GEOSTATISTICAL ANALYSIS OF BATHING WATER QUALITY IN TURKEY

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ABSTRACT

GEOSTATISTICAL ANALYSIS OF BATHING WATER QUALITY IN TURKEY

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In this study geostatistical methods were applied to critically analyze historical bathing water quality (BWQ) data available for Turkish coastal areas. The specific objective of this study is the determination of the critical bathing sites of Turkey. In order to determine the critical bathing sites, a geostatistical method called indicator kriging is used via ArcGIS. Indicator kriging was applied using three microbial BWQ parameters, namely total coliforms (TC), fecal coliforms (FC) and fecal streptococci (FS) and threshold values set to the guideline concentrations given in the Turkish Bathing Water Quality Control Regulation (Official Gazette Notice 26048, 2006). The thresholds were 500 CFU/ 100 mL for TC and 100 CFU/100mL for both FC and FS. The critical bathing sites of each of the four coastal zones of Turkey; Mediterranean, Aegean, Marmara and Black Sea were determined regarding different 'critical condition' criteria defined for each coastal zone. For Marmara and Black Sea regions, which showed worse BWQ, this criteria is defined as the "bathing sites with >90% threshold exceedance probabilities at least three times in last two analysis periods". On the other hand, for coastal zones showing better profile this criteria is defined as "bathing sites with >70% threshold exceedance probabilities at least three times in last two analysis periods". The analyses conducted illustrated for Marmara, Mediterranean and Black Sea regions only one bathing site is classified as in critical condition and for Aegean region no critical areas were determined.

Keywords: GIS, Geostatistics, Kriging, Bathing Water Quality, Fecal Pollution

ÖZ

TÜRKİYE KIYI SULARINDA YÜZME SUYU KALİTESİNİN JEOİSTATİSTİKSEL ANALİZİ

Doğan, Nazlı Barçın
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Ağustos 2019, 295 sayfa

Bu çalışmada jeoistatistiksel yöntemler kullanılarak Türkiye kıyı sularındaki tarihsel yüzme suyu kalitesi (YSK) verileri analiz edilmiştir. Bu doğrultuda çalışmanın amacı; Türkiye kıyı sularındaki kritik YSK'ya sahip alanların jeoistatistiksel metotla belirlenerek olası risk faktörlerinin değerlendirilmesi olarak belirlenmiştir. Kritik yüzme alanlarının belirlenmesi amacıyla ArcGIS programının Jeoistatistiksel Sihirbaz eklentisinde de yer alan ve jeoistatistiksel bir yöntem olan indikatör kriging (IK) yöntemi kullanılmıştır. Limit aşma olasılıklarını gösteren haritaların oluşturulması için kullanılan sınır değerler, Yüzme Suyu Kalitesi Kontrolü Yönetmeliği'nde (26048 Sayılı Resmi Gazete, 2006) yer alan kriterler olarak belirlenmiştir. Bu çalışmada IK toplam koliform (TC), fekal koliform (FC) ve fekal streptokok (FS) olmak üzere üç mikrobiyolojik YSK parametresine uygulanmıştır. TC parametresi için sınır değer 500 CFU/100 mL, FC ve FS için ise 100 CFU/100 mL olarak belirlenmiştir. Analizler sonucunda Akdeniz, Ege, Marmara ve Karadeniz olmak üzere Türkiye'nin dört kıyı alanındaki kritik yüzme alanlarının belirlenmesi amaçlanmıştır. Kritik bölgelerin belirlenebilmesi amacıyla her kıyı bölgesi için farklı bir kriter belirlenmiştir. Marmara ve Karadeniz gibi daha kötü YSK durumuna sahip olan kıyı bölgelerinde bu kriter "limit aşma sınırının son iki analiz periyodunda en az üç kere %90'ı aşmış olması" şeklinde tanımlanırken, daha iyi YSK durumuna sahip olan Akdeniz ve Ege bölgelerinde bu kriter “limit aşma sınırının son iki analiz periyodunda en az üç kere %70’i aşmış olması” olarak tanımlanmıştır. Analiz sonuçları Marmara, Akdeniz ve Karadeniz bölgelerinde birer kritik bölge oldugunu gosterirken, Ege’de kritik alanın olmadığı dikkat çekmiştir.

Anahtar Kelimeler: CBS, Jeoistatistik, Kriging, Yüzme Suyu Kalitesi, Fekal Kirlilik

Dedicated to my beloved mother and in the memory of my brother…

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LIST OF ABBREVIATIONS

ASE	Average Standard Error
BLUE	Best Linear Unbiased Estimator
BSIMAP	Black Sea Integrated Monitoring and Assessment Programme
BWD	Bathing Water Directive
BWQ	Bathing Water Quality
CEP	Caribbean Environment Programme
CFU	Colony Forming Unit
EC	*Escherichia coli*
EU	European Union
FC	Fecal Coliforms
FS	Fecal Streptococci
GA	Geostatistical Analysis
GIS	Geographic Information System
IE	Intestinal Enterococci
IK	Indicator Kriging
LPI	Local Polynomial Interpolation
MAP	Mediterranean Action Plan
ME	Mean Error
MPN	Most Probable Number
MSE	Mean Standardized Error

MSFD	Marine Strategy Framework Directive
OK	Ordinary Kriging
PK	Probability Kriging
PSU	Practical Salinity Unit
RMSE	Root Mean Square Error
RMSSE	Root Mean Square Standardized Error
RSP	Regional Seas Programme
RWQ	Recreational Water Quality
RWQC	Recreational Water Quality Criteria
SDG	Sustainable Development Goal
SK	Simple Kriging
TC	Total Coliforms
TR	Republic of Turkey
UNEP	United Nations Environment Programme
US	United States of America
US EPA	United States Environmental Protection Agency
WFD	Water Framework Directive
WHO	World Health Organization
WWTP	Wastewater Treatment Plant

CHAPTER 1

INTRODUCTION

1.1. Background Information

Surface and coastal waters are used for many different purposes including transportation, recreational and leisure activities such as swimming, and fishing, hydroelectricity production, and as a receiving body of the effluent streams of treatment plants fed by domestic and/or industrial wastewaters. Not all of these activities are compatible with each other. The quality of water is especially important when it is used for recreational and leisure activities such as swimming, diving, sailing and fishing and a contaminated water may expose individuals to a number of different health hazards including pathogenic microorganisms. As water-based recreation is an extremely important component of tourism and a driving force in attraction of touristic activities throughout the world, there is a need to establish an effective water quality monitoring program for recreational waters. The importance of preserving good quality in bathing waters is already acknowledged by most countries in the world as poor bathing water quality (BWQ) may impact thousands of people adversely.

The studies on relationship between public health issues and environmental quality dates back to the 1970s. Between 1961 and 1970, due to direct interaction with water, 130 outbreaks of water borne diseases and 46,374 cases of illness were observed, only in the United States (Taylor Jr., Craun, Faich, McCabe, & Gangarosa, 1972) and between 1937-1986, 34 water borne disease outbreaks were recorded in the United Kingdom (Galbraith, Barrett, & Stanwell-Smith, 1987). In the following years, due to the increase in population and faster development of technology, the number of water-borne disease outbreaks showed an increasing trend. The number of outbreaks were increased by 5 times from 1978 to 2006 only in the US (Beach, 2007). Decision makers questioned the impacts of BWQ on these outbreaks and this led to a thorough examination of BWQ and its relation to public health. Gastroenteritis, diarrhea, swimmer’s itch, eye-ear-throat infections, cryptosporidiosis, giardiasis, leptospirosis and legionellosis are some common diseases associated with BWQ and many studies proved the solid relationship between such diseases and insufficient BWQ (Giampoli & Spica, 2014; WHO, 1997; WHO, 2003; Gouvernement du Québec, 2018; Prieto, et al., 2001; Pond, 2005; Papastergiou, et al., 2012; Wymer, 2007; King, et al., 2015). In some cases, these health effects reached to serious levels. BWQ related diarrhea rates were between 3 to 8% based on health surveys conducted in 2004-2005 in Germany and 9% in Canada between 1998-2012 (Wiedenmann, et al., 2006; Sanborn & Takaro, 2013). A study conducted in Spain, records skin and eye infection rates of 2 and 1.5%, respectively, out of 20,000 bathers in a contaminated bathing site (Kamizoulis & Saliba, 2004).

Pathogen microorganisms may originate from sewage, animal feces, solid wastes, wastewater discharges and also related to the meteorological events such as precipitation (Kelly, et al., 2018; WHO, 2010). Pathogen microorganisms are usually found in small quantities in contaminated waterbodies, however, impacts of them are observable regardless of their quantities. Direct testing of pathogens is unaffordable and impractical; therefore, indicator bacteria are monitored for fecal contamination assessments (US EPA & The Ocean Conservancy, 2006). Due to their relation to the water related illnesses indicator bacteria, namely, total coliforms (TC), fecal coliforms (FC), fecal streptococci (FS), *Escherichia coli* (EC) and intestinal enterococci (IE) are commonly used as BWQ parameters. The monitored BWQ parameters vary from country to country, and there are some differences in monitoring and regulatory practices. Regardless of the differences in the regional practices, BWQ monitoring aims to determine the degree of fecal pollution in bathing waters, if any. As the exposure to fecally contaminated bathing water increases, the number of bathers struggling from bathing water related diseases, such as gastroenteritis, increase (Figure 1.1) (WHO, 2001). This strong correlation between fecal contamination and the number of influenced bathers, dictates an accurate quantification of fecal contamination to avoid public health problems. Authorities must use monitored BWQ data to take necessary precautions to prevent an outbreak in case of a fecal pollution.

