DEVELOPMENT OF WATER QUALITY INDEX AS A SUSTAINABILITY INDICATOR IN KÜÇÜKÇEKMECE WATERSHED, İSTANBUL

by

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ABSTRACT

Küçükçekmece Watershed which is located in the European side of Istanbul is a highly deteriorated and polluted region as a result of unplanned urbanization and industrialization. The purpose of this study is to assess the water quality trends in Küçükçekmece Lagoon and in its tributaries Eşkinoz and Sazlıdere Creeks by using an aggregate water quality index (WQI) which helps to evaluate water quality trends in an easier and consistent way.

The index has been formed based on the critical issues of the watershed including organic contamination, euthrophication and stresses on aquatic species. The indicators that were selected to represent these issues were dissolved oxygen, chemical oxygen demand, chlorophyll-a, total nitrogen to total phosphorus ratio, nitrate, orthophosphate, turbidity, electrical conductivity and pH. These parameters have been normalized and subsequently aggregated by a weighted sum function. The final scores were represented on a scale between 0 and 100 where the values between 85 and 100 corresponds to excellent, 85 and 70 to fair, 70 and 50 to mediocre, 50 and 30 to critical and below 30 to very poor.

The water quality data evaluated by the index was obtained from two different monitoring programs covering the total of 14 stations and for a monitoring period of more than 5 years. According to the results, the most polluted stations been found as E2 and E3 at Eşkinoz Creek followed by Stations at the Lagoon and Sazlıdere Creek. Water quality in station D3, which is located on Sazlıdere Dam, was found as relatively better with a mean index score over 60. During the seasons of algal blooms, sharp declines have been observed in the index scores at most of the stations and the water quality dropped below "critical" or "very poor" levels. Consistently, low normalized COD scores have been observed in many stations, which can be accepted as an evidence of high industrial and domestic effluent discharges into the Basin. In between 1999 and 2006, a parallel relationship have been observed in terms of land-use changes and the declining trends of normalized dissolved oxygen scores at stations S3 and S4 on Sazlıdere Creek.

ÖZET

Küçükçekemce Havzası, İstanbul'un Avrupa yakasında bulunmakta olup yüksek oranda ve plansız şehirleşme ve endüstrileşme sonucunda ekolojik açıdan tahrip olmuştur. Bu çalışmanın amacı, Havzada kirlilik yükünde meydana gelen değişimleri bir su kalitesi indeksi yardımıyla ortaya koymaktır. Su kalitesinin indeksle ifade edilmesinin verilerin değerlendirilmesinde ve tutarlı bir biçimde analiz edilmesinde faydalı olacağı düşünülmüştür.

Geliştirilmiş olan su kalitesi indeksi, Havza'daki organik kirliliğin, ötrofikasyonun ve sucul canlılar üzerindeki stressin etkilerini değerlendirmeyi hedeflemiştir. Bu amaçla indekse çözünmüş oksijen, toplam azot-toplam fosfor oranı, nitrat, ortofosfat, klorofil-a, kimyasal oksijen ihtiyacı, bulanıklık, iletkenlik ve pH parametreleri dahil edilmiştir. Bu parametreler, normalize edildikten sonra ağırlıklandırılmış toplam yöntemiyle birleştirilmiş ve indeksin sıfır ile 100 arasındaki puan cetveline yerleştirilmişlerdir. Bu puan cetveline göre su kalitesi 100 – 85 arası mükemmel, 85-70 arası iyi, 70-50 arası vasat, 50-30 arası kritik ve 30-0 arası çok kötü olmak üzere beş sınıfa ayrılmıştır.

Değerlendirme sürecinde kullanılan veriler, iki ayrı izleme programından temin edilmiş olup, Havza genelinde 14 izleme istasyonunu ve beş yıldan fazla bir zaman dilimini kapsamaktadır. Elde dilen sonuçlara göre Eşkinoz Deresi üzerinde bulunan E2 ve E3 izleme istasyonlarında su kalitesinin en düşük olduğu saptanmıştır. Sazlıdere Barajında bulunan D3 izleme istasyonunda ise su kalitesinin en yüksek olduğu saptanmıştır. Havza'da daha önceden belirlenen “alg patlaması” dönemlerinde indeks puanlarında önemli düşüşler olduğu tespit edilmiş ve bu dönemlerde su kalitesinin bir çok istasyonda “kritik” ve “çok kötü” sınıflar düzeyine gerilediği gözlemlenmiştir. Bunun yanında Kimyasal oksijen ihtiyacı (KOI) puanının sürekli olarak çok düşük olarak bulunması, Havzaya yüksek miktarlarda evsel ve endüstriyel atıksu deşarjı'nın bir göstergesi olarak yorumlanabilir. Çalışma sonucunda bulunan bir başka bulgu ise 1999 ve 2006 yılları arasında Sazlıdere üzerinde bulunan S3 ve S4 istasyonlarının çözünmüş oksijen puanlarında gözlenen düzenli düşüşün aynı dönemlere meydana gelen arazi kullanımındaki değişiklerle ile paralellik taşıması olmuştur.

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LIST OF SYMBOLS/ABBREVIATIONS

Symbol	Explanation	Units used
A_L	Lake surface area	(km^2)
A_W	Watershed Size	(km^2)
BOD_5	5-day Biochemical Oxygen Demand	(mg/L)
COD	Chemical Oxygen Demand	(mg/L)
DO	Dissolved Oxygen	(mg/L)
EC	Electrical Conductivity	(mS/cm)
SOD	Sediment Oxygen Demand	(mg/L)
T	Temperature	(°C)
TKN	Total Kjeldahl Nitrogen	(mg/L N)
TN	Total Nitrogen	(mg/L N)
TOC	Total Organic Carbon	(mg/L)
TP	Total Phosphorus	(mg/L P)

AS	Anthropogenic System
BC	British Columbia
C_i	Normalized value of i^{th} parameter in the water quality index
CV	Coefficient of variation
DON	Dissolved Organic Nitrogen
DSI	State Hydraulic Works
DSR	Driving forces-states-responses Framework
DST	Decision Support Tool
EPA	Environmental Protection Agency
IISD	International Institute for Sustainable Development
ISKI	Istanbul Water and Sewerage Administration
KEMG	Küçükçekmece Environmental Management Group

NS	Natural System
NSF	National Sanitary Foundation
OECD	Organization for Economic Co-operation and Development
P_i	Relative weight of i^{th} parameter in the water quality index
PON	Particulate Organic Nitrogen
SD	Sustainable Development
S.DEV.	Standard Deviation
SS	Strong Sustainability
TÜBİTAK	The Scientific and Technological Research Council of Turkey
WQI	Water Quality Index
WS	Weak Sustainability

1. INTRODUCTION

Water is indisputable the most precious resource of all; its abundance and distribution have shaped the diversity of life on earth, and affected the culture and civilization of mankind. Today, world's water resources have been exposed to serious degradations. In the forthcoming era, water might be a scarce resource for the majority of communities which might cause catastrophic results as Serageldin asserted, "The wars of 21st century will be over water instead of oil" (Shiva, 2007).

Conservation of water resources requires a conceptual approach with well-defined objectives and a coherent management strategy. The problems related to water resources today can not be solved from a singular aspect and without the involvement of concerned parties. At this stage, decision support tools play an important role in watershed management by simplifying these complicated tasks and enabling better evaluation of related policies. These tools can vary such as those based on spatial analysis or those enhancing participation of stakeholders and community to the decision-making processes.

Küçükçekmece Watershed which contains a Lagoon system adjacent to Marmara Sea is one of the most deteriorated regions of İstanbul. To evaluate the reasons and causes of environmental degradation in the Watershed and to compare it with previous periods from a multi-dimensional aspect, a framework of sustainability indicators was proposed as a decision support tool. For this purpose, two main categories of indicators were defined: anthropogenic and natural system indicators. This study only focused on water quality as a natural system indicator in the framework of sustainability indicators.

The purpose of this study is to develop a water quality index to assess the water quality in Küçükçekmece Watershed. The primary objective of the developed index is to assess "sustainability of aquatic ecosystem", by focusing on critical issues such as stresses on aquatic species, euthrophication and organic contamination. For this purpose, a methodology consisting of selection of appropriate water quality parameters, development of normalization functions, assignment of weight factors to parameters and development of an aggregation function has been followed to achieve a final index score.

The reasons for choosing the index approach for representing water quality in Küçükçekmece Watershed was its simpler procedure and the advantages over models requiring larger data sets both for development and validation. Indices are adapted from the discipline of economics to environmental sciences and are widely used for assessment of water quality since their first application by Horton (1965).

2. CONCEPTUAL BACKGROUND

2.1. Sustainability Concept

2.1.1. Nature-Society Dialectic

The ecological problems seen in the 21st century undoubtedly expose mankind with important questions to answer: Are we going to endanger our common future by insisting on continuing with our "modern" life-style? Do we have the power and the will to transform our societies to a form that is in harmony with the existing planet?

In 1963, Rachel Carson has compared the society's reluctance to embrace ecological theory with Darwin's theory of evolution in the Victorian era (Foster, 2001). In the 21st century, the anthropogenic impacts on the ecosystem are excessively evident than in 1960's; and the causes of global ecological problems still persist or even grow. The most evident sign of this trend is the climate change phenomenon. The concentration of greenhouse gases in the atmosphere is expected to be double compared to the pre-industrial era in the following decades, which is assumed as a critical threshold in climate change.

Today the evidences show that the degradations in the ecosphere are without dispute directly related to anthropogenic reasons. In this context, to deal with ecological problems which humans are the major actors, it is necessary to explicate the mankind-nature dialectic and relate ecology to the evolution of our civilization and culture as mankind. Bookchin (1991) claims: "the ecological crisis is a result of the hierarchical organization of power and the authoritarian mentality rooted in the structures of our society". Furthermore, he questioned the modern view which embraces the idea that "mankind should rule the nature in order to continue its survival" by claiming that "The notion that man must dominate nature emerges directly from the domination of man by man" (Bookchin, 1991). Haberl et al. (2006) called mankind's process of dominating nature as "colonization of ecosystems".

From this aspect, the industrial age can be seen as the last phase of this “colonization” process, exposing the whole planet to an “ecological crisis” with events such as global warming, extinction of living organisms, depletion of resources and pervasive poisoning due to emission of new chemicals. Between the short period of 1970 and 2000, the following consequences have taken place (Kovel, 2002):

- Half of the wetlands have been destroyed throughout the world.
- Half of the forests have been demolished.
- 40 percent of the agricultural land has lost its productivity.
- The global warming increased the earth about 0.37 °C. Additionally the ice on the North Pole has started to melt for the first time in 50 million years of time.
- Food resources at the floor of the oceans are depleted by about 50 percent, endangering about ten million species which are out of scientific knowledge.
- 13 out of the World’s most important of 17 fish nests have been destroyed or their fish populations have seriously declined.

2.1.2. Sustainability: Origins and Definitions

The origins of the verb “sustain” goes back to the 13th century. It comes from Latin roots “sub” and “tenere”, meaning to “uphold” or “to keep”. The adjective form “sustenable” was first used around 1400s and the modern form “sustainable” in 1611 (Wheeler, 2004).

In modern times, sustainability is used in various meanings. From an anthropocentric approach, it is defined as “the fate of natural resources, prevention of their depletion or occurring permanent damages” (The Merriam-Webster, 2007). Another perspective does not restricts the concept with “resources”, but takes into account biodiversity: “Configuring civilization and human activity so that society and its members are able to meet their needs and express their greatest potential in the present, while preserving biodiversity and natural ecosystems, and planning and acting for the ability to maintain these ideals indefinitely” (Wikipedia, 2007).

In environmental management, sustainability is either conceptualized as strong or weak. Strong sustainability (SS) asserts that the conservation of "natural capital" or the ecosystem is indispensable and comes before any other criteria. The weak definition of sustainability (WS) on the other hand focuses on a concept of "aggregate well-being" which has social, economic and environmental aspects (Jamieson, 1998). The SS concept is more appreciated by environmentalists and ecologists as putting environmental protection at the first place whereas WS concept is more likely to be embraced by conventional economists (Jamieson, 1998). The "aggregate well-being" described in weak sustainability has some fundamental contradictions: "Clear-cutting forests and driving species to extinction would pass the weak sustainability test, so long as human well-being does not decline as a result. In principle human well-being would not decline so long as other goods that are substitutable for forests and species could by purchased with money that these policies would produce" (Jamieson,1998).

In this context as Pannell and Schilizzi (1999) described, "the multiplicity of definitions that have been proposed for sustainability and ambiguities related to its meaning reduce its applicability in practical decision making processes".

2.1.3. Sustainable Development

The terms "sustainability" and "development" were first coupled in the post World War II period. Subsequently in the 1960's, environmentalism became a popular movement; Rachel Carlson's famous book "Silent Spring" published in 1962 was considered to be a turning point in the understanding of the interconnections among the environment, the economy and human well-being (IISD, 2007). Additionally "Our Synthetic Environment" (Bookchin, 1962) and "The Population Bomb" (Ehrlich, 1968) contributed to the increase in "public awareness" in 1960's (Şahin, 2004).

In 1972, the famous environmental report called "The limits to growth" was published by the "Club of Rome" (Meadows et al., 1972). The report defined a computer based model to simulate trends of industrial growth, population increase and depletion of natural resources and concluded that the natural limits for the economic growth will be reached at somewhere near the half of the 21st century, which might have catastrophic results. They argued that "it is possible to alter these growth trends and to establish a condition of ecological and economic stability that is sustainable far into the future" and instead defined a "zero-growth theory". The work of Meadows et al. (1972) has drawn the attention of the international community and especially played a very important role in political development of ecology movements (Şahin, 2004). Nevertheless, it was understood in a short time that ceasing the economic growth was not adaptable to the "grow-or-die nature" of the global economy (Douthwaite, 1999).

During the same year with the "Limits to Growth" report, the UN Conference on Human Environment held in Stockholm recognized "the importance of environmental management and the use of environmental assessment as a management tool", which has been accepted as an important step for the "sustainable development" concept (Mebratu, 1998).

However, the first use of the sustainable development (SD) was in 1987 by Brundtland Commission's "Our Common Future" report and SD was defined as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Wheeler, 2004). Later on, Brundtland Commission's definition was embraced world-wide by UN, World Bank and other international institutions. Subsequent to the conceptual agreement, sustainable development strategies were proposed in the preparatory meetings of the UN Rio de Janeiro "The Earth Summit" in 1992. These strategies included national action plans for the promotion of sustainable development, Agenda 21 policies, and conventions on biodiversity and climate change (Mebratu, 1998).

In a majority of these strategies and policies, there are three fundamental aspects: economic development, social welfare and the environment (Figure 2.1.). Sustainable development's goal is to achieve the interactive zone where the three systems interact (Mebratu, 1998; Roldan and Valdes, 2002; Krajnc and Glavic, 2005).

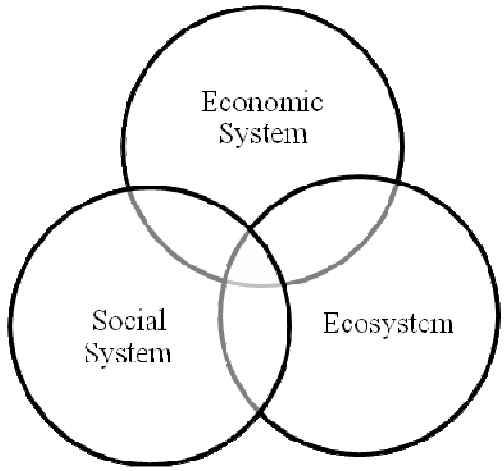

Figure 2.1. Three clusters of sustainable development

2.1.4. Critiques of Sustainable Development

Although sustainable development found wide acceptance on the level of international and national organizations, there were serious objections as well. The major critiques can be grouped into three categories: those finding the expression ambiguous, those believing that economic aspects are predominant over the others and those objecting to the development paradigm.

The most common objections emerge from the concept's ambiguity. Bartelmus (2003) asserts that "For industry, sustainable development is an opportunity for innovation and new markets, governments have used it as a means of soothing "green" objections to economic growth; and certain groups of civil society see it as a weapon against globalization and merciless competition" and Jamieson (2002): "The balance between fruitful ambiguity and outright contradiction is a delicate one, and ultimately the idea of sustainable development could not bear the weight of competing interpretations". According to Mebratu (1998), sustainable development is today on the way of becoming a "cliché".

The second category of objections is related to the concerns about the predominance of economy in sustainable development policies. In decision-making processes, the monetary values are likely to be preferred over social and ecological aspects. The weak sustainability which is mostly accepted as a baseline of sustainable development is likely to trade-off the environment if economic benefits ensure “a better well-being”, which is a very subjective condition.

The third and the strongest objection claims that sustainable development perpetuates the old development paradigms which has roots in “civilizing and christianization native communities outside of Europe in early times and modernization idea in the industrial age” and which is defined as “misunderstanding of the Third and Fourth World cultures, and arrogance of the west” (Chodorkoff, 2003).

Latouche (2002) have further carried the objection by claiming that these two concepts “sustainability” and “development” are antinomies as finite resources versus everlasting development.

2.1.5. Ecological Sustainability Approach

From an ecological approach for sustainability, human and non-human nature are parts of a whole rather than two connected separate systems (Figure 2.2.). In this understanding, ecological sustainability can only exist when these embedded systems are in a dynamic harmony with each other. These embedded systems are defined as:

- Natural System (NS): All biotic -from the basic life forms to the complex- and abiotic components in the ecosphere and their inter-relationships.
- Anthropogenic System (AS): Human society and its interventions in the nature.
- Economy: Activities related to the production, distribution, and consumption of goods and services.

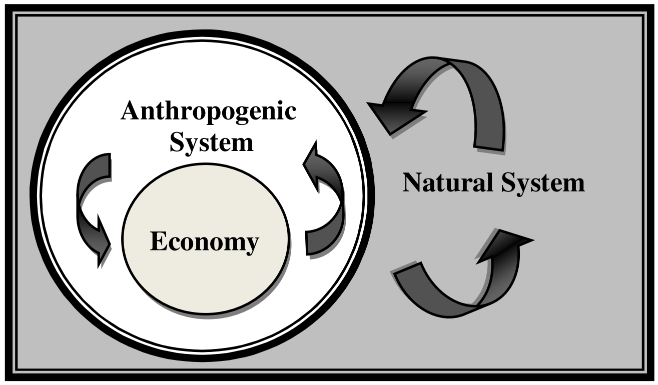

Figure 2.2. The relationship between natural system and anthropogenic system

On the cosmic level, natural system sets the most outer physical boundaries. The AS exists as a cluster within NS and there is a dynamic balance between the two systems in terms of resource usage and pressures.

The anthropogenic system as a whole has the ability to transform or "colonize" the nature; however when the equilibrium between NS and AS is lost (i.e. climate change), the existence of mankind will be under threat as well. The most inner cluster, economy is a sub-system of AS and its dimensions should not be exaggerated to replace all anthropogenic values nor should it jeopardize the boundaries of the natural system.

2.2. Sustainability of Watersheds

2.2.1. Watersheds as Essential Elements of Natural System

Freshwater resources exist within watersheds (Gönenç, 2006). Water resources can not be protected or managed in a sustainable manner without being considered as part of watersheds. From an aspect of ecological sustainability, watersheds are not only limited to their physical definition "topographically delineated area that can collect water" (EPA, 2007) but also as "living terrestrial system consisting of intricately interacting biotic and abiotic components" (Cruz, 1999). As a third factor and perhaps the most influencing one in the modern world, human population with its demands and interventions determines the fate or even existence of watersheds. According to World Resources Institute (2007), some recent consequences of these interventions are:

- In the 21st century, about 1.4 billion people live in river basins where water is overused to the extent that serious environmental damage results.
- The World's 42 most important watersheds have lost more than 75 percent of their original forest cover.
- By 2025, at least 3.5 billion people—or 48 percent of the world's projected population—will live in water-stressed river basins.
- Recent estimates show that half of the wetlands which cover about 12.8 million km^2 of the earth had been lost in the 20th century.

2.2.2. Integrated Watershed Management

The idea of watersheds as appropriate units for resource planning and management emerged in 1800s (Blomquist and Schlager, 2005). Today, the term integrated watershed management is preferred to express "the process of guiding and organizing land and other resource uses in a watershed to provide desired goods and services without adversely affecting soil and water resources" (Cruz, 1999). Alternatively, "watershed management is not so much about managing natural resources, but about managing human activity as it affects these resources" (Conservation Ontario, 2001).

The objectives of watershed management programs can be miscellaneous: supplying water, flood control or "ecosystem restoration" aiming a return to a more natural and less engineered state (Loucks, 2000). In a vast majority of occasions, the decision-makers should consider different aspects and apply multi-objective solutions which inevitably involve some trade-offs between various goals (Novotny, 2003). Loucks (2000) has expressed this multi-lateral nature of watershed management as: "no single discipline, no single profession, no single agency or interest group alone has the wisdom to make these trades-offs".

2.2.3. Decision Support Tools for Watershed Management

In integrated watershed management, decision support tools (DST) have been developed for processing and analyzing collected data and simplifying decision-making processes of managers and stakeholders. Generally the development and the use of these tools require collaboration between different disciplines such as computer science, decision theory, statistics, psychology, information and knowledge engineering and organizational science as well as environmental sciences (Mysiak et al., 2005). Some widely used decision support tools in watershed management are:

- Models, which might cover a wide range of topics such as water quality, hydrology, hydrodynamics, ecosystems etc.
- Spatial tools and geographical information systems
- Indicator sets and indices: Including biological, hydrological, socio-economic indicator set and indices which aggregate various indicators.

2.3. Framework of a Sustainability Index for the Küçükçekmece Watershed

To analyze current problems of Küçükçekmece Watershed, a composite index has been proposed as a decision support tool (Taner et al., 2007). The proposed index consists of indicators that have been selected according to on-going, completed studies in the region. The conceptual framework of the index is based on the ecological sustainability approach (Figure 2.2). Hereby, the indicators have been grouped in two categories: natural and anthropogenic system indicators. The sub-indicators within these two categories are as follows[1]:

- Natural system indicators. Composed of three sub-indicators: hydrology, water quality (by an aggregate index), and biodiversity (i.e. evaluation of fish species).
- Anthropogenic system indicators. Two sub-indicators are “socio-economic pressure on water (i.e. water consumption)” and “watershed management” indicator aiming to evaluate the performance of authorities (i.e. coverage of environmental infrastructure).

[1] For more detailed explanation of the index framework, see Taner et. al (2007).

To express the inter-relationship of these two categories, Organization for Economic Co-operation and Development's "driving forces-states-responses" (DSR) framework has been used (OECD, 1996). In this context, driving forces symbolize the behavior of the public that affects natural system (i.e. water demand). The features of the natural system are named as "states", such as water quality or biodiversity. There is a bilateral relationship between driving forces and states: the anthropogenic system depletes water resources meanwhile being affected from the consequences of its actions. The "responses" represent the actions of authorities which regulate "driving forces" (i.e. by legislations) and remediating "states" (i.e. water quality improvement).

The main framework of the index and the DSR perspective is given on Figure 2.3.

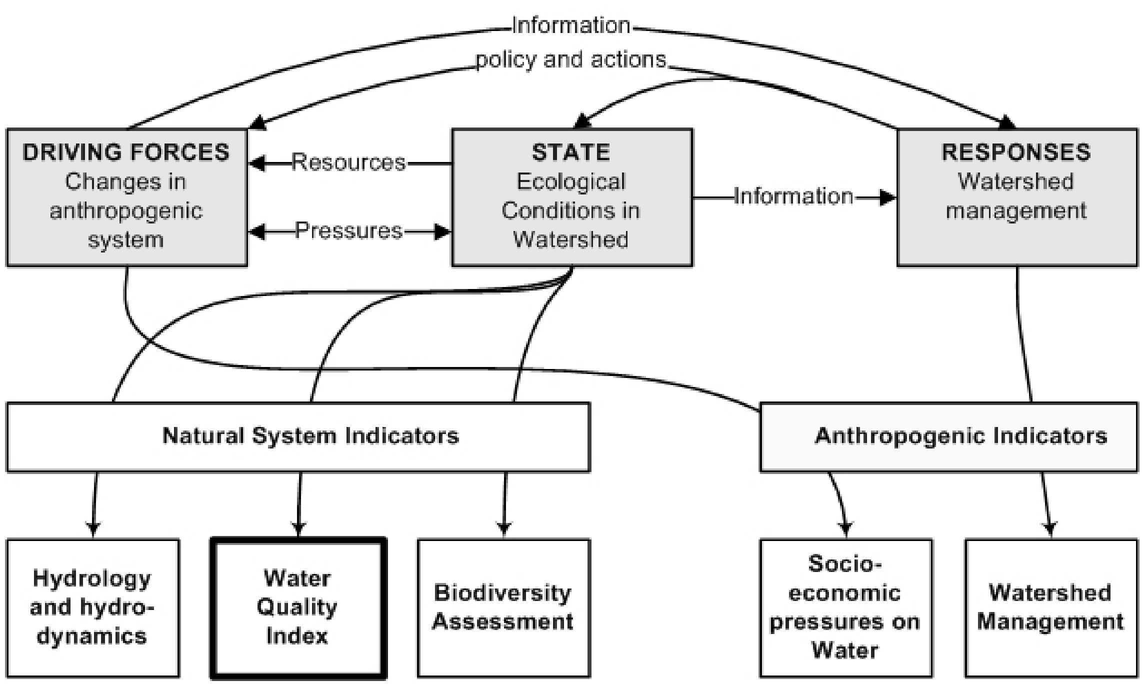

Figure 2.3. Simplified framework of the Sustainability Index

Within this framework of the Sustainability Index, the scope of this thesis is restricted with development, application and analysis of the "Water Quality Index" which is under the natural system indicators category (Figure 2.3.).

