, USGS National Land

Cover Database (NLCD), USGS Land Cover Institute (LCI) and MODIS Land Cover are the most known variations.

Corine Land Cover 2006 (CLC 2006) obtained by EEA was used in this study. EEA uses photo-interpretation of satellite images for the land use (www.eea.europea.eu). It shows both human land use and land cover changes in the ecosystems. After validation of CLC 2000 images with the images such as ground based photography and written observations, the accuracy became higher than % 85.

Corine Land Cover has classes at 3 hierarchical levels. The first one includes general idea of the cover type, however, the third has very detailed information down to the type of agriculture. For this study the first level categories was used. The land cover types of the studied catchments are ‘Artificial surfaces, Agricultural areas, Forest and semi natural areas, Wetlands and Water bodies’. Artificial surfaces involve manmade structures and areas such as urban area, industrial, commercial and transport units, mine and dump sites etc.

Validation of the land cover data has been done by using Google Earth, because there is confusion especially with wetland and water body types. For instance, land cover map of Lake Abant catchment acquired from the original Corine Land Cover map is shown in Figure 2.10. In contrast to this original map, there is no wetland ecosystem in the area in fact. Thus this wetland area was re-classified as forest and semi natural areas. The second issue is water body. Water bodies generally represent the lakes in the study area, however catchment and lake data were evaluated separately in the analysis. Thus lake or water body was extracted from the catchment data and the land cover map was revised accordingly (Figure 2.11). If catchment includes another lake, pond etc apart from its own lake, in this case the water body layer was used. Only 3 lake catchments include other water bodies: Lake Eymir, Lake Mogan and Lake Sarıkum.

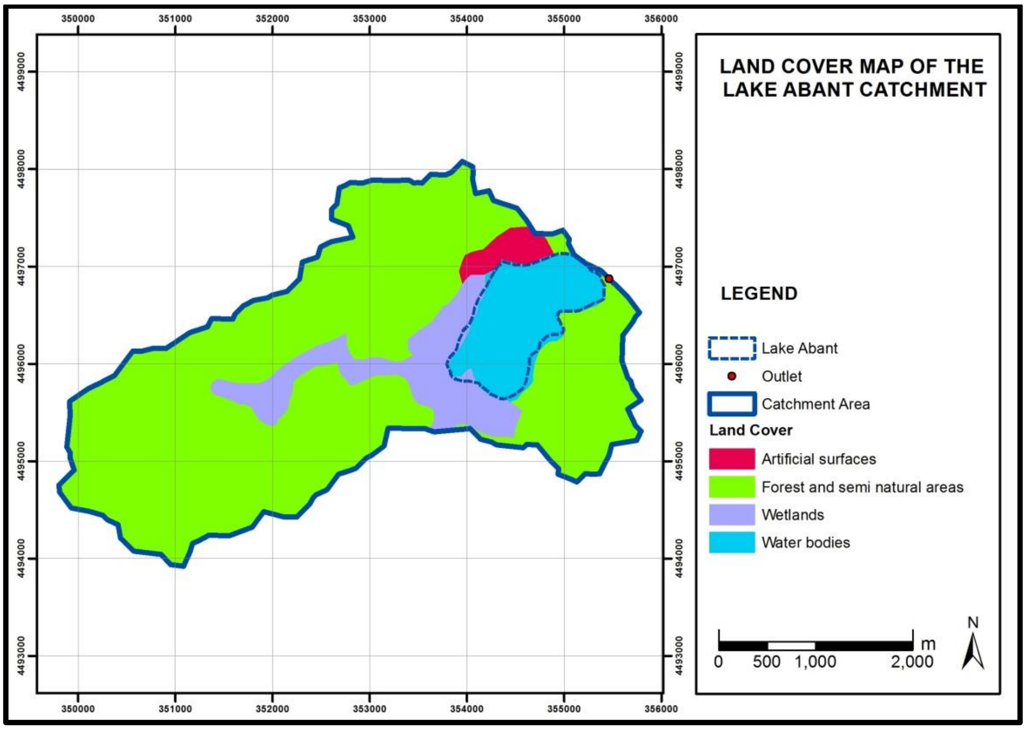

Figure 2.10 Original land cover map of the Lake Abant Catchment

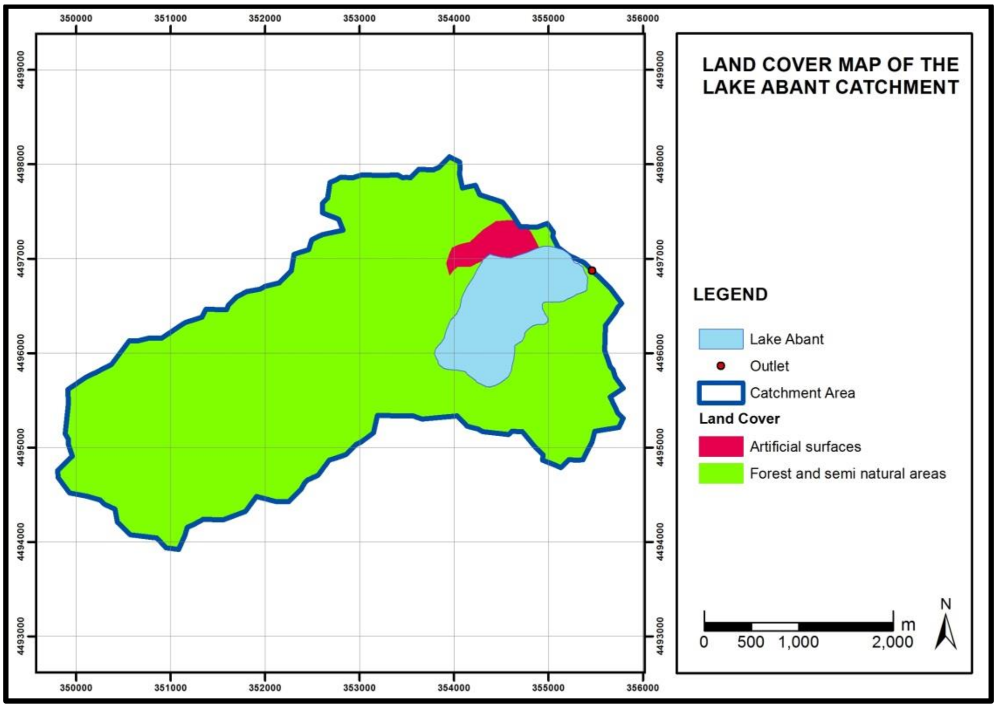

Figure 2.11 Revised land cover map of the Lake Abant Catchment

Area of each land cover class was calculated firstly in square kilometers then converted to percentage. The reason is that particularly two big catchment (Lake Eymir and Lake Mogan) have very big agricultural areas, covering more than 80 % of the total. The area of the each land cover class of Lake Abant Catchment was shown in Table 2.4.

Table 2.3 Land Cover Area of the Lake Abant Catchment

Corine Land Cover	**Area (km²)**	**Area (%)**
Artificial surfaces	0.28	2.36
Forest and semi natural area	11.57	97.64

Climate data of the catchments were obtained from World Clim (www.worldclim.org). The World Clim includes global climate data except Antarctica. The raster data has 30 km² resolution and was generated by interpolation of long-term weather station data. The data have different variables such as total precipitation and monthly mean, minimum and maximum temperature, and also 19 derived bioclimatic variables defined from monthly data. In this study two types bioclimatic variables, 'BIO1' for Annual Mean Temperature and 'BIO12' for Annual Precipitation, were used (Table 2.5).

Table 2.4 Annual Climatic Variables of Lake Abant Catchment

Variables	**Value**
Annual Precipitation	713.29 mm
Annual Mean Temperature	7.56 ºC

2.2 Statistical Analysis

Minitab 17 statistical software was used for statistical analysis. Principal component analysis (PCA) and regression analysis are the main analysis of this study. PCA is used to reduce the high multidimensionality down into a few synthetic variables which are easier to interpret, and to explain trophic status of the lakes with the used variables. The covariance structure in the variables can be understood with a principal component analysis. Regression analysis was implemented to generate equations to describe the statistical relationship between the lake and catchment variables. Regression results showed the direction, size and significance of the relationship between the selected catchment characteristics and lake trophic status. Analyses were repeated with various subsets of study lakes in order to explore whether the exclusion of particular lakes would improve the results.