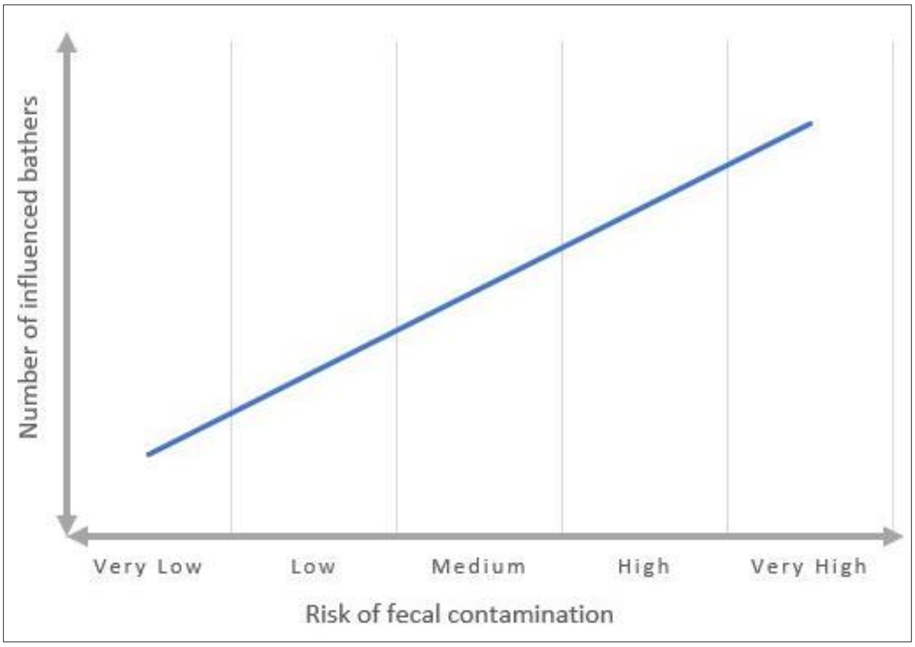


Figure 1.1. Correlation between the presence of fecal contamination and influenced bather number (Adopted from: WHO, 2001)

1.2. Problem Definition

BWQ monitoring activities are important however, costly especially for a country such as Turkey where three sides are covered by a coastline. To assess BWQ of Turkish coastline three microbiological BWQ parameters, namely, TC, FC and FS are monitored continuously throughout bathing season. For BWQ monitoring, samples are taken periodically from bathing sites determined by the Ministry of Health. The evaluation of the collected BWQ data is critical to take managerial action such as determining the need for restoration of a nearby wastewater treatment plant (WWTP), change of discharge location of a WWTP, opening other monitoring stations etc. however, discussion of these recorded data is the main concern to evaluate whether a bathing site is appropriate or not, or to determine if there is a requirement for management options such as restoration of WWTP discharge locations, additional collection of additional samples, evaluation of marinas located closer to bathing areas and so on.

Currently, BWQ evaluation practices in Turkey are conducted regarding a publicly available dataset which is provided in “http://yuzme.saglik.gov.tr” and the screenshot of the application showing the monitored bathing sites in Sinop coastline is provided in Figure 1.2.

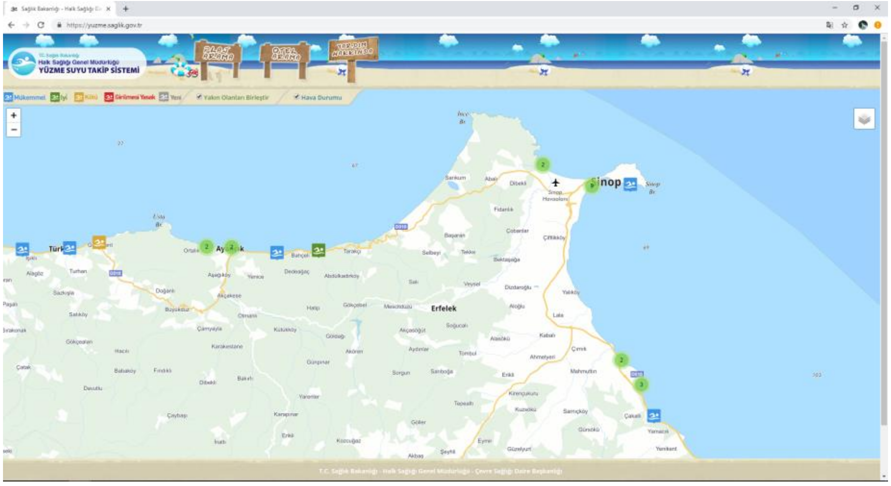


Figure 1.2. Monitored Bathing Sites along Sinop Coastline by Nationwide Bathing Water Monitoring System

As shown in Figure 1.2, this application provides a spatial BWQ point-wisely. Yet, the points specified by green with a number such as 2 or 9 shows that when users zoom in they can see the results of 9 other bathing sites in the region, which is not practical to evaluate the BWQ along a region since there can be unmonitored sites which can also be used for bathing. Therefore, rather than a discrete dataset as shown in Figure 1.2, spatially continuous BWQ dataset is more essential for elimination of potential public health risks.

A comprehensive spatio-temporal data analysis of BWQ, which enables the user to visualize the results on a map with a certain reliability is important. A method that enables the prediction of BWQ of the coastal areas lacking a monitoring station is extremely valuable to determine any potential health risks and the possibility of opening those areas for bathing in the future. Geostatistical analysis (GA) used in this study fills this important gap by providing visual maps showing the critical regions with insufficient BWQ together with an error prediction.

1.3. Objectives of the Study

Historical BWQ data was used in this thesis. The objectives are to determine the critical bathing sites of Turkey by adopting GA and discuss the possible reasons of insufficient BWQ in these critical regions.

1.4. Scope of the Study

This study was conducted along the coastline of Turkey, the coastal regions can be listed as Mediterranean, Aegean, Marmara and Black Sea coastlines. The data used in this study was obtained from the Ministry of Health – General Directorate of Public Health. Monitoring applications are conducted regarding the Bathing Water Quality Control Regulation and three microbial parameters, i.e. TC, FC and FS, were monitored periodically. The dataset used in this thesis belongs to the years between 1993 – 2018. Within the scope of this study, a geostatistical method called indicator kriging was used to predict the critical bathing areas. This method enables the prediction of BWQ in non-monitored locations using the data available for the monitored regions. As a result, probability maps referring to threshold exceedance probabilities of each coastal zone (both monitored and non-monitored) were determined. The error maps associated with the exceedance probability maps provides information about the accuracy of the estimations.

1.5. Structure of the Study

This thesis is organized as follows. In Chapter 2, mostly background information is provided and literature review on global practices on BWQ monitoring are summarized. It involves an extensive literature review including globally used BWQ monitoring parameters, historical development of BWQ monitoring applications in the developed countries such as US and in Turkey. In addition to literature review on

BWQ monitoring, Chapter 2 presents a general overview of geostatistical methods that are used in water quality studies. Kriging technique used in this thesis is detailed in this chapter. Chapter 3 comes up with the used methodology and describes the software used in this study. Results of this study is presented in Chapter 4, separately for each coastal zone, namely Mediterranean, Aegean, Marmara and Black Sea. Results of the analyses are also discussed in the same section comparatively with the relevant literature. In Chapter 5, conclusion section, overall evaluation of the study is provided and unlike Chapter 4, in this section brief comparison of different coastal zones takes place. In Chapter 6 recommendations for future studies is provided.

CHAPTER 2

LITERATURE REVIEW

2.1. Currently Used Bathing Water Quality Parameters

2.1.1. Microbiological Parameters

Sewage and feces are two main sources of fecal pollution and the most commonly used fecal indicators are TC, FS, IE, FC and EC. (WHO, 2001; Pepper, Gerba, & Gentry, 2015). Formerly, some other microorganisms were also used as BWQ indicators such as *Pseudomonas aeruginosa* (Foster, Hanes, & Lord, 1971), coliphages (Ibarluzea, et al., 2007) and *Clostridium perfringens* (Shibata, Solo-Gabriele, Fleming, & Elmir, 2004). *P. aeruginosa* is a pathogen microorganism itself and therefore, using it as an indicator microorganism required additional tests for other pathogens (Liang, et al., 2015). Also, studies revealed that *P. aeruginosa* has significant correlation with indicator microorganisms EC and FC (Liang, et al., 2015). *C. perfringens,* on the other hand, is still polemical. Some researchers defend the idea that EC or FC are more practical indicators since in a small contaminated region, concentration of these indicators is very high which is easy to investigate, however, others argue that *C. perfringens* is more persistent, therefore, selecting it as an indicator eliminates the time limitation since it is a more persistent species (Skanavis & Yanko, 2001; Bisson & Cabelli, 1980). Today, since most of the times concentration of *C. perfringens* is below the limit of detection, it is not preferred as an indicator microorganism and same applies to coliphages (WHO, 2001). In this part, those widely used BWQ assessment parameters, reasons lying behind their selection as BWQ criteria and relationship between their concentrations will be discussed. Quality classes based on the concentration of BWQ standards and globally adopted BWQ criteria are going to be presented later. Figure 2.1 provides the widely used indicator microorganisms and their taxonomic classification.

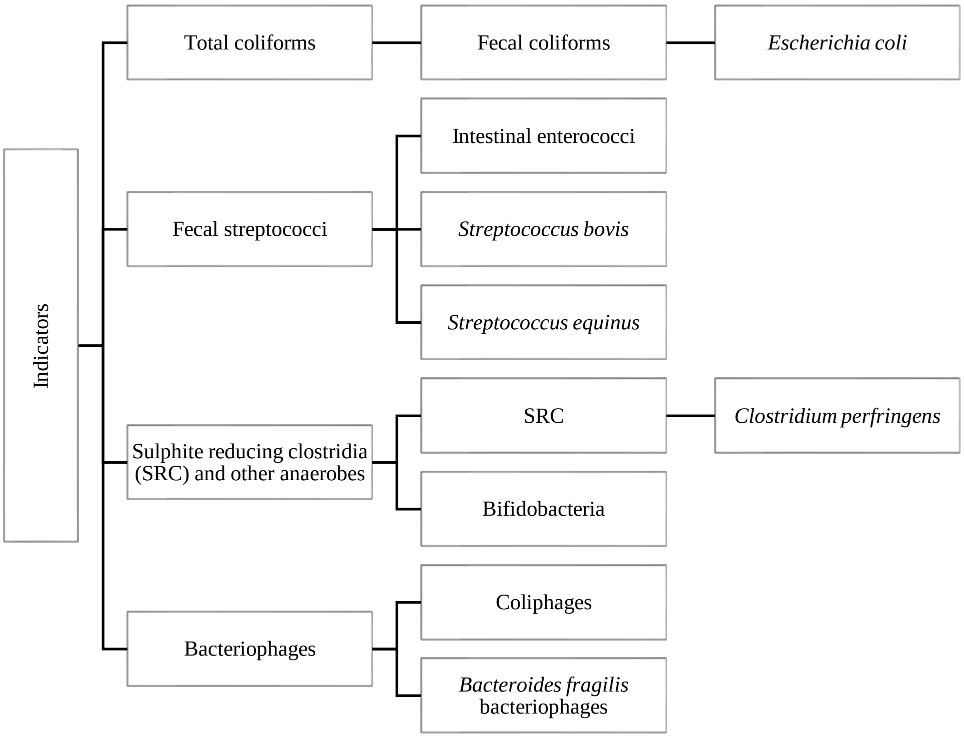


Figure 2.1. Widely used indicator microorganisms (Adapted from: WHO, 2001)

2.1.1.1. Total Coliforms

Total coliforms (TC) are used to identify the presence of pollution due to natural sources such as vegetation or soil, hence the presence of TC does not confirm fecal contamination (Washington State Department of Health, 2016). Therefore, although used in some countries TC is not a critical parameter most of the time, as fecal pollution is the main concern for BWQ (US EPA & The Ocean Conservancy, 2006). In many regulations regarding BWQ, such as 1976 version of the European Bathing Water Directive (BWD), TC is considered as a BWQ indicator (Kay & Fawell, 2007). However, in recent studies or revised regulations TC is mostly not included among the BWQ monitoring parameters (European Commission, 2006; US EPA, 2018c). On the other hand, the number of TC is a good indicator for measurement of wastewater treatment process' effectiveness, which makes TC a useful parameter in BWQ assessments in areas where wastewater treatment plants discharge their effluents to bathing waters (Lea, 1996; Bernasconi, Daverio, & Ghiani, 2003).