3. WATER QUALITY INDICES

3.1. The Purpose of Water Quality Indices

The three principal stages in evaluation of a water body's quality are defining objectives, selecting a set of parameters and assessment of results. The objectives are guidelines adapted to a particular body of water (British Columbia Ministry of Environment, 2007) that explains the assessment approach and perspectives. Subsequent to the statement of objectives, a consistent set of parameters should be chosen which might require subjective decisions while a water body might contain hundreds of constituents and parameters that explain physical and bio-chemical conditions (Tchobanoglous et al., 2003) and while it is practically impossible or very costly to monitor every one of these parameters.

The assessment phase can be relatively complex as the individual parameters might explain different aspects of water. Moreover, the meaning of a single parameter might vary based on the previously set specific goals: "a high dissolved oxygen concentration is essential if good fishing is to be found in a body of water, but only of a marginal value for drinking water supplies" (Gupta et al., 2003).

The primary purpose of water quality indices is to simplify and clarify these phases in water quality assessment by "transforming large quantities of water characterization data into a single number, which represents the water quality level" (Sanchez, 2006). This single number makes information more easily and rapidly understood than a long list of numerical values for a large variety of parameters (Debels et al., 2005).

With this single index number, one of the most daunting prospects which is turning very complex water quality data into information which is understandable and usable by nonscientists e.g., managers, planners and general public is achieved (Stambuck and Gilijanovic, 1999; Gupta et al. 2003). Besides, it is also possible to make comparisons between different sampling sites (Debels et al., 2005).

3.2. General Methods of Water Quality Indices

Water quality indices developed so far can be grouped into subjective or objective indices according to their methodology. Both indices have considerably wide application area, although subjective indices have been more popular and cited more in the literature. Their primary features are described in the following subsections:

3.2.1. Objective Indices

Objective indices are constructed upon expert opinions and questionnaires. With this method, water quality data are statistically analyzed according to given threshold values by institutions or as they appear in legislations. They do no include any subjective inferences such as the decisions of the experts on normalization functions or weighting factors (Gupta et al., 2003).

The most important examples of these indices are the British Columbia Water Quality Index (BC-WQI) and its modification by the Canadian Council of Ministers (See appendix A). Harkins (1974) statistical method which is based on Kandall's nonparametric multivariate ranking procedure is another important example (Gupta et al., 2003) which is calculated as:

$$WQI_H = \sum_{i=1}^{n} \frac{(R_{in}-R_{ic})^2}{var_i} \tag{3.1}$$

where;

n equals to the number of parameters being used;

R_{in} is the rank of n^{th} water sample according to the value of the i^{th} parameter when compared to the values of that parameter among all the p water samples;

R_{ic} is the control value of the i^{th} parameter.

var_i is the rank variance for the i^{th} parameter.

var_i is calculated as:

$$var_i = \frac{1}{12p}\left[(p^3 - p) - \sum_{j=i}^{k_i}(t_{ij}^3 - t_{ij})\right] \tag{3.2}$$

where;

p is the total number of samples in the particular data set under consideration, observations plus the number of control points

$t_{ij,}$ is the number of elements involved in the j^{th} tie encountered in ordering the measured values of the i^{th} parameter

$k_{i,}$ is the total of ties encountered in ranking the measured values of the i^{th} parameter

For the Harkin's index, a low WQI score means a less deviation from the control value that is set by R_{ic}, thus a high quality of water; while a high score means a large deviation from the control value and thus corresponding to poor water quality. A major drawback of this index is cited by Landwehr and Deininger (1974) as "the dependence of single sample scores on the ranking of the control value". This means that the score of a single water sample might change in different data sets.

3.2.2. Subjective Indices

Subjective indices are simpler and easier to apply than objective indices. They are based assumptions and decisions on concentration-acceptability relationships of the parameters defined by the index developer with or without the help of other experts (Gupta et al., 2003).

There are three main elements of a subjective water quality index:

- Normalization functions: The task of normalization functions is to convert measured values of parameters to a dimensionless value which is expressed as C_i on the scale of the index. Normalization functions are specially developed for every different parameter in the index and are formed based on water quality standards, related threshold values or expert opinions.

- Specific weights: Specific weights which are represented with the initial P_i, help to rank parameters according to their significance in the desired evaluation method. Although it is not absolutely necessary to assign weight factor in indices, they enhance the ability of indices.
- Aggregation formula: It is the final stage, where normalized parameters are aggregated with a formula to calculate the index score.

Most common methods that have been used in subjective indices are un-weighted and weighted sum and multiplicative functions, root sum power, harmonic square mean and maximum and minimum operators (Gupta et al., 2003; Debels et al.; 2005; Sarkar and Abbasi, 2006). These methods are summarized on Table 3.1.

Table 3.1. Aggregation methods used in water quality indices

Un-weighted sum,	$WQI_A = \left(\frac{1}{n}\right)\sum_{i=1}^{n} C_i$	Weighted sum,	$WQI_A = \sum_{i=1}^{n} P_i C_i$
Un-weighted product,	$WQI_M = \left(\prod_{i=1}^{n} C_i\right)^{1/n}$	Weighted product,	$WQI_M = \prod_{i=1}^{n} C_i^{P_i}$
Root sum power,	$WQI = \left(\sum_{i=1}^{n} C_i^p\right)^{1/p}$	Harmonic square mean,	$WQI_H = \sqrt{\frac{n}{\sum_{i=1}^{n} \frac{1}{C_i^2}}}$
Maximum operator,	$WQI = C_{max}\{C_1, C_2 \ldots C_n\}$	Minimum operator	$WQI = C_{min}\{C_1, C_2 \ldots C_n\}$

Among these, the un-weighted sum method causes an “ambiguity problem” (Sarkar and Abbasi, 2006) as the index does not give any idea about the individual role of single indicators. Assigning weight factors to parameters partially solves this problem, while relatively more important variables dominate the overall index score.

In the weighted sum method, problem of “eclipsing” has been noted (Gupta et al., 2003), as high overall index scores hide unacceptable low values of few parameters. Hence, Liou et al. (2003) suggested that the weighted sum methods should be preferred when there is a positive correlation between the normalized values of parameters. In that case, it is unexpected to have only one variable whose normalized rating is very low and all the others having a high rating or vice versa. Harmonic squares mean is suggested as an improvement over both weighted methods (Dojlido et al., 1994).

The multiplicative aggregation is a popular technique and it mostly solves “eclipsing” and “ambiguity” problems (Liou et al., 2003). However the restriction of this method is the “over-exaggeration” problem which takes place when a single parameter has a score close to zero which causes the aggregate index score to drop significantly due to multiplication of individual scores (C_i). Additionally, when more variables are used in this function, the sensitivity will be lower since the individual weights of the function will get smaller (Smith, 1990).

The root sum power is specified as a better alternative than weighted and multiplicative aggregation methods: “as p becomes larger in its formula, the ambiguity in the aggregation becomes smaller” (Sarkar and Abbasi, 2006).

The other two methods, maximum and minimum operators have not been used in any of the proposed indices so far (Abbasi 1999). Maximum operator index can be viewed as the limiting case of the root sum power index as p approaches to infinity. It is suited to applications in which an index must report if at least one recommended limit is violated and by how much (Abbasi, 1999).

3.4. Water Quality Indices in Practice

The first primitive form of water quality index was introduced more than 150 years ago in Germany where the presence or absence of certain organisms in water was used as indicator of fitness or otherwise of a water source (Sarkar and Abbasi, 2006).

However, the actual forms of indices have not been used until 1960's, until water quality scientists and experts have adapted the index theory from economics (Sarkar and Abbasi, 2006). The first water quality indices were proposed by Horton (1965) and Brown et al. (1970). Subsequently, WQIs have been widely used by administration boards or research institutes in various countries, especially in the United States and Canada.

The most widely used and best known index so far is the National Sanitary Foundation's water quality index (NSF-WQI). It is developed by more than 140 water quality scientists who were surveyed about 35 quality tests (GREEN, 2007). Following NSF's index, Oregon Department of Environmental Quality formed their own index for evaluating streams for general recreational use including swimming and fishing (Cude, 2001). Oregon's index has been used until 1983; and afterwards upgraded to a more sophisticated form.

Besides the United States, another important index was developed in British Columbia named as "BC-WQI". The unique feature of this index was its statistical factors which were easily calculated and were flexible in a variety of situations (BC Ministry of Environment Website). It was composed of three factors named as: Scope (F_1), Frequency (F_2) and Amplitude (F_3) (Lumb et al., 2006). Later on Canada Council of the Ministers implemented some modifications by changing the aggregation method of BC-WQI.

Selected water quality indices are given with their parameters, aggregation functions and evaluation scales on Appendix A.

4. STUDY AREA: KÜÇÜKÇEKMECE WATERSHED, ISTANBUL

4.1. Physical Properties

Küçükçekmece Watershed is geographically positioned at 41° 00' N latitude and 28° 45' E longitude, in the European side of Istanbul (Figure 4.1.). Geo-morphologically, the watershed is located between two wide plains of nearly 100 meters in the north and south directions (Yıldırım and Adatepe, 2004). It's adjacent to Marmara Sea on the southern side and two important highways, D-100 and TEM passes within the region.

The feature that makes the watershed unique is the existence of a coastal lagoon which is connected to the Marmara Sea through a narrow channel which is 1km in length and 1.5m in depth. The Lagoon's surface area is approximately 15.22 km^2 and its volume is about of $145x10^6$ m^3; its length and width are 7.5 km and 4 km, respectively (Üstün et al., 2005). The average depth of the lagoon is about 8.3 meters and maximum depth is 20 meters near its southern side. The total drainage area of the lagoon is 340 km^2.

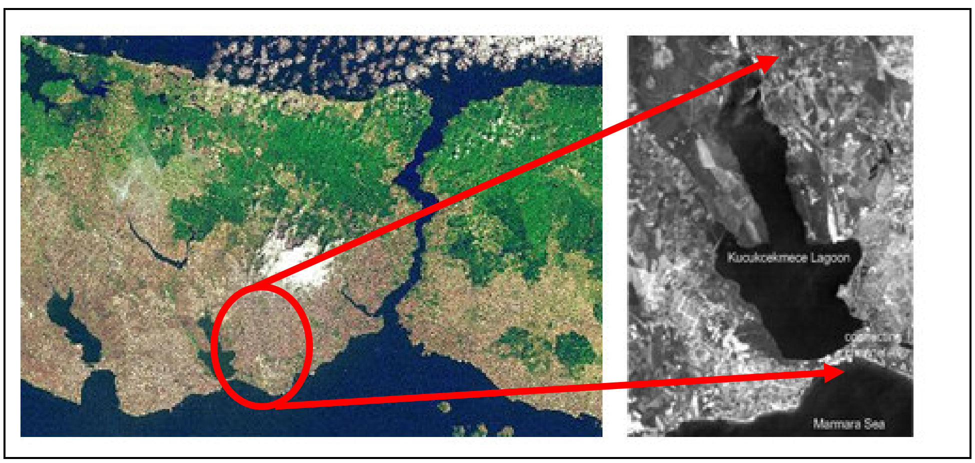

Figure 4.1. Location of Küçükçekmece Watershed

The three freshwater sources flowing to Küçükçekmece Lagoon -from west to the east- with their long term mean flow rates are Eşkinoz (0.24 m^3/s), Sazlıdere (0.86 m^3/s) and Nakkaş (0.29 m^3/s), respectively (Figure 4.2.) (Bağdatlıoğlu, 1996). After 1998, freshwater flow to the lagoon is notably reduced, upon initiation of the Sazlıdere Dam on the Lagoon's most important tributary creek (Taner et al., 2007). Presently, the Dam is used for supplying water to Istanbul with an annual capacity of 85 x 10^6 m^3 (Altinbilek, 2006).

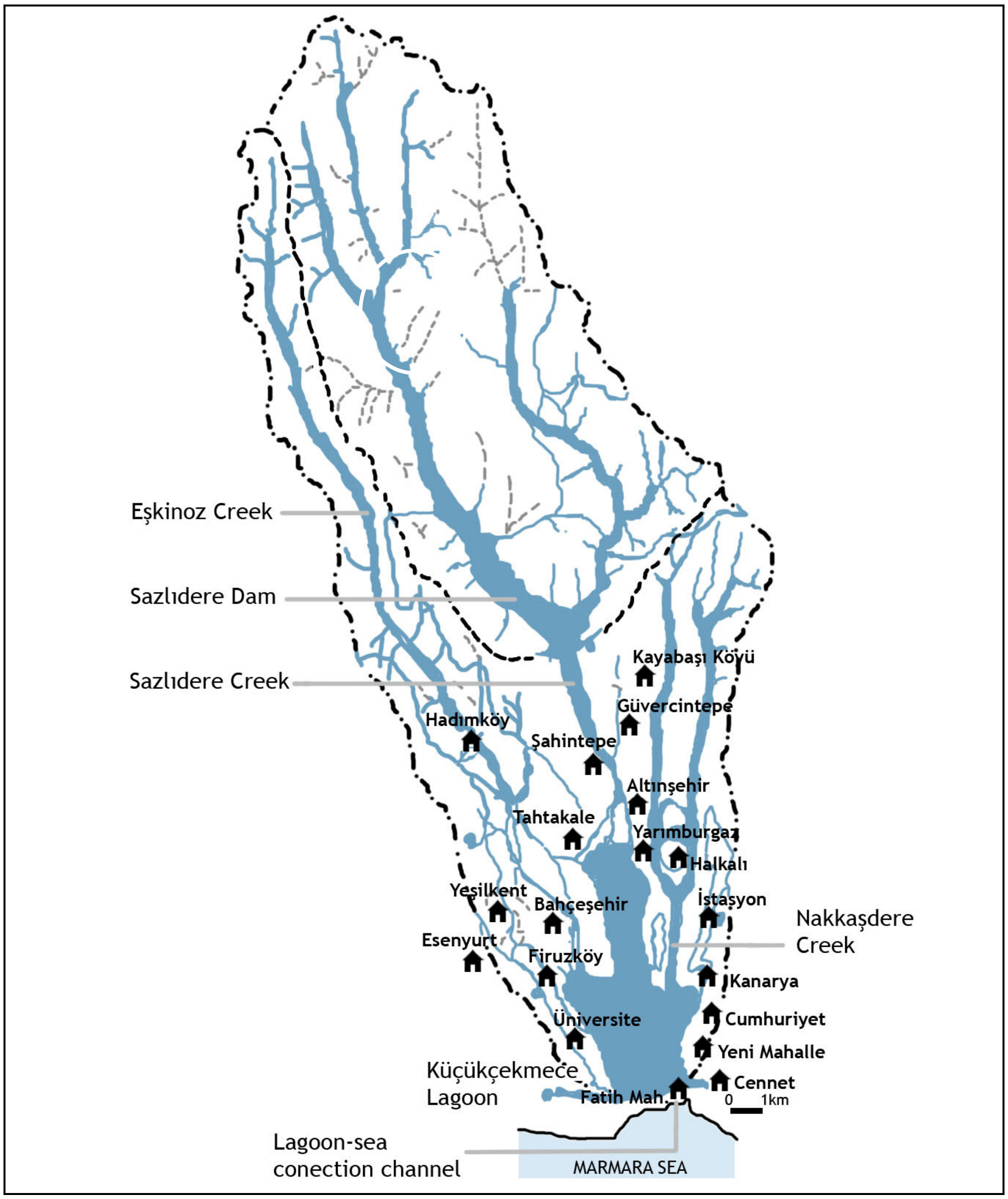

Figure 4.2. Settlements and freshwater resources in Küçükçekmece Watershed

4.2. Socio-Economic Structure

4.2.1. Population and Urbanization:

The first settlement in Küçükçekmece Region was established in the name of "Rhagion" during the years of Byzantium rule (Akyapı, 2005). The village has maintained its Greek population until 1600s and afterwards with Turkish migration, has grown into a town and taken the name "Küçükçekmece" (Akyapı, 2005). According to Tuncer (1999) the prominent development and urbanization of the region occurred in the 1950's upon completion of major road connections and improvements in suburban railway system.

According to the population data of Küçükçekmece Municipality between 1990 and 2000 (Table 4.1.), the Watershed's population has increased five times between the same period and has reached to 680000 in 2005 (Karakaş and Tabak, 2005).

Table 4.1. Regional population change in Küçükçekmece

Year of Census	1935	1941	1970	1980	1990	2000
Population	707	780	43385	81503	112264	600000

The enormous population increase in the 1990's is a result of migration waves from various parts of Turkey, especially from eastern and south-eastern Anatolia, the Black Sea and Marmara regions and from Eastern European countries such as Bulgaria and Romania (Taner and Aytaç, 2004).

The migrations did not occur as a homogenous distribution throughout the region and as a result formed diverse socio-economic and socio-cultural sub-regions within Küçükçekmece. As an example, Hadımköy district is mostly formed by former East Europeans citizens (Taner and Aytaç, 2004).

4.2.2. Means of Livelihood

Agriculture and stockbreeding, which have been the major activities in the region for a long time, lost its significance after the 1990's with the rapid industrialization and urbanization. Demirci et al. (2005) showed the dramatic changes in land use by comparing aerial photographs of years 1963, 1996 and 2004 (Figure 4.3.). Nowadays, agriculture is mostly restricted with several villages of Hadımköy and surrounding areas of Sazlıdere Dam (Taner and Aytaç, 2004).

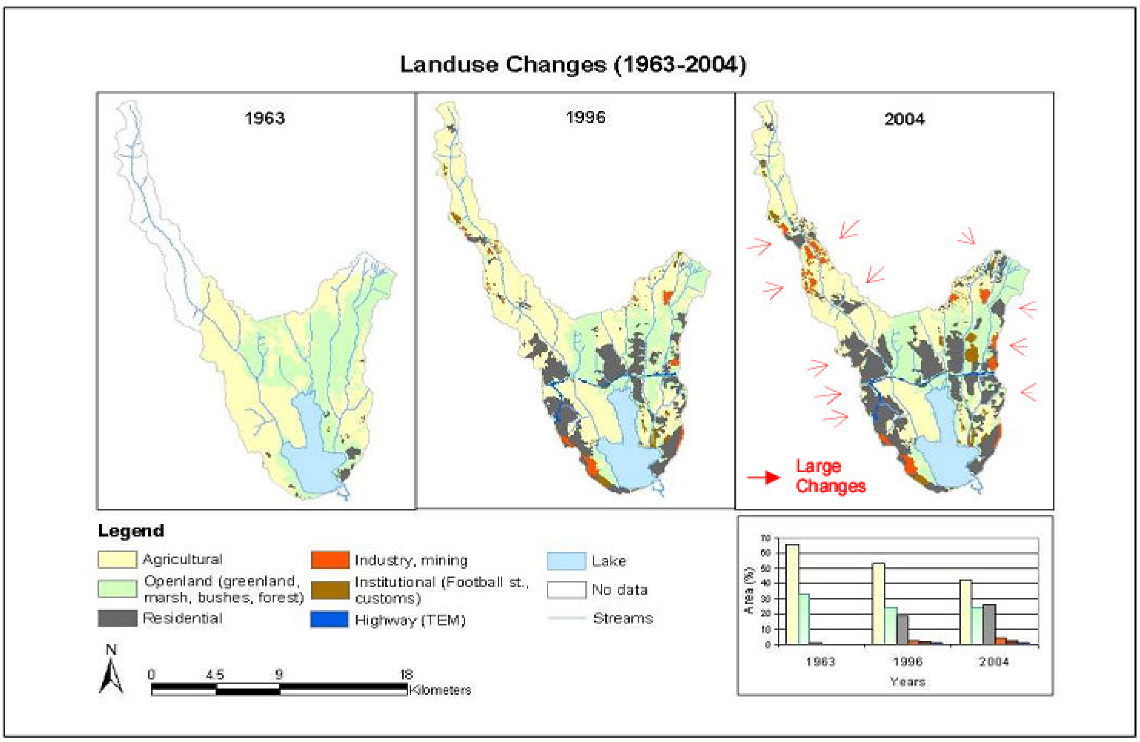

Figure 4.3. Land-use Changes in Küçükçekmece Watershed (Demirci et al., 2005)

In the early 1990's, industrial facilities moved from the central Istanbul to peripheral districts such as Küçükçekmece mainly due to relatively low land prices, transportation advantages and loose control of the authorities (Taner and Aytaç, 2004). Today, the most industrialized districts in the region are Kayabaşı, Hadımköy, Firüzköy and Hoşdere (Okumuş, 2007). In these districts, metal and textile sectors are the leading sectors, followed by petrol-plastic and paper-packing-printing industries (Table 4.2. and Figure 4.4.).

Table 4.2. Industrial Sectors in Küçükçekmece Watershed

Industrial Sectors	**Number of Industries**		
	Hadımköy	**Kayabaşı**	**Firüzköy**
Metal	58	40	4
Textile	44	12	22
Petrol and Plastics	27	12	10
Stone and soil based	3	4	-
Paper, packing and printing	19	5	2
Chemical	21	5	4
Forestry and furnishing	4	2	3
Pharmaceuticals	2	-	-
Storage and shipping	23	-	-
Food	10	-	-

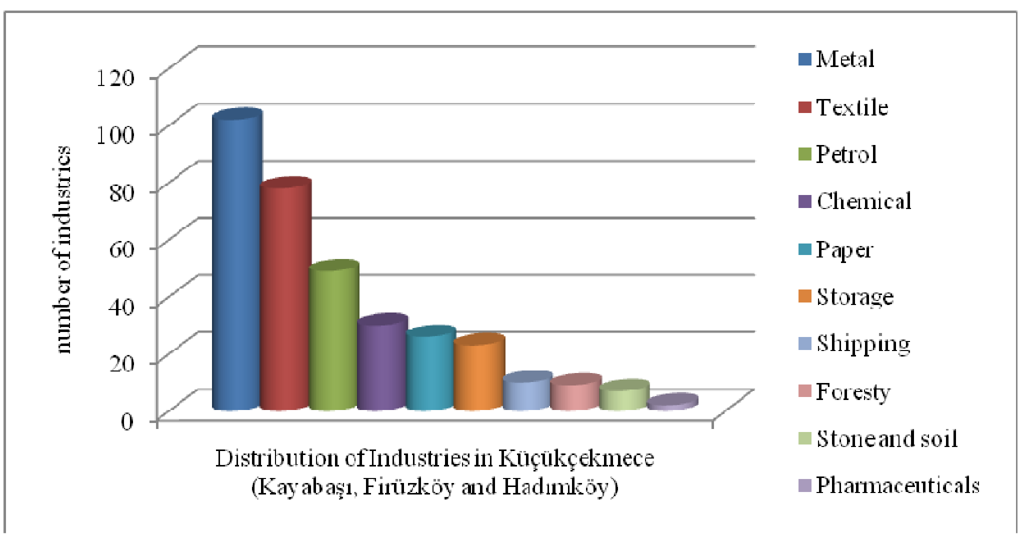

Figure 4.4. Industrial sectors in Küçükçekmece Watershed

4.3. Administrative Status

In Istanbul, there are several institutions that have duties for protecting and managing water resources, these are:

- Istanbul Metropolitan Municipality
- Local municipalities
- Istanbul Water and Sewerage Administration (ISKI)
- State Hydraulic Works (DSI).

The organizational structure which hinders congregation of all duties and decision processes in one hand causes disadvantages in planning and auditing processes of water resources. In some cases, the jurisdiction of institutions might overlap or contradict which slows down or handicaps developing solutions to environmental problems. According to Üstün et al. (2004), this problem is one of the most important barriers for developing solutions to Küçükçekmece's environmental problems.

Another problematic issue rises due to the "legal status" of the watershed. In 2006, ISKI has established a new regulation that restricted the term "watersheds" to those only determined to be at "drinking quality standards" (ISKI, 2006). Since Küçükçekmece Lagoon has already been deteriorated and drastically urbanized, it is not regarded in the official list of "watersheds". Hence, required measures to rehabilitate the lagoon are neglected and the Lagoon is left vulnerable to further degradations (Taner et al., 2007). The current application also contradicts with "Ramsar Convention on Wetlands" which states coastal lagoons should be protected and wisely used (Ramsar, 2004).

4.4. Climate and Meteorology

Küçükçekmece' climate shows features of the Marmara and Western Black-sea (Okumuş, 2007) which is hot and low precipitation in summer; temperate and high precipitation in winter seasons. The topographical structure and the lagoon are influential on the climate characteristics (Okumuş, 2007). The precipitation that falls between October and March is recorded as %70 of the total precipitation (Üstün et al., 2005). Meteorological data for 2004 and 2005 on precipitation, humidity, wind direction and wind intensity are given in Tables 4.3 and 4.4, respectively.