CHAPTER 3

RESULTS

3.1 General overview of the lakes and their catchment

A total of 38 lakes and their catchments were analyzed in this study. These shallow lakes are situated mostly in western and northwestern Turkey, are usually small in size, and occur in a wide range of climatic, topographical and land use conditions. Relevant variables measured or derived for the catchment of each lake are provided in Table 3.1.

Most lakes have a relatively small catchment area (median 6.2 sq.km.) with only nine catchments larger than 100 ha. The largely overlapping catchments of Lake Mogan and Lake Eymir (since the former flows into the latter) are outliers, with 931.6 and 981.6 sq.km. of catchment area, respectively. The ratio of lake surface area to its catchment is on average 5.8%.

Land use within the catchments varies from almost fully agricultural use in the flat landscapes in central Turkey to totally forested natural cover in the uplands with better precipitation (Figure 3.1). One lake (Taşkısığı) stands out due to a high percentage (28%) of adjacent artificial (urban) surface. Several others have much smaller proportions of artificial surface within their catchments. A few lakes have up to 8% wetland in the catchment.

The original catchment and lake variables were not standardized in common unit, thus descriptive statistics of variables had a wide range of variances (Table 3.2).

Table 3.1 Catchment variables of 38 shallow lakes

Lakes	Latitude	Longitude	Mean elevation (m)	Mean slope	Catchment Area (km^2)	Precipitation (mm)	Temperature (°C)	Artificial surfaces (%)	Agricultural areas (%)	Forests and semi natural areas (%)	Wetlands (%)	Water bodies (%)
Abant	40.60°	31.26°	1449.540	13.15°	11.860	713.29	7.57	2.36	0.00	97.64	0.00	0.00
Poyrazlar	40.84°	30.46°	67.930	9.19°	4.300	818.09	14.00	2.10	7.01	85.51	5.37	0.00
Derin	40.94°	31.74°	1072.180	22.16°	5.591	693.18	9.23	0.00	0.00	100.00	0.00	0.00
Koca	40.85°	32.46°	1331.660	10.26°	8.070	815.76	7.92	0.00	26.15	65.18	8.67	0.00
Keçi	40.83°	32.44°	1239.950	8.8°	0.583	774.50	8.70	0.00	6.98	93.02	0.00	0.00
Çubuk	40.50°	30.84°	1320.570	16.86°	10.904	690.04	8.29	0.00	14.60	85.40	0.00	0.00
Nazlı	40.94°	31.74°	1072.180	22.16°	5.591	693.18	9.23	0.00	0.00	100.00	0.00	0.00
Serin	40.94°	31.74°	1072.180	22.16°	5.599	693.18	9.23	0.00	0.00	100.00	0.00	0.00
Pedina	41.84°	27.90°	138.420	8.25°	8.998	604.00	12.93	0.00	0.00	100.00	0.00	0.00
Mogan	39.62°	32.74°	1121.690	5.83°	931.603	387.15	10.51	4.19	87.25	7.00	1.29	0.28
Karagöl Denizli	37.73°	29.49°	1433.050	18.76°	1.730	582.83	10.77	0.00	14.45	85.55	0.00	0.00
Karagöl Kıbrısçık	40.36°	31.93°	1438.420	7.95°	0.290	609.00	8.50	0.00	0.00	100.00	0.00	0.00
Hamam	41.83°	27.96°	40.750	4.19°	3.090	593.66	13.31	0.00	0.00	100.00	0.00	0.00
Büyük	40.94°	31.74°	1072.180	22.16°	5.580	693.18	9.23	0.00	0.00	100.00	0.00	0.00
Gölcük Bolu	40.65°	31.63°	1423.370	17.98°	1.720	707.88	7.78	0.00	0.00	100.00	0.00	0.00
Yeniçağa	40.79°	32.02°	1181.400	8.37°	145.381	705.54	9.04	3.52	47.47	48.26	0.75	0.00
Gölhisar	37.09°	29.62°	1188.650	10.86°	77.127	570.50	11.92	1.36	38.69	56.90	3.05	0.00
Saka	41.79°	27.98°	56.830	5.8°	4.757	593.30	13.30	0.00	0.00	93.57	6.43	0.00
Gebekirse	38.01°	27.31°	153.700	10.71°	9.060	730.35	16.23	0.00	44.09	55.91	0.00	0.00
Gerede	40.80°	32.17°	1343.350	7.44°	1.713	785.00	8.14	0.59	5.28	94.13	0.00	0.00
Kaz	40.24°	36.13°	817.330	10.63°	40.160	432.01	11.41	0.00	57.96	42.04	0.00	0.00
Saklı	37.78°	29.40°	1031.550	8.59°	1.290	556.50	12.13	0.00	67.69	32.31	0.00	0.00
Baldımaz	36.69°	28.83°	180.450	17.11°	1.962	1016.71	17.63	0.00	0.00	100.00	0.00	0.00
İnce	40.94°	31.74°	1072.180	22.16°	5.599	697.70	9.13	0.00	0.00	100.00	0.00	0.00
Gölcük Ödemiş	38.31°	28.03°	1120.260	11.78°	6.740	842.29	11.48	0.00	50.37	49.63	0.00	0.00
Taşkısığı	40.86°	30.39°	52.950	7.23°	12.028	819.00	14.10	28.51	2.18	69.31	0.00	0.00
Mert	41.89°	27.87°	185.070	8.18°	106.246	613.12	12.69	0.32	6.30	91.61	1.78	0.00
Erikli	41.93°	27.93°	91.210	6.5°	67.320	600.69	13.04	0.00	0.07	98.96	0.96	0.00
Barutçu	38.03°	27.33°	190.670	12.58°	13.290	733.70	16.11	0.00	46.84	53.16	0.00	0.00
Karagöl İzmir	38.56°	27.22°	938.330	14.1°	1.200	843.20	12.10	0.00	0.00	100.00	0.00	0.00
Emre	39.11°	30.45°	1210.120	7.04°	18.970	481.53	9.94	0.00	10.81	89.19	0.00	0.00
Gölcük Simav	39.17°	29.08°	1345.920	9.28°	1.306	864.50	9.50	0.00	0.00	100.00	0.00	0.00
Yayla	38.05°	28.77°	1174.500	7.45°	2.030	747.08	11.43	0.00	0.00	100.00	0.00	0.00
Sarıkum	41.97°	34.92°	82.500	7.74°	66.120	712.37	13.82	0.00	46.61	49.61	2.01	1.78
Büyük Akgöl	41.04°	30.53°	61.850	7.67°	29.804	878.66	13.62	0.00	17.44	82.56	0.00	0.00
Eymir	39.63°	32.74°	1121.130	5.96°	981.683	387.73	10.50	4.62	84.65	8.39	1.22	1.12
Küçük Akgöl	40.88°	30.43°	38.510	7.99°	1.300	827.33	14.12	0.00	0.00	100.00	0.00	0.00
Azap	37.57°	27.47°	99.240	10.57°	22.518	722.46	17.33	0.00	5.04	94.96	0.00	0.00