2.1.1.2. Fecal Coliforms

Fecal coliforms (FC) are a sub-group of TCs and together with fecal streptococci (FS) they form the two general groups of fecal contamination indicators. Thus, mostly this quality parameter is coupled with FS. The FC to FS ratio gives information about the source of pollution (i.e. human or non-human, Table 2.1) (US EPA, 2018d). As indicator microorganisms, FC are mainly used to point out the existence of *Salmonella spp.* (Francy, Myers, & Metzker, 1993), which is the main cause of gastrointestinal illnesses (diarrhea, fever, abdominal cramps and so on) (Giannella, 1996). Although, in most of the countries FC criteria for BWQ was replaced with EC, in some countries, such as Turkey, India, Brazil, Australia and New Zealand, FC is still used as fecal contamination indicators for bathing waters.

2.1.1.3. Escherichia Coli

E. coli (EC), a sub-group of FC, which is the most appropriate group of coliforms to indicate fecal pollution from warm-blooded animals and humans (WHO, 2001). In most of the current monitoring applications, including EU and US monitoring programs, rather than FC, EC is preferred as fecal indicator microorganism. This parameter gives more accurate results in determination of fecal contamination in freshwaters, since contribution of pathogens to EC concentration is higher than total or fecal coliform bacteria concentrations (US EPA, 2018d). In 1976 BWD, there were no criteria including this parameter but by 2006 revision, EC was listed as a monitoring parameter (European Commission, 2006).

2.1.1.4. Fecal Streptococci

Fecal streptococci (FS) are another group of fecal contamination indicator. They are commonly used to identify the source of pollution based on FC/FS ratio (Sinton, Donnison, & Hastie, 1993; US EPA, 2018d). Currently, intestinal enterococci (IE), a subgroup of FS, are used as BWQ monitoring parameter instead of FS in many countries including US, Canada, Australia and South Africa. Also, enterococci is accepted as BWQ parameter in EU Directive.

Table 2.1. *Sources of Fecal Pollution Depending on FC/FS Ratio (Gerba & Pepper, 2004)*

FC/FS Ratio	*Source of Pollution*
> 4.0	Strong evidence that pollution is of human origin
2.0 – 4.0	Good evidence of the predominance of human wastes in mixed pollution
0.7 – 2.0	Good evidence of the predominance of domestic animal wastes in mixed pollution
< 0.7	Strong evidence that pollution is of animal origin

2.1.1.5. Intestinal Enterococci

IE is one of the most common types of FS (WHO, 2001). According to Boehm and Sassoubre (2014), concentrations of enterococci measured in coastal recreational waters contaminated by wastewater treatment plant effluents were strongly correlated to the number of bathers that struggle from gastrointestinal illnesses. Even though in 1976 European BWD enterococci was not considered as a monitoring parameter, in 2006 version, FS was replaced with IE (European Commission, 1976; European Commission, 2006). Studies show that by using IE as indicator microorganism, fecal pollution can be identified more accurately in marine environment, i.e. salt water (US EPA, 2018d). In fact, enterococci, intestinal enterococci and fecal streptococci usually refer to same parameter in BWQ monitoring and only one of them is used as BWQ parameter (Table 2.2).

All five of these parameters are currently used around the world, however, studies show that EC and IE are more precise indicators, since most of the pathogens are classified under these two indicators and they are subgroups of FC and FS (Georgiou & Bateman, 2005). For example, 2006 revision of BWD required replacement of previous parameters (i.e. TC, FC and FS) with EC and IE. Table 2.2 provides the monitored parameters in BWQ monitoring programs of several countries.

Table 2.2. BWQ Monitoring Parameters in Different Countries

Countries/ Legislations	_BWQ Monitoring Parameters_*				
	TC	*FC*	*FS*	*IE*	*EC*
Albania				✓	✓
Argentina				✓	✓
Australia and New Zealand				✓	✓
Bosna and Herzegovina	✓				
Brazil		✓		✓	✓
Canada				✓	✓
Egypt	✓		✓		✓
EU				✓	✓
Hong Kong					✓
India	✓	✓	✓		
Israel		✓		✓	
Japan				✓	
Lebanon	✓				✓
Libya		✓			
Malaysia	✓	✓			
Montenegro				✓	✓
Morocco			✓		✓
North Macedonia	✓	✓	✓		
South Africa				✓	✓
Switzerland				✓	✓
Syria		✓			
Tunisia	✓	✓	✓		
Turkey	✓	✓	✓		
US				✓	✓

*TC: Total coliforms, FC: Fecal coliforms, FS: Fecal streptococci, EC: *E. coli*, IE: Intestinal enterococci

In our study, mostly developed and developing countries were selected and BWQs used in 51 countries out of 241 countries were analyzed (Figure 2.2). In Figure 2.2

“NI” indicated the countries whose BWQ standards are not included and “1 parameter” refers to countries those are using only one parameter for BWQ monitoring. The “1 parameter” may refer to different parameters depending on the country in question, for example, it is TC in Bosnia and Herzegovina, EC in Hong Kong, IE in Japan, and FC in Libya and Syria. Canada, Australia and New Zealand also classified as “1 parameter” countries, since, they monitor only IE for marine waters and only EC for freshwaters.

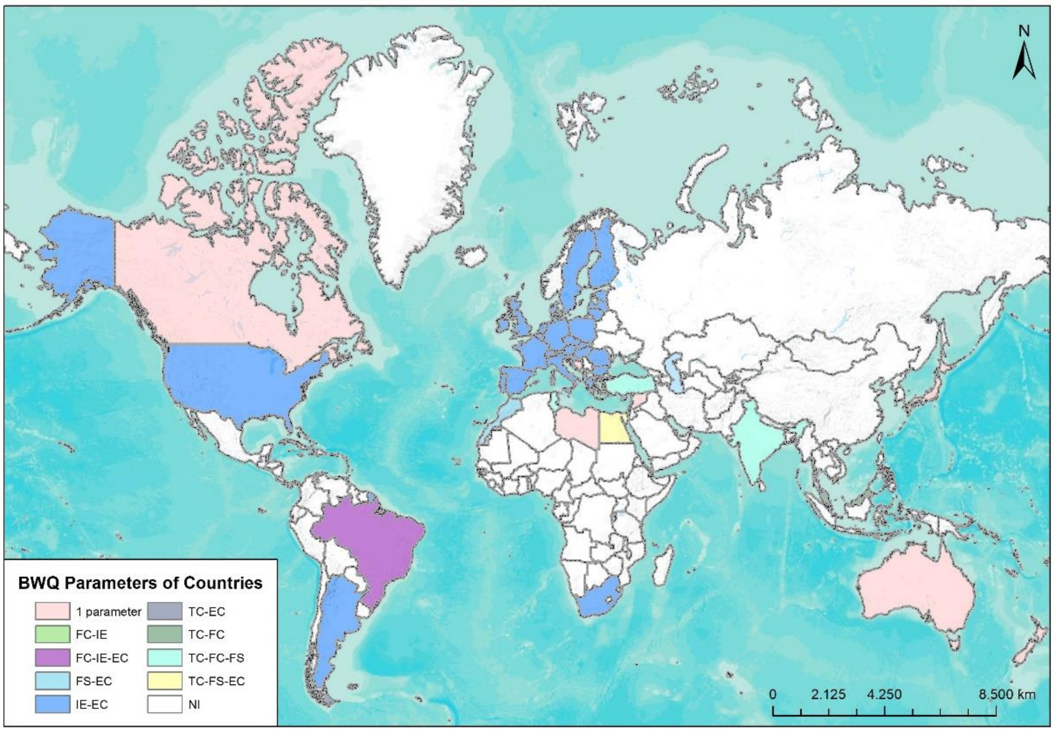


Figure 2.2. BWQ Parameters of Various Countries

Out of 51 countries, 33 countries, including all EU countries, use IE coupled with EC, 4 countries (North Macedonia, India, Tunisia and Turkey) use TC, FC and FS for BWQ monitoring. Other 6 countries adopt unique combination for BWQ parameters in their related legislations. For example, Malaysia monitors TC and FC for BWQ assessment, on the other hand, Egypt collects data for TC, FS and EC parameters, Brazil monitors FC, IE and EC, Lebanon assesses TC and EC concentrations for BWQ investigations, Israel monitors FC and IE to evaluate BWQ and Morocco considers FS and EC. Figure 2.3 shows the adoption percentages of each parameter out of 51 countries.

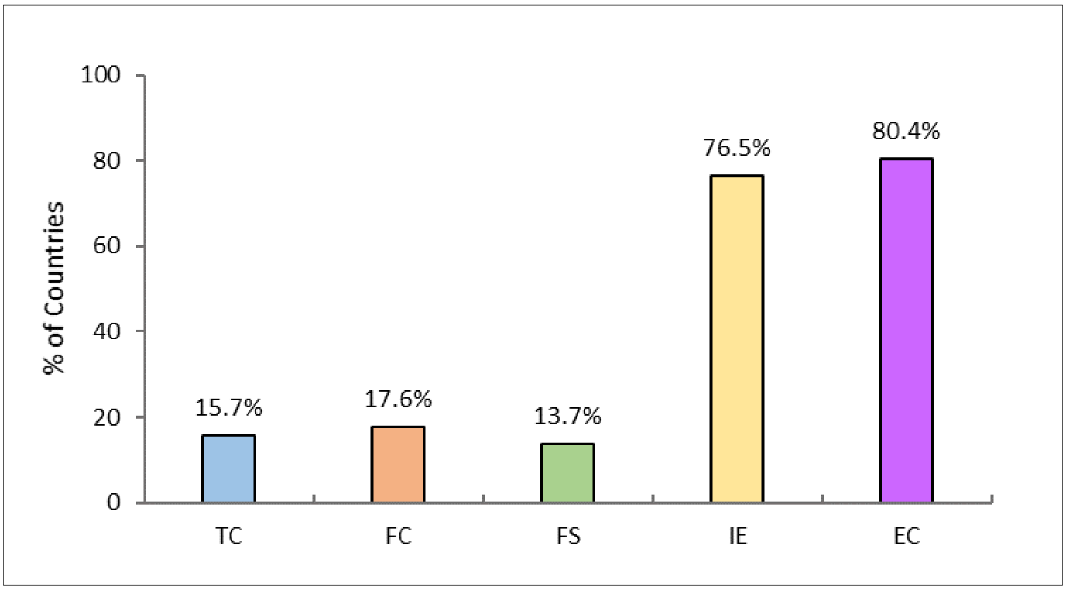


Figure 2.3. Percent of Countries Using Each BWQ Parameter (out of 51 countries)

According to Figure 2.3, IE and EC are most preferred BWQ monitoring parameters among the countries analyzed here, the reason is that European BWD requires monitoring of this combination. Also, some EU candidate countries and countries which accommodate tourists mostly from Europe, such as Montenegro and Albania monitor IE and EC for BWQ assessment.