Table 4.3. Meteorological data for Küçükçekmece in 2004 (Gökağaçlı, 2007)

2004													
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Avg.**
Avg. temp. °C	4,9	5,5	8,3	12	16,4	21,2	23,9	23,5	20,8	14,2	12,1	8,7	14,2
Min. temp °C	-6,1	-7,2	-1,7	1,3	1,4	14	16,3	16,2	11,4	11,1	-0,8	0,1	4,6
Max. temp °C	13,8	19,6	21,8	24	25	29,9	31,6	32,8	32	26,2	24	17,9	24,8
Avg. humid.(%)	76,1	73,3	70,4	66,8	67,8	69,4	62,9	70,9	68,9	75,3	70,2	73,2	70,4
Min. humid.(%)	5,6	51	45	46,7	43,7	52,7	48,7	58	52,7	58	8,3	52,7	43,5
Max. humid.(%)	94,7	95	95	91,3	95,3	89,3	75	89,3	83	93,7	94,3	93	90,7
T. Precip. (mm)	153,5	70,2	66,2	22,4	25,1	58,5	25,2	69,5	2,8	142,1	56,6	45,1	61,4
Wind sp. (m/s)	8,03	7,27	8,04	5,86	4,66	4,07	5,68	4,7	6,05	5,18	7,22	6,16	6,07
Wind direction	NMW	SW	NNE	NNE	SSW	NE	NE	NE/N	NNE	NE	NE	SSW	

Table 4.4. Meteorological data for Küçükçekmece in 2005 (Gökağaçlı, 2007)

2005													
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Avg.**
Avg. temp. °C	6,8	5,8	7,1	12,1	16,7	20,8	24,6	25,4	-	14,9	10	8,2	13,8
Min. temp °C	-1	-2,4	-2	1	7,8	13	15,8	19,3	-	7	0	-3	5,04
Max. temp °C	16,1	1,7	17,5	25,8	27	30,4	31,3	34,4	-	25,2	19	14,8	22,1
Av. Humid. (%)	80,6	72,6	71,8	67,4	73,3	62,7	68,4	67,3	-	72,5	79,3	77	72,1
Min. humid. (%)	49	36	47	46	45	42	54	48	-	61	58,7	62	49,8
Max. humid.(%)	94,3	95	93,3	89	93	84,3	90,7	85,3	-	90,7	96,3	95	91,5
T. Precip. (mm)	113	151	45,1	21,7	21,7	20,2	67,5	27,4	-	42,7	75,9	88,2	61,3
Wind sp. (m/s)	6,73	8,08	7,88	7,01	5,96	6,89	7,08	6,61	-	6,7	6,97	2,66	6,59
Wind direction	NNW	SW	NE	NNW	NNE	NE	NE	NE	-	NE	NNW	NE	

4.5. Ecological Status

4.5.1. Flora and Fauna

Throughout the centuries, various ecologically important regions and endemic species have existed in Küçükçekmece Watershed. The wetland in the northern Lagoon hosted to cormorant, seagull and other birds; Yarımburgaz Cave with its unique formations and plant species; Ispartakule Valley with rare lawns and limestone are a couple of examples to Küçükçekmece's unique ecological features (Taner and Aytaç, 2004). Furthermore, the richness of Lagoon's biodiversity in the past is cited in other studies (Tuncer, 1999; Üstün et al., 2005).

Today, the scope of ecological degradation is easily visible throughout the watershed. According to Altinbilek (2006), Küçükçekmece is nowadays the second largest system carrying Istanbul's industrial and domestic pollution load. The results of a recent TÜBİTAK project has supported this claim by addressing problems of increasing heavy metal concentration, organic loads in the Lagoon (Üstün et al., 2006). Today, *cyprinus sp.*, *esox lucius* and *siluriformes sp.* have managed to survive in the Lagoon among many others (Üstün et al., 2005).

4.5.2. Water Quality

Water quality in Küçükçekmece Lagoon and in its tributaries has declined rapidly in the last couple of decades. Today, especially Eşkinoz creek is acting like an open discharge channel in terms of pollution load. In the region, contaminants are easily carried by creeks to the Lagoon with the aid of non-porous character and sand-silt formation of the riverbeds (Yıldırım and Adatepe, 2004).

The poor environmental infrastructure in residential areas, inadequate treatment systems in industrial facilities and reduction of freshwater input from Sazlıdere Creek are major causes of pollution in Küçükçekmece Lagoon.

To analyze the current conditions of the Lagoon and its tributaries' quality and to determine the sources of pollution in Küçükçekmece Watershed, two different studies have been carried out by State Hydraulic Works (DSI, 2006) and by so called "Küçükçekmece Environmental Management Group (KEMG)" (Üstün et al., 2005; Üstün et al.,2006).

In DSI's quality monitoring program, water at various sampling stations on Sazlıdere Creek, Nakkaş Creek and Küçükçekmece Lagoon have been analyzed since the 1980's through present. After the 1990's some stations have been abandoned and the program has been restricted to Sazlıdere upon initiation of Sazlıdere Dam. The latter monitoring program executed by KEMG have started in 2002 with three sampling stations on Sazlıdere Creek D1, D2 and D3 and expanded to nine stations at 2006.

The water quality index developed in this study has used the data of both monitoring studies -DSI's and KEMG's- despite their different approaches. The sampling stations of both studies are summarized in Table 4.5 and sketched on Figure 4.5, respectively.

Table 4.5. Sampling Stations in DSI's and KEMG's monitoring programs

Monitoring Program	Station	Location	Start-End Date	Interval
DSI	S1	Şamlar	1984-1998	monthly
	S2	Sazlıbosna	1990-1996	monthly
	S3	Dursunköy	1997-2006	monthly
	S4	Haraçcı	1999-2006	monthly
	S5	Kayabaşı	1990-1994	monthly
KEMG	D1	Near Sazlıdere outlet	2002 -	monthly
	D2	Sazlıdere outlet	2004 -	monthly
	D3	Sazlıdere Dam	2004 -	monthly
	E2	near Hadımköy	2005 -	monthly
	E3	near Bahçeşehir	2005 -	monthly
	10	Lagoon (near channel)	2005 -	monthly
	11	Lagoon (Eşkinoz outlet)	2005 -	monthly
	12	Lagoon (middle)	2005 -	monthly
	13	Lagoon (near Sazlıdere outlet)	2005 -	monthly

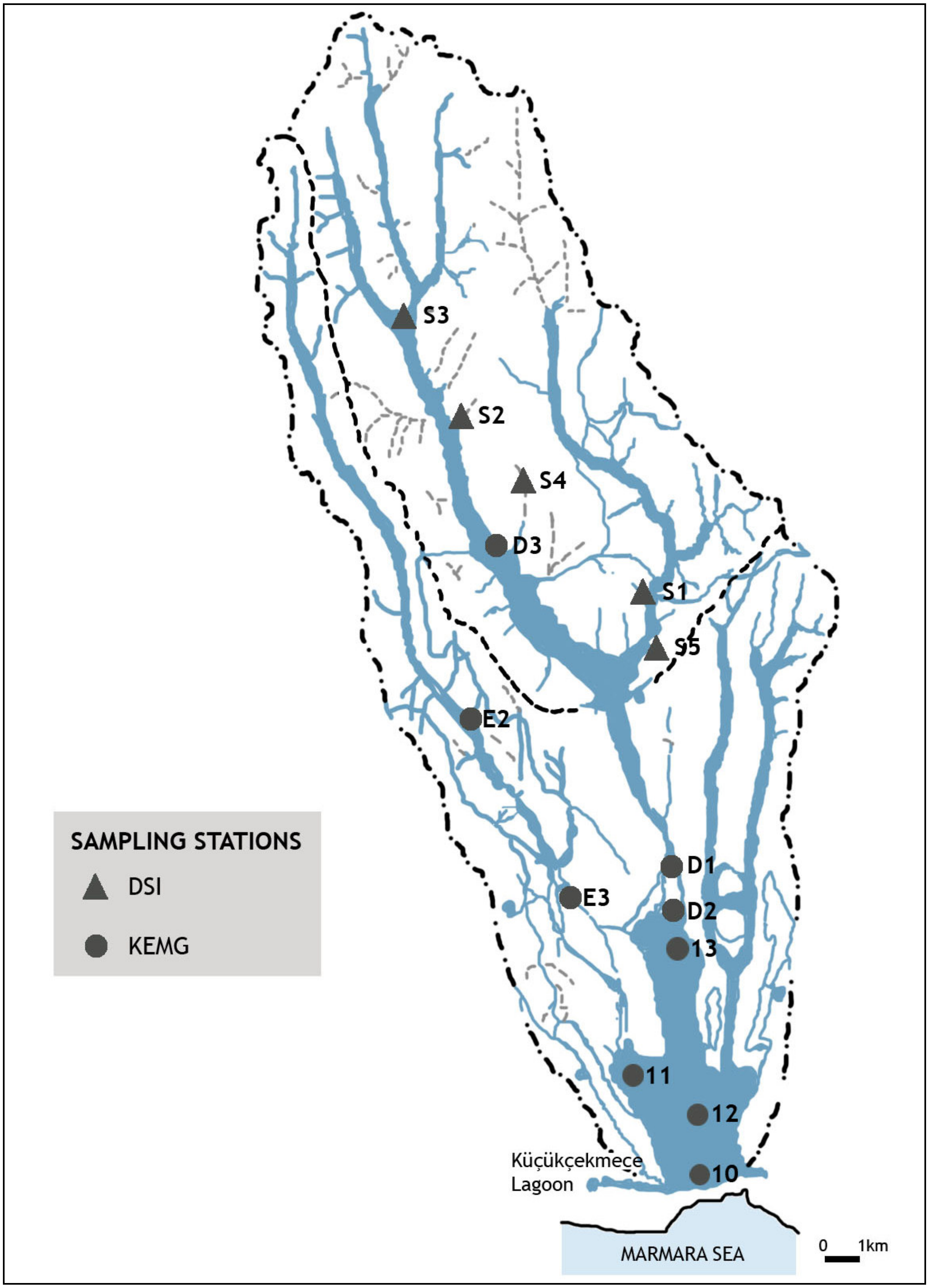

Figure 4.5. Sampling stations at Küçükçekmece Watershed

Figure 4.6. Sampling station D1

Figure 4.7.Sampling station D3

Figure 4.8. Sampling station E2

Figure 4.9. Sampling station E3

Figure 4.10. Sampling station 10

Figure 4.11. Sampling station

D2

5. METHODOLOGY OF WATER QUALITY INDEX

The methodology of the water quality index study consists of five principal steps:

- Selection of parameters that reflect an aggregate characteristic of water quality
- Construction of normalization curves for each parameter on a uniform scale.
- Assigning of weight factors to parameters based on their relative significance.
- Selection of an aggregation formula to express a final index value.
- Regression analyses to transform parameters and to complete missing data.

5.1. Selection of Parameters

5.1.1. General Considerations

The most important property of a water quality index is selecting a parameter set that is consistent with pre-defined index objectives. In the Küçükçekmece case, the primary objective is defined as aquatic ecosystem’s sustainability. Hence, the index targets the following issues in the watershed: (a) stresses on aquatic biodiversity (b) change in trophic status (c) concentrations of organic and inorganic pollutants.

Subsequently, parameters that are used in the two different monitoring programs – State Hydraulic Works’ (DSI) and Küçükçekmece Environmental Monitoring Group’s (KEMG) – have been compared with each other to consider various alternatives. It was seen that the programs did not overlap in terms of parameters, as their priorities, technical resources and budget constraints differ. The solution that was developed to overcome the inconsistency problem was using common parameters in both programs and using transformation methods between alternative parameters in absolutely necessary conditions.

The common parameters were water temperature, pH, electrical conductivity, turbidity, color, dissolved oxygen, free chloride, ammonia nitrogen, nitrite, nitrate, alkalinity, orthophosphate and total coliform. The complete list of parameters is given on Table 5.1.

Table 5.1. Parameters used in DSI's and KEMG's monitoring programs

State Hydraulic Works (DSI)		**Küçükçekmece Environmental Management Group (KEMG)**	
T_w (°C)	NH_3-N (mg/L)	Turbidity (NTU)	SS (mg/L)
pH	NO_2 (mg/L)	T.Coli (EMS/100mL)	VSS (mg/L)
EC (mhos/cm)	NO_3 (mg/L)	Secchi Disk (cm)	T_w (°C)
Turbidity (NTU)	Alkalinity (mg $CaCO_3$/l)	Salinity	pH
Color (Pt-Co)	A-CO_3 (mg/L)	EC (mS/cm)	NH_3-N (mg/L)
DO (mg/L)	T-H (mg/L)	DO (mg/L)	NO_2 (mg/L)
BOD_5 (mg/L)	o-PO_4 (mg/L)	Color (Pt-Co)	NO_3 (mg/L)
PV (mg/L)	SO_4 (mg/L)	Alkalinity (mg $CaCO_3$/l)	Cl (mg/L)
Cl (mg/L)	Si (mg/L)	COD_{water} (mg/L)	o-PO_4 (mg/L)
Fe (mg/L)	T.Coli (EMS/100ml)	$COD_{sediment-water}$ (mg/L)	TP (mg/L)
Na (mg/L)	E.Coli (EMS/100ml)	$COD_{sediment}$ (mg/L)	Viscosity
K (mg/L)	F-Strp (EMS/100ml)	SO_4 (mg/L)	ORP
Ca (mg/L)		TKN (mg/L)	

Among this wide list, the parameters have been selected and grouped according the problems or conditions that they indicate as:

- Stresses on aquatic biota: Dissolved oxygen
- Trophic state parameters: TN/TP, nitrate, orthophosphate and chlorophyll-a
- Organic contamination: chemical oxygen demand
- Complementary parameters: pH, turbidity and electrical conductivity
- Indirectly included parameters: temperature and salinity (for DO calculation).

The mean values of water quality data of sampling stations belonging to both monitoring programs are given on Appendix B. The measurement methods used in KEMG's study is given on Appendix C.

The major role of these selected parameters in water quality, the primary processes controlling their fate and their calculation steps are described below:

5.1.2. Dissolved Oxygen

The dissolved oxygen (DO) concentration shows the amount of free oxygen dissolved in water. It is one of the essential criteria for sustaining aquatic life, especially for higher organisms. For instance, DO concentrations below 3-4 mg/L and %60 as saturation are life threatening for fish species (Mervin, 2001; Gürel et al., 2005). The primary mechanisms that control the concentration of dissolved oxygen in water are as follows (Figure 5.1.):

- Re-aeration. The atmosphere is the primary source of dissolved oxygen. The diffusion rate of oxygen from atmosphere to surface water is controlled by factors such as water velocity, water depth and wind speed (Gürel et al., 2005).
- Photosynthesis. The photosynthesis process is the second most important supply of dissolved oxygen in water. It is carried out by autotrophic organisms that produce organic matter and oxygen by consuming carbon dioxide in water. However, together with respiration processes, photosynthesis can add and deplete significant amount of dissolved oxygen and cause seasonal variations in aquatic environment (Gürel et al., 2005).
- Oxidation processes. DO is consumed either by aerobic organisms in oxidation process of organic matter or in chemical oxidation of organic and inorganic matter such as ferrous iron or sulphide. DO needed for these processes are expressed in terms of biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD).
- Sediment oxygen demand (SOD). The sediment layer in water bodies usually contains organic matter that are settled down or transported by hydrodynamic processes. As oxygen in overlaying water diffuses from water to sediment, this organic matter is decomposed (Gürel et al., 2005).

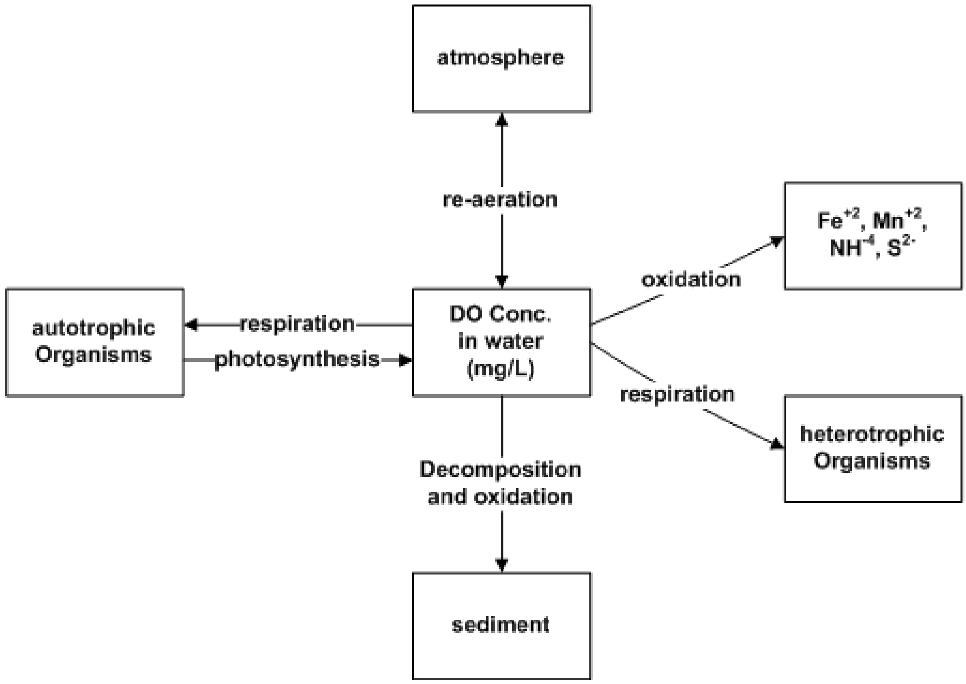

Figure 5.1. Processes affecting DO concentration in water (Gürel et al., 2005)

DO can be expressed in two ways: (a) as concentration (mg/L) (b) as saturation ratio (%). In euthrophic lakes, DO concentration itself might be dominantly influenced by photosynthetic activity (Debels, 2004) hence resulting super-saturation of DO during day time when biological activity is high. In such cases, DO values as concentration can be misleading while the negative impact of euthrophication is disregarded. DO as percentage of saturation on the other hand allows divergent assessments for DO values in under-saturated and super-saturated zones. Thus, to reflect the impacts of euthrophication in the index better, DO is expressed as saturation ratio.

According to Henry's law, solubility of oxygen in water is related to its partial pressure in atmosphere (Tchobanoglous et al., 2003). Other factors that are effective on saturation concentration are barometric pressure, temperature and salinity.

In the water quality index, the saturation ratio of every water sample was calculated as follows:

(A) Saturation concentration of DO is determined based on DO solubility and salinity (ppt) and temperature ($^{\circ}$C) relationship (Tchobanoglous et al., 2003).

(B) Saturation ratio of DO is calculated as dividing the measured DO concentration by the saturation concentration that is read from the solubility table (Eq. 5.1).

$$\text{DO saturation ratio} = 100 \times \frac{DO_{measured}\ (mg/L)}{DO_{saturation}\ (mg/L)} \quad (5.1)$$

5.1.3. Trophic state parameters

Trophic status of water bodies are related to the taxonomy of organisms present, their productivity and chemical quality of water (Novotny, 2001). Although there is still a lack of a precise definition of "trophic status" (Novotny, 2001), inland waters have been roughly classified into three classes as follows (Table 5.2.):

- Oligotrophic lakes, which have clear water with minimum biological activity;
- Mesothrophic lakes, with moderate nutrients and biological productivity
- Eutrotrophic lakes, with extremely rich in nutrients with high biological productivity.

Table 5.2. Classification of lakes according to their trophic status (EPA, 1974)

Parameter		Oligotrophic	Mesotrophic	Euthrophic
TP (mg/L)	mean range (n)	0.008 0.003-0.018	0.027 0.011-0.096	0.084 0.016-0.390
TN (mg/L)	mean range (n)	0.660 0.310-1.600	0.750 0.360-1.400	1.900 0.390-6.100
Chl.-a (mg/m^3)	mean range (n)	1.7 0.3-4.5	4.7 3-11	14 2.7-78
Peak Chl.-a (mg/m^3)	mean range (n)	4.2 1.3-11	16 5-50	43 10-280

The natural process of a water body proceeding from oligotrophy to euthrophy as a result of bio-geochemical processes is called "euthrophication" (Figure 5.2). However this natural process is altered by anthropogenic factors which are together named as "cultural euthrophication" (EPA, 2000) reducing the process time from thousands of years to decades. "Cultural euthrophication" occurs either as a result of direct release of nutrient-rich materials to aquatic environments by agricultural, industrial or urban activities or indirectly by disturbing the top vegetation and exposing soil to erosion (EPA, 2000).

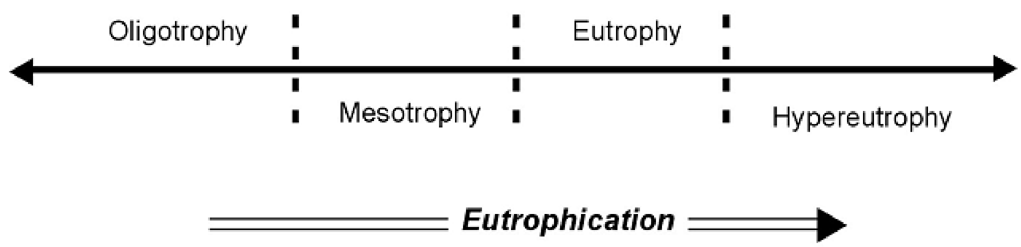

Figure 5.2. Trophic continuum (EPA, 2000)

The common adverse effects of euthrophication in water bodies are:

- Reduction of light penetration due to phytoplankton layer on the upper level.
- Cyclic fluctuations in DO levels, as supersaturation of oxygen in water during day time in productive season and significant drops at nights (Novotny, 2001).
- Proliferation of toxin producing phytoplankton species in aquatic environment such as cyanobacteria.

The trophic state score ($C_{Trophic\ State}$) in the WQI was calculated in three steps:

(A) The normalized score of three parameters, orthophosphate ($C_{o\text{-}PO4}$), nitrate (C_{NO3}) and chlorophyll-a ($C_{chlorophyll\text{-}a}$) is calculated.

(B) "Limiting nutrient" for primary biological activity is determined based on the total nitrogen over total phosphorus (TN:TP) ratio. According to the limiting nutrient, either nitrate (NO_3) or orthophosphate (o-PO_4) is selected as the nutrient score:

$$C_{Nutrient} = \left\{ \begin{array}{l} \text{If TN:TP} < 10\ , C_{NO_3} \\ \text{If TN:TP} \geq 10\ , C_{o\text{-}PO_4} \end{array} \right\} \quad (5.2)$$

where ;

$C_{Nutrient}$ is the nutrient score
C_{NO_3} is the normalized nitrate score
$C_{o\text{-}PO_4}$ is the normalized orthophosphate score
TN:TP is the ratio of total nitrogen over total phosphorus as concentration (mg/L)

(C) Subsequent to determination of $C_{nutrient}$, it has been compared to the score of chlorophyll-a and their minimum is selected as the trophic state score (Eq. 5.3).

$$C_{trophic\ state} = \text{Minimum}\left(C_{nutrient}, C_{chlorophyll\text{-}a}\right) \quad (5.3)$$

where;

$C_{trophic\ state}$ is the final score for trophic state
$C_{nutrient}$ is the nutrient score
$C_{chlorophyll\text{-}a}$ is the normalized chlorophyll-a score

In particular cases when one of the scores -either the $C_{nutrient}$ or $C_{chlorophyll\text{-}a}$ - is not available, the other one is directly selected as $C_{trophic\ state}$.

5.1.3.1. Total Nitrogen to Total Phosphorus (TN:TP) Ratio. In aquatic environment, nitrogen (N) and phosphorus (P) are accepted as the primary stimulants of biological production. The general composition of algae cell is $C_{106}H_{263}O_{110}N_{16}P_1$ (Gürel et al., 2005), thus the optimum molecular ratio of N to P for algae growth is 16 which is also called as "Redfield ratio" (Gürel et al., 2005). In terms of total nitrogen over total phosphorus (TN:TP), the ratio is accepted as 10 such that nitrogen is the limiting nutrient in the environment when TN:TP is less than 10 and phosphorus is the limiting nutrient in vice versa conditions (EPA, 2000).

The abundance of primary nutrients, nitrogen and phosphorus, in water bodies is determined by various factors. In general, freshwater ecosystems tend to be P limiting whereas temperate estuaries and coastal waters are found to be N limiting (Carpenter et al., 1998). This is primarily due to more efficient recycling of phosphorus and high rate of denitrification in coastal waters (Gürel et al., 2005). Additionally it has been reported that low TN:TP ratios are found in systems that receive significant amounts of sewage effluent (EPA, 2000).

For coastal lagoons like Küçükçekmece, determination of limiting nutrient is relatively more important as they act like a transitional phase between freshwaters and coastal waters. Hence, TN over TP ratio is accepted as very important and calculated in every water sample prior to determination of trophic status scores.