Table 3.2 Descriptive statistics of catchment and lake variables

Variables	Mean	SE Mean	StDev	Minimum	Median	Maximum
Catchment						
Latitude	40.014	0.248	1.528	36.690	40.718	41.972
Longitude	30.381	0.353	2.177	27.224	30.460	36.133
Elevation (m)	790.3	89.1	549.1	38.5	1072.2	1449.5
Slope (°)	11.463	0.882	5.437	4.190	9.235	22.160
Catchment area (km^2)	69.0	34.8	214.5	0.3	6.2	981.7
Precipitation (mm)	690.3	22.2	137.2	387.1	701.6	1016.7
Temperature (°C)	11.258	0.435	2.609	7.568	11.088	17.325
Artificial surfaces (%)	1.252	0.762	4.699	0	0	28.509
Agricultural areas (%)	18.1	4.18	25.78	0	5.16	87.25
Forest and semi natural areas (%)	79.73	4.35	26.79	7.00	93.30	100.00
Wetlands (%)	0.83	0.316	1.948	0	0	8.674
Water bodies (%)	0.0837	0.0549	0.3385	0	0	1.7828
Lake						
Surface of the lake (km^2)	0.784	0.235	1.449	0.001	0.24	7.986
Dissolved oxygen (mg L^{-1})	6.662	0.48	2.958	0.578	6.719	15.32
Chlorophyll a (µg L^{-1})	19.97	3.26	20.13	2.35	13.34	95.13
Secchi depth (cm)	1.34	0.255	1.571	0.2	0.9	9
Maximum depth (cm)	427.1	58.6	361.5	55	355	1740
Secchi depth/maximum depth	0.3742	0.0429	0.2642	0.0532	0.3267	1
Total phosphorus (µg L^{-1})	121	21.2	130.6	15	72.4	632.6
Total nitrogen (µg L^{-1})	1009	92.4	569.5	238.8	941.2	2180.3
Total biovolume of cyanobacteria (%)	28.71	5.69	35.1	0	7.93	99.49
Plant volume infested (%)	16.15	3.36	20.7	0	7.15	75.66
Plant coverage (%)	36.11	4.73	29.16	0	32.2	88.57
Alkalinity (meq L^{-1})	2.568	0.416	2.563	0.5	1.5	11.2
Conductivity (µS cm)	2313	783	4827	102	328	24392

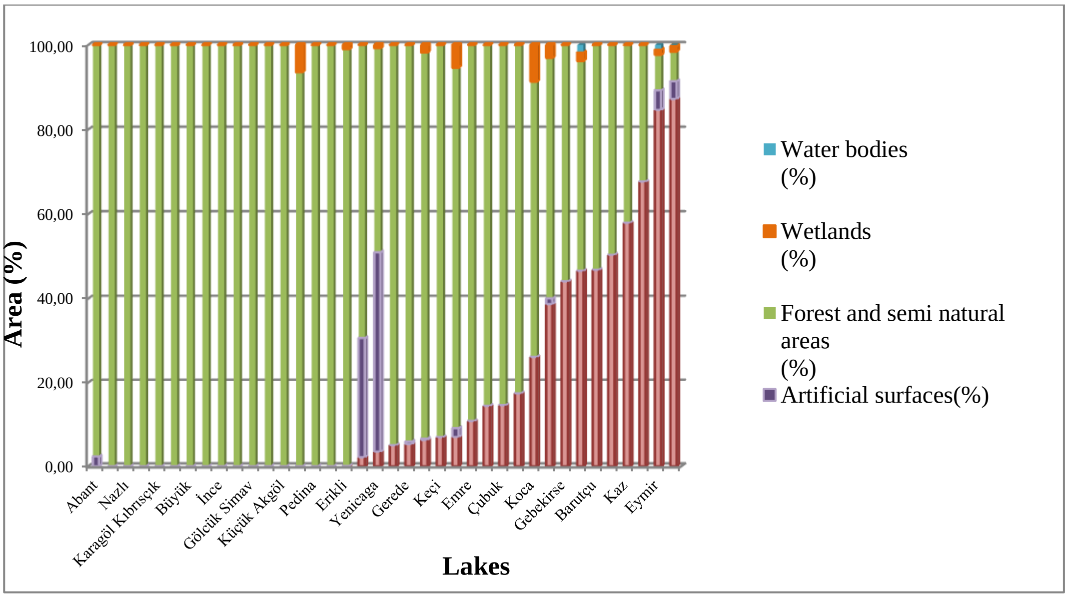

Figure 3.1 Land use in the 38 shallow lake catchments

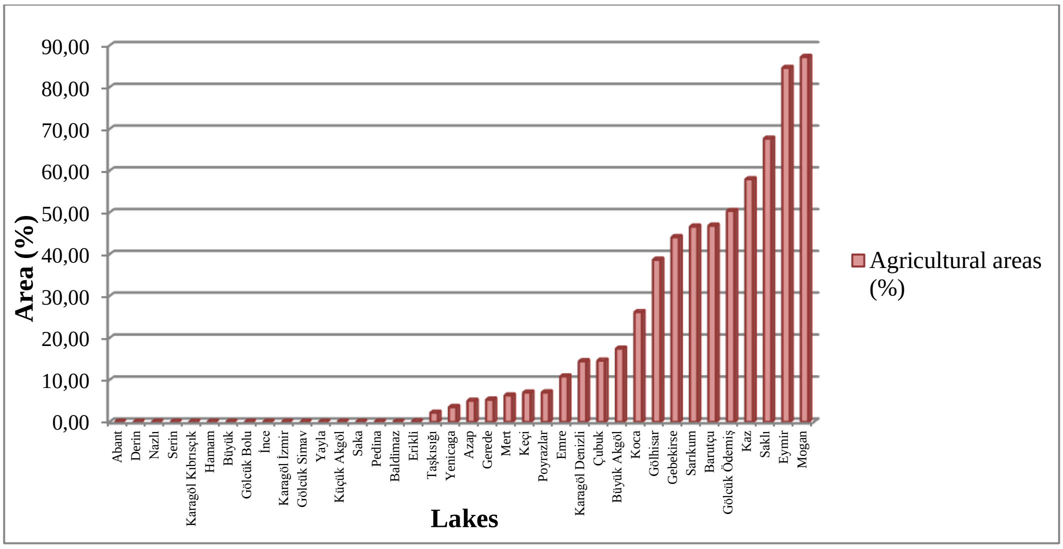

Figure 3.2 Agricultural land use in the catchments

3.2 Evaluation of Lake Trophic Status with PCA

Principal Component Analysis (PCA) was used to summarize the trophic status of the shallow lakes. PCA is acquired with four lake variables as total phosphorus (TP), total nitrogen (TN), Chlorophyll a (Chl-a) and Secchi depth (Figure 3.3). The first component (PC1) is indicative of the trophic status of shallow lakes. Figure 3.4 also shows the linear regression analysis PC1 with cyanobacteria.

Table 3.3 Eigenanalysis of the Correlation Matrix

Variation	PC1	PC2
Eigenvalue	2.6713	0.6745
Proportion	0.668	0.169
Cumulative	0.668	0.836

Table 3.4 Loading of the variables

Variable	PC1	PC2
TP	0.512	-0.193
TN	0.558	0.05
Secchi depth	-0.445	-0.786
Chl-a	0.478	-0.585