2.1.2. Other Monitoring Parameters

Primary parameters recognized during discussion of BWQ are usually microbiological parameters, yet, there are some other non-microbiological parameters monitored within the context of BWQ monitoring applications. 1976 BWD, proposed BWQ criteria including physico-chemical parameters such as pH, nutrients, dissolved oxygen, heavy metals, transparency, mineral oils, phenols, surfactants, pesticides and cyanide (European Commission, 1976). WHO, also recommends monitoring of these physico-chemical parameters in addition to monitoring of aesthetic concepts such as odor, color, litter and so on, and additional microbiological parameters like algae and cyanobacteria, and biological parameters such as shellfish (WHO, 2003).

2.2. Historical Development of Bathing Water Quality Monitoring Practices and Global Legislative Framework

2.2.1. United States

The significance of microbial quality of recreational waters was first considered in 1922 by American Public Health Association’s (APHA) Committee on Bathing Beaches (Dufour and Schaub (Wymer, 2007). In 1924, the Committee published a report which highlights that existing information on bathing water are not enough for development of standards because collected data and monitoring points are limited to make conclusions on the relation of standardized microorganism concentrations and public health issues (Wymer, 2007). It was not until 1932 when a study conducted in Connecticut constituted the basis of bathing water quality standards Foster, et al. (1971). In the 1932 study W. J. Scott established microbiological standards for bathing waters, which provided classification of BWQ from excellent to unsatisfactory based on coliform content of evaluated water body (Foster, Hanes, & Lord, 1971; Scott, 1951). Table 2.3 provides the first ever known recommended microbial BWQ criteria.

Table 2.3. *Recommended Bacteriological Standards for Bathing Waters as Established by Scott in 1932 (Foster, Hanes, & Lord, 1971)*

Class	Coliforms/100 ml	Sanitary Description
A+	0 – 10	Excellent
A-	11 – 50	Good
B	51 – 500	Fair
C	501 – 1000	Satisfactory
D	>1000	Unsatisfactory

Although, Scott’s study is a milestone in the development of BWQ criteria, up to 1948 epidemiological evidences were insufficient for proposal of recreational water quality standards. In 1948, The Federal Water Pollution Control Act, also known as the Clean Water Act, was responsible from evaluation of water resources, however, there was no specified actions for BWQ. It was only a law used to address the presence of water pollution (US EPA, 2018a). Between 1948 and 1950 US National Technical Advisory Committee (NTAC) collected epidemiological data for the purpose of BWQ evaluation. In 1965, by Water Quality Act recognized that water quality may also be important for swimming waters (Poe, 1995). Later, in 1968, NTAC proposed regulatory BWQ standards for the first time as a result of epidemiological data collection studies conducted between 1948 – 1950. Four years later, in 1972 US Environmental Protection Agency (EPA) investigated the correlation between BWQ and infectious diseases by a long-term recreational water quality monitoring program (Dufour, 1984). Correspondingly, due to increasing public health issues, requirement for a revision in Clean Water Act has become a must and in 1972 it was updated and EPA’s authority on water resources was enlarged and a long-term recreational water quality monitoring program was established (US EPA, 2018a; Dufour, 1984; US EPA, 2002).

In 1986, first US Recreational Water Quality Criteria (RWQC) were published with the title of “Bacteriological Ambient Water Quality Criteria for Marine and Fresh Recreational Waters”. It was the first national criteria for the US and consists of only microbial quality elements (US EPA, 1986). However, 1986 regulation did not consider non-gastrointestinal illnesses, such as skin, eye, ear infections, or acute febrile respiratory illnesses as BWQ related public health issues which was an important gap (Boehm, et al., 2009). After that, in 2000, Beaches Environmental Assessment and Coastal Health Act, shortly the BEACH Act, was signed into law and a regular program on BWQ monitoring was started. This action plan aims to investigate pathogens and their indicators in recreational waters to develop proper management strategies and improve environmental quality by decreasing health risks depending on BWQ (US EPA, 2018b).

Then in 2004, RWQC was revised for the first time and based on this revision each state became responsible for determining and monitoring its own criteria for BWQ (US EPA, 2004). Considering the latest scientific knowledge, technological development and public comments, in 2012, RWQC is updated again and tools used for assessing and managing recreational waters improved and diversified by this update. Also, preparation of a five-year review has become requirement which should include current research studies and technological developments on the topic (US EPA, 2012a; US EPA, 2012b). In 2018, first five-year review published, which explains actions those are taken during 2012 – 2017 period (US EPA, 2018c). Effects of the 2012 revision have still not been reported, however, it is expected to observe solid improve in BWQ of US beaches (US EPA, 2012b). Table 2.6 provides the recreational water quality criteria for US.

2.2.2. Europe

In Europe, on the other hand, there is no similar study to Scott's which lay the foundations of BWQ standards. United Kingdom (UK) took the leading role in BWQ monitoring/assessment activities in Europe. In late 1920s, beach pollution was investigated as an important sanitation problem around UK beaches, there were massive amounts of liquid and solid waste disposals to bathing waters (Hassan, 1999). In 1936, typhoid epidemic outbreak was observed in Bournemouth, UK, where there is a high potential of recreational water use (Hassan, 2003). In this outbreak, approximately 1000 people were infected, and 57 of them died (Hassan, 2003). Poor BWQ was one of the main reasons in this tragic event, as a result the importance of BWQ on public health was highlighted.

In 1960, Coastal Anti-Pollution League (CAPL) was established in UK as a non-governmental organization initiated by J.A. and Daphne Wakefield, who lost their daughter after bathing in polluted sea water (John, 2000). According to Hassan (1999), the league was one of the first environmental pressure groups which rises awareness on correlation between insufficient BWQ and public health issues. CAPL pressured the government to compile a BWQ monitoring program to prevent new deaths and as a result the "Golden List of Clean Beaches" of England and Wales was announced by the government (Hassan, 2003). This program included only beaches where the coliform density was less than 10,000 / 100 ml. Also, no litter or flies was a pre-condition to be ranked in the list and the beaches where sewage disposal occurred were placed in the "Black List" (Hassan, The Seaside, Health and the Environment in England and Wales since 1800, 2003; Foster, Hanes, & Lord, 1971).

BWQ monitoring applications in UK inspired continental Europe and in 1970s studies for development of a Bathing Water Directive was launched by European Commission. As a result, in 1976, European Commission published the "Council Directive of 8 December 1975 concerning the quality of bathing water (76/160/EEC)" (Kamizoulis & Saliba, 2004; Kay & Fawell, 2007; European Commission, 1976).

In 1976, European Commission implemented "Council Directive of 8 December 1975 concerning the quality of bathing water (76/160/EEC)" (Kamizoulis & Saliba, 2004; Kay & Fawell, 2007), which is the first EU Directive on BWQ. In this Directive standards for both microbiological and physico-chemical parameters determined. TC, FC, FS, *Salmonella spp.* and enteroviruses were microbial BWQ parameters used in 1976 BWD (Table 2.4). Color, pH, mineral oils, transparency, dissolved oxygen, ammonia and pesticides are some physico-chemical parameters measured within the scope of 1976 BWD (European Commission, 1976). Mandatory values in BWQ criteria shown in Table 2.4 refer to criteria where the 95% of samples should satisfy and guide values represent the criteria which should be satisfied for 80% of TC and FC, and 90% of FS (European Commission, 1976). If the mandatory values are exceeded, then bathing in relevant location become unhealthy, therefore, should be banned.

Table 2.4. *1976 Bathing Water Directive Microbiological Criteria* (European Commission, 1976)

Parameters	*Guide*	*Mandatory*	*Minimum Sampling Frequency*
Total Coliforms /100 ml	500	10,000	Fortnightly (1)
Fecal Coliforms /100 ml	100	2,000	Fortnightly (1)
Fecal Streptococci /100 ml	100	-	(2)
Salmonella /1 liter	-	0	(2)
Entero viruses PFU/10 liters	-	0	(2)

(1) When a sampling taken in previous years produced results which are appreciably better than those in this Annex and when no new factor likely to lower the quality of the water has appeared, the competent authorities may reduce the sampling frequency by a factor of 2.

(2) Concentration to be checked by the competent authorities when an inspection in the bathing area shows that the substance may be present or that the quality of the water has deteriorated.

Later, in 1994, the Directive Council published a proposal with the objective of revising 1976 BWD. According to this Proposal adaptation of Directive to scientific and technical progress is necessary and a revision was a requirement. The Proposal stated that the number of parameters should be reduced, since microbial parameters are sufficient for evaluation of public health risks. Therefore, it was decided that elimination of physico-chemical parameters is an appropriate change. In addition to elimination of physico-chemical parameters, the number of microbial parameters were also reduced. Withdrawal of TC and *Salmonella*, replacement of enteroviruses with bacteriophages, and FC with EC, and also addition of presence of sewage solids parameter was recommended (European Commission, 1994). An update on threshold values for FS were also discussed, but current threshold values were found as "sufficient" and revision was found as unnecessary (Bernasconi, Daverio, & Ghiani, 2003). The objective of the revision was basically the improvement of cost-effectiveness and utilization of more precise BWQ assessment (European Commission, 1994). According to European Parliament, estimated administrative expenses were very high to accomplish this revision and information provided in the Proposal was insufficient, therefore, the proposal was rejected (European Parliament, 1996).