For finding TN over TP ratios, TNs were calculated by the summation of three nutrient species (Eq. 5.4) while TPs were directly taken as measured o-PO_4 mg/L values. NO_2-N is neglected for calculation of TN.

$$\text{TN (mg/L)} = \text{TKN-N (mg/L)} + NO_2\text{-N (mg/L)} + NO_3\text{-N (mg/L)} \qquad (5.4.)$$

5.1.3.2 Nitrate as a Nitrogen Indicator. Nitrate is an important compound in water bodies and included in most basic water quality surveys and multi-purpose monitoring programs (Chapman, 1992). The role of nitrate in aquatic ecosystems should be evaluated within the nitrogen cycle, as its concentration is dependent on various processes simultaneously taking place (Figure 5.3.).

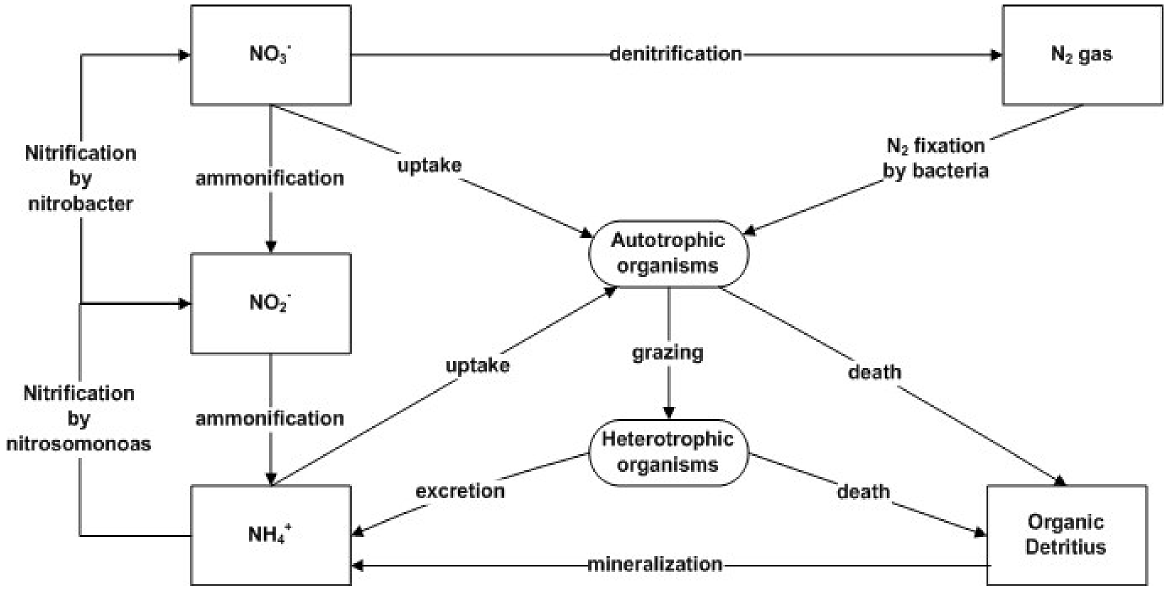

Figure 5.3. Nitrogen cycle in aquatic systems (adapted from Gürel et al., 2005).

In aquatic environment, nitrogen is available both in organic and inorganic form. Inorganic forms of nitrogen exist at different oxidation stages such as ammonium ion (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-) based on conditions mostly related to pH and dissolved oxygen concentration (Table 5.3).

Table 5.3. Oxidation States of Nitrogen

Nitrogen Form	Oxidation State of N
Ammonium, NH_4^+	-3
Unionized ammonia, NH_3	-3
Nitrogen gas, N_2	0
Nitrite, NO_2^-	+3
Nitrate, NO_3^-	+5

The organic forms of nitrogen on the other hand are present in particulate form (PON) as phytoplankton and as detritus or in dissolved form (DON) as amino acids, urea, etc. The transformation of organic nitrogen back to inorganic phase occurs by mineralization processes (Gürel et al., 2005).

The main sources of nitrogen in aquatic environment are atmospheric fixation (Eq. 5.5), agricultural and urban run-offs, industrial discharges and from groundwater sources; while the main sinks are sediment accumulation and by denitrification (Eq. 5.6.).

$$N_2 + \text{nitrogen fixing bacteria} \rightarrow \text{protein} \quad (5.5)$$

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2 \quad (5.6)$$

In the nitrification process, ammonium is oxidized to nitrite by *Nitrosomonas* (Eq. 5.7) and to nitrate by *Nitrobacter* (Eq. 5.8). Nitrification takes place both in water column and sediment and depends on factors such as pH, temperature, salinity.

$$NH_4^+ + 3/2\ O_2 + \text{Nitrosomonas} \rightleftharpoons 2H^+ + NO_2^- + H_2O \quad (5.7)$$

$$NO_2^- + \tfrac{1}{2}\ O_2 + \text{Nitrobacter} \rightleftharpoons NO_3^- \quad (5.8)$$

Another pathway in the nitrogen cycle is ammonification, which reduces NO_3^- to NH_4^+, and takes place occasionally under anaerobic conditions (Gürel et al., 2005).

Among nitrogen species, nitrate is the most oxidized form in water and it is highly soluble. Its natural sources are igneous rocks, land drainage and plant and animal debris (Chapman, 1992).

Nitrate concentration in surface waters not subjected to contamination is below 5 mg/L and commonly less than 1 mg/L. For humans, concentrations over 45 mg/L cause methemoglobinemia in infants and over 100 mg/L may cause physiological distress in adults (Fierro and Nyer, 2006).

5.1.3.3 Orthophosphate as phosphorus indicator (o-PO_4, mg/L): Phosphorus, has been used frequently with secchi disk depth and chlorophyll-a to assess trophic state of ponds and lakes (EPA, 2000). In aquatic environment, it can be found either in particulate or dissolved phase's trough the phosphorus cycle (Figure 5.4.).

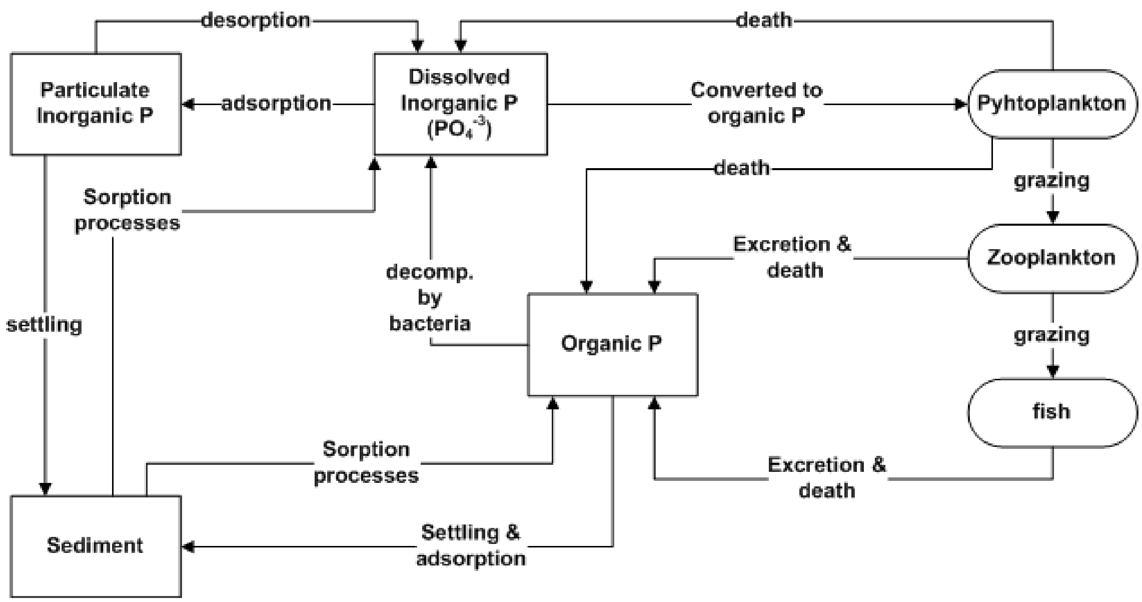

Figure 5.4. Phosphorus cycle in aquatic systems (Adapted from Gürel et al., 2005).

Particulate forms of phosphorus are plankton, precipitates of phosphorus and phosphorus adsorbed to particulates (Gürel et al., 2005). Dissolved forms on the other hand can either be organic as excreted matter macromolecular colloidal phosphorus (NC State University, 2007) or inorganic such as orthophosphates and polyphosphates.

Equilibrium concentrations of different phosphate forms such as PO_4^{-3}, $HP0_4^{-2}$ and $H_2PO_4^-$ are dependent on pH of the environment (Chapman, 1992).

The most readily form of phosphorus species for biological activities are orthophosphate (Tchobanoglous et al., 2003). Polyphosphates compounds are first broken down into orthophosphates before being further break down processes (Eq. 5.9).

$$Na_4P_2O_7 + H_2O \rightleftharpoons 2Na_2HPO_4 \quad (5.9)$$

The natural sources of phosphorus include composition of organic matter and weathering of rocks (Chapman, 1992), while detergent containing wastewaters, industrial effluents and fertilizers are anthropogenic sources.

The critical condition for inorganic phosphorus has been established as somewhere near 0.005 mg/L under summer growing conditions (Sawyer et al., 2003).

5.1.3.4 Chlorophyll-a (mg/L): The green pigment chlorophyll is vital for photosynthesis which allows obtaining energy from light and it is present in most plants, algae and cyanobacteria. For the purpose of water quality assessment, chlorophyll provides an indirect measure of algal biomass available in water (Chapman, 1992). Among the three chlorophyll forms a, b and c; chlorophyll-a has the widest appliance for determination (Chapman, 1992).

In general, water bodies with low level of nutrients (i.e. oligotrophic lakes) have low levels of chlorophyll concentration (Chapman, 1992). However, presence of excessive N and P does not necessarily mean an increase in algal mass, while other factors such as temperature, salinity, pH and light penetration are also effective on the growth of algae.

The purpose of using chlorophyll-a parameter additional to nutrients is to reflect the effect of "euthrophication" in a more precise way in the index. When algal blooms occur under adequate conditions, low $C_{chlorophyll\text{-}a}$ is expected and used as $C_{trophic\ state}$. However, at times when algal blooms does not occur despite nutrient availability, the potential "blooming" risk will be reflected by utilizing $C_{nutrient}$ instead of $C_{chlorophyll\text{-}a}$.

Figure 5.5. Algal bloom in Küçükçekmece Lagoon at November 2004

5.1.4. Chemical Oxygen Demand (COD, mg/L):

COD is the measure of the oxygen equivalent of the organic matter in a water sample that is susceptible to oxidation by a strong chemical oxidant such as dichromate (Chapman, 1996). Besides COD, total organic carbon (TOC) and biochemical oxygen demand (BOD_5) are alternative parameters used for determination of organic matter content in waters. As, BOD_5 only shows the biodegradable portion of the organic content, it is not sufficient to represent the water body profile especially where there is high industrial effluent discharges. COD's disadvantage on the other hand is the oxidation of additional inorganic compounds such as the ferrous ion (Chapman, 1992).

Along with dissolved oxygen and trophic state indicators, a priority is given to COD in the water quality index. The purpose of this decision it to express the correlation between industrial development and water quality decline in the region. It is supposed that a high COD concentration (i.e. more than 200 mg/L) is an evidence of industrial effluents in natural waters while COD concentrations range between 0-20 mg/L in unpolluted waters (Chapman, 1992).

5.1.5. Electrical Conductivity (EC, mS/cm)

Electrical conductivity (EC) is a measure of water's ability to conduct an electrical current. The flow of current in water is accomplished by the movement of ions when the liquid is under the influence of an electrical field (US Salinity Lab., 2007). The ions that contribute to electrical conductivity are chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, and iron (BASIN, 2007). Conductivity is expressed in microsiemens per centimeter (mS/cm) in SI units and expressed as specific conductivity at a reference temperature which is generally taken as 25°C.

In water quality assessment programs, conductivity is especially important on deciding water source's specific use. For instance, a high level of conductivity is not desired for agricultural purposes while it affects soil structure and crop yield status (Tchobanoglous et al., 2003). Nevertheless, the singular usage of conductivity parameter is limited as it only gives an aggregate profile of water (Texas University, 2007).

The sources of conductivity in waters might be as a result of anthropogenic activity or natural processes. The natural factors that effect conductivity are: (Lakeacess, 2007)

- The geological structure of the watershed
- The ratio between watershed size and lake surface area (A_W:A_L)
- Evaporation rate of water

Generally, no regulatory limits are present internationally or at national level for electrical conductivity. EC values of open seas are approximately 50 mS/cm, while the permitted level for agricultural water use is below 0.75-2.00 mS/cm (Texas University, 2007).

5.1.6. pH

PH represents the effective concentration of hydrogen ions in water on a negative logarithmic scale between 0 and 14. Pure water at 22°C has an equal concentration of H_3O^+ and OH^- ions at 1.0 x 10^{-7} moles which corresponds to a pH level of 7 (BASIN, 2007). In waters pH values between 0 between 7 is accepted as acidic and between 7 and 14 as alkaline.

The importance of pH comes from its influence on bio-chemical and physico-chemical processes occurring in water. Enzymes taking place in biological activities needs a certain pH range -generally between 6.5 and 8.5 to function properly. In freshwaters, the pH level is dependent on the following factors:

- Geology and soil structure (BASIN, 2007).
- Solubility of carbon dioxide in water.
- Respiration of aquatic organisms.
- Photosynthetic activities of plants, algae and cyanobacteria.
- Acid rains in forms of nitric acid and sulfuric acid.
- Presence of strong and weak acids in water (Chapman, 1992).

Unpolluted water bodies generally have a pH value between 6 and 8.5 and values outside of this range indicate presence of certain effluents, particularly when continuously measured with conductivity (Chapman, 1992). Some significant pH ranges regarding aquatic ecosystems and human health and use are given on table 5.4:

Table 5.4. pH ranges and their effects in aquatic ecosystem

pH range	**Impact on water**
pH < 6.0	Mayflies and stoneflies die off.
pH < 5.5	Dysfunction of reproduction system in fishes
pH < 5.0	Fish population die off
pH< 4.0	Critical level for all aquatic life forms

5.1.7. Turbidity (NTU)

Turbidity concept is related to interference of light through the water (Chapman, 1992) and measured in terms of nephelometric turbidity units (NTU). In natural waters, the causes of turbidity may range from purely inorganic substances such as clay and silt to those that are largely organic in nature like planktons (Sawyer et al., 2003). Anthropogenic sources of turbidity are mainly as a result of erosion from logging, mining and dredging operations (EPA, 2000).

Although turbidity is as weak water quality indicator alone, turbidity-induced changes might change the composition of an aquatic community. The most significant effect of turbidity is on light penetration which causes the photosynthetic activity on benthic levels to be restricted. Additionally, large amounts of turbidity causing matter may clog the gills of fish and shellfish and kill them directly (Water University, 2007).

For anthropogenic water uses, the importance of turbidity is mostly related to aesthetical aspects and issues related to wastewater treatment (Sawyer et al., 2003). Additionally, particles causing turbidity might provide attachment sites for heavy metals and toxic organic compounds such as PCBs, PAHs and pesticides (Water on the Web, 2007).

5.2. Normalization of Parameters

5.2.1. Basis of Normalization

To normalize indicator on an equal basis, an index scale has been defined such that, the healthiest case in terms of water quality gets 100 points while the poorest gets zero out of 100. The scoring scale is described on Table 5.5.:

Table 5.5. The scale of Küçükçekmece Water Quality Index

C_i value	Condition	Explanation
100-85	Excellent	Ecosystem is healthy. No major evidence of anthropogenic pollution
85-70	Fair	Water quality is good; however there are traces of contamination.
70-50	Mediocre	Aquatic life is under stress. Remediation is necessary.
50-30	Critical	Water quality is seriously degraded. The threshold levels that threat aquatic life is reached.
30-0	Very poor	Biodiversity is mostly lost. Water is extremely polluted.

Subsequently, concentration values of each parameter have been assigned to specified Ci values on the table 5.5 considering the following sources:

- International standards: UN Economic Commission for Europe (UNECE, 1994)
- National regulations: (Turkish Water Quality Control Legislation (Resmi Gazete, 2004), EPA, National Recommended Water Quality Criteria, (EPA, 2002); EPA Nutrient Water Quality Criteria (EPA, 2005); Australian and New Zealand Guidelines (ANZECC, 2000); Mauritus Island Legislation (Gönenç, 2006)
- Water quality indices: Prati (1971), Pesce (2000), Debels (2005), Sanchez, (2006).

Related information on international and national criteria is given in appendix D.

The assigned water quality values for each parameter in their native units and the corresponding C_i values are as follows (Table 5.6):

Table 5.6. Measured parameter values and their corresponding index (C_i) values

Normalized (C_i) values	**100 (excellent)**	**75 (Fair)**	**50 (Mediocre)**	**25 (Critical)**	**0 (Very Poor)**
DO Sat. (%)	For DO> 95 and DO≤100	For DO>73 and ≤130	For DO>60 and DO≤145	For DO>40 and DO≤ 164	For DO>0 and DO<200
NO_3-N (mg/L)	≤0.5	4.8	12	28	>100
o-PO_4 (mg/L)	≤0.025	0.15	0.5	1.25	>5
Chl.-a (mg/m^3)	0	2.8	8	20	>90
COD (mg/L)	0	10	25	50	80
pH	For pH>7.5 and pH≤8	For pH>6.5- and pH≤9.0	For pH>6.0- and pH≤9.5	For pH>5.7 and pH≤10	For pH < 5.7 and ph > 10.0
Turb. (NTU)	5 ≤	12.5	30	58	120
EC(mS/cm)	0.6≤	1.1	2	5.2	15

5.2.2. Normalization Curves

Normalization curves were formed based on measured parameter values and their corresponding C_i values (Table 5.6). For the preciseness of functions, intermediate values have been entered at every ten points on the index scale. Subsequently, best fitting functions for each curve have been defined using TableCurve-WIN© software.

The normalization curves for parameters are given in Figure 5.6 to Figure 5.14. The X-axis on the graph shows the expected values of parameters in their native units and the Y-axis shows the dimensionless normalized values (C_i). The formulas for each normalization functions and r squared (r^2) values are given on Appendix E.

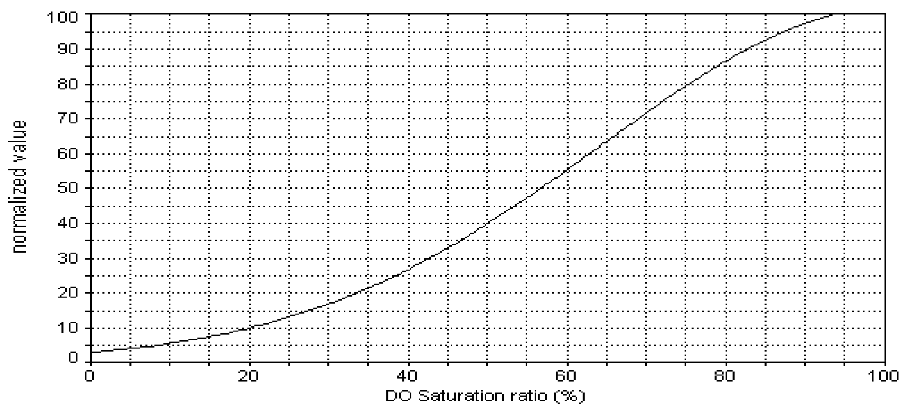

Figure 5.6. DO Normalization Curve (under-saturated)

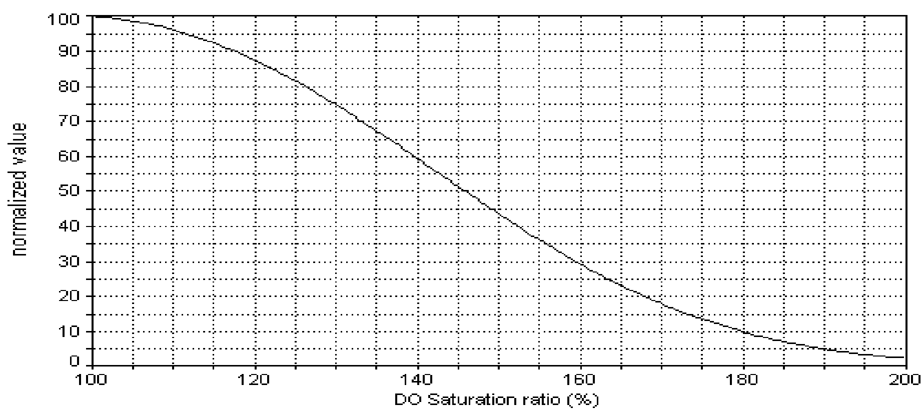

Figure 5.7. DO Normalization Curve (super-saturated)