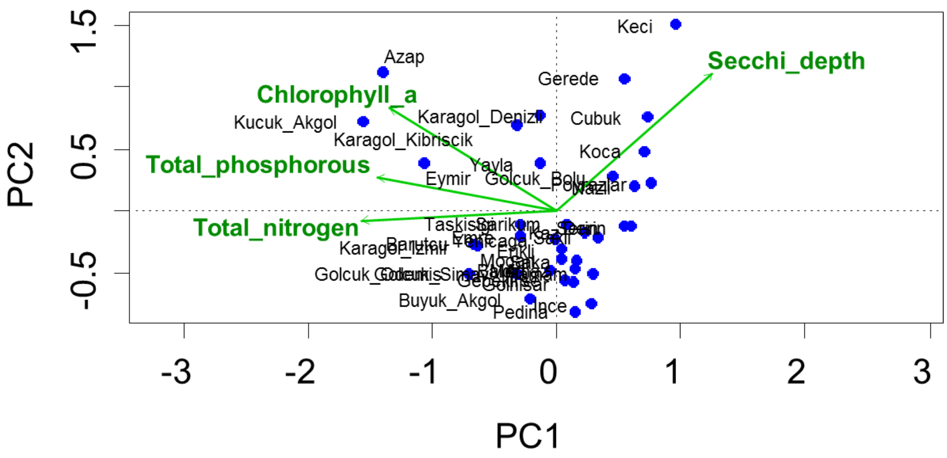

Figure 3.3 Principal Component Analysis with TP, TN, Chl-a and Secchi Depth

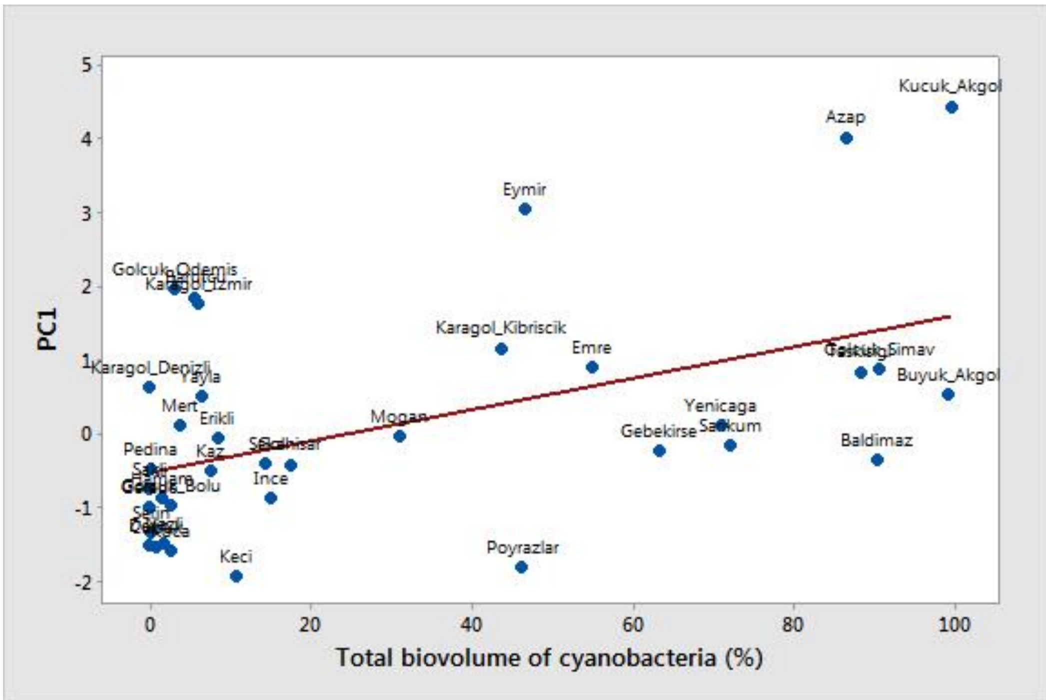

Figure 3.4 Linear regression plots for lakes with cyanobacteria vs PC1, P-Value=0.002, R-sq(adj)=21.90%

3.3 Catchment Variables Effect on Lake Trophic Status with 36 Lakes

PC1 as a trophic status indicator and catchment variables were assessed with simple and multiple linear regressions. Lake Abant and Lake Büyük were removed for the analysis, because these lakes are deeper (maximum depth>1500 cm) than other lakes. Firstly 36 lakes were analyzed by simple regressions. These analyses showed that there was no significant relation with the variable of catchment and lake. Only 3 catchment variable as temperature, latitude and longitude had showed significant relation with PC1 (Table 3.5). PC1 versus significant catchment variables had been shown in Figure 3.5 - Figure 3.7.

Table 3.5 PC1 vs catchment variables with 36 lakes

Catchment Variable	R-sq (Adj)	P-value
Temperature	**14.41%**	**0.013**
Latitude	**9.41%**	**0.038**
Longitude	**6.25%**	**0.077**
Catchment Area	3.00%	0.158
Precipitation	0.00%	0.931
Forest and semi natural areas	0.48%	0.288
Agricultural area	0.00%	0.669
Artificial surfaces	0.00%	0.553
Water bodies	0.00%	0.347
Wetland	1.84%	0.207
Slope	3.26%	0.149
Elevation	1.98%	0.200

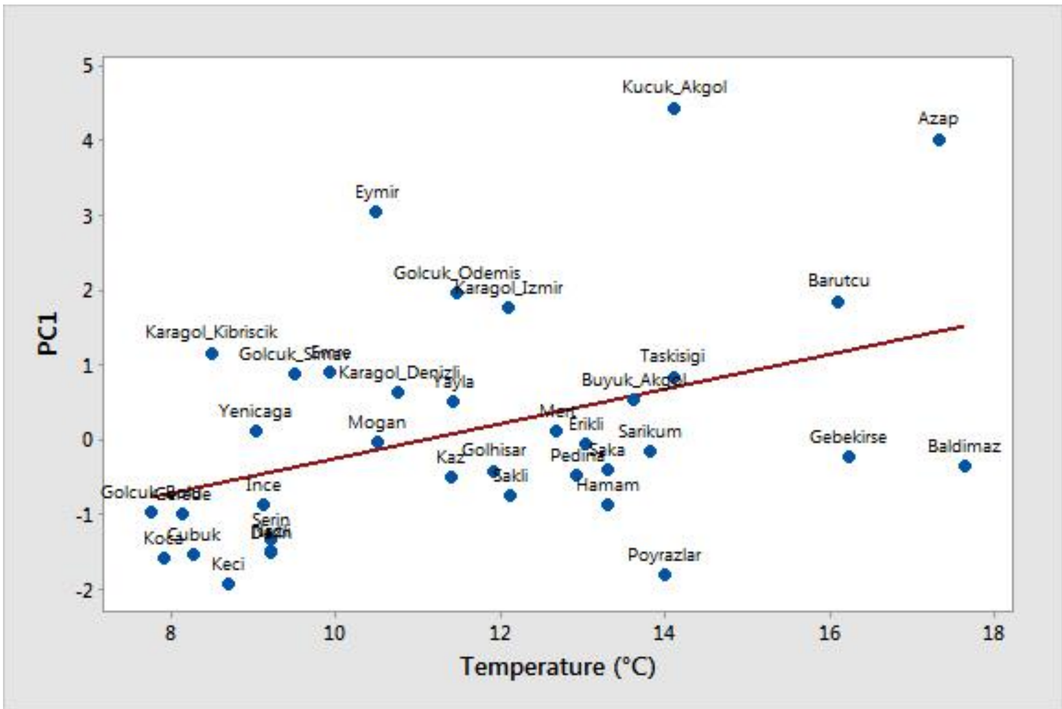

Figure 3.5 Linear regression plots for lakes with PC1 vs temperature, P-Value=0.013, R-sq(adj)=14.41%

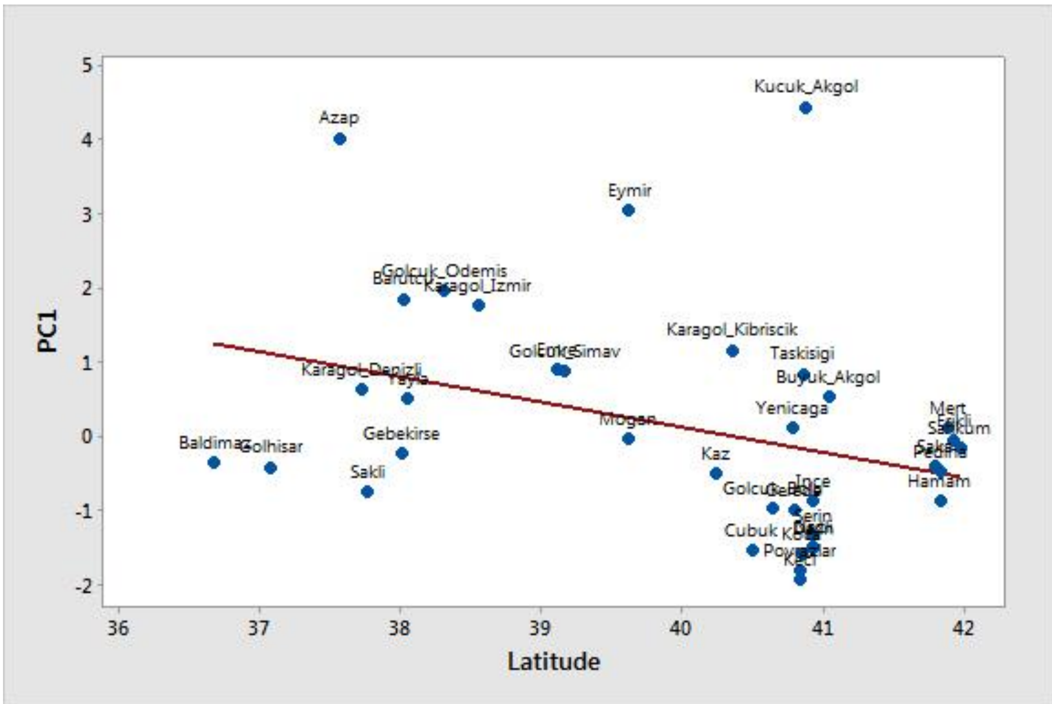

Figure 3.6 Linear regression plots for lakes with PC1 vs latitude, P-Value= 0.038, R-sq(adj)=9.41%