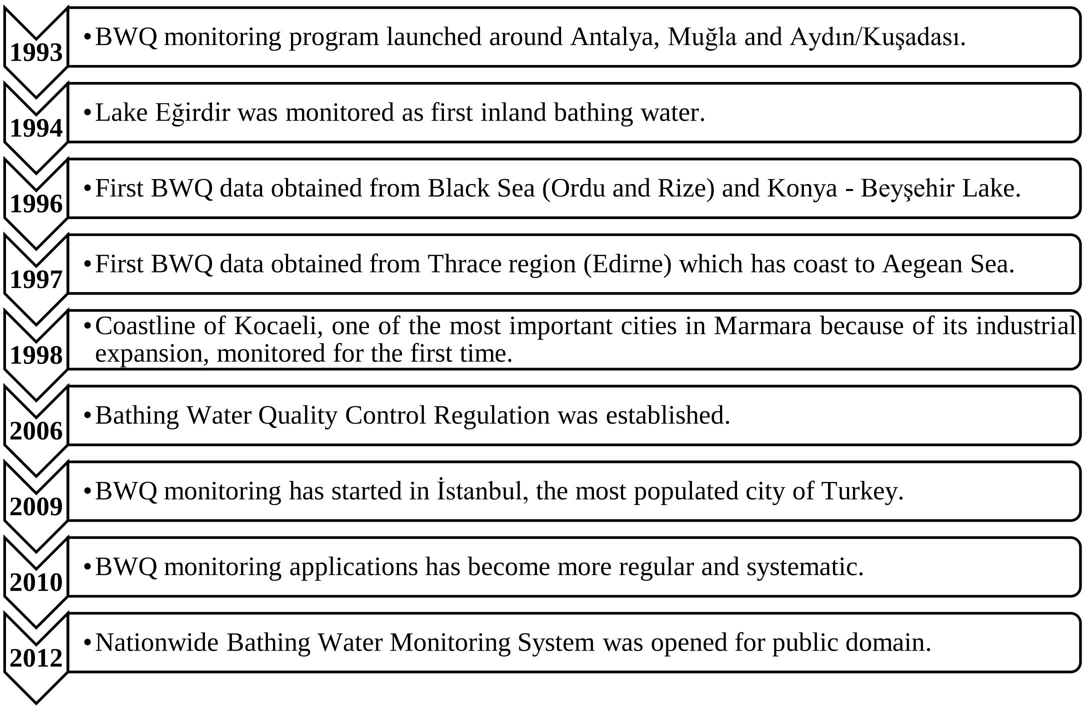
In 2000 “Communication from the Commission to the European Parliament and the Council (COM (2000)” was published. The main scope of this Communication was to launch a brainstorming session with all related parties and stakeholders to develop a new BWD. In this document, it was stated that “It will look not only at monitoring water quality but also at actively tackling pollution sources, in particular wastewater discharges and agricultural run-off. These sources will also have to be marked and addressed in the river basin management plans foreseen in the Water Framework Directive.” (European Commission, 2000). By the help of this action, it is aimed to adopt more integrative approach in BWQ monitoring, since environmental stresses such as pollutant discharges and other diffused pollution sources threaten BWQ and public health. Based on COM (2000), a new proposal, entitled “Proposal for a Directive of the European Parliament and of the Council concerning the quality of bathing water” was published in 2002. Within the context of this Proposal, widespread surveys were conducted to determine the general opinion of Europeans on environmental issues, especially on recreational water resources. As a result, it has been observed that 71 % of the were Europeans concerned about the deterioration of the quality of natural resources and they believed that current BWD is insufficient about BWQ monitoring and management. Therefore, publication of a new BWD became an obligation (European Commission, 2002). Based on 2002 Proposal, “Directive 2006/7/EC of the European Parliament and of the Council of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC” published in 2006. This version of the Directive is in force since 2008.

Member states have been implementing this version of the Directive since 2008. Revised points in the Directive are going to be discussed in next parts.

2.2.3. Turkey

Turkey is a Mediterranean country with a high beach tourism potential due to climatic conditions (Republic of Turkey Ministry of Culture and Tourism, 2019). Turkey is also a candidate state sustaining the studies required for EU integration. As a semi-island country, development of BWQ assessment is also a part of EU integration process. Besides the economic, environmental and public health aspects, monitoring of BWQ is also important for this integration process. For this purpose, 1976 version of European BWD has been adapted to Turkish Legislation as Bathing Water Quality Control Regulation (Yüzme Suyu Kalitesi Kontrolü Yönetmeliği) in 2006.

BWQ monitoring in Turkey was first started in 1993 around Antalya, Muğla and Aydın/Kuşadası, which are the most popular tourism locations. Therefore, data used in this study trace to 1993. In 2010, data collection activities become more systematic and this improvement in monitoring activities directly affected the quality of measurements. In 1993, there were 177 monitoring points, however, in 2017 this number increased up to 1250 and currently there are monitoring points in all bathing areas. Figure 2.4 shows the historical development of BWQ monitoring network in Turkey.



1993	• BWQ monitoring program launched around Antalya, Muğla and Aydın/Kuşadası.
1994	• Lake Eğirdir was monitored as first inland bathing water.
1996	• First BWQ data obtained from Black Sea (Ordu and Rize) and Konya - Beyşehir Lake.
1997	• First BWQ data obtained from Thrace region (Edirne) which has coast to Aegean Sea.
1998	• Coastline of Kocaeli, one of the most important cities in Marmara because of its industrial expansion, monitored for the first time.
2006	• Bathing Water Quality Control Regulation was established.
2009	• BWQ monitoring has started in İstanbul, the most populated city of Turkey.
2010	• BWQ monitoring applications has become more regular and systematic.
2012	• Nationwide Bathing Water Monitoring System was opened for public domain.

Figure 2.4. Timeline of Development of BWQ Monitoring Network in Turkey (General Directorate of Public Health, 2018)

2.3. Currently Applied Bathing Water Quality Monitoring Practices

2.3.1. European Union

According to Water Framework Directive (WFD), bathing waters are classified as protected areas, which should be protected from environmental stresses such as pollution discharges and agricultural runoffs (European Commission, 2000). Therefore, reaching good environmental status has priority for bathing water. For this purpose, European Commission published BWD for defining the BWQ standards and monitoring measures. Also, it should be highlighted that BWD should be implemented based on both WFD and Marine Strategy Framework Directive (MSFD) (European Commission, 2000; European Commission, 2008). As stated in Chapter 2.2.2 in 2006, BWD was revised to improve monitoring and management measures in a cost-effective way. Therefore, "Directive 2006/7/EC of the European Parliament and of the Council of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC" published in 2006. This version of the Directive is in force since 2008. By this revision number of monitored microbiological parameters were reduced to two, FC parameter was replaced by EC and FS parameter was replaced by IE (Table 2.5). Also, different thresholds were determined for inland and coastal bathing waters. Moreover, monitoring of physico-chemical parameters were eliminated as recommended in 1994 Proposal, and four BWQ classes were defined, namely poor, fair, good and excellent. Also, recommendations for beach management options were also provided to improve BWQ (European Commission, 2006). Today, in addition to 28 EU countries, Switzerland, Albania and Montenegro implement BWD (2006/7/EC) (EEA, 2018; Morsko Dobro, 2017).

Table 2.5. *European Bathing Water Directive Quality Standards (European Commission, 2006)*

Parameter	*Water Resource*	*Excellent Quality*	*Good Quality*	*Sufficient*
Intestinal enterococci (cfu/100 ml)	Inland waters	200*	400*	330**
	Coastal and transitional waters	100*	200*	185**
Escherichia coli (cfu/100 ml)	Inland waters	500*	1000*	900**
	Coastal and transitional waters	250*	500*	500**

**Based upon a 95-percentile evaluation.*
***Based upon a 90-percentile evaluation.*

After the revision of the directive, some researchers investigated its impacts on BWQ. For example, Mansilha, et al. (2009), investigated the impacts of revision on monitoring and assessment of BWQ by measuring both old parameters, i.e. TC, FC and FS, and current parameters, i.e. IE and EC, in 25 coastal beaches in Portugal. The results showed that there was a strong correlation between FC - EC, and FS – IE (Manshilha, Coelho, Heitor, Amado, & Martins, 2009). Although, they give similar results by means of BWQ, FC and FS are large groups of microorganisms which may carry bacteria from some environmental resources other than sewage or animal feces. In addition to more precise BWQ determination, revision of BWD also provided some economic benefits. There were records showing support to the revised BWD (2006) as the estimations showed medical and care-giving and work costs will be lowered due to decrease in recreational water related illnesses (Georgiou & Bateman, 2005). However, currently there is no study revealed that the medical costs are lowered after BWD revision, it is still a foresight.

2.3.2. United States

As mentioned in Chapter 2.2.1 considering the latest scientific knowledge, technological development and public comments, in 2012, RWQC is updated and tools used for assessing and managing recreational waters improved and diversified by this update. Also, preparation of a five-year review has become requirement which should include current research studies and technological developments on the topic

(US EPA, 2012a; US EPA, 2012b). In 2018, first five-year review published, which explains actions those are taken during 2012 – 2017 period (US EPA, 2018c). Effects of the 2012 revision have still not been reported, however, it is expected to observe solid improve in BWQ of US beaches (US EPA, 2012b). Table 2.6 provides the recreational water quality criteria for US.

Table 2.6. *US Recreational Water Quality Criteria (US EPA, 2012a)*

Criteria Elements	*Estimated Illness Rate (NGI*): 36 per 1,000 primary contact recreators*		*OR*	*Estimated Illness Rate (NGI*): 32 per 1,000 primary contact recreators*	
	Magnitude			*Magnitude*	
Indicator	GM* (cfu/100 ml)	STV* (cfu/100 ml)		GM* (cfu/100 ml)	STV* (cfu/100 ml)
Enterococci – marine and fresh	35	130		30	110
E. coli - fresh	126	410		100	320
Duration and Frequency: The waterbody GM should not be greater than the selected GM magnitude in any 30-day interval. There should not be greater than a ten percent excursion frequency of the selected STV magnitude in the same 30-day interval.					

**GM: Geometric mean, STV: Statistical threshold value, NGI: NEEAR – GI illness (National Epidemiological and Environmental Assessment of Recreational Gastrointestinal illness)*

2.3.3. Turkey

In January 2006, BWD (76/160/EEC) was adapted by former Ministry of Environment and Forestry to Turkish Legislation as Bathing Water Quality Control Regulation (Official Gazette Notice 26048, 2006; T.R. Ministry of Health, 2008), which provide receiving body standards rather than discharge standards, unlike other water quality related legislations, namely, Water Pollution Control Regulation and Regulation on Urban Wastewater Treatment.

Turkey aims to improve legislative context on BWQ by evaluating cost-effectiveness of BWD (2006/7/EC) (Yükseler, et al., 2009; T.R. Ministry of Health, 2008). Fecal pollution related microbiological BWQ criteria limits adopted by Turkey is provided in Table 2.7, which is applicable to all bathing waters nationwide both inland and coastal. Please note that there are other parameters in the BWQ regulation (full list given in Appendix, Table B-1), however, within the scope of this thesis only three parameters listed in Table 2.7 were considered. All of the analyses conducted in this study, considered guideline values indicated in Table 2.7.