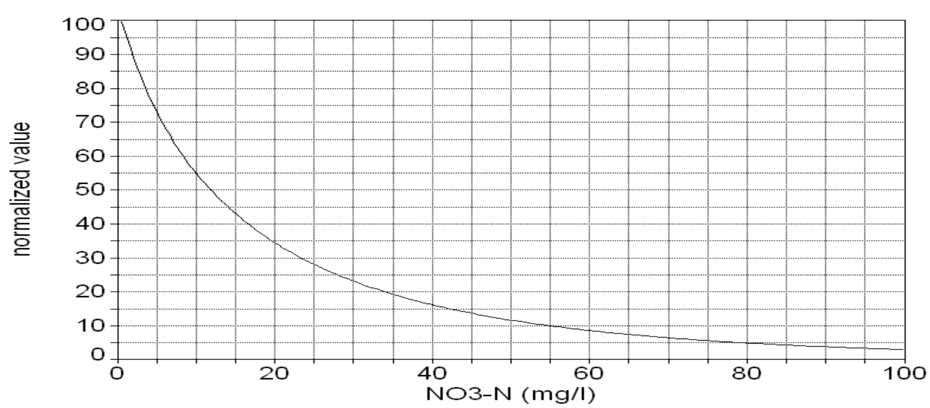

Figure 5.8. Nitrate Normalization Curve

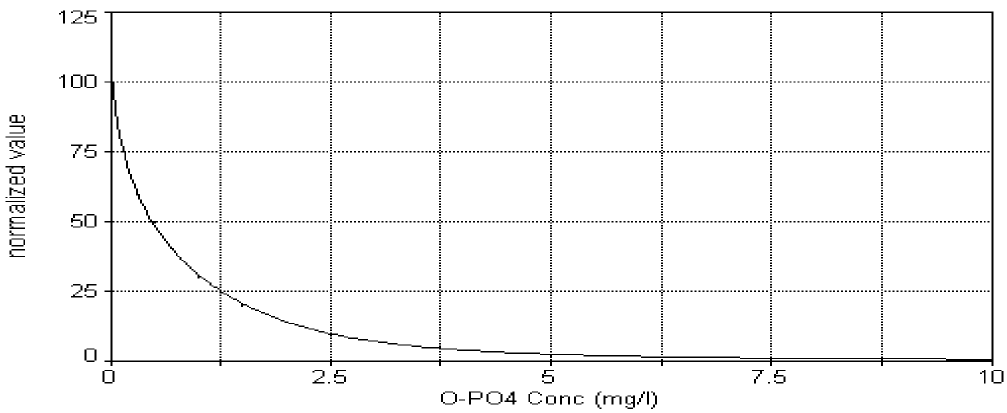

Figure 5.9. Orthophosphate Normalization Curve

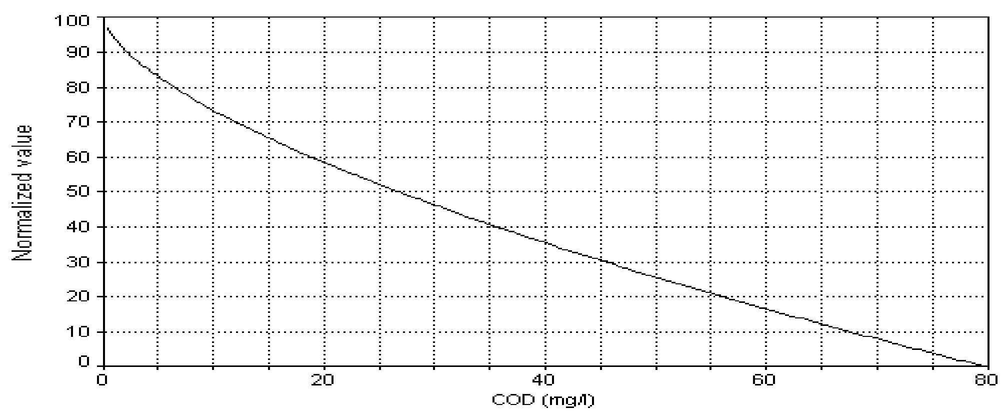

Figure 5.10. COD Normalization Curve

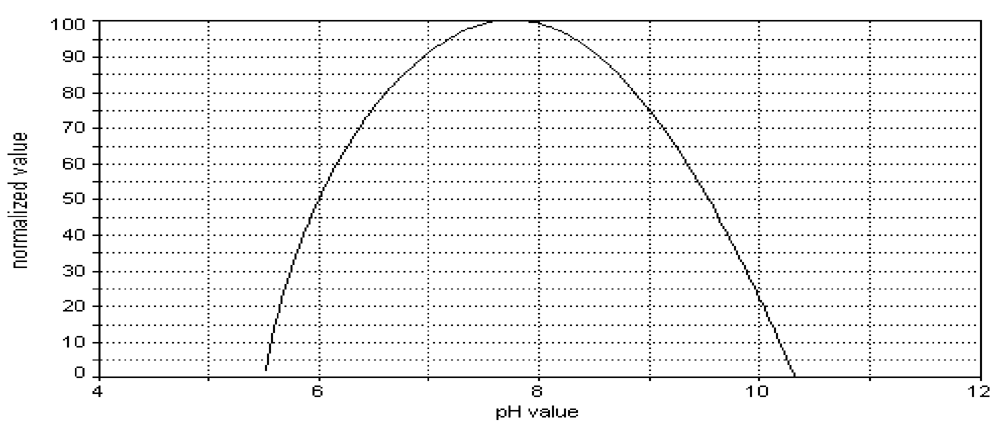

Figure 5.11. pH Normalization Curve

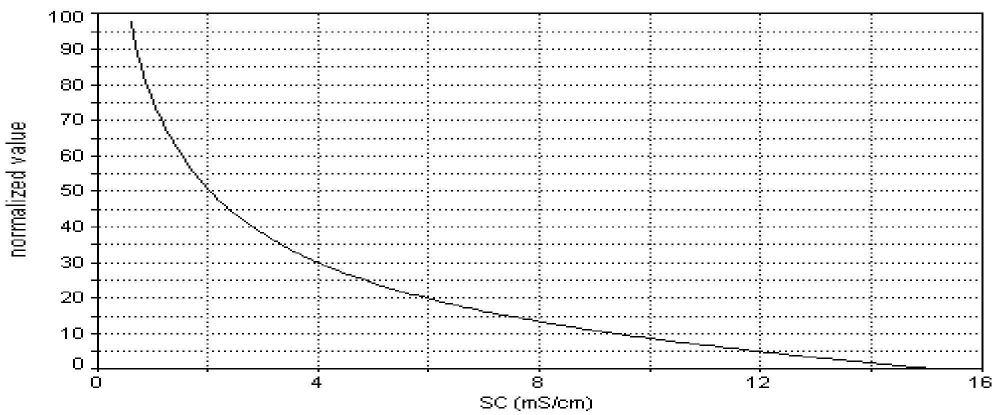

Figure 5.12. Electrical Conductivity Normalization Curve

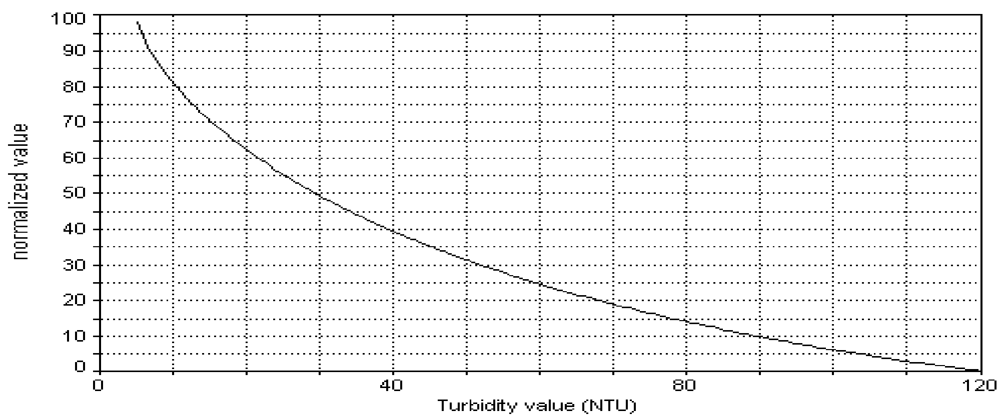

Figure 5.13. Turbidity Normalization Curve

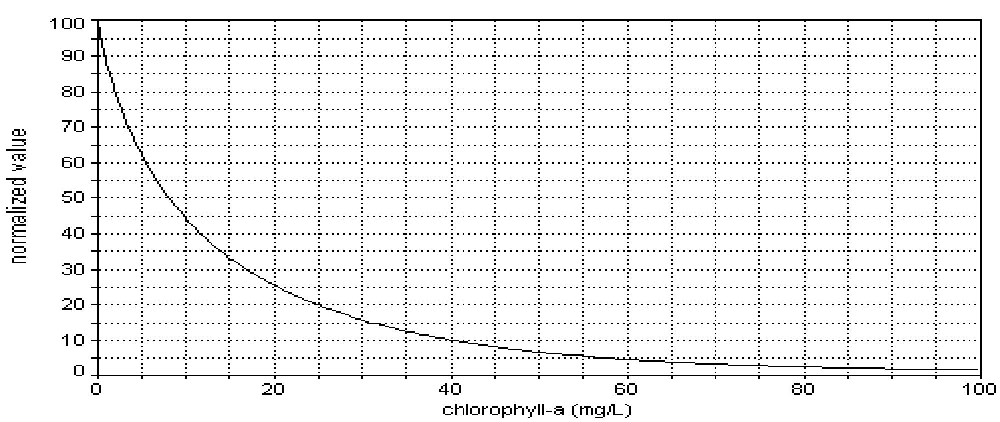

Figure 5.14. Chlorophyll-a normalization curve

5.3. Weight factors

Weight factors (P_i) assigned to the parameters shows their relative significance within the index. The weight factors have been distributed such that their summation is equal to one (Eq. 5.10).

$$\sum_{i=1}^{n} Pi=1 \tag{5.10}$$

According to their significance on the aquatic ecosystem, the parameters have been ordered as DO, Trophic State, COD, pH, EC and turbidity (Table 5.7).

Table 5.7. Individual weights (P_i) of water quality parameters

Parameter	DO	Trophic S.	COD	pH	EC	turbidity
Weight (Pi)	0.25	0.24	0.23	0.10	0.09	0.09

5.4. Aggregation Formulas

The aggregation formulas previously given on Chapter 3 have been evaluated in terms of appropriateness for the data of Küçükçekmece. Tested methods are multiplicative methods, harmonic square mean, root sum power function and weighted sum (Table 3.1.).

Among these methods, the multiplicative aggregation was not found appropriate for Küçükçekmece’s data set, since the parameters with very low scores have an absolute influence on the index. As in the extreme case, when C_i gets a zero value, the index score becomes zero as well. The second alternative, harmonic square mean formula has also caused a similar problem while the C_i value is in the denominator part (Table 3.1.).

The original root sum power function given on Table 3.1 does not include any weight factors. This formula has been modified to include individual weight factors (P_i) in two different ways; as in Eq. 5.11 and Eq. 5.12, respectively. Index scores have been found relatively high in the first and very low in the second case, which did not fit to the evaluation scale described on Table 5.5. and Table 5.6., respectively.

$$WQI_{R1}=\sqrt{\sum_{i=1}^{n} C_i^2 P_i} \tag{5.11}$$

$$WQI_{R2}=\sqrt{\sum_{i=1}^{n} (C_i P_i)^2} \tag{5.12}$$

The weighted sum formula (Eq. 5.13) has been found as the most suitable aggregation method for the data set of Küçükçekmece despite the previously given potential problems (see Chapter 3).

$$WQI_A=\sum_{i=1}^{n} P_i C_i \tag{5.13}$$

5.5. Methods for Missing Data

KEMG's and DSI's monitoring programs cover approximately two and more than five years, respectively. Through these periods, some parameters could not be measured periodically due to various reasons such as meteorological conditions, experimental failures, technical problems etc...

In order to utilize the available data set in the best way and to fill the gaps, correlations between parameters have been analyzed. According to these analyses, the values have been transformed for the missing cases, when a reasonable relationship between the parameters has been found.

The transformation methods applied here do not propose "absolute" solutions and theoretically the quality of the data is reduced while one parameter is transformed into another. However in practice, it is an approach that is developed for mandatory cases, where increasing the quantity of the data is absolutely necessary.

5.6.1. Total Kjeldahl Nitrogen (TKN) and Nitrate (NO_3) Relationship

For sampling stations D1 and D3 on Sazlıdere Creek, a linear relationship was found with r^2 values 0.795, and 0.95, respectively. At station D2, TKN was inversely proportional to NO_3 thus, the relationship have not been reflected to the data although the r^2 value is 0.99 (Figure 5.15).

In Eşkinoz Creek stations E2 and E3 showed a weak linear relationship with r^2 values of 0.62 and 0.46, respectively (Figure 5.16). The relationship on the Lagoon was stronger, with r^2 values 0.79 for 10, 0.92 for 11, 0.92 for 12 and 0.90 for 13 (Figure 5.17).

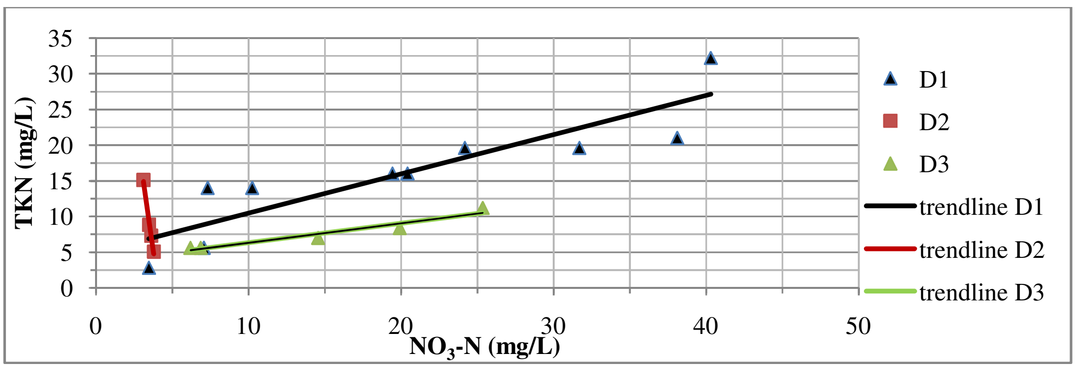

Figure 5.15. TKN and NO_3-N relationship at Stations D1, D2 and D3

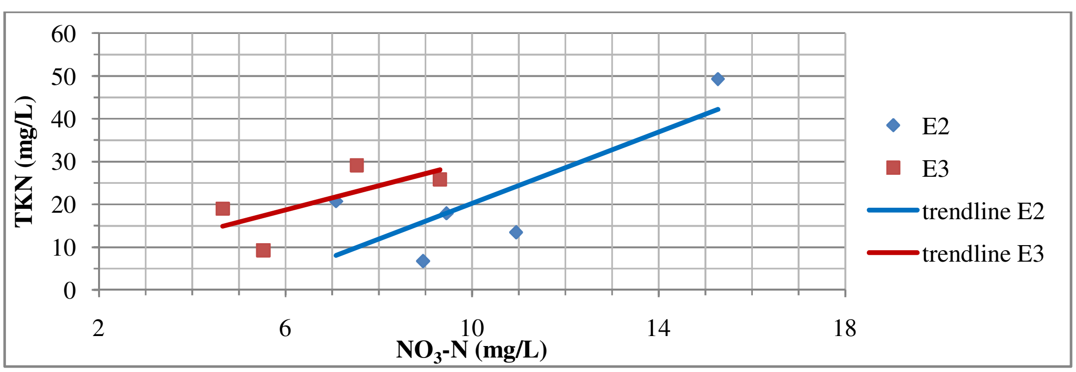

Figure 5.16. TKN and NO_3-N relationship at Stations E2 and E3

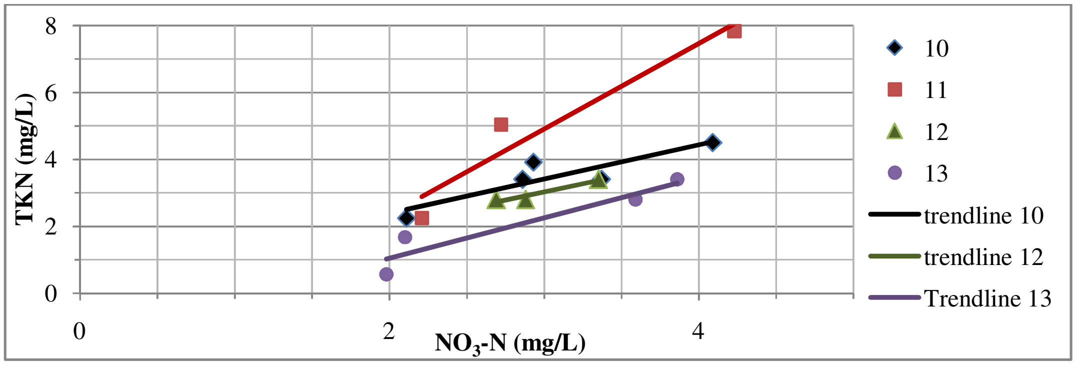

Figure 5.17. TKN and NO_3-N relationship at Stations 10, 11, 12 and 13

5.6.2 Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD_5) relationship

The most important inconsistency between DSI's and KEMG's monitoring program was the utilization of different parameters for measurement of organic matter BOD_5 and COD, respectively. To overcome this problem, BOD_5 values in DSI's data have been transformed to COD based on following assumptions.

- Station D3 has been accepted as representing DSI's sampling stations S1 to and S5 while both D3 and all DSI's stations were all located on Sazlıdere Dam (Figure 4.5).
- The contamination sources were accepted to have the same character in terms of COD over BOD_5 over the years of observation in both monitoring programs.
- Temporal changes on bio-chemical and physico-chemical profile of the Lagoon and its tributary Creeks have been neglected.
- Meteorological factors such as precipitation, wind speed and magnitude are neglected.

Based on these assumptions, a linear relationship has been found between BOD_5 and COD based on monthly measurements collected between May and July 2004 (Table 5.8 and Figure 5.18) with r^2 value of 0,99. For the Stations S1 to S5, BOD_5 values have been multiplied by 3.

Table 5.8. COD and BOD_5 relationship at station D3

Date	BOD_5	COD	COD/BOD_5
May-04	120	355	2.958
Jun-04	32	95	2.969
Jun-04	35	101	2.886
Jul-04	35	100	2.857

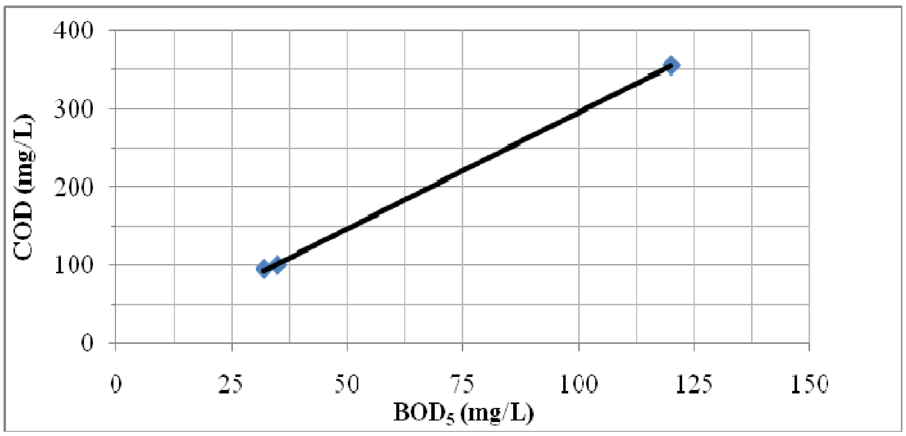

Figure 5.18. BOD_5 and COD relationship at sampling station D3

5.6.3. Total Nitrogen to Total Phosphorus (TN:TP) Ratio

In the aquatic environment, total nitrogen to total phosphorus ratio is used together with the "Redfield ratio" to determine limiting nutrient for primary biological production. In the TN:TP graphs (Figure 5.19. to 5.27.), Redfield ratio is represented with a diagonal line which TN equals to 10 times TP and it splits the graph into two as P limiting upper region and N limiting lower region.

In a vast majority of occasions –57 out of 53- nitrogen is found as the limiting nutrient in Küçükçekmece Watershed for primary production. The exceptional cases have been observed on E2 and E3 which were known as receiving high amounts of industrial effluents (Fig 5.25 and Fig 5.26). The stations D1 to D3 on Sazlıdere Creek and through 10 to 13 at the Lagoon have been found as absolutely "N limiting".

Based on these results, TN:TP ratios for stations D1 to D3, 10 to 13 and for stations S1 to S5 was assumed as “N limiting” in cases where the ratio could not be calculated because of a missing parameter value.

No modifications have been carried out for stations E2 and E3 Eşkinoz Creek since “P Limiting” months were observed throughout the data range.