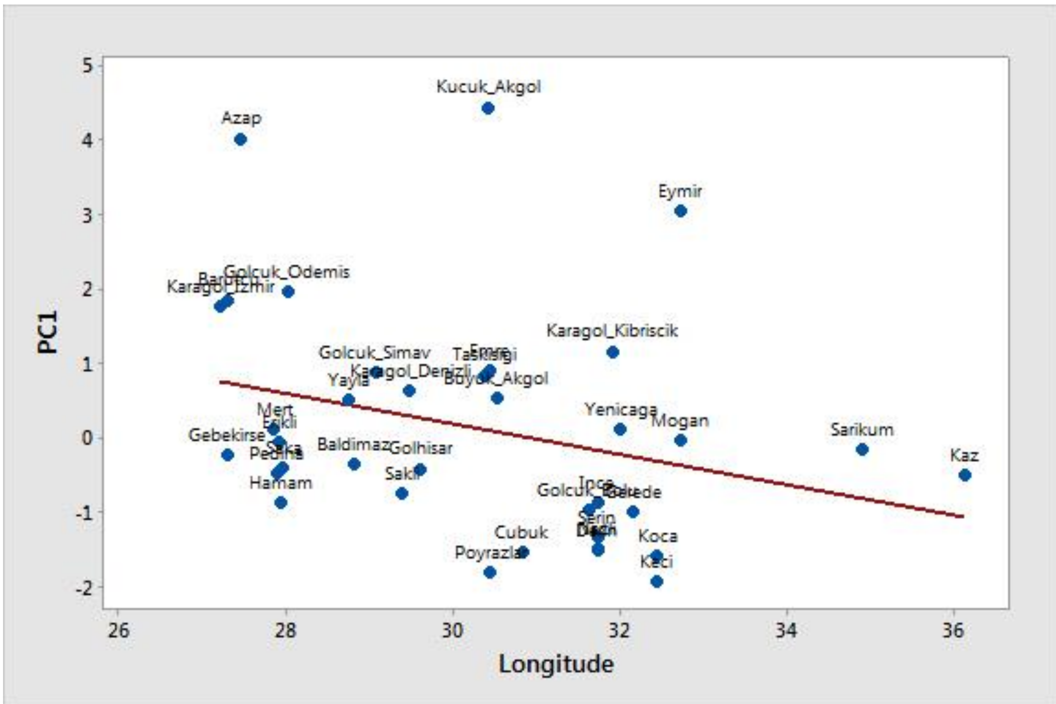

Figure 3.7 Linear regression plots for lakes with PC1 vs longitude, P-Value= 0.077, R-sq(adj)=6.25%

PC1 versus different catchment variables had been tested by multiple regression analysis. As a method stepwise selection of terms had been chosen. Stepwise removed and added terms to the model for the purpose of identifying a useful subset of the terms. Multiple regression analysis with 36 lakes had showed that the significant features for PC1 are ‘slope, wetland, latitude and temperature’ (Table 3.6).

Table 3.6 Coefficients of the multiple regression analysis

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	12.6	7.5	1.68	0.103	
Slope	-2.71	1.33	-2.04	0.05	1.24
Wetlands	-0.466	0.29	-1.61	0.119	1.14
Latitude	-0.281	0.163	-1.72	0.095	1.28
Temperature	0.1437	0.0917	1.57	0.127	1.23

Regression Equation-1

PC1 = 12.60 - 2.71 Slope - 0.466 Wetlands - 0.281 Latitude + 0.1437 Temperature

P-value of the multiple regression analysis was 0.008 and R-sq (adj) was 26.75%. Slope has the most and negative effect on the trophic status of the lakes, because it had the biggest coefficient in the equation showed above. Temperature had the positive effect on PC1, wetlands and latitude has the negative effect on PC1.

3.4 Catchment Variables Effect on Lake Trophic Status with 30 Lakes

Six lakes have had high TN (much more than 1.000 µg L^{-1}), despite their entirely forested catchment area. These lakes as Lakes Azap, Karagöl Kıbrısçık, Karagöl İzmir, Gölcük Simav, Küçük Akgöl and Baldımaz were evaluated as outlier. According to Burns et al. (2000), their trophic state was highly eutrophic and nutrient enrichment category was ‘very high’. Simple and multiple regressions for PC1 versus the same catchment variables were applied without these lakes. Significant catchment variables versus PC1 were catchment area, forest and semi natural areas, latitude, agricultural area and temperature (Table 3.7). For the significant catchment variables simple linear regression graphs had been shown in Figure 3.8 - Figure 3.12.

Table 3.7 PC1 vs catchment variables with 30 lakes

Catchment Variable	R-sq (Adj)	P-value
Catchment Area	**20.07%**	**0.008**
Forest and semi natural areas	**19.67%**	**0.008**
Latitude	**12.98%**	**0.029**
Agricultural area	**12.84%**	**0.029**
Temperature	**11.04%**	**0.041**
Water bodies	7.51%	0.078
Slope	7.10%	0.084
Artificial surfaces	6.08%	0.101
Longitude	2.69%	0.19
Precipitation	2.03%	0.216
Elevation	0.00%	0.519
Wetland	0.00%	0.528

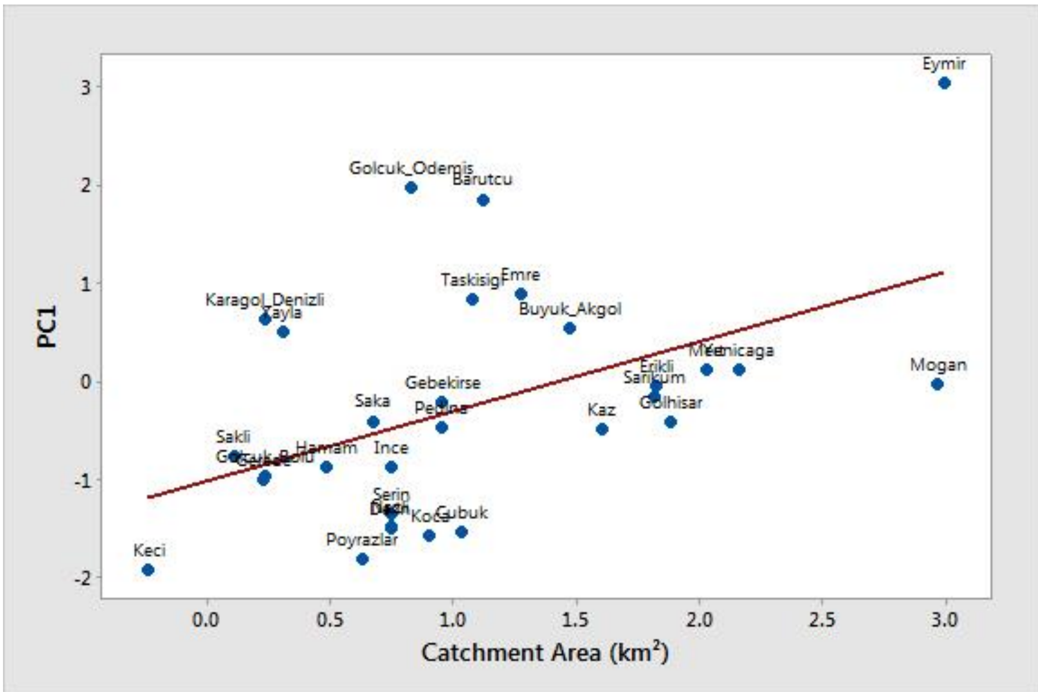

Figure 3.8 Linear regression plots for lakes with PC1 vs catchment area, P-Value=0.008, R-sq(adj)=20.07%