Table 2.7. *Microbial BWQ Monitoring Criteria for Turkey (Official Gazette Notice 26048, 2006)*

Parameter	*Criteria (cfu/100 mL)*	
	Guideline[*]	*Mandatory*[**]
Total Coliforms	500	10,000
Fecal Coliforms	100	2,000
Fecal Streptococci	100	1,000

[*] *95% of samples should satisfy mandatory values for all BWQ parameters*
[**] *80% of samples should satisfy guide values for TC and FC, 90% of samples should satisfy guide values for FS*

Similar to 1976 version of BWD, Turkish BWQ legislation also recommend 95% of samples should satisfy mandatory values and guide values represent the criteria which should be satisfied for 80% of TC and FC, and 90% of FS. Sample collection procedure is started 15 days prior to beginning of bathing season and samples are collected fortnightly. However, if any concrete pollution source such as wastewater discharges around sampling point is investigated, then additional samples are also collected and evaluated. In order to collect representative samples a repeatable and easy to conduct protocol is used. Samples are taken from 0.3 m depth below the water surface and at the distance from the coastline in which depth of the bathing site reaches to 1 m (General Directorate of Public Health, 2008). Also, samples are taken within the bathing period to represent if there is a risk of bathing water related public health issues (General Directorate of Public Health, 2008). Membrane filtration method is used to count the colonies of indicator microorganisms (Official Gazette Notice 26048, 2006).

Monitoring sites are determined by a commission consists of provincial institution representatives, such as municipality competent, provincial directorate of environment and urbanization officials, provincial directorate of health officials and nongovernmental organizations, under governor. Currently, information regarding monitored sites are released to public by The Nationwide Bathing Water Monitoring System website. The Nationwide Bathing Water Monitoring System is made available to public, free of charge and an example of the shared map is shown in Figure 2.5.

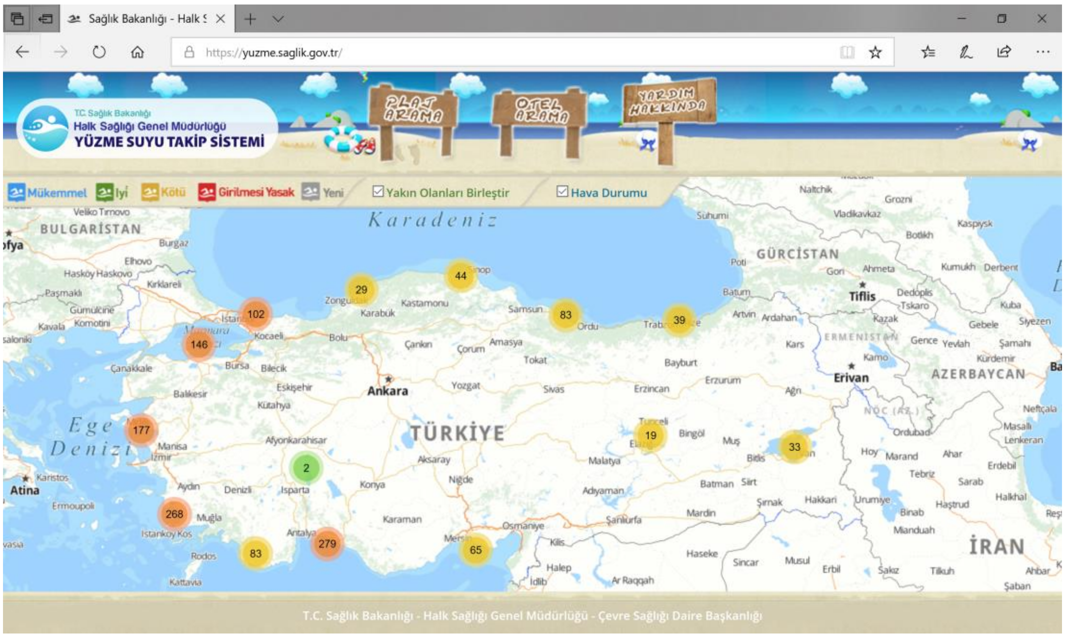


Figure 2.5. Nationwide Bathing Water Monitoring System (General Directorate of Public Health, 2019)

2.3.4. Other Countries

Other than European countries and US, there are also some coastal countries which developed their own BWQ criteria. Australia, New Zealand, Canada and South Africa are some developed countries with BWQ monitoring programs. As island continental countries Australia and New Zealand have same BWQ monitoring guidelines and criteria. Australia is a country composed of territories which leads each state to develop its own monitoring program (ANZECC & ARMCANZ, 2003). For example, New South Wales state have a BWQ monitoring program named as Beachwatch (NSW Government, 2018). This program provides information about BWQ classes of beaches by the help of geographic information system (NSW Government, 2018). This program is open to public view, which increases public awareness about BWQ and encourages people to use beaches in a clean way (NSW Government, 2018). Australia and New Zealand mainly adopt BWQ criteria recommended by WHO, although, BWQ guidelines of Australia and New Zealand handle marine and freshwater recreational waters, separately. Both governments accept IE as marine and EC as freshwater BWQ monitoring parameter. Also, in Australia and New Zealand guidelines, 3 BWQ states are defined with color codes, i.e. surveillance (green), alert (amber) and action (red). Relevant actions which should be taken in each state are also provided in the guidelines (ANZECC & ARMCANZ, 2003). For example, banning the contact of recreational water and delivering this information to public by newspapers, radio, notices delivered through shops are widely used methods to deliver relevant information to public (ANZECC & ARMCANZ, 2003).

Canada is another developed country which developed its own BWQ standards, even though the country is often associated with cold climate, southern region of the country is a proper region for recreational activities (Government of Canada, 2019). Similar to Australia and New Zealand, Canada also has territories, but unlike Australia and New Zealand in this case, each territory has its own BWQ criteria which is provided in Table 2.8 (Canada Ministry of Health, 2012). Most of the Canada territories consider IE and EC as BWQ monitoring parameters. Intestinal enterococci are mostly used in BWQ determination of marine waters, on the other hand EC is used to assess BWQ of freshwaters in Canada (Table 2.8).

Table 2.8. *BWQ Monitoring Parameters in Canada Territories (Swim Drink Fish Canada, 2017)*

Territory	EC	IE	FC
British Columbia	+	+	-
Alberta	-	-	+
Saskatchewan	+	-	-
Manitoba	+	-	-
Ontario	+	-	-
Québec	+	+	-
New Brunswick	+	+	-
Prince Edward Islands	+	-	-
Nova Scotia	+	+	-
Newfoundland and Labrador	Beaches are not monitored routinely.		
Nurnavut, Northwest Territories and Yukon	Monitoring is conducted on an as-needed basis.		

In addition to Australia, New Zealand and Canada, South Africa also has its own standards on BWQ which is related to WHO standards. As a warm climate country, South Africa coasts are popular tourism destination. Therefore, country adopts comprehensive guidelines on beach management measures and microbial BWQ criteria (eThekwini Municipality, 2019). South Africa Government also monitors IE and EC depending on WHO suggestions (Government of South Africa, 1996). There are also some other developed and developing countries which adopt BWQ criteria. Table 2.9 shows BWQ indicators and regulatory criteria for different countries.

There are also some non-EU countries which apply BWD. North Macedonia is also a European but non-EU country applying 1976 BWD. Although, it has no coastal waters, some of the inland waters in the country are used for recreational purposes. Ohri, Struga, Trpejca, Ljubaništa are some important lakes that are also used for bathing/recreational purposes. Therefore, North Macedonia also adapted 76/160/EEC to its own national legislative procedure on BWQ (Republic of Macedonia, 2018).

India is another country which has high potential of recreational water use. In addition to bathing/swimming purposes, religious ceremonies and cultural tourism increase the significance of monitoring BWQ of both inland and coastal water resources. Although, studies conducted in India are not enough for comprehensive discussion on BWQ, a legislative procedure exists for BWQ monitoring in the country. In 2015, Indian Government published a notification on BWQ monitoring and adopted standards in this notification are criteria stated by BWD (76/160/EEC) (Government of India Ministry of Environment, Forest and Climate Change, 2015).

Table 2.9. *Microbial BWQ Parameters Regulatory Limits for Some Coastal Countries*

Countries/ Legislations	*Parameters*						
	TC	*FC*	*FS*	*IE*	*EC*	*Remarks*	*Reference*
Argentina	-	-	-	33	126	Geometric mean of the samples should not exceed given values.	(Government of Argentina, 2017)
Australia and New Zealand	-	-	-	280	-	Marine water	(ANZECC & ARMCANZ, 2003)
	-	-	-	-	550	Freshwater	
Bosna and Herzegovina	500	-	-	-	-	Coastal	(Government of Bosnia and Herzegovina, 2013)
	2000					Inland	

Countries/ Legislations	Parameters						
	TC	*FC*	*FS*	*IE*	*EC*	*Remarks*	*Reference*
Brazil	-	1000	-	100	800	Given values are the minimum requirements.	(Lamparalli, Pinto, Camolez, Sato, & Hachich, 2013)
EU[1]	-	-	-	185	500	Coastal	(European Commission, 2006)
				330	900	Inland	
Canada	-	-	-	35	-	Coastal	(Canada Ministry of Health, 2012)
				-	200	Inland	
Egypt	500	-	100	-	100	-	(EEAA, 2000)
Georgia	-	200				Freshwater	(GAEPD, 2015)
		100				Coastal	
Hong Kong					180	-	(Government of Hong Kong, 2018)
India	50	1.8	1.8	-	-	Criteria is given in terms of MPN/100 ml.	(Government of India Ministry of Environment, Forest and Climate Change, 2015)
Israel	-	400	-	105	-	-	(State of Israel, 2002)
Japan	-	-	-	1000	-	Rather than enterococci, colon bacillus is used as indicator.	(Government of Japan, 2018)
Lebanon	500	-	-	-	100	-	(Lebanon Ministry of Energy and Water, 2012)
Libya	-	100	-	-	-	50% of data	(UNEP, MAP, & WHO, 2010)
		1000				90% of data	
Malaysia	5000	400	-	-	-	-	(Government of Malaysia, 1999)
Morocco	-	-	100	-	2000	-	(UNEP, MAP, & WHO, 2010)
North Macedonia[2]	500	100	100	-	-	-	(Republic of North Macedonia, 2018)
South Africa	-	-	-	185	500	Given values are the minimum requirements.	(Government of South Africa, 1996)
Syria	-	1000	-	-	-	-	(UNEP, MAP, & WHO, 2010)

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[1] In addition to all EU countries, Switzerland, Albania and Montenegro also adopt this criteria.

[2] 1976 version of BWD.