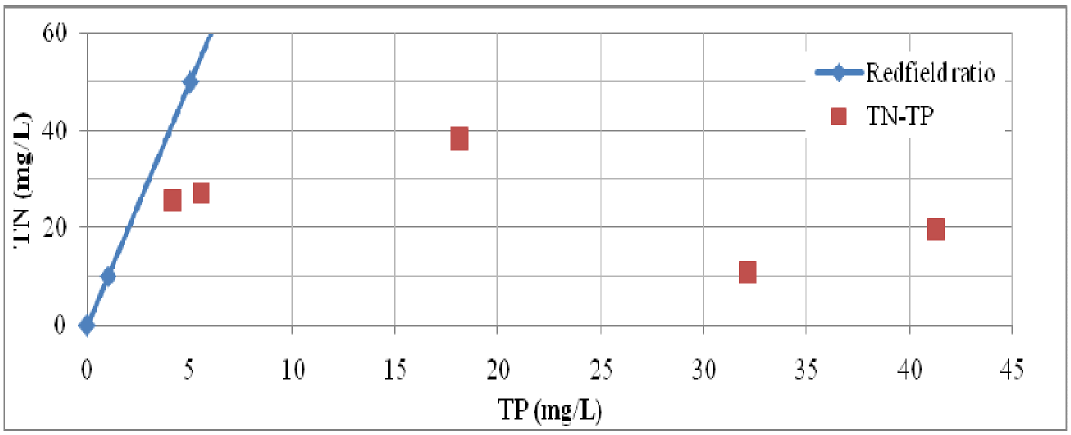

Figure 5.19. TN over TP ratios for Station D1

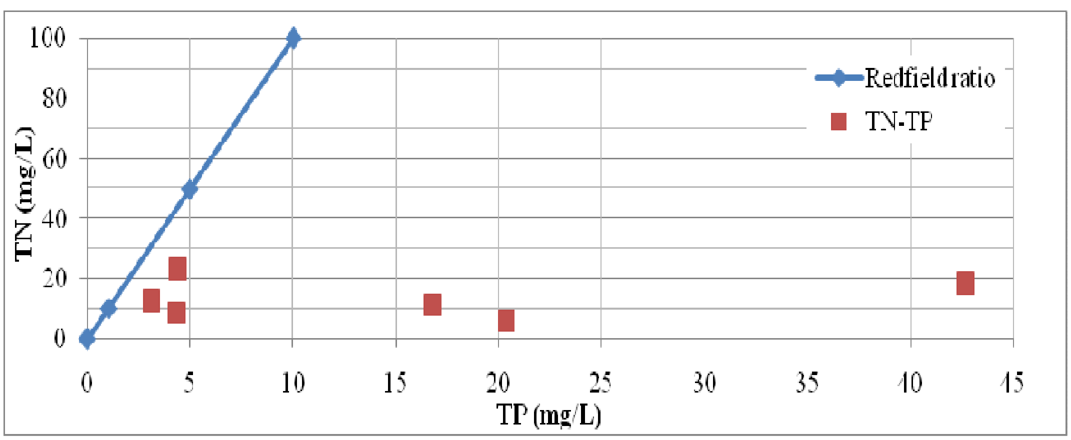

Figure 5.20. TN over TP ratios for Station D2

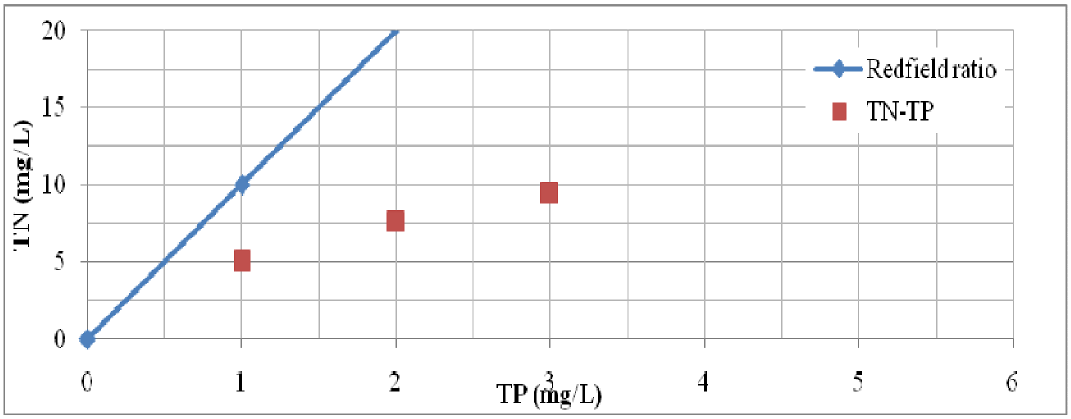

Figure 5.21. TN over TP ratios for Station D3

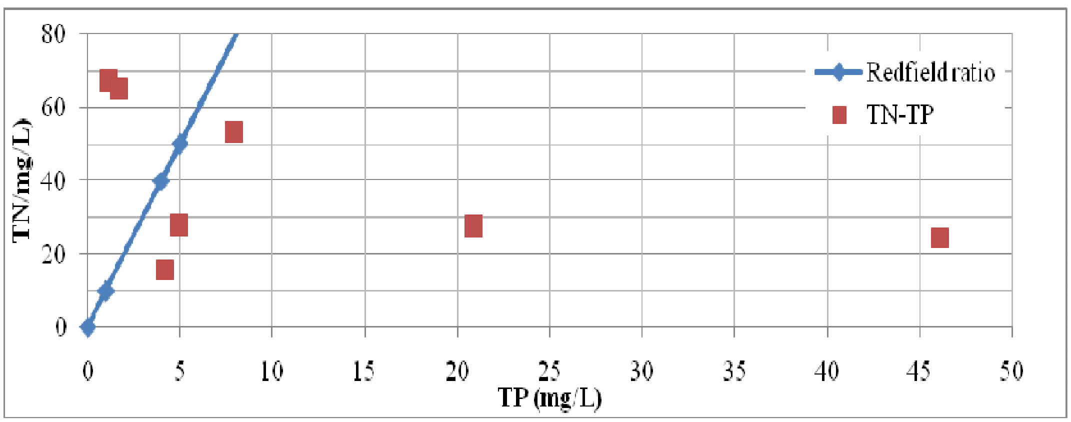

Figure 5.22. TN over TP ratios for Station E2

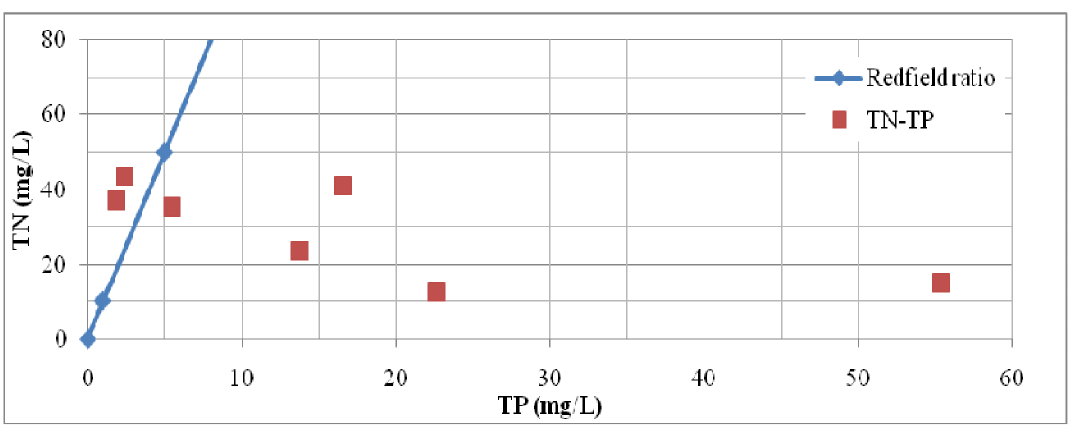

Figure 5.23. TN over TP ratios for Station E3

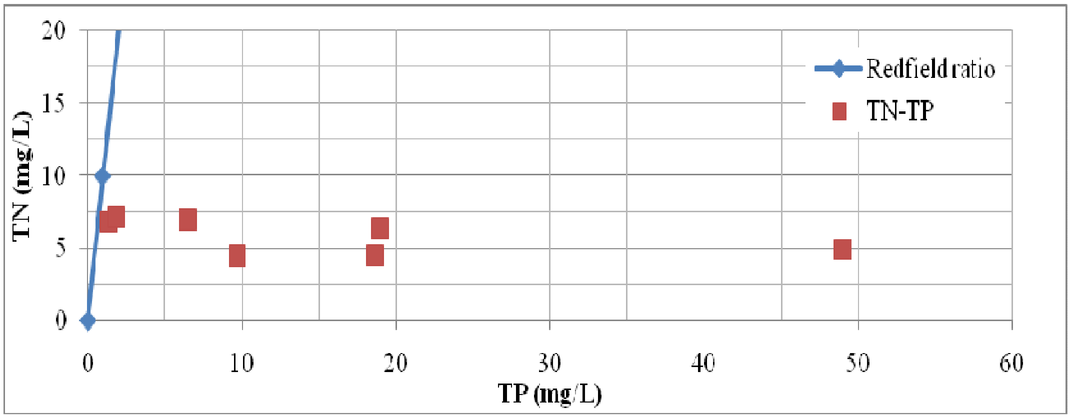

Figure 5.24. TN over TP ratios for Station 10

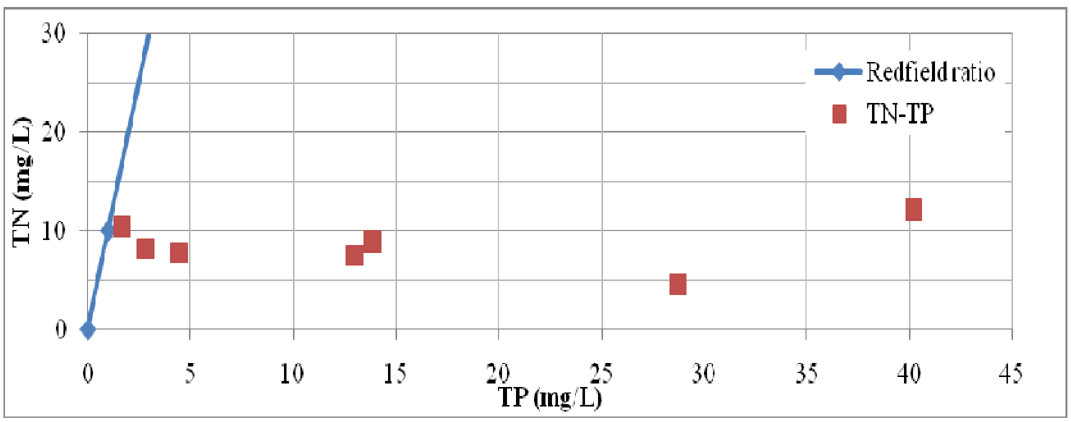

Figure 5.25. TN over TP ratios for Station 11

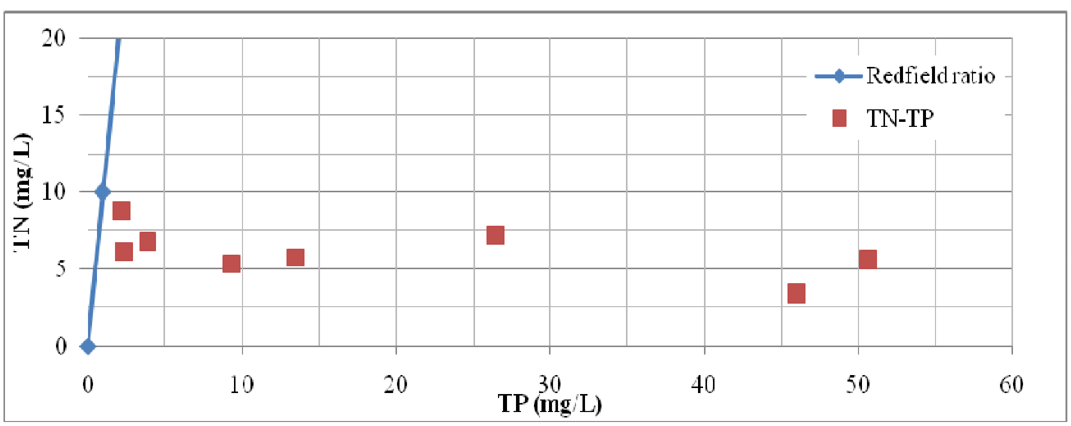

Figure 5.26. TN over TP ratios for Station 12

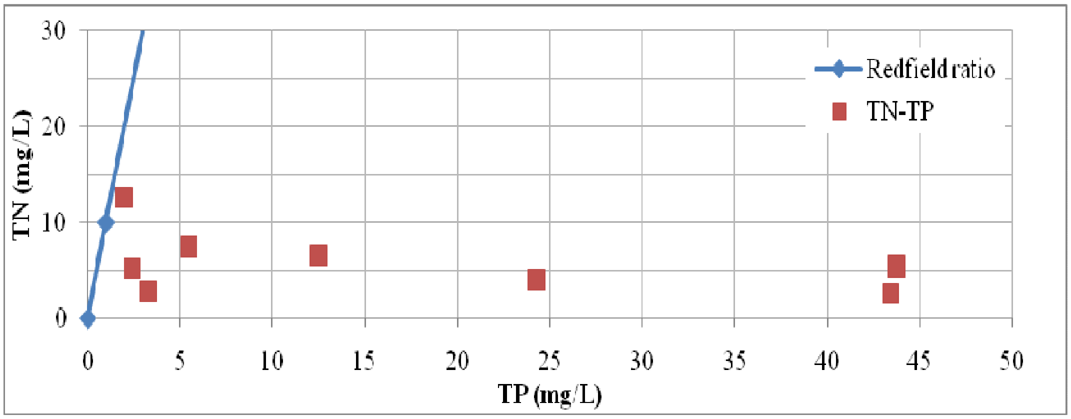

Figure 5.27. TN over TP ratios for Station 13

6. RESULTS AND DISCUSSION

6.1. Sampling Stations of Küçükçekmece Environmental Management Group (KEMG)

6.1.1. Sazlıdere Stations (D1, D2, D3)

According to the WQI, the stations at Sazlıdere Creek were ranked as D3>D2>D1 with mean values 67, 49, 37 and median values 63, 46, 40, respectively. Station D3, which is located on Sazlıdere Dam was classified as “mediocre”; while stations D1 and D2 were classified as “critical”. The notable difference between D1 and D2 can be explained by the specific features of the sampling sites. Station D2 is located at a relatively shallow place while the samples from D1 had to be taken right from the shoreline where water is mostly still. The scores of the three stations D1, D2 and D3 are summarized in Table 6.1 and Figure 6.1.

Table 6.1. Index Scores for Stations D1, D2 and D3

Station	Date	Score	remarks	Date	Score	remarks
D1	Nov-05	24	euthrophication	Jan-07	40	
	Dec-05	21	euthrophication	Feb-07	19	lowest
	Feb-06	53	peak	Mar-07	37	
	Oct-06	25	euthrophication	Apr-07	51	
	Nov-06	49		Jun-07	42	
	Dec-06	46				
D2	Feb-06	57		Mar-07	46	
	Nov-06	60	peak	Apr-07	56	
	Jan-07	41		Jun-07	43	
	Feb-07	38	lowest			
D3	Nov-05	77		Feb-07	68	
	Dec-05	36	euthrophication	Mar-07	60	
	Feb-06	56		Apr-07	88	peak
	Nov-06	63		Jun-07	81	
	Jan-07	51	low			

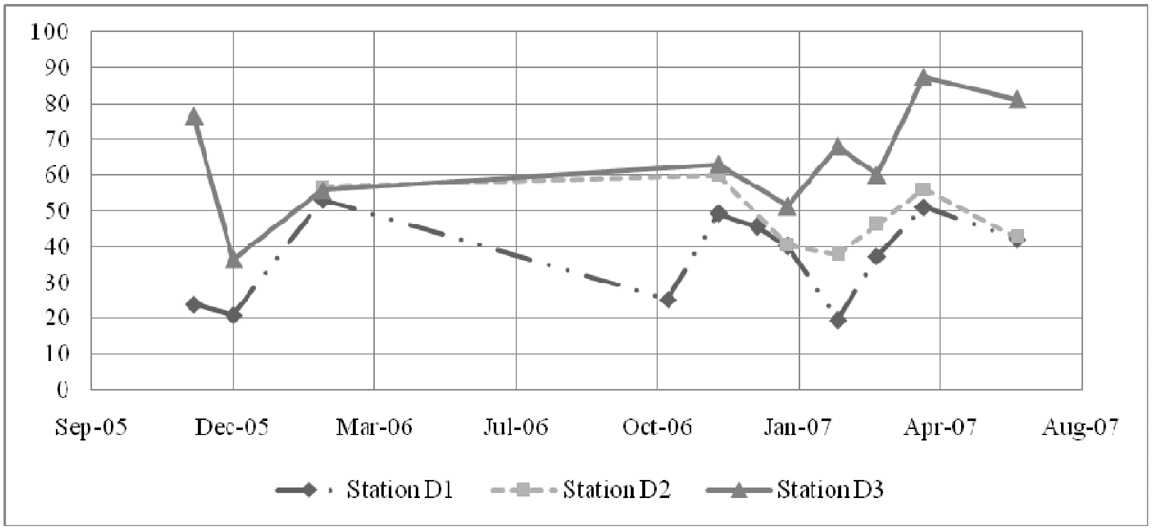

Figure 6.1. Chart Representation of Index Scores for Stations D1, D2 and D3

Among the three lowest scores for station D1 - November 2005, December 2005 and February 2007 - two of them overlapped with previously reported “algal bloom” periods. During these months, it was observed that normalized dissolved oxygen scores of D1 and D3 dropped below 25 (Figure 6.2).

In general, COD scores were very poor at all times, although D3 was slightly better. The trophic status and turbidity scores of D2 and D3 were found oscillating while D1 oscillated oppositely of the other two stations. In terms of electrical conductivity, station D3 had a constant normalized score of 100 whereas D1 and D2 decreased through the monitoring period (Figure 6.2).

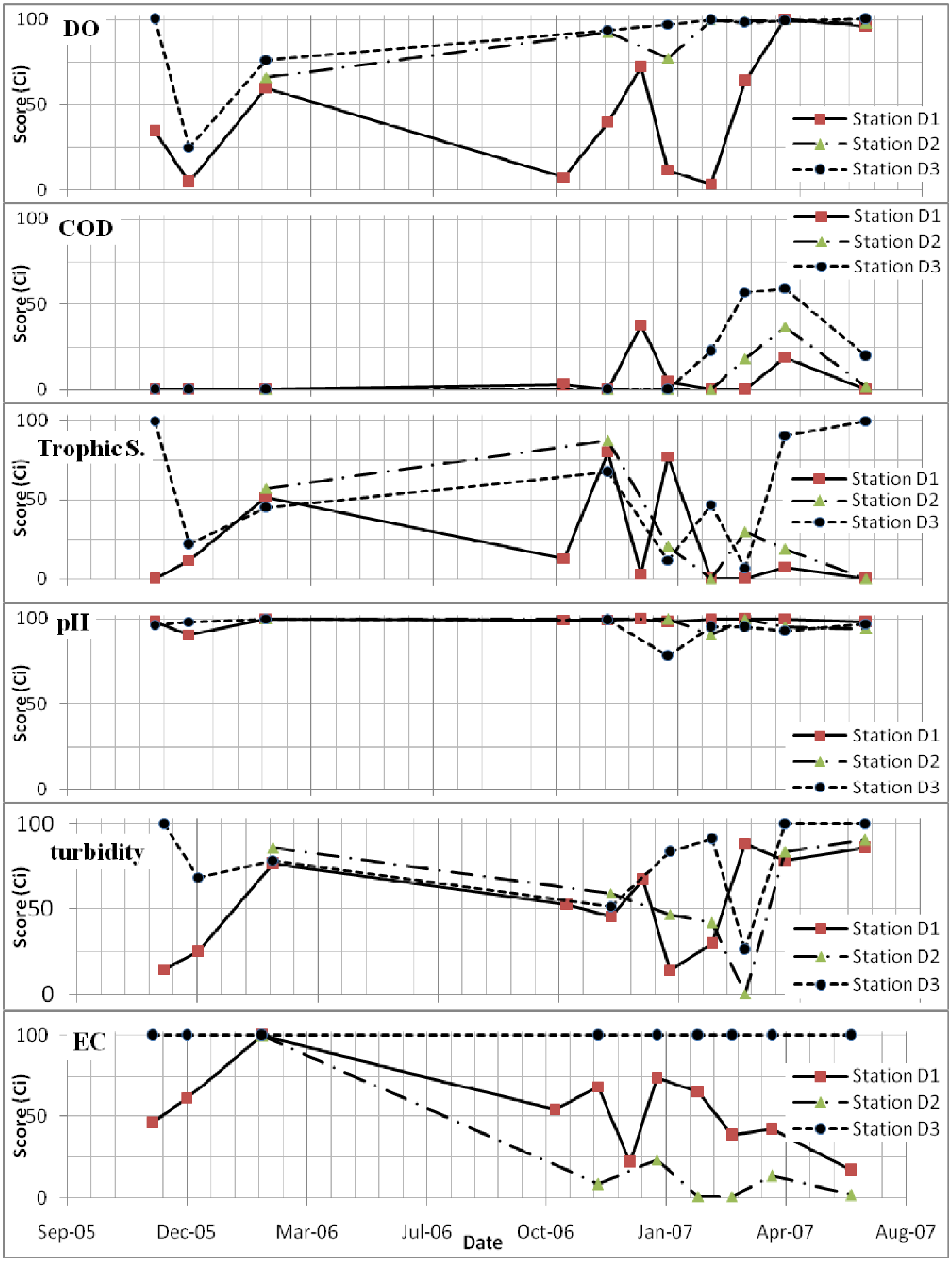

Figure 6.2. Parameter scores for stations D1, D2 and D3

6.1.2. Eşkinoz Stations (E2 and E3)

Stations E2 and E3 are located in the upstream part of Eşkinoz Creek which receives high amounts of industrial and domestic discharges from nearby settlements. The mean index scores of these two stations E2 and E3 were found as the lowest scores in the Watershed, 35 and 34, respectively (Table 6.2. and Figure 6.3.) The most dramatic result was obtained for COD with a constantly zero index score for both stations (Figure 6.4). The trophic state parameter was sensitive to seasonal changes and the lowest index scores were observed at December 2005 and spring of 2007 (Figure 6.4). Since no data was available for 2005 and 2006, it was not possible to interpret if these consequences were periodical or singular cases.

Table 6.2. Index scores for stations E2 and E3

Station	Date	Score	remarks	Date	Score	remarks
E2	Nov-05	30		Dec-06	46	
	Dec-05	27	euthrophication	Jan-07	39	
	Feb-06	54	peak	Feb-07	26	lowest
	Oct-06	29		Mar-07	27	
	Nov-06	34		Apr-07	39	
E3	Nov-05	31		Jan-07	41	
	Dec-05	22		Feb-07	31	
	Oct-06	39		Mar-07	22	lowest
	Nov-06	46	peak	Apr-07	32	

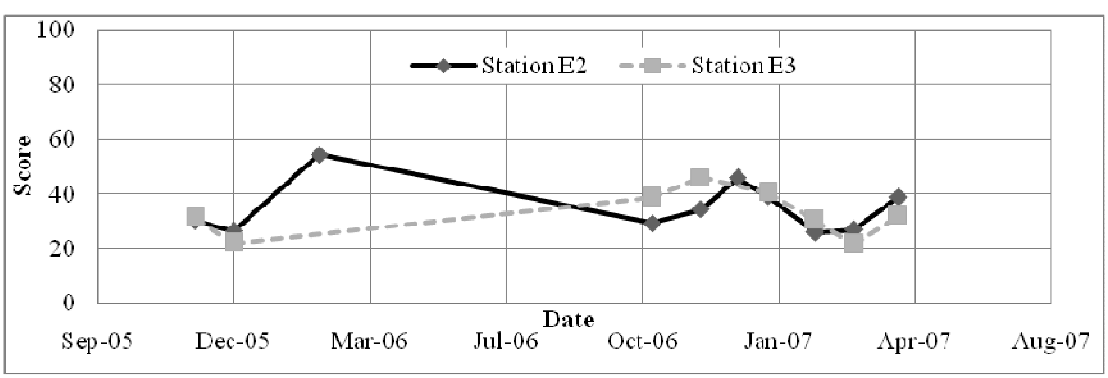

Figure 6.3. Chart representation of index scores for stations E2 and E3

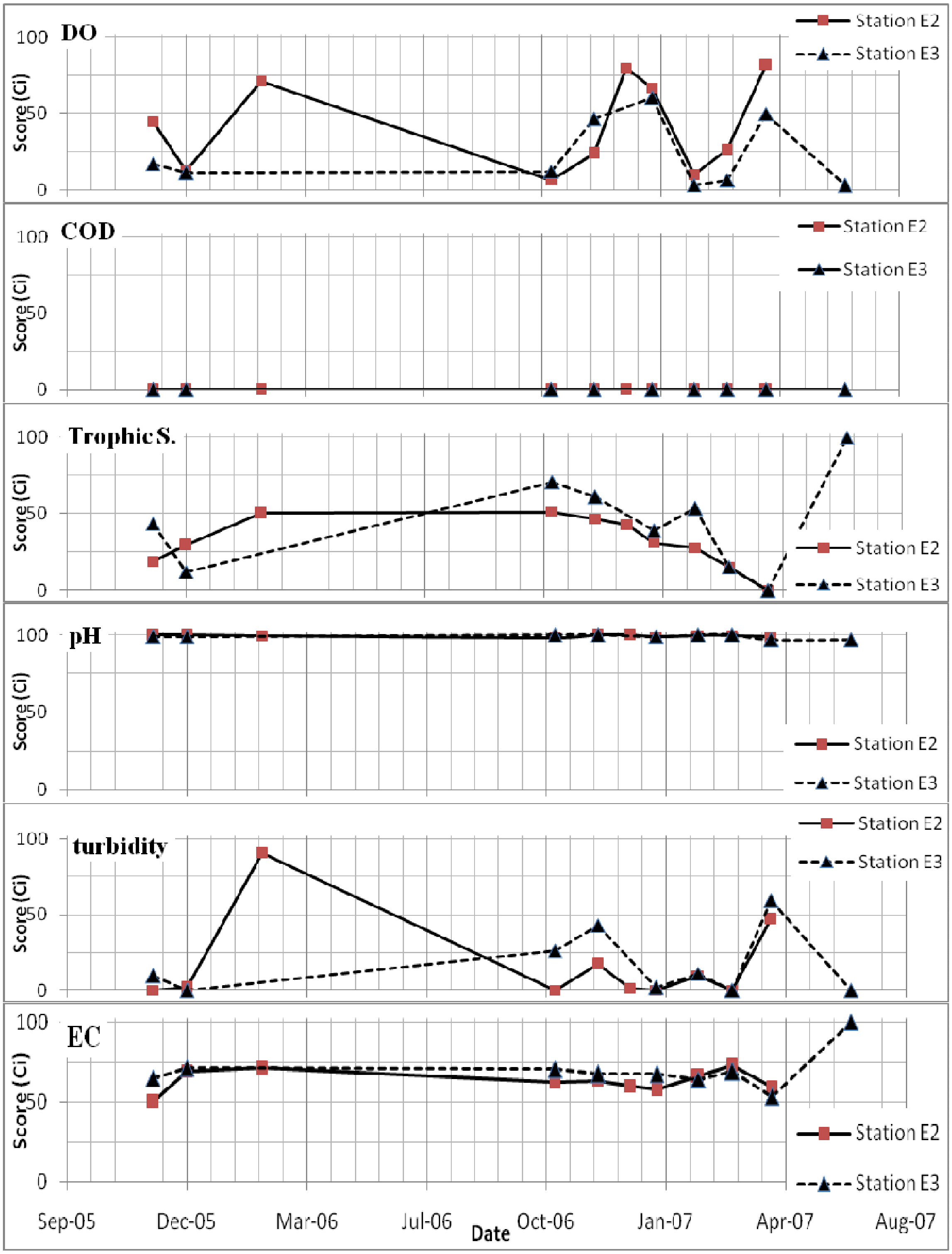

Figure 6.4. Parameter scores for stations E2 and E3

6.1.3. Küçükçekmece Lagoon Stations (10, 11, 12 and 13)

Throughout the Lagoon, the scores mostly indicate “critical” levels (Table 6.3 and Figure 6.5.). The mean index scores of stations 10, 11, 12 and 13 have been interpreted together with their locations in the Lagoon as fallows:

- Stations 10 located near the connection channel between the Lagoon and Marmara Sea and station 11 located in the middle part of the Lagoon have showed a mean index score of 43.
- Stations 11 located near the outlet of Eşkinoz Creek and station 13 located near the outlet of Sazlıdere Creeks have showed lower mean index scores of 41 and 40, respectively.

The seasonal variations were influential on the water quality at Küçükçekmece Lagoon; the lowest index scores were mostly obtained during spring and winter months of November, December and February which were also parallel to the previously reported algal blooming periods.

The normalized EC scores were observed as poor at all stations which can be explained with the influence of Marmara Sea (Figure 6.6.). At stations 11 and 13, the restricted escalations in EC scores can be related to the effect of winter and spring precipitations. However, the stations 10 and 11 are closer to the Sea compared to the other stations, thus being exposed to a greater influence of saline water (Figure 6.6.).

Among the other remarkable results, COD ratings have been observed as constantly “very poor” while pH scores always were in the “excellent” range; turbidity scores have shown oscillations between 50 and 100 (Figure 6.6.).

Table 6.3. Index scores for 10, 11, 12 and 13

Station	Date	Score	remarks	Date	Score	remarks
10	Nov-05 Dec-05 Feb-06 Mar-06	43 30 44 39	 euthrophication	Apr-06 Nov-06 Mar-07 Apr-07	44 57 40 51	 peak
11	Nov-05 Dec-05 Feb-06 Mar-06 Apr-06	50 27 47 45 43	peak euthrophication	Nov-06 Dec-06 Feb-07 Apr-07	39 38 26 53	
12	Nov-05 Dec-05 Feb-06 Mar-06 Apr-06	43 32 47 36 36	 euthrophication	Dec-06 Feb-07 Mar-07 Apr-07	48 41 51 54	 peak
13	Dec-05 Feb-06 Mar-06 Jul-06 Nov-06	24 43 49 32 39	euthrophication peak	Dec-06 Feb-07 Mar-07 Apr-07	38 35 47 42	

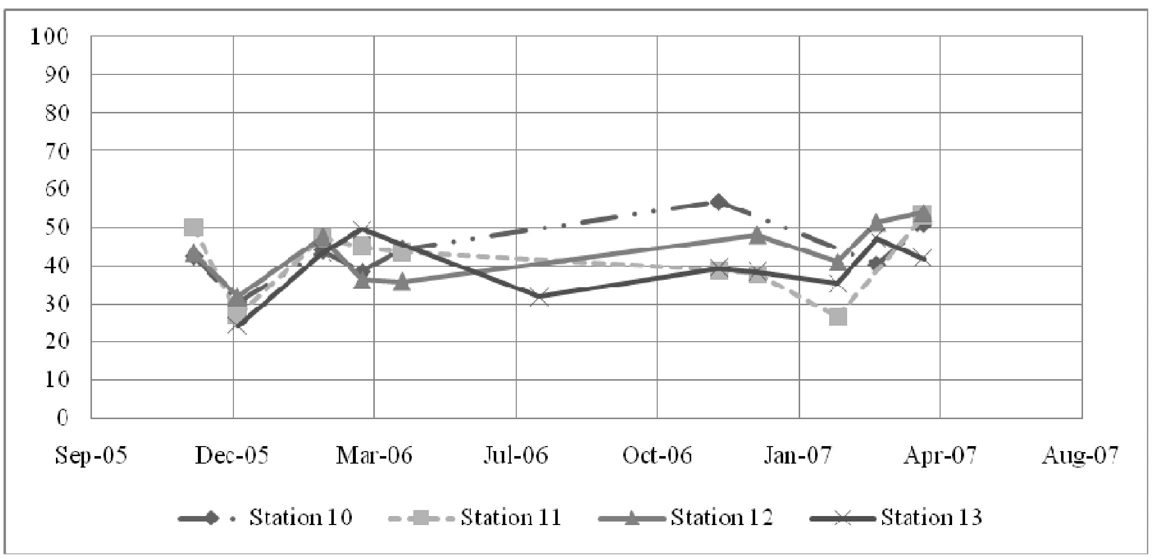

Figure 6.5. Chart representation of index scores for stations 10, 11, 12 and 13.