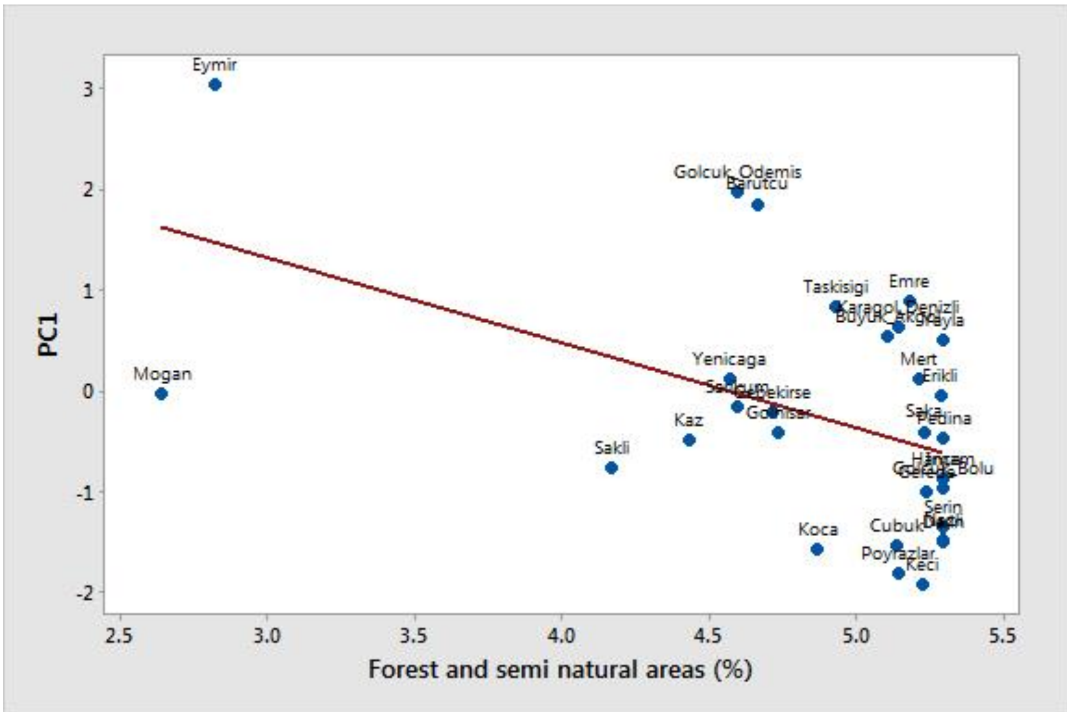

Figure 3.9 Linear regression plots for lakes with PC1 vs forest and semi natural areas P-Value=0.008, R-sq(adj)=19.67%

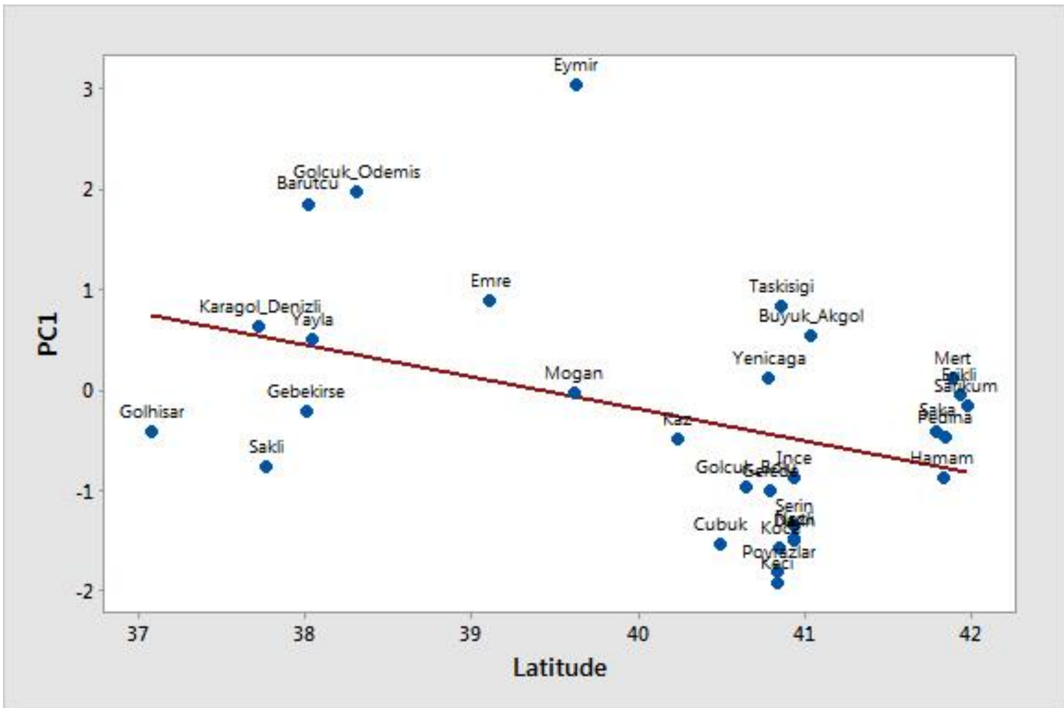

Figure 3.10 Linear regression plots for lakes with PC1 vs latitude, P-Value= 0.029, R-sq(adj)=12.98%

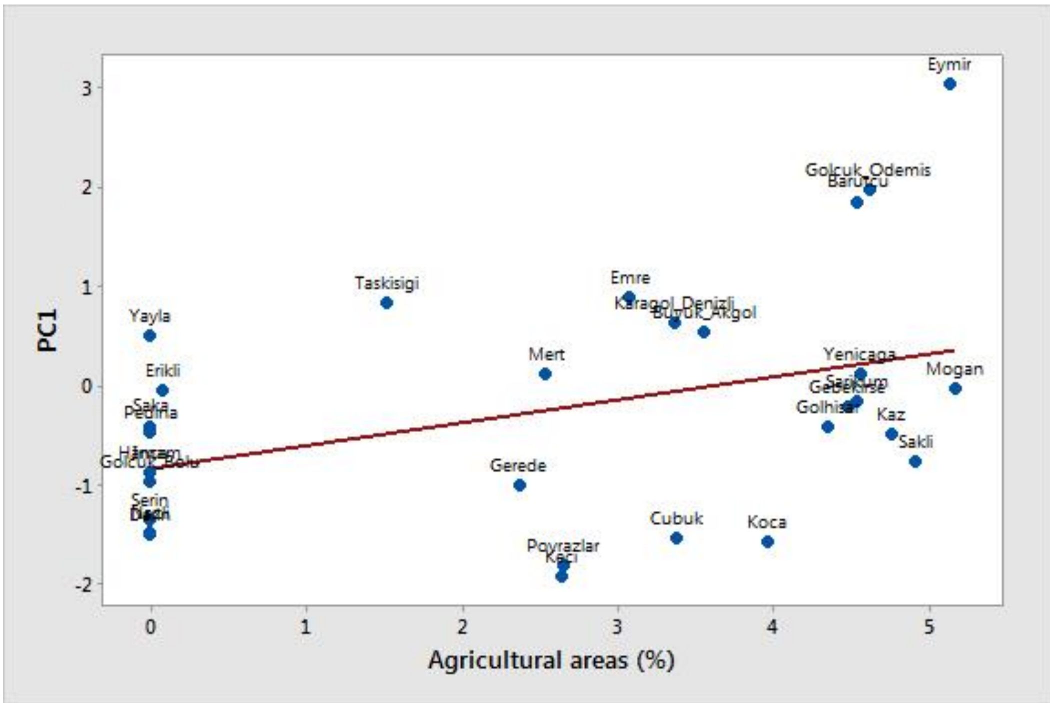

Figure 3.11 Linear regression plots for lakes with PC1 vs agricultural area, P-Value= 0.029, R-sq(adj)=12.84%