Countries/ Legislations	*Parameters*						
	TC	*FC*	*FS*	*IE*	*EC*	*Remarks*	*Reference*
Tunisia	500	100	100	-	-	-	(UNEP, MAP, & WHO, 2010)
Turkey[3,2]	500	100	100	-	-	-	(Official Gazette Notice 26048, 2006)
USA[4]	-	-	-	130 110	410 320	Illness rate of 0.036 Illness rate of 0.032	(US EPA, 2012a)
WHO/UNEP	-	-	-	200	-	-	(WHO, 2003)

2.3.5. Global Programs Regarding Bathing Water Quality

There are several institutions that are specialized on tourism activities such as United Nations Development Programme (UNDP) and United Nations World Tourism Organization (UNWTO), yet, UNEP and WHO are the major decision makers of BWQ standards among all UN organizations, since their missions cover improvement of both environmental and public health (WHO, 2019; UNEP, 2019). Almost, all BWQ standards depend on recommendations provided by WHO, although, as can be seen from Table 2.10 countries have their own unique criteria. On the other hand, UNEP provide investigation of effectiveness of BWQ standards regionally (UNEP, 2018b). In this part, WHO guidelines and related UNEP programs are reviewed.

2.3.5.1. WHO Guidelines for Safe Recreational Water Environments

WHO activities on bathing and recreational waters have been started in 1970s and WHO recommends standards, management options and safety measures for beaches (WHO, 2003; Kamizoulis & Saliba, 2004). As a result of the mounting evidence of significant health impact and public concern regarding recreational water and bathing beach quality, in late 1990s, WHO has initiated development of a document with the provisional title of “WHO Guidelines for Safe Recreational Water Environments” (WHO, 1998) and that was officially published in 2003 (WHO, 2003).

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[3] Formerly (before 2011), Ministry of Environment and Forestry was responsible from application of the Turkish regulation.

[4] Statistical threshold values (STV) are provided.

WHO Guidelines is not a binding document. It is a reference document which can be used by governments or other institutions in preparation of legislations or evaluation of measured data. European BWD, RWQC, BWQ related regulations of South Africa, Australia, New Zealand and some other countries are developed based on WHO Guidelines (European Commission, 2006; US EPA, 2012a; Government of South Africa, 1996; WHO & UNEP, 2011). WHO recommends statistical methods for BWQ evaluation using the collected data. WHO Guidelines suggest monitoring of intestinal enterococci as BWQ parameter and defines four quality BWQ classes from A to D (Table 2.10). Guidelines also provide the percent risk per exposure for gastrointestinal illnesses (GI) and acute febrile respiratory illnesses (AFRI) for each quality class.

Table 2.10. *Guideline Values for Microbial Quality of Marine Recreational Waters (WHO, 2003)*

Class	*IE (/100 mL)*	*Estimated risk per exposure**
A	≤ 40	<1% GI illness risk <0.3% AFRI risk
B	41 – 200	1-5% GI illness risk 0.3-1.9% AFRI risk
C	201 – 500	5-10% GI illness risk 1.9-3.9% AFRI risk
D	> 500	>10% GI illness risk >3.9% AFRI risk

**GI: Gastrointestinal Illnesses, AFRI: Acute Febrile Respiratory Illnesses*

Other than microbial BWQ, WHO Guidelines also provide methodologies for bathing water related health risk assessment and management, evaluation physico-chemical agents such as temperature, pH, salinity content, transparency, depth of bathing waters, management of aesthetic issues, management of beach sand quality, injury prevention measures in beaches, identification and management options for algae and cyanobacteria and so on (WHO, 2003).

2.3.5.2. UNEP Programs

“The United Nations Environment Programme (UNEP) is the leading global environmental authority that sets the global environmental agenda, promotes the coherent implementation of the environmental dimension of sustainable development within the United Nations system, and serves as an authoritative advocate for the global environment (UNEP, 2018a).” To accomplish their mission, a Sustainable Development Agenda was announced with 17 Sustainable Development Goals (SDGs) which are aimed to be completed until 2030 (UN, 2018). SDGs are related with both socio-economic state of societies and conservation of ecological integrity. Figure 2.6 shows the list of SDGs.

Figure 2.6. List of Sustainable Development Goals *(IMF, 2019)*

“Clean Water and Sanitation: Ensuring access to water and sanitation for all” is considered as main SDG related to improvement of BWQ (UN, 2018). BWD, RWQC and other countries’ BWQ related standards are developed regarding this SDG (European Commission, 2018) and UNEP provided Regional Seas Programme (RSP) for the same reason. The impact of its activities started to show up and in a close future, improvement in BWQs in regional seas, such as Mediterranean, Black Sea and Caribbean is expected to be observed (UNEP, MAP, & WHO, 2010; UNEP & CEP, 1993; The Commission on the Protection of the Black Sea Against Pollution, 2009).

In 1974, RSP was constituted to maintain a unique approach for the protection of coastal and marine environment for international seas, such as Mediterranean, Black

Sea, Baltic Sea, Red Sea, because of the presence of varying management practices and environmental concerns from country to country (UNEP, 2018b). For instance, in the case of Mediterranean, coastal countries which are EU members, apply BWD, MSFD and WFD criteria and management actions. On the other hand, non-EU coastal countries adopt their national programs. Shellfish concentrations, waste discharges, presence of algae and cyanobacteria, development of agricultural practices, runoffs due to climatic events are some examples of varying factors depending on countries' geographic, socio-economic and ecological conditions and may affect both fresh and marine waters' quality. Regional seas are transboundary water resources which are affected by anthropogenic activities and natural conditions take place in all coastal countries. Therefore, monitoring regional seas is highly significant to determine the critical locations and reduce the negative impacts of one country's activities to another coastal country. RSP is mainly an environmental pollution and climate change monitoring program providing prevention/mitigation measures, although, for some touristic regions, such as Mediterranean, Caribbean, Baltic and Black Sea, BWQ monitoring activities are in force (UNEP, 2018b).

Since early 1970s, various environmental stresses largely due to uncontrolled coastal discharges of untreated or partially-treated municipal and industrial wastes, have been recorded among Mediterranean Sea (Kamizoulis & Saliba, 2004). Therefore, Mediterranean Action Plan (MAP), which is the first RSP, was established in 1974 under the Barcelona Convention (UNEP & MAP, 2018). It has 22 participants, i.e. Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, Greece, France, Israel, Italy, Lebanon, Libya, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, Syrian Arab Republic, Tunisia, Turkey and EU (UNEP, MAP, & WHO, 2010). Figure 2.7 shows the countries with a coastline to Mediterranean.

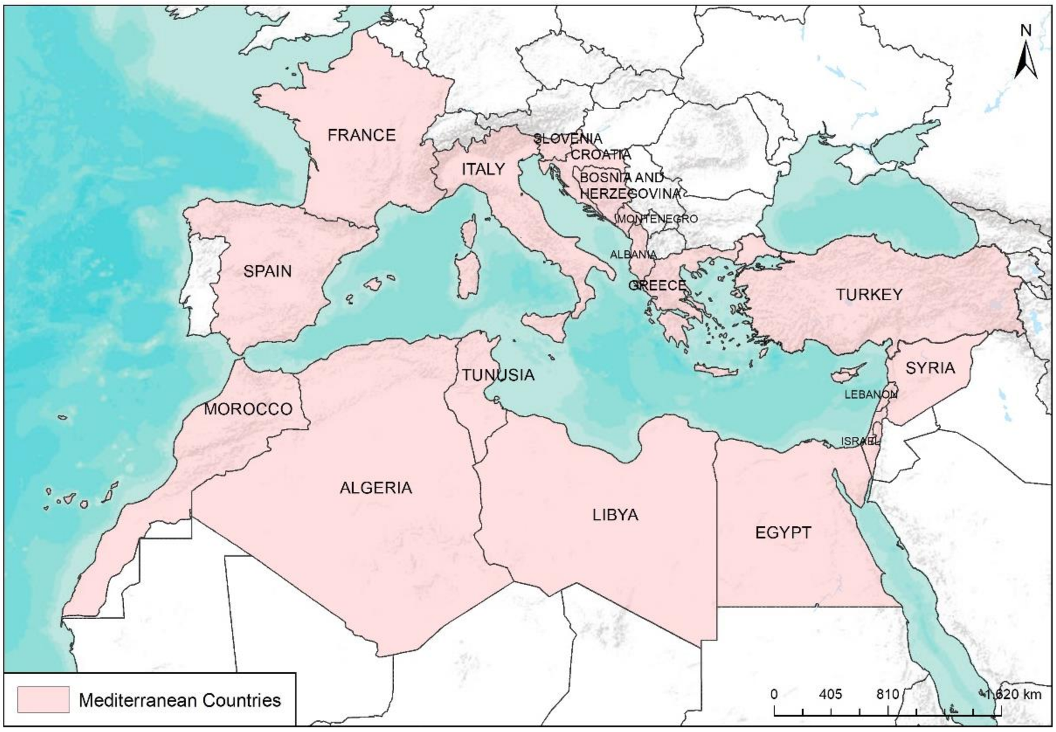
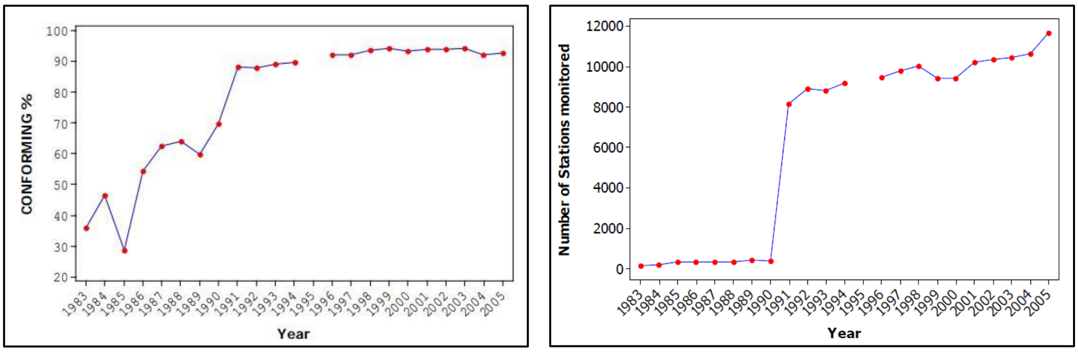


Figure 2.7. Participating Countries in Mediterranean Action Plan

Starting from 1983, several bathing water-related cases were recorded in the Mediterranean region. Gastrointestinal illnesses symptoms around Egypt, Israel and Turkey coasts, skin, ear and eye infections around Spain and France beaches were observed (Kamizoulis & Saliba, 2004). These observations were especially recorded in beaches located closer to polluted areas. After launching MAP, effectiveness of monitoring activities and status of Mediterranean improved year by year until 2005 (UNEP, MAP, & WHO, 2010). Figure 2.8 shows the annual change in percentage of bathing beaches conforming national BWQ standards of participating countries recorded by MAP.