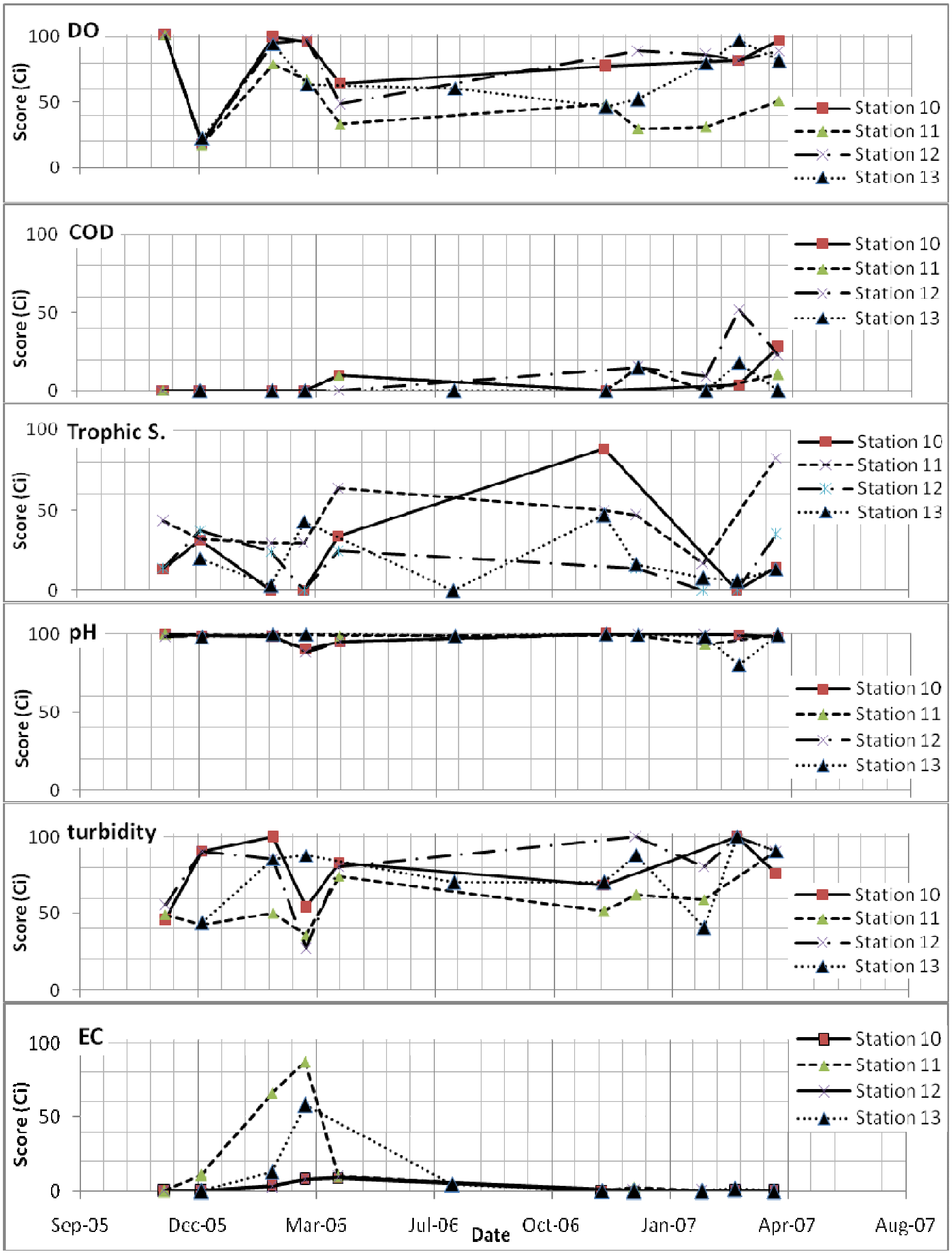

Figure 6.6. Parameter scores for stations 10, 11, 12 and 13

6.2. Sampling stations of State Hydraulic Works (DSI)

6.2.1. Stations S1 and S5

Stations S1 and S5 are located on the eastern side of Sazlıdere Dam. Relatively long term data was available for both S1 and S5 (for about eight and four years, respectively). For both stations, the mean and median index scores were above 75, which correspond to the "fair" class according to the index (Figure 6.7. and Figure 6.8.).

For station S1, the index scores have mostly stayed in the range of 75 to 85 with an average of 81 and a standard deviation of 5.52. A particular result was the "mediocre" index scores -at October 1997 as 68 and at July 1998 as 69- which occurred within the last two years period (Table 6.4). These two scores might be accepted as the early signs of a degradation trend while it is known that the major land-use changes in the Watershed has taken place in the second half of 1990's (Taner and Aytaç, 2004; Demirci et al., 2005). Nevertheless, the water quality data after 1996 was not sufficiently low to verify this hypothesis.

Table 6.4. Index scores for station S1

Station	Date	Score	Date	Score	Date	Score	Date	Score
S1	**Jan-90**	81	**Mar-91**	81	**Jun-92**	87	**Feb-94**	78
	Feb-90	74	**Jul-91**	88	**Jul-92**	87	**Mar-94**	89
	Mar-90	81	**Aug-91**	85	**Aug-92**	86	**Apr-94**	85
	Apr-90	72	**Sep-91**	81	**Sep-92**	83	**Mar-96**	86
	May-90	77	**Oct-91**	80	**Oct-92**	88	**Feb-97**	74
	Jun-90	83	**Nov-91**	78	**Mar-93**	85	**Mar-97**	83
	Jul-90	85	**Dec-91**	75	**Jun-93**	81	**Aug-97**	78
	Aug-90	84	**Jan-92**	76	**Aug-93**	88	**Oct-97**	68
	Sep-90	83	**Feb-92**	78	**Sep-93**	87	**Feb-98**	81
	Oct-90	86	**Mar-92**	82	**Oct-93**	90	**Mar-98**	78
	Dec-90	72	**Apr-92**	81	**Nov-93**	89	**Jul-98**	69
	Jan-91	78	**May-92**	84	**Dec-93**	83	**Dec-98**	75
	Feb-91	77						

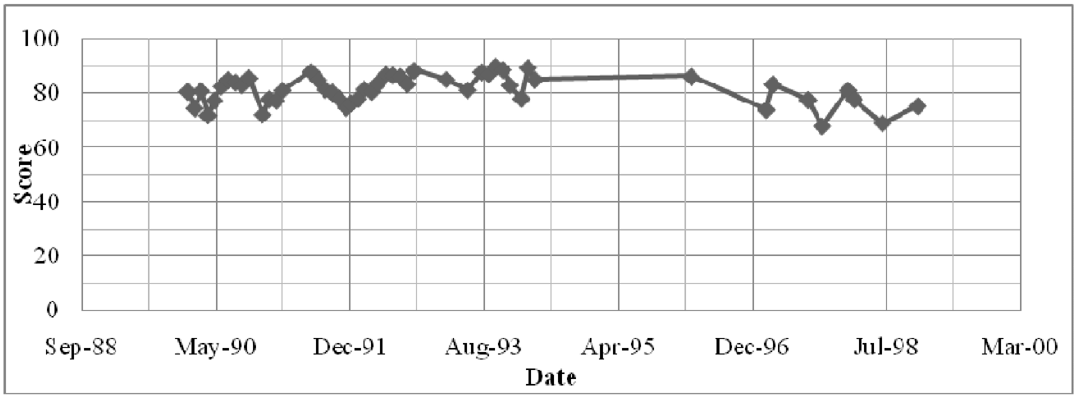

Figure 6.7. Chart representation of index scores for station S1

Table 6.5. Index scores for station S5

Station	Date	Score	Date	Score	Date	Score	Date	Score
S5	**Jan-90**	79	**Oct-90**	86	**Oct-91**	82	**Nov-92**	81
	Mar-90	83	**Jan-91**	79	**Nov-91**	76	**Apr-93**	89
	Apr-90	85	**Feb-91**	75	**Jan-92**	77	**Jul-93**	77
	May-90	82	**Mar-91**	83	**Feb-92**	77	**Aug-93**	83
	Jul-90	85	**Jul-91**	89	**Mar-92**	80	**Sep-93**	78
	Aug-90	85	**Aug-91**	88	**Aug-92**	81	**Oct-93**	86
	Sep-90	79	**Sep-91**	83	**Sep-92**	81		

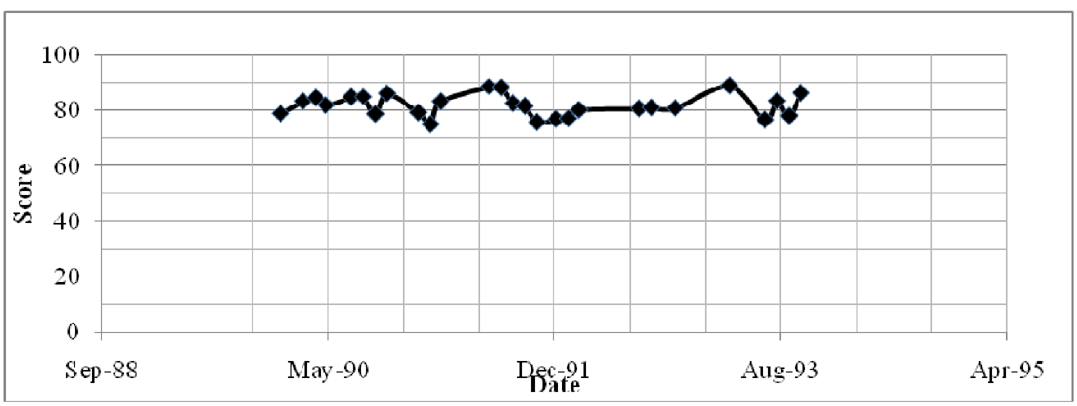

Figure 6.8. Chart representation of index scores for station S5

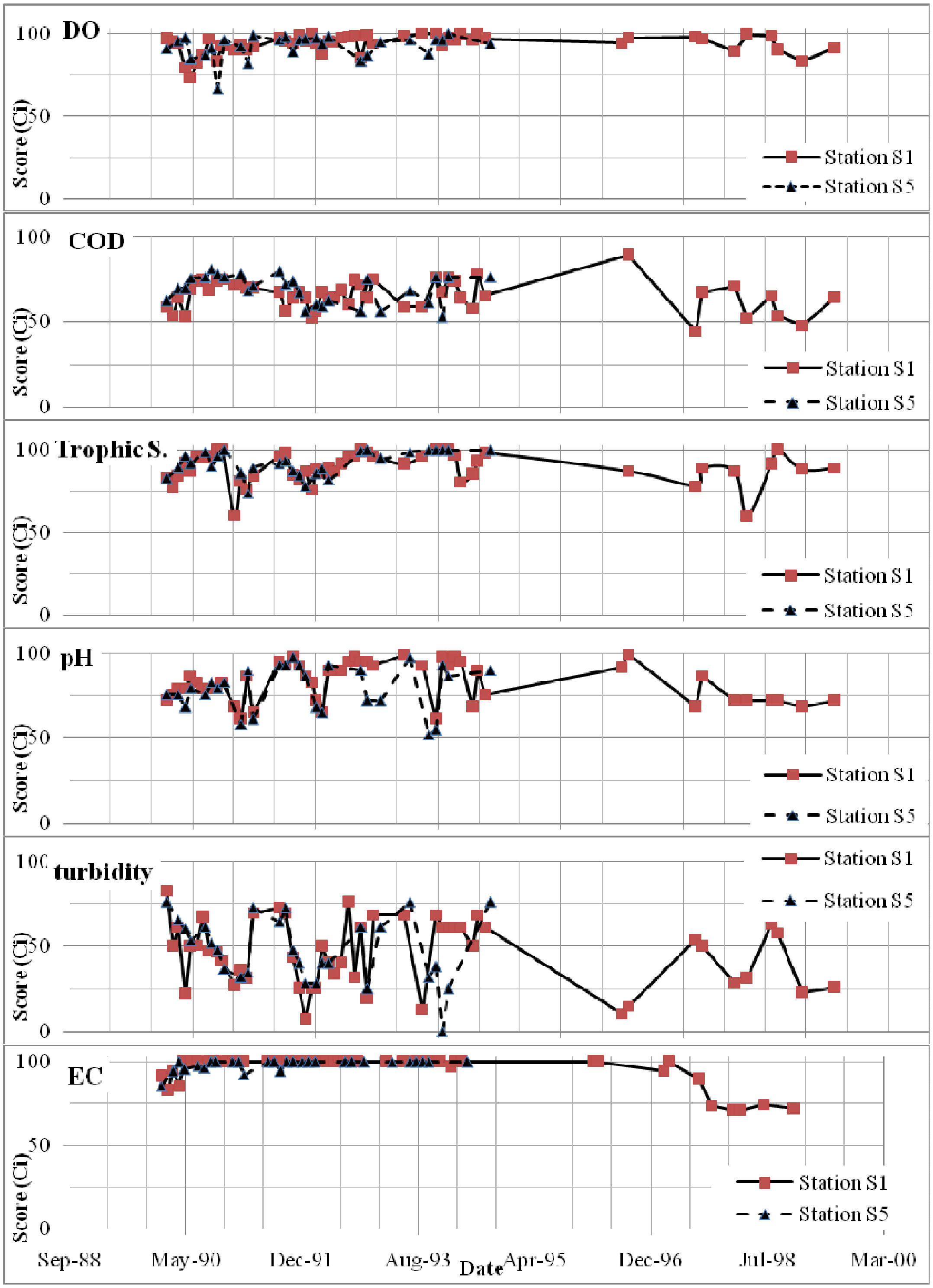

Figure 6.9. Parameter scores for Stations S1 and S5

6.2.2 Stations S3 and S4

For most sampling dates, stations S3 and S4 showed index scores above 75 (Table 6.6.). Lowest index scores were mostly observed at December 2001, February 2005 and December 2005 for S3 and February 2003, December 2004 and October 2006 for S4 (Table 6.6.). On the basis of individual parameters, index scores for DO, COD and pH were similar for both S3 and S4 (Figure 6.11.). Station S4 was slightly better in terms of trophic state score and lower in terms of EC score (Figure 6.11.).

Table 6.6. Index scores for stations S3 and S4

Station	Date	Score	Date	Score	Date	Score	Date	Score
S3	**Feb-99**	86	**Dec-01**	62	**Apr-04**	84	**May-05**	76
	Apr-99	87	**Apr-02**	84	**Jun-04**	93	**Dec-05**	67
	Feb-00	83	**Oct-02**	89	**Aug-04**	75	**Feb-06**	74
	Jul-00	87	**Feb-03**	65	**Oct-04**	84	**Apr-06**	83
	Oct-00	84	**Apr-03**	79	**Dec-04**	80	**Oct-06**	77
	Feb-01	86	**Jul-03**	75	**Feb-05**	65	**Dec-06**	84
	Oct-01	72	**Feb-04**	82	**Apr-05**	88		
S4	**Feb-99**	83	**Apr-02**	87	**Feb-04**	80	**Feb-05**	76
	Apr-99	87	**Aug-02**	85	**Apr-04**	82	**Feb-06**	78
	Feb-00	81	**Sep-02**	88	**Jun-04**	80	**Apr-06**	86
	Apr-00	88	**Feb-03**	73	**Dec-04**	66	**Oct-06**	75
	Feb-01	86	**Apr-03**	73				

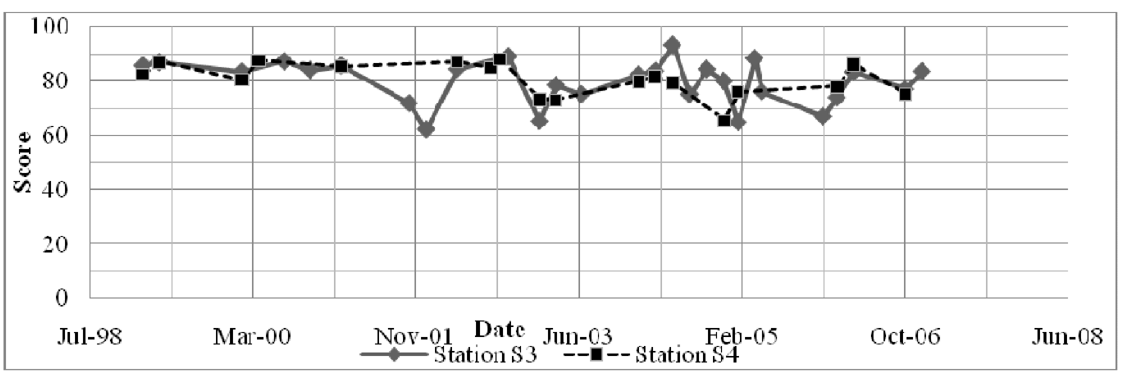

Figure 6.10. Chart representation of index scores for stations S3 and S4

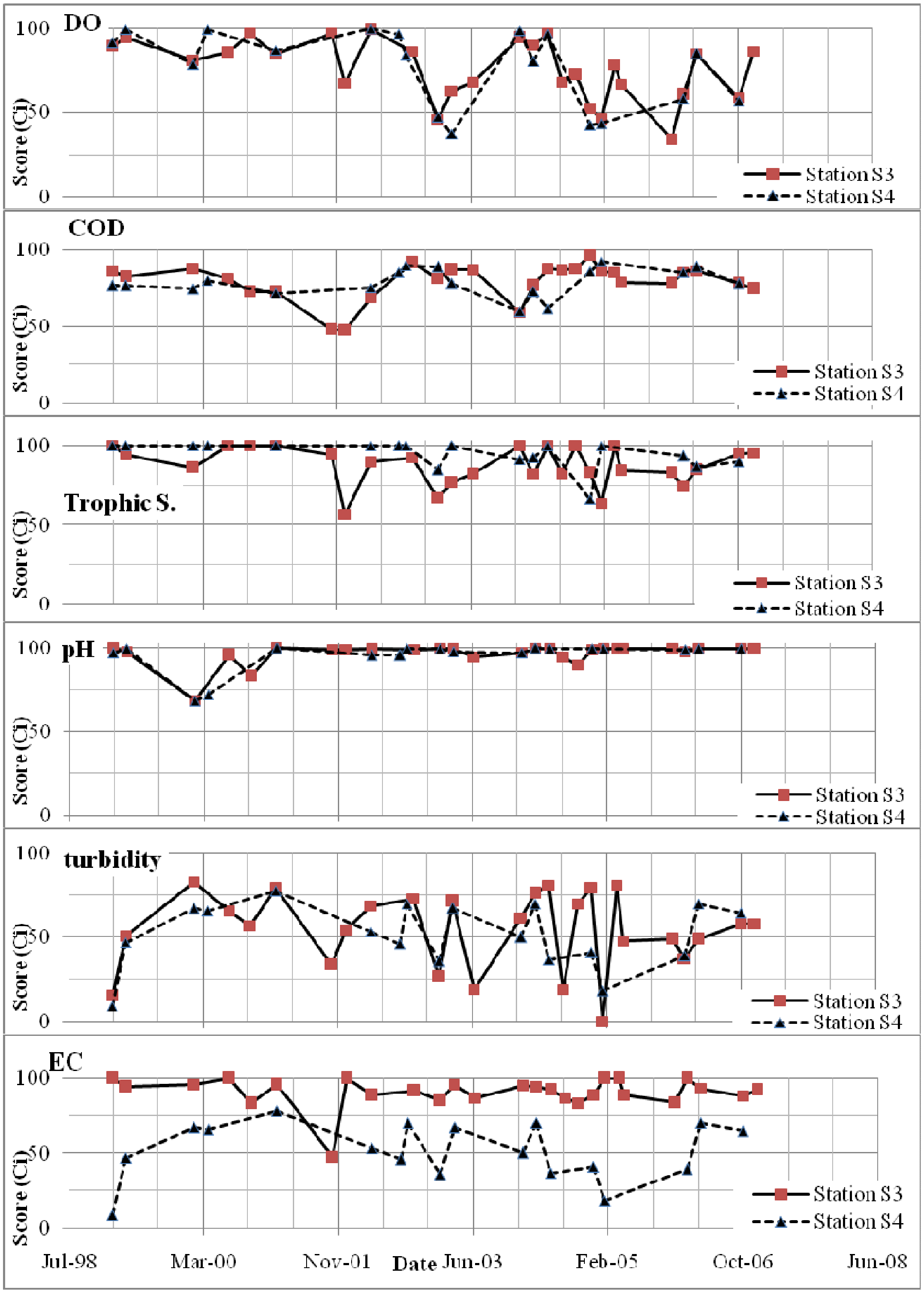

Figure 6.11 - Parameter scores for stations S3 and S4

6.2.3 Station S2

At station S2, the DO and COD ratings ranged between 100-80 and 80-60, respectively (Table 6.7). Similar to DSI' other sampling stations, the trophic state score has showed seasonal oscillations and has dropped below 80 occasionally in winter and spring seasons. Turbidity parameter were observed as the most problematic in terms of individual parameter scores (Table 6.13).

Table 6.7. Index scores for S2

Station	Date	Score	Date	Score	Date	Score	Date	Score
	Feb-90	77	**Mar-91**	85	**Apr-92**	81	**Feb-94**	83
	Mar-90	85	**Jul-91**	93	**May-92**	85	**Apr-94**	91
	Apr-90	83	**Sep-91**	85	**Jun-92**	86	**Jun-94**	85
	May-90	84	**Oct-91**	83	**Jul-92**	90	**Nov-95**	84
S2	**Jun-90**	85	**Nov-91**	83	**Aug-92**	85	**Feb-96**	82
	Aug-90	84	**Dec-91**	75	**Apr-93**	89	**Apr-96**	84
	Dec-90	78	**Jan-92**	76	**Jun-93**	86	**Aug-96**	82
	Jan-91	81	**Feb-92**	77	**Dec-93**	81	**Oct-96**	80
	Feb-91	79	**Mar-92**	75				

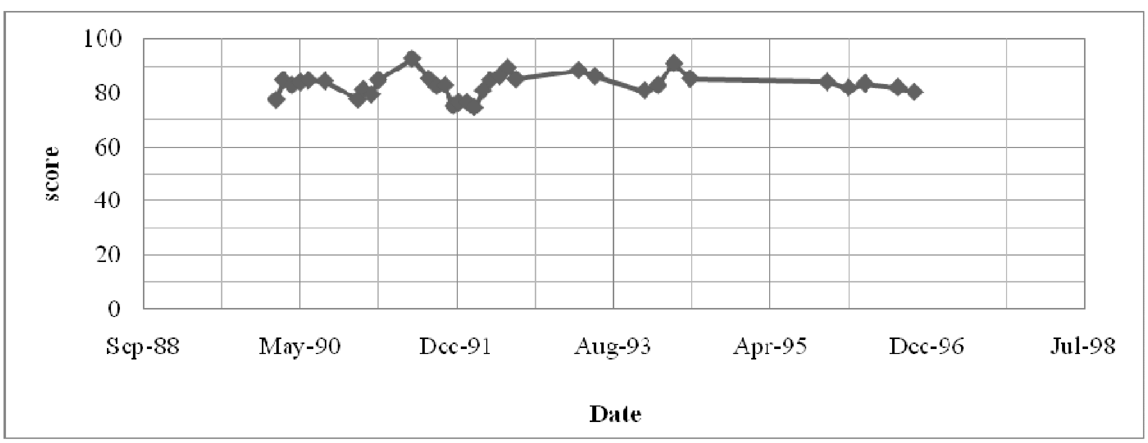

Figure 6.12 Chart representation of index scores for station S2

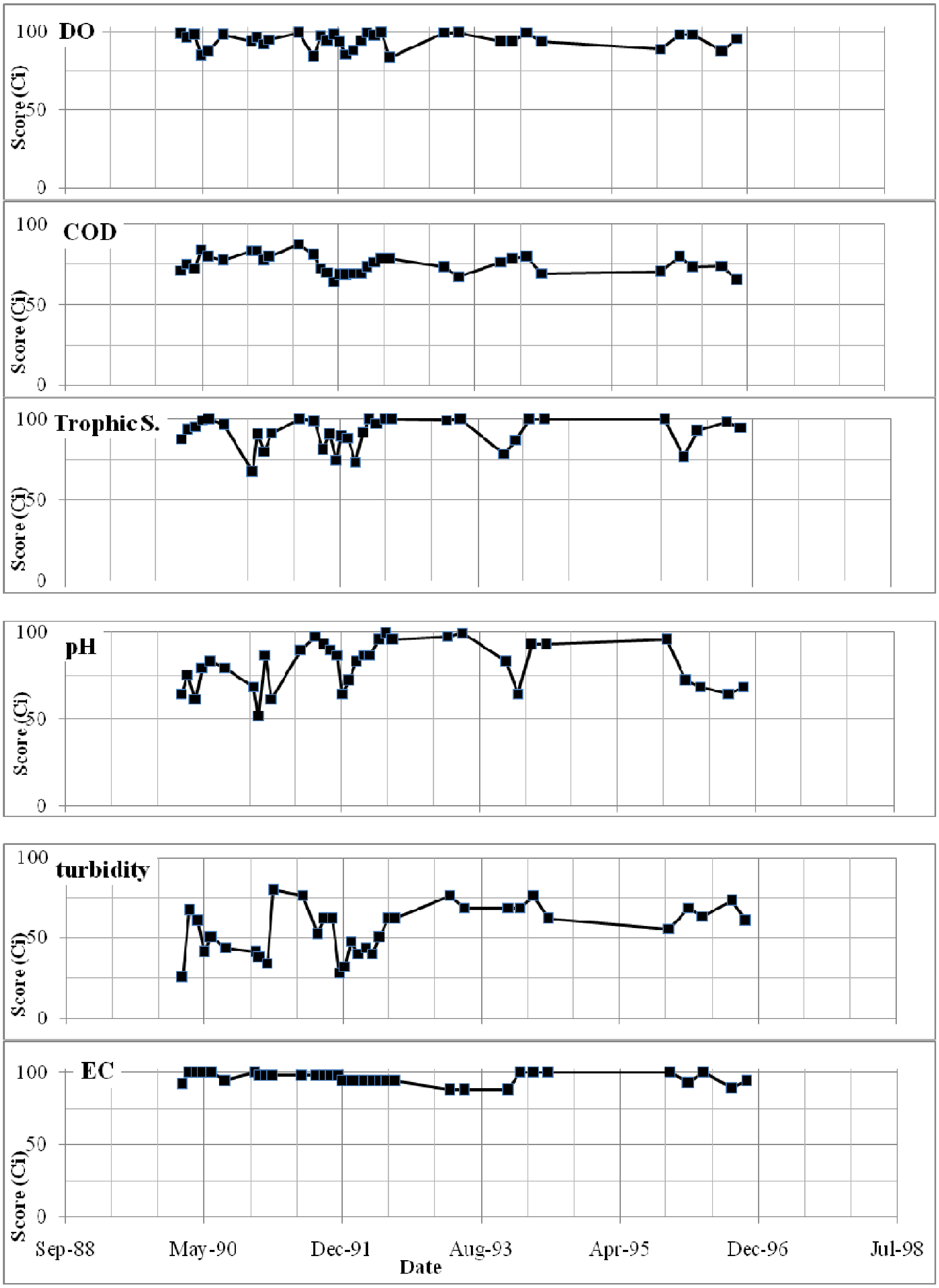

Figure 6.13. Parameter scores for station S2

6.3 Statistical Analyses

6.3.1. Comparison of Stations

As McBean and Rovers (1998) suggested, the fundamental statistical parameters in water quality studies are measures of center (mean, median and mode) and measures of spread (variance, standard deviation and coefficient of variation). The statistical results of index scores including these parameters and minimum and maximum scores of both KEMG and DSI's sampling stations are summarized on Table 6.8. and Table 6.9., respectively.