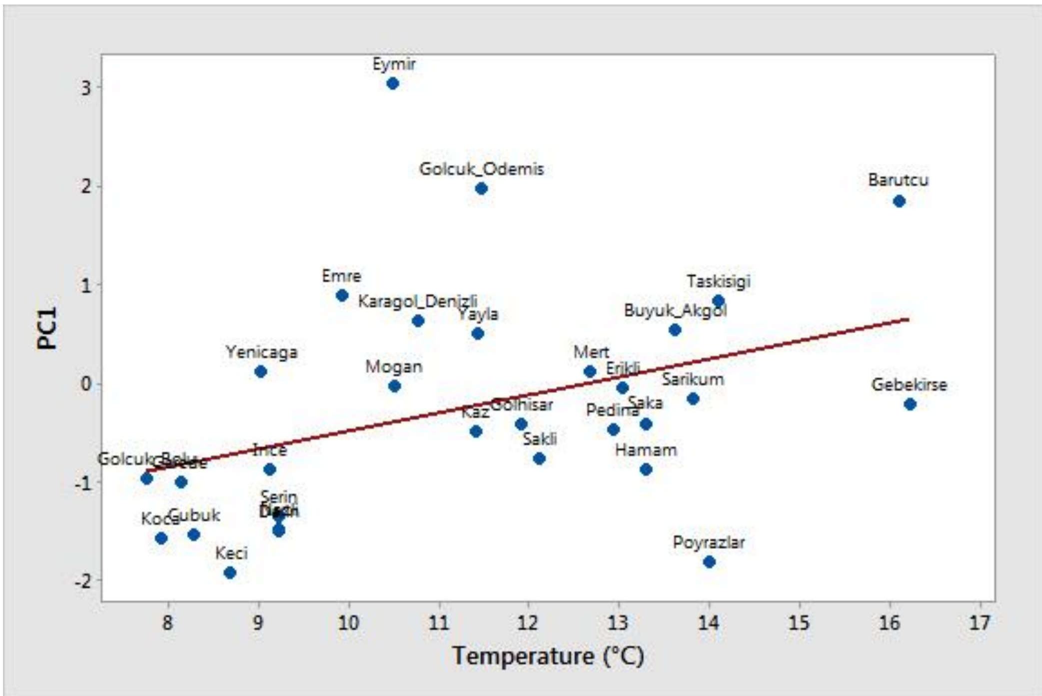

Figure 3.12 Linear regression plots for lakes with PC1 vs temperature, P-Value=0.041, R-sq(adj)=11.04%

Two multiple regression analysis had been tested for 30 lakes. Firstly PC1 versus the significant catchment variables had been tested (Table 3.8).

Table 3.8 Coefficients of the multiple regression analysis with significant catchment variables

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	12.44	6.16	2.02	0.055	
Catchment area	0.669	0.335	2.00	0.057	2.36
Latitude	-0.34	0.151	-2.26	0.033	1.67
Forest and semi natural areas	-0.207	0.45	-0.46	0.649	2.96
Temperature	0.1313	0.0748	1.75	0.092	1.08
Agricultural area	-0.084	0.131	-0.64	0.531	2.34

Regression Equation-2

PC1 = 12.44 + 0.669 Catchment area - 0.340 Latitude - 0.207 Forest and semi natural areas + 0.1313 Temperature - 0.084 Agricultural area

In this analysis, relationship was weak that p-value is 0.005, R-sq (adj) was 37.68%. The order of importance was as expected from the from simple regression analysis above.

Finally, multiple regression analysis was done with PC1 versus all catchment variables with stepwise method. The significant variables have been added and non-significant variables were removed by stepwise method. PC1 versus the significant variables were ‘slope, catchment area, latitude, wetlands, lake area and precipitation’, respectively (Table 3.9).

Table 3.9 Coefficients of the multiple regression analysis with all catchment variables

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	18.06	4.210	4.29	0.000	
Slope	-2.414	0.780	-3.09	0.005	1.27
Catchment area	1.375	0.275	5.00	0.000	2.48
Latitude	-0.453	0.102	-4.42	0.000	1.2
Wetlands	-0.445	0.174	-2.56	0.018	1.23
Lake area	-0.364	0.123	-2.96	0.007	2.02
Precipitation	0.00206	0.001	1.61	0.122	1.45

Regression Equation-3

PC1 = 18.06 - 2.414 Slope + 1.375 Catchment area - 0.453 Latitude - 0.445 Wetlands - 0.364 Lake area + 0.00206 Precipitation

P-value of the multiple regression analysis was 0.000 and R-sq(adj) was 60.13%. Slope had the biggest and positive effect on PC1. Latitude, slope, wetland and lake were related with PC1 negatively. Precipitation had the least and negative effect on PC1.

CHAPTER 4

DISCUSSION

4.1 Catchment and Lake Trophic Status Relations among 36 Lakes

In accordance with the hypothesis, lake trophic status should have been affected mostly by catchment properties and land use. Nielsen et al. (2012) showed that agricultural land use in the catchment area had the most effect on the lake water quality in 414 Danish lakes. In contrast with his study, in the current study, agricultural or forest and semi natural areas were not the influential catchment variable solely if the analysis includes 36 lakes. The significant catchment variables affecting independently trophic status of the lakes were ‘temperature, latitude and longitude’.

Stepwise multiple regression analysis was applied to evaluate the cumulative effect of catchment characteristics on lake trophic status. Lake trophic status was summarized with concentrations of total phosphorous, total nitrogen, Chlorophyll a and Secchi depth as PC1 value. Stepwise multiple regression analysis showed that ‘slope, wetland, latitude and temperature’ are the significant factors affecting lake trophic status (PC1), respectively.

According to first multiple regression analysis, slope had the most influence on PC1. The less steep slope in the catchment, the more nitrogen and phosphorous run into the lakes. On the other hand, similar studies found that slope of the catchment associated with erosion has positively profound influence on the total phosphorus and total suspended solids (Ekholm et al, 2000). In our study area, hilly catchments are generally covered by forests, thus the relationship between PC1 and slope was negative. Even if the catchment was steeply slope land, phosphorus and nitrogen runoff would be limited due to the forest existence.

Second indicator of the trophic status of the shallow lakes was presence of wetlands. With respect to the analysis if the catchments involve wetlands, there was less nitrogen and phosphorous. Different studies around the world prove that "at least 2–7% of the total catchment needs to be in wetland habitat to see a significant increase of water quality at the catchment scale, a remarkably narrow range" (Verhoeven et al., 2006). Wetlands can take part as net basin for nitrogen and phosphorus both seasonally and annually (Valk et al., 1980, Detenbeck et al., 1993). In addition to nutrient absorption by food web dynamics and secondary succession of upland forests, wetlands also retain nutrients and release humid materials that contribute to lake resilience mechanisms (Carpenter et. al., 1997). Similar to former studies the multiple regression analysis revealed that wetlands can be buffer ecosystem for preventing high nutrient concentrations running into the study lakes.

The other predictors of nutrient concentrations (PC1) were temperature and latitude. Temperature of the catchment was positively and latitude was negatively related with the trophic state of the lake. The studied lakes were located in the four climate zones that included Marmara, Black Sea, Central Anatolia and Aegean Regions. Previous studies addressed the temperature influence on eutrophication in warm climatic regions. Due to the differences in biological interactions, warm lakes prone to have much more algal blooms and dense floating plant compared to cooler northern latitude lakes (Jeppesen et al., 2007). In Southern Europe drought, lower input to lakes, excessive use of water for irrigation and high evaporation cause to salinization problem prevalently (Williams, 2001; Zalidis et al., 2002; Jeppesen et al., 2009). Studies on two shallow Mediterranean lakes (Lake Eymir and Lake Mogan) have suggested that despite the lower external nutrient loading with less precipitation in the dry periods, in-lake TP was high due to internal processes such as evaporation and internal loading which contrast with observations from cold temperate lakes (Beklioğlu and Tan, 2008; Özen et al., 2010). One reason is summer phytoplankton biomass increase (Beklioğlu and Tan, 2008). Another reason is that because of differences in trophic state and zooplankton grazing capacity, saline lakes are more conducive to turbidity than freshwater lakes (Jeppesen et al., 1994, 2007; Barker et al., 2008; Jeppesen et al., 2009).

4.2 Catchment and Lake Trophic Status Relations among 30 Lakes

Multiple regression analysis was repeated with 30 lakes. Six eutrophic lakes that had high nitrogen were evaluated as outliers with totally forested catchments. Firstly simple linear regression analysis of lake trophic status (PC1) against catchment variables was carried out. The significant catchment characteristics that solely affected lake trophic state were 'catchment area, forest and semi natural areas, latitude, agricultural area and temperature'. The relations in the simple linear regression analysis were so weak, thus multiple regression analysis also was tried with these significant catchment variables. In this analysis, the relation was still weak that R-sq (adj) is 37.68%, but the relations are as expected except agricultural areas. Based on this analysis, if there is less agricultural area, nitrogen and phosphorous concentration increase. This finding contradicts with the previous studies. For instance, Nielsen et al. (2012) found that excessive agricultural land use in the catchment area trigger high TP, TN and Chl a. Catchment area explains best the lake trophic state in this multiple regression analysis. If catchment area was larger, the nutrient concentration was higher. Studies on the catchment scale effect on water quality declared that there is strong relation between the size of the catchment and lake performance (Alsharif et al., 2012). They used Chl a as surrogate for the overall water quality and nutrient level (Tu, 2011), then clarified the land use influence on lake water quality. They found that larger catchments had higher possibility for runoff and transport of contaminants may be due to larger catchments tending to involve more agricultural and urban area. In our case, this result is probably due to the influence of Lake Mogan (and Lake Eymir) which have disproportionally large agricultural land in their equally large catchment. Lake Mogan largely lies in a flat landscape, where surface runoff is negligible compared to hilly land. Moreover, extensive cereal agriculture with little fertilizer input and/or soil tillage is the norm in those catchments. Therefore, the observed relationship between catchment slope and trophic status is likely confounded by distribution of extensive agricultural land among the catchments. There was negative relationship between the forest and PC1 due to the key role of forests as a nutrient sink (Houlahan et al., 2004). Forests retain the soil and reduce erosion; however spatial distance of the forest to the water body can change the correlation between the forest and nutrient concentrations (Houlahan et al., 2004). Temperature and latitude influence as well as in the second multiple regression analysis. High temperature and low latitude trigger nutrient concentrations.

Due to weak relationship in the second multiple regression analysis, the third multiple regression analysis with stepwise method has been done PC1 versus all catchment variables. The significant variables as 'slope, catchment area, latitude, wetlands, lake area and precipitation' were added by stepwise method. The relation was the strongest among the other two multiple regression analysis that p-value is 0.000 and R-sq (adj) is 60.13%. Catchment slope and size are the strongest predictors of PC1. These finding concur with other studies where slope of the terrain and land use type are the main two determinants in of the catchments with regard to carrying contaminants (Basnyat, et al.1999; Zampella et al. 2007; Chang et. al., 2008). There is an unexpected negative relationship between lake nutrient concentrations and catchment slope. Chang (2008) studied the subcatchments of the Wulin catchment in Taiwan. He revealed that among the landscape characteristics (land use, soil type and slope), average slope of the area explain best the amount of the pollutants. Contrasting to our results he found that highest slope expose to more contaminants. The reason of our unforeseen result derived from the studied mountain lakes where forested catchments are located usually in hilly areas. Nielsen (2012) found that forest area in the catchment is one of the independent variables that lowered the concentrations of TN, TP and Chl a. Anbumozhi (2005) studied four subcatchments in Japan, Indonesia and India, showed the nutrient retention buffer zone effect of riparian forests.

According to this analysis PC1 was affected secondly by catchment area. There were many studies that nutrient loading influence can be altered at different spatial extent (eg: Houlahan et. al, 2004; Buck et. al., 2004; Fraterrigo et. al., 2008; Akasaka et. al., 2010; Wagner et. al., 2011). These studies showed that both in lake mechanisms within the physical, chemical and biological variables of the lake change at the different landscape scale and the land use effect on lake water quality vary at different spatial extent. To reduce the urban areas effect on macrophyte diversity that inversely related with the lake turbidity "management efforts should focus on the creation of buffer zones within the relevant spatial extent from the pond edge" (Akasaka et. al., 2010).

The third predictor of PC1 was latitude which affected conversely. Latitude impact correlated with the temperature. The lower latitude the higher temperature increase nutrient concentrations. This response expected and found in the first multiple regression analysis. The next factor was wetlands had negative relationship with the PC1, because of their high potential for nutrient retention. This expected result was also found in the first multiple regression analysis.

The other driver of PC1 was lake area which had negative effect on nutrient concentrations. It may be related with the higher nutrient retention time in the smaller size lake. All studied lakes were shallow, deep lakes were removed from the analysis thus there was no lake depth influence which is correlated with the retention time. Phosphorus enrichment caused remarkable decline in the species richness as zooplankton and submerged macrophytes (Jeppesen et al., 2000). The studies from 32 European and 66 North American lakes showed that with lake size, species richness increase (Dodson, 1991). Our results suggest this indirect and negative relationship between the lake depth and phosphorus.

The last factor is precipitation trigger the PC1. If there was high precipitation, with the high surface runoff, phosphorous loading from the non-point sources increase. This contradict with the findings of Beklioğlu and Tan (2008) studies in Lake Eymir and Lake Mogan that despite the less precipitation, concentrations of N and P rise due to internal loading. Precipitation had the least influence with the PC1 ($p>0.005$, coefficient<0.003) in the multiple regression analysis, possibly because studied catchments situate in different climatic conditions.

CHAPTER 5

CONCLUSION

In this study, catchment characteristics including geographical properties and land use affect the trophic status of shallow lakes in Turkey was hypothesized. For the geographical properties latitude, longitude, slope, elevation, precipitation and temperature of the catchments were evaluated. It was hypothesized that more intensive the land use e.g. agriculture, urbanization lead to higher nutrients in lakes compared to lakes with intact natural vegetation in their catchment. This expectation contradict with our results that agriculture has low influence on the trophic state of the lakes. There is only significant and positive relationship between the agricultural area and nutrient concentrations (R-sq (adj)=12.84%, p=0.029), when analyzing 30 lakes and their catchments. This result may due to the dry farming areas in the studied catchments. Irrigated farming catchments trigger to surface run off and erosion leads to carrying high fertilizer material.

In our study, last multiple regression analysis among 30 lakes showed the strongest relationship between the catchment characteristics and trophic state (R-sq (adj)= 60.13%, p=0.000). The significant catchment variables were ‘slope, catchment area, latitude, wetland, lake area and precipitation’ respectively. According to this analysis slope and area of the catchment were the strongest drivers of the lake trophic status. While catchment area had positive relationship, slope of the catchment had negative relationship with the lake trophic status. By way of faster run-off and lower nitrogen uptake by vegetation, nitrogen concentration increase in the steep catchments (Kopacek et al., 1995; Kamenik et al., 2001). Our contrasting result of slope and nutrient concentrations relations may most probably due to the forest existence in the hilly mountain catchments in the study area. Latitude, wetland and lake area had negative relationship with the nutrient concentrations. Low latitude correlated with high temperature and small lakes prone to be more eutrophic lakes. Wetlands acts as nutrient retention buffer zone, thus if catchments include wetlands, there is less nutrient concentrations. The final factor has the least impact on lake trophic status also trigger the nutrient concentrations probably by surface run off and atmospheric deposition.

P losses by surface erosion and runoff from the nonpoint sources has well-known role for eutrophication (Sims et. al., 1998). Soil type and geology are substantially important transport processes for P from fertilizers, animal wastes etc accumulates in agricultural top soils which more erodible soil components (Sims et. al., 1998). Despite the soil type and geology effect on the trophic state, due to difficulties of generation or acquire of these data, these were not studied in this thesis. For the future works, carried material by surface run off can be calculated to reveal the land use of the catchment influence on the lakes.

In conclusion, solely land use type cannot be indicator of shallow lake trophic status in Turkey. The studied catchments were not in the homogeneous region in terms of topography, climate, soil and location, thus without geographical properties, land use especially agriculture did not explain the trophic state as expected. Many studies in European countries study the relationship between the catchment and lake with much more samples. Moreover profound effect of agriculture in these lakes resulted from the intensive agriculture with high fertilizer. In our study, there is less information about the agriculture type with respect to irrigation type and fertilizer amount. In addition to lack information the catchment data, for the lakes there should be more information such as retention time and inflow of point sources to the lakes.

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