Table 6.8. Statistical results of stations D1, D2, D3, E2, E3, 10, 11, 12 and 13

Stations	Min	Max	Mean	Median	S.Dev.	Variance	CV
D1	19	53	37	40	12,67	160,48	0,34
D2	38	60	49	46	8,91	79,47	0,18
D3	36	88	64	63	15,91	253,00	0,25
E2	26	54	35	32	9,45	89,36	0,27
E3	22	46	34	32	8,83	77,94	0,26
10	30	57	43	43	7,92	62,80	0,18
11	26	53	41	43	9,45	89,23	0,23
12	32	54	43	43	7,59	57,66	0,18
13	32	49	40	39	6,25	39,03	0,15

Table 6.9. Statistical results of stations S1, S2, S3, S4 and S5

Stations	Min	Max	Mean	Median	S.Dev.	Variance	CV
S1	68	90	81	81	5,42	29,33	0,07
S2	75	93	83	83	4,27	18,24	0,05
S3	62	92	80	83	8,13	66,02	0,10
S4	66	88	81	81	6,29	39,52	0,08
S5	75	90	82	82	4,16	17,29	0,05

6.3.2. Seasonal Variations

The water quality data measured by DSI has covered a longer period compared to KEMG's monitoring program - S1 from 1990 to 1993, S2 and S5 from 2000 to 2006, S3 and S4 from 1999 to 2006, while KEMG's stations measured from 2005 to 2007 – thus, it was possible to interpret on seasonal behaviors by using the index scores obtained from DSI's water quality data.

In order to analyze the relationship between precipitation and water quality, the months were grouped into two as the precipitation season from October to March and the dry season from March to October. This classification was based on the study of Üstün et al. (2005) which states that 70 percent of the annual precipitation in the watershed occurs between the months of October and March (Üstün et al., 2005). The results showed that from stations S1 to S5, the mean index scores at dry seasons were evidently higher than those in rainy seasons (Table 6.10).

Table 6.10. Seasonal analysis of index scores for stations S1, S2, S3, S4 and S5

Stations	S1	S2	S3	S4	S5
Rainy Season (October to March)	79	80	78	78	80
Dry Season (March to October)	83	85	85	86	83

This result might seem controversial while water quality in receiving waters generally declines during summer seasons as biological activity increases. However additional factors such as intensity of pollution from non-point sources (i.e. agricultural and urban run-off), application periods of agricultural fertilizers which might change this general trend should be considered also.For Küçükçekmece Watershed, the effects of these additional factors are not yet completely known which might be important reasons for seasonal changes in water quality.

6.3.3. Long-term Dissolved Oxygen Trends

At stations S3 and S4, there was a constant decrease in the dissolved oxygen two years mean score from 1999 to 2006 (Table 6.11.). The stations S1, S2 and S5 on the other hand which were monitored between 1990 and 1993 have showed no significant trends in terms of dissolved oxygen mean scores (Table 6.12.).

Table 6.11. Mean DO scores for stations S3 and S4

Date	Station S3	Station S4
1999 - 2000	90	93
2001 - 2002	87	92
2003 - 2004	72	67
2005 - 2006	65	61

Table 6.12. Mean DO scores for stations S1, S2 and S5

Date	Station S2	Station S5	Station S1
1990	91	89	89
1991	96	93	95
1992	96	92	95
1993	99	95	98

Based on the fact that dissolved oxygen as percentage of saturation is a powerful indicator to evaluate ecological stresses in aquatic environment (chapter 5), these results can be interpreted as an evidence of deterioration from 1999 to 2006.

The remote sensing study by Demirci et al. (2005) and observations of Taner and Aytaç (2004) have previously referred to the significant land-use changes in the watershed after the second half of 1990’s which also supports the results obtained by the analysis of DO mean scores.

7. CONCLUSIONS

Küçükçekmece water quality index proposed within the multi-dimensional framework of sustainability indicators has evaluated water quality trends in the Lagoon and its tributary creeks. The evaluation was based on State Hydraulic Works' (DSI) monitoring program that was carried out at 5 stations and for a period of more than 5 years and Küçükçekmece Environmental Management Group's (KEMG) program consisting of monitoring of 9 stations and for a period of 2 years.

The study has achieved important steps on the way to become a functional "decision support tool". The following conclusions were drawn in the study:

- The water quality index developed in this study was found effective for indicating water quality problems and trends in Küçükçekmece Watershed especially those related to the presence of organic contamination, euthrophication and aquatic stress.
- The methods applied for the missing data were useful for increasing the quantity of the data and hence improving the adaptability of the water quality index for Küçükçekmece Watershed. These methods were regression analysis of NO_3-N and TKN parameters, the analysis of total nitrogen over total phosphorus ratios and the transformation of BOD_5 parameter to COD.
- The results of the water quality index indicated the seasonal fluctuations in water quality of Küçükçekmece Watershed, related to the algal blooming events. The minimum index scores were obtained during euthrophication based algal blooming seasons (October, November and December) at the majority of occasions. The correlation between low index scores and algal blooms can be accepted as a success of the index in indicating the euthrophication phenomenon in Küçükçekmece Watershed.
- Index scores that the water quality greatly dropped in the occasions of algal blooming and recovered in the subsequent months (February, March and April).
- The index results indicated a notable difference between the mean scores of dry and wet seasons. In dry season, between March and October, receiving about 30 percent of the total precipitation the long term mean index scores at Stations S1 to S5 were found to be higher than the wet season averages.

- The developed water quality index showed that the station D3 at Sazlıdere Dam have a relatively better water quality followed by Küçükçekmece Lagoon stations, Sazlıdere Creek and Eşkinoz Creek stations.
- The trends in the index scores was found useful for indicating increasing pollution load in Küçükçekmece Watershed as a result of rapid industrialization and urbanization after the second half of 1990's. The drops in dissolved oxygen scores at stations S3 and S4 between 1999 and 2006 can be accepted as an evidence of this condition.
- The COD index scores that were constantly at the "very poor" level in the stations of KEMG's monitoring program were another important indicator of industrial and domestic discharges in the Küçükçekmece Watershed.

8. RECOMMENDATIONS

Within the study of “Development of water quality Index in Küçükçekmece Watershed”, following recommendations were suggested for further studies:

- Improving the index effectiveness in terms of toxicity is an important upgrade, especially for Watersheds which receive high amounts of industrial discharges as Küçükçekmece Watershed. For this purpose, an aggregate sub-index based on selected heavy metals can be introduced in further studies. This aggregate sub-index can be formed by based on the lethal doses for the dominant species in the water body.
- The improvement of the water quality database can provide more possibilities for increasing the index performance. Additionally, meteorological data can be interpreted together with the water quality data for a better validation of the index.

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APPENDIX A. SELECTED WATER QUALITY INDICES

Table A.1. Developers, parameters, aggregation methods and purposes of selected water quality indices

Name	Reference	Parameters / factors	Aggregation formula	Remarks
Horton's Index	Horton (1965)	DO, pH, coliforms, electrical conductivity, alkalinity, chloride, CCE, sewage treatment	$I = \sum_{i=1}^{n} (P_i C_i) M_1 M_2$	first developed index
NSF WQI	US National Sanitary Foundation (1970)	DO, BOD, turbidity, total solids, nitrate, phosphate, pH, temperature, faecal coliforms, pesticides, toxic elements	$I = \sum_{i=1}^{n} P_i C_i$	most well-known index in water quality
BC WQI	British Columbia Ministry of Environment, Canada	Scope: F_1= % of guidelines exceeded Frequency: F_2= % of measurements at least one guideline were exceeded. Amplitude: F_3= measure of the max. amount of objectives not being met	$I = [(F_1)^2 + (F_2)^2 + (F_3/3)^2]^{1/2}$	formed for comparison for streams
CCME WQI	Canada Council of Ministers of Environment, Canada	F_1 =(failed var./ total var.) x 100 F_2 =(failed measr./ total measr.) x 100 F_3 =(nse / (0.01nse + 0.01) (*nse:* normalized sum of excursions)	$I = 100 - (\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732})$	improved version of BCQI and used widely in Canada.
O-WQI (Original)	Cude (2001)	DO Conc., BOD_5,pH, total solids, ammonia + nitrate nitrogen, and faecal coliform	$I = \sum_{i=1}^{n} P_i C_i$	assessment of freshwaters General recreational use.

Table A.1. Developers, parameters, aggregation methods and purposes of selected water quality indices (continued)

Name	Reference	Parameters or factors	Aggregation and scale	Remarks
O-WQI (Modified)	Cude (2001)	temperature, DO Conc. , DO (super-saturation) BOD_5, pH, ammonium + nitrate nitrogen, total phosphates, total solids and fecal coliform	$I = \sqrt{\dfrac{n}{\sum_{i=1}^{n} \dfrac{1}{SI_i^2}}}$	an improved version of the previous index
Prati's Implicit Index	Prati et al. (1971)	DO Sat (%), pH, BOD, COD, permanganate, suspended solids, ammonia, nitrates, chlorides, iron, manganese, alkyl benzene sulfonates, carbon chloroform extract	Arithmetic mean aggregation method: $I = \frac{1}{13}\sum_{i=1} Ii$	Prati's index is utilized for evaluation of surface waters in Ferrana, Italy.
River Pollution Index	McDufie and Haney (1973)	Oxygen Deficit (%), BOD_5, Refractory Organic Matter, T. Coliform, Non-VSS, Average Nutrient Excess, Dissolved Salts, Temperature	$I = \sum_{i=1}^{n} Ci * 10/(n+1)$	Applied in New York State U.S.A
Heavy Metal Evaluation Index (HEI)	Edet and Offiong (2003)	As, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn.	$HEI = \sum_{i=1}^{n} H_c / H_{mac}$ H_c = monitored value H_{max}= maximum admissible conc.	applied in Nigeria
WQI for Taiwan	Liou et al.; (2003)	I_i group: DO, BOD_5,NH_3-N I_j group: SS and turbidity I_k group: feacal coliform Temperature (C_{tem}), pH (C_{pH}), toxicity (C_{tox})	$I = C_{tem}C_{ph}C_{tox}\left[\left(\sum_{i=1}^{3} I_iW_i\right)x\left(\sum_{j=1}^{2} I_jW_j\right)x\left(\sum_{k=1}^{1} I_kW_k\right)\right]^{\frac{1}{3}}$	a generalized stream water quality index. Applied to Keya River (Taiwan)

Table A.1. Developers, parameters, aggregation methods and purposes of selected water quality indices (continued)

Name	Reference	Parameters or factors	Aggregation and scale	Other notes
Fuzzy WQI	Icaga (2006)	Temperature, pH, DO, chloride, sulphate, NH_3, nitrite, nitrate, total dissolved solids, color and sodium	Fuzzy logic algorithm based on fuzzy set theory	applied to Eber Lake (Turkey)
Alternative WQI	Said et al.; (2004)	DO, specific conductivity, turbidity, total phosphorus and fecal coliform	$\log\left[\frac{(DO)^{1.5}}{(3.8)^{TP}(Turb)^{0.15}(15)^{FCol/1000}+0.14(SC)^{0.5}}\right]$	there is no need to standardize the variables. The index range is 0-3.
The Florida Stream WQI	SAFE (1995)	Turbidity, TSS, DO, BOD, phosphorus, nitrogen, total and fecal coliform, biodiversity (Beck's biotic index)	Arithmetic mean	-
Aquatic Toxicity Index (ATI)	Wepener et al., (1992)	pH, DO, turbidity, ammonium, TDS, fluoride, potassium, orthophosphates, total zinc, manganese, chromium, copper, lead and nickel	$I = \frac{1}{100}\cdot\left(\frac{1}{n}\sum_{i=1}^{n} q_i\right)^2$	Toxicity has been designed according to salmonoid spawning.
Dinius WQI	Dinius (1987)	DO, BOD, Coliform, E-coli, pH, alkalinity, hardness, chloride, SC, temperature, color, nitrate	$I = \sum_{i=1}^{n} I_i^{W_i}$	used for public supply, recreation, fish shellfish, agriculture and industrial uses
Specific Pollution Index	Nunes (2003)	Includes a very large list of diatom taxa with frequent updates.	$SPI = \left(\sum_{i=1}^{n} A_i I_i V_i\right) / \left(\sum_{i=1}^{n} A_i V_i\right)$ (A_i= relative abundance of taxon I, i_i="sensitivity index of taxon, v_i= indicator value of taxon i.	river pollution, especially in mine containing watersheds

Table A.2. Normalization scales of selected water quality indices

Normalization values (C_i)		**100**	**90**	**80**	**70**	**60**	**50**	**40**	**30**	**20**	**10**	**0**
DO Sat. (%)	Prati (1971)	88-112			75-125		50-150			20-200		>20,<200
	Cude (2001)	100	110	120	125	145	160	180	200	225	275	300
COD (mg/l)	Pesce and Wunderlin (2000); Sanchez (2006)	<5	<10	<20	<30	<40	<50	<60	<80	<100	≤150	>150
	Prati (1971)	<10			<20		<40			<80		>80
	Debels (2005)	<1.2	<5.0	<7.5	<10.0	<12.5	<15.0	<20.0	<25.0	<30.0	≤40	>40
NO_3-N (mg/L)	Pesce and Wunderlin (2000); Sanchez (2006)	<0.5	<2.0	<4.0	<6.0	<8.0	<10.0	<15.0	<20.0	<50.0	≤100	>100
	Prati (1971)	4		12			36			108		>108
	Debels (2005)	<0.5	<2.0	<4.0	<6.0	<8.0	<10.0	<15.0	<20.0	<40.0	≤70.0	>70.0
Turb. (NTU)	Pesce and Wunderlin (2000)	<5	<10	<15	<20	<25	<30	<40	<60	<80	≤100	>100
	Liou et. al (2004)	0		4	15				50			120
o-PO_4 (mg/L)	Pesce and Wunderlin (2000); Sanchez (2006)	<0.16	<1.60	<3.2	<6.4	<9.6	<16.0	<32.0	<64.0	<96.0	≤160	>160
	Debels (2005)	<0.025	<0.05	<0.100	<0.200	<0.300	<0.500	0.750	<1.00	<1.500	≤2.00	>2.000
EC (µS/cm)	Pesce and Wunderlin (2000); Sanchez (2006)	<750	<1000	<1250	<1500	<2000	<2500	<3000	<5000	<8000	≤12000	>12000
	Debels (2005)	<600	<700	<850	<1000	<1250	<1500	<2000	<2500	<3000	≤3500	>3500
pH	Pesce and Wunderlin (2000); Sanchez (2006)	7	7-8	7-8.5	7-9	6.5-7	6-9.5	5-10	4-11	3-12	2-13	1-14
	Prati (1971)	6.5-8		6.0-8.4			5.0-9.0			3.9-10		<3.9,>10
	Gupta (2003)		5.4-8.6				3.5-10.5				2.3-11	
	Debels (2005)	7.0	6.9-7.5	6.7-7.8	6.5-8.3	6.2-8.7	5.8-9.0	5.8-5.5	5.5-5.0	5.0-4.5	4.5-4.0	>4
Chl.a (mg/m^3)	Hambright et al. (2000)	4				>0.3,<10						0, >30

APPENDIX B. MEAN WATER QUALITY DATA FOR SAMPLING STATIONS

Table B.1. Mean water quality data for stations D1, D2, D3, E2, E3, 10, 11, 12 and 13

Stations / n*	Time Interval		DO (mg/L)	Temp. (^{0}C)	EC (mS/cm)	salinity (ppt)	COD (mg/L)	TKN (mg/L)	NO_3 (mg/L)	TP (mg/L)	o-PO_4 (mg/L)	turbidity (NTU)	pH	Chl.a (mg/L)
D1 n=11	Nov 05 Jun 07	mean	5,2	13,10	2,46	1,13	221,66	19,43	8,64	18,86	18,51	34,82	7,60	113,81
		S.D.	3,29	6,95	1,93	1,14	214,07	9,30	11,38	16,57	8,67	27,68	0,28	107,55
D2 n=7	Feb 06 Jun 07	mean	9,43	13,73	9,28	5,23	105,17	10,20	3,64	17,75	7,50	19,00	7,88	48,60
		S.D.	1,48	8,67	5,21	3,13	57,97	7,17	1,40	15,71	4,27	13,36	0,43	62,39
D3 n=9	Nov 05 Jun 07	mean	9,84	11,34	0,38	0,00	1053,94	6,05	8,61	17,94	1,28	15,22	8,09	11,48
		S.D.	2,54	7,79	0,14	0,00	1870,90	2,83	10,25	18,58	1,56	17,58	0,48	17,82
E2 n=10	Nov 05 Apr 07	mean	5,18	12,79	1,42	0,49	570,08	31,32	12,83	14,23	15,03	436,40	7,73	12,58
		S.D.	2,66	3,96	0,28	0,15	550,17	19,89	4,63	17,07	7,53	1017,24	0,19	10,92
E3 n=9	Nov 05 Jun 07	mean	3,17	15,11	1,16	0,48	371,93	35,22	12,95	19,95	12,79	96,63	7,71	6,94
		S.D.	2,30	5,89	0,48	0,19	277,33	40,92	13,69	21,32	6,01	68,50	0,28	9,55
10 n=8	Nov 05 Apr 07	mean	9,47	10,51	14,17	7,89	1133,59	11,46	10,97	8,90	7,55	13,00	8,06	73,02
		S.D.	3,47	3,63	2,90	1,82	1942,20	10,59	10,28	8,88	7,11	11,51	0,26	83,64
11 n=9	Nov 05 Apr 07	mean	6,14	11,74	10,55	6,05	646,80	21,89	9,89	14,63	6,19	25,22	7,69	8,24
		S.D.	2,39	3,44	6,02	3,82	1002,31	24,00	9,16	10,65	3,09	11,78	0,30	8,14
12 n=9	Nov 05 Apr 07	mean	9,29	10,69	14,38	8,63	770,43	7,79	7,89	7,30	5,10	13,89	7,96	109,20
		S.D.	3,24	3,27	2,78	2,20	1213,35	6,74	6,89	5,15	1,42	17,17	0,38	165,65
13 n=9	Nov 05 Apr 07	mean	8,59	11,86	12,51	6,79	394,46	8,35	8,05	15,24	4,64	14,89	7,73	41,87
		S.D.	3,65	5,80	4,84	2,93	387,40	9,96	8,24	16,03	2,32	12,88	0,45	31,13

* n equals to the number of samples being taken between the time interval

Table B.2. Mean water quality data for stations S1, S2, S3 and S4

Stations / n*	**Time Interval**		**DO (mg/L)**	**Temp (^{0}C)**	**EC (mS/cm)**	**salinity (ppt)**	**COD (mg/L)**	**TKN (mg/L)**	**NO_3 (mg/L)**	**TP (mg/L)**	**o-PO_4 (mg/L)**	**turbidity (NTU)**	**pH**
S1 n=54	May.84 Dec 98	mean	9,66	13,67	0,56	0,00	103,36	-	2,27	-	0,49	38,70	7,83
		S.D.	1,58	6,82	0,20	0,00	677,27	-	1,94	-	0,35	24,05	0,38
S2 n=34	Feb 90 Oct 96	mean	10,09	12,94	0,61	0,00	9,09	-	1,69	-	0,41	26,97	7,93
		S.D.	1,43	6,74	0,08	0,00	3,20	-	1,55	-	0,34	13,95	0,42
S3 n=27	Feb 99 Dec 06	mean	8,42	12,26	0,70	0,00	7,63	-	2,40	-	0,66	31,63	7,25
		S.D.	1,87	7,01	0,21	0,00	7,24	-	2,30	-	0,59	28,48	0,32
S4 n=18	Feb 99 Oct 06	mean	8,58	11,44	0,75	0,00	7,46	-	1,12	-	2,22	32,28	7,29
		S.D.	2,15	6,22	0,24	0,00	4,90	-	1,58	-	3,90	22,77	0,39
S5 n=28	Jan 90 May.94	mean	9,89	13,90	0,53	0,00	9,21	-	1,61	-	0,34	39,68	7,99
		S.D.	1,60	7,25	0,09	0,00	3,97	-	1,17	-	0,27	42,51	0,39

* n equals to the number of samples being taken between the time interval.

APPENDIX C. ANALYSIS METHODS USED IN KÜÇÜKÇEKMECE ENVIRONMENTAL MANAGEMENT GROUP'S MONITORING PROGRAM

Table C.1 – Measurement methods for parameters

Paramater	**analysis method or device used**
DO (mg/L)	with WTW Oxi 330i/set
Temp (°C)	with WTW Oxi 330i/set
Salinity (ppt)	with WTW Cond 330i/set
EC (mS/cm)	with WTW Cond 330i/set
pH	with WTW pH 330i/set
Chlorophyll a (mg/m^3)	Spectrophotometric method (APHA, 1995)
NO_3-N (mg/L)	Ultraviolet spectrophotometric screening method (APHA, 1995)
o-PO4 (mg/L)	Spectrophotometric method (APHA, 1995)
COD (mg/L)	Open reflux method (APHA, 1995)
Turbidity (NTU)	Nephelometric method (APHA, 1995)
TKN (mg/L)	Macro Kjeldahl Method (APHA, 1995)
Nitrite (mg/L)	Colorimetric method (APHA, 1995)

APPENDIX D. SELECTED INTERNATIONAL AND NATIONAL WATER QUALITY STANDARDS

Table D1. Selected International and National Water Quality Regulations

Regulations		DO (% Sat.)	COD (mg/L)	NO_3-N (mg/L)	o-PO_4 (mg/L)	pH	Turbidity (NTU)	S. Cond. (µS/cm)	Chlorophyll-a (mg/m^3)
Turkey Water Quality Control Legislation (Resmi Gazete, 2004)	**Class I**	90	25	0.5		6.5-8.5			
	Class II	70	50	1		6.5-8.5			
	Class III	40	70	20		6.0-9.0			
	Class IV	<40	>70	>20		Outside of 6.0-9.0			
Canada (ANZECC 2000)						6.5 - 9.0	8-10		
Australia (Gönenç, 2006)							2-200*	90-900	<1µg/l
Mauritus Island (Gönenç, 2006)	**Protected**			0.3	0.05	7.5-8.5			
	Fisheries			0.8	0.08	6.5-8.5			
	Industrial			1.0	0.1	7.0-8.5			
UN Economic Comission for Europe (UNECE, 1994)	**Class I**	90-110	3			6.5-9.0			<2.5
	Class II	70-90 or 110-120	3-10			6.3-6.5			2.5-10
	Class III	50-70 or 120-130	10-20			6.3-6.0			10-30
	Class IV	30-50 or 130-150	20-30			6.0-5.3			30-110
	Class V	<30 or >150	>30			<5.3			>110

APPENDIX E. FORMULAS AND R SQUARED VALUES OF NORMALIZATION FUNCTIONS

Table E.1. Parameters, their normalization functions and r^2 values

Parameter	Normalization functions	r^2 value
DO (sat. %)	DO ≤100, $\ln y=0.955+0.072x+0.0004x^2$ DO>100, $\ln y=3.937+0.0002x^2-1.48*10^{-6}x^3$	0.9946 0.9970
NO_3-N (mg/L)	$y=\left(\frac{9.96-0.08x+0.0283x^2}{1-0.054x+0.002x^2+5.7*10^{-5}x^3}\right)^2$	0.9960
o-PO_4 (mg/L)	$y=\frac{1}{0.0341+0.007x^{2.5}-0.024e^{-x}}$	0.9980
Chl-a (mg/m^3)	$y=\frac{1}{0.01+0.0012x+7*10^{-7}x^3}$	0.9984
COD (mg/L)	COD ≥80, y=0 0<COD<80, $y=100.421-6.45x^{0.63}$	0.9990
pH	pH ≤5.5 and pH≥10.3, y=0 5.5<pH<10.3, $y=272488+1563x+\frac{982990}{\ln x}+\frac{1700316}{x}+87575*e^{-x}$	0.9994
EC (mS/cm)	$y=-0.429-0.735x+\frac{220.808}{x}-\frac{211.524}{x^{1.5}}+\frac{67.49}{x^2}$	0.9996
Turb. (NTU)	Turb≤5, y=100 Turb>5, $y=134.954+0.61x+19.014x^{0.5}+678.177e^{-x}$	0.9994