(a) (b)

Figure 2.8. Change in (a) percentage of bathing beaches conforming per year for all countries participating and (b) number of BWQ monitoring stations (UNEP, MAP, & WHO, 2010)

Other than MAP, there are also regional UNEP programs established for West Africa, Caribbean, Northwest Pacific, East Asian Seas, Caspian Sea, East Africa, Antarctic, Arctic, Baltic, Black Sea, North-East Atlantic, North-East Pacific, Pacific, Red Sea and Gulf of Aden, ROPME Sea Area[5], South Asian Seas and South-East Pacific regions (UNEP, 2018b). In addition to MAP, monitoring programs developed for Caribbean and Black Sea regions are also used for BWQ assessment. Other programs are used only for monitoring of marine ecosystem.

Caribbean Environment Programme (CEP) was launched in 1976 and in 1981 Caribbean Action Plan (CAP) was adopted by 22 coastal countries (UNEP, 2018c). Similar to other RSPs, CEP also provide environmental and climate change monitoring practices and mitigation actions. Additionally, CEP also provides BWQ monitoring program to minimize or prevent public health issues related to recreational activities. For BWQ monitoring purposes, in 1991, "Seminar on Monitoring and Control of Sanitary Quality of Bathing and Shellfish-Growing Marine Waters in the Wider Caribbean" was conducted in Jamaica and repeated in 1993 (UNEP & CEP, 1993). Since the main pollution source in the region was wastewater discharges and insufficiency of wastewater management options, recent studies, conducted by CAP,

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[5] Regional Organization for the Protection of Marine Environment (ROPME) Sea Area, refers to the coastal areas of the Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia and United Arab Emirates.

are mainly focused on improvement of wastewater management practices. Therefore, no other documents were published specific to BWQ monitoring and assessment after 1993, however, latest technical reports state that, there is a requirement for development of recreational water quality standards nationally in the region (UNEP, CEP, & GPA, 2011). Therefore, no solid results have been obtained by CAP in terms of BWQ monitoring system, yet, after implementation of recommended wastewater management practices, it is expected that a regular BWQ monitoring program will be established and comments on BWQ in the region will become more accurate (UNEP & CEP, 2019).

In comparison with CAP, The Commission on the Protection of Black Sea Against Pollution (Black Sea Commission) provides more integrative monitoring program comprehending both environmental components and sanitation related issues recorded in the region (The Commission on the Protection of the Black Sea Against Pollution, 2009). Therefore, BWQ evaluation approaches of Black Sea Commission is similar to MAP, rather than CAP. The Commission was established in 1992 by 6 participating countries and in 1996 a Strategic Action Plan (SAP) was prepared. Although, BWQ objectives were not discussed on regional level, Article 55 states that "A uniform measurement technique for bathing water quality with a common quality assurance support mechanism shall be developed. It is advised that the Istanbul Commission, upon the recommendations of its Advisory Group on Pollution Monitoring and Assessment, develop this uniform measurement technique by December 1997. Transparency shall be encouraged through the publication and free exchange of data from bathing water quality measurements on at least an annual basis." Later on, in 2002, The Black Sea Integrated Monitoring and Assessment Program (BSIMAP) was launched to monitor several environmental parameters, including PCBs, PAHs, heavy metals, nutrients, oils and microbiological indicators (The Commission on the Protection of the Black Sea Against Pollution, 2009). In the case of BWQ, BSIMAP stated that to compile national information on the BWQ and review Draft Guidelines for monitoring of the BWQ, monitoring microbiological indicators is highly significant (The Commission on the Protection of the Black Sea Against Pollution, 2009). Previously, BSIMAP did not oblige participants to monitor BWQ parameters, however, in agenda, that covers 2017 - 2022, participants are obliged to monitor BWQ parameters. An improvement in BWQ of Black Sea coasts is expected as a result of this change (The Commission on the Protection of the Black Sea Against Pollution, 2009).

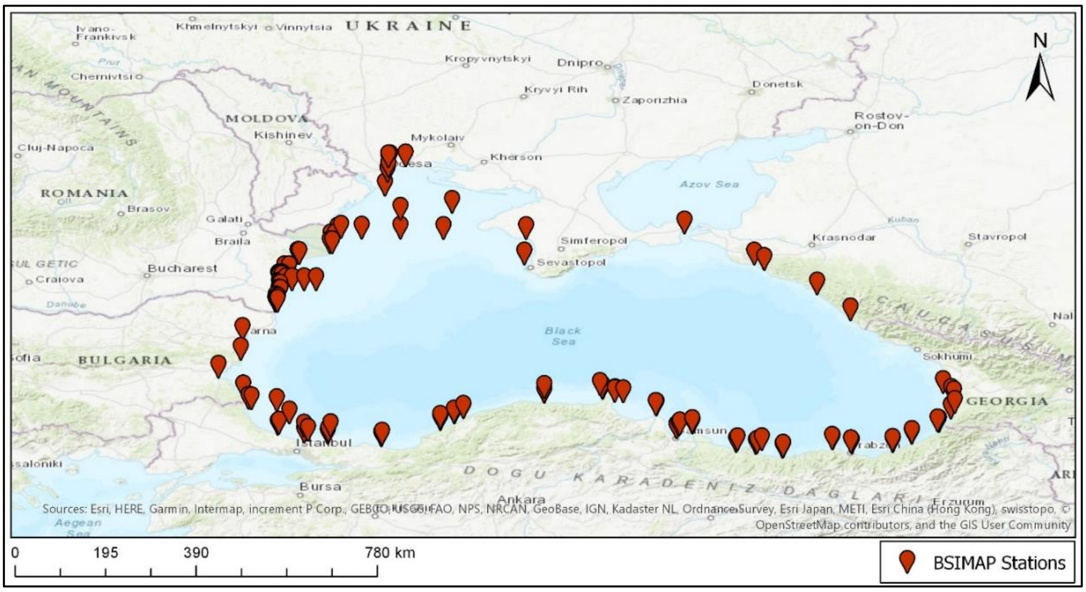


Figure 2.9. BSIMAP Stations (The Commission on the Protection of the Black Sea Against Pollution, 2018)

2.3.5.3. Blue Flag Program

Blue Flag is a worldwide eco-label initiated in 1985 in France and used to classify bathing beaches, marinas and boats with respect to BWQ, beach safety, environmental management (waste management, water efficiency etc.), educational practices and so on (FEE, 2015). The program was applied only in EU countries until South Africa has become a participant as a non-EU country in 2001 (FEE, 2018). It is a global program which is currently conducted by Foundation of Environment and Education (FEE) and applied in 45 countries including EU countries, Canada, Turkey, Mexico, Russia, South Africa, Brazil, Japan, Jordan, Iceland, Dominican Republic, Puerto Rico and New Zealand (TÜRÇEV, 2014). Today, it is used to increase attraction of touristic places without conflicting elements of sustainable/environment-friendly tourism. Figure 2.10 shows the participant countries in Blue Flag Program.

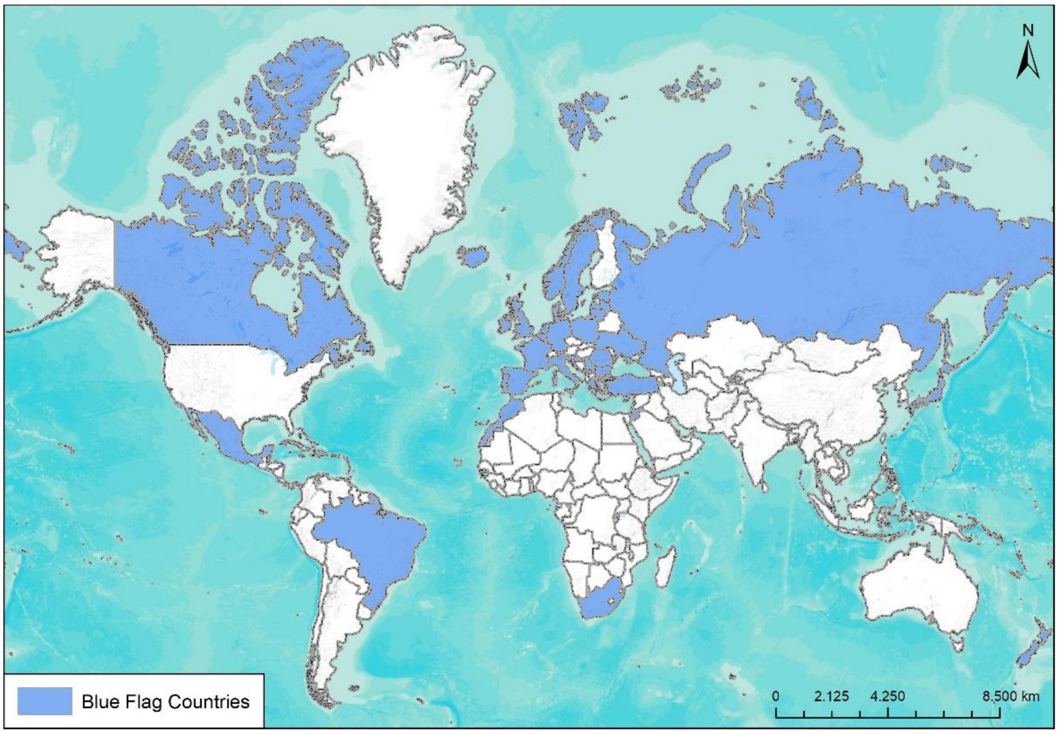


Figure 2.10. Countries Adopting Blue Flag Program

The main purpose of Blue Flag Program is to encourage application of sustainable beach management practices and improve beach qualities, however, enhanced tourist attraction to the Blue Flag beaches also show itself as a benefit of the program. Table 2.11 provides the Blue Flag criteria.

Table 2.11. *Blue Flag Criteria (TÜRÇEV, 2018)*

Parameter	*Criteria (cfu/100 mL)*	
	Coastal and Transitional Waters	*Inland Waters*
FC or EC	250	500
FS or IE	100	200

FC: Fecal coliforms, EC: *E. coli*, FS: Fecal streptococci, IE: Intestinal enterococci

According to a survey, conducted by Lucrezi, et al. (2015), around South African beaches, 62% of beachgoers stated that “Blue Flag attracts tourism”. Another study denoted that, the estimated tourism loss due to losing Blue Flag status could be 6.8 million pounds per year, because of the visitors who tend to choose beaches with Blue Flag award (McKenna, Williams, & Cooper, 2011). Therefore, Blue Flag and similar programs are certainly beneficial for improvement of BWQ as it impacts the public opinion. Figure 2.11 shows the 2018 top 10 countries with Blue Flag beaches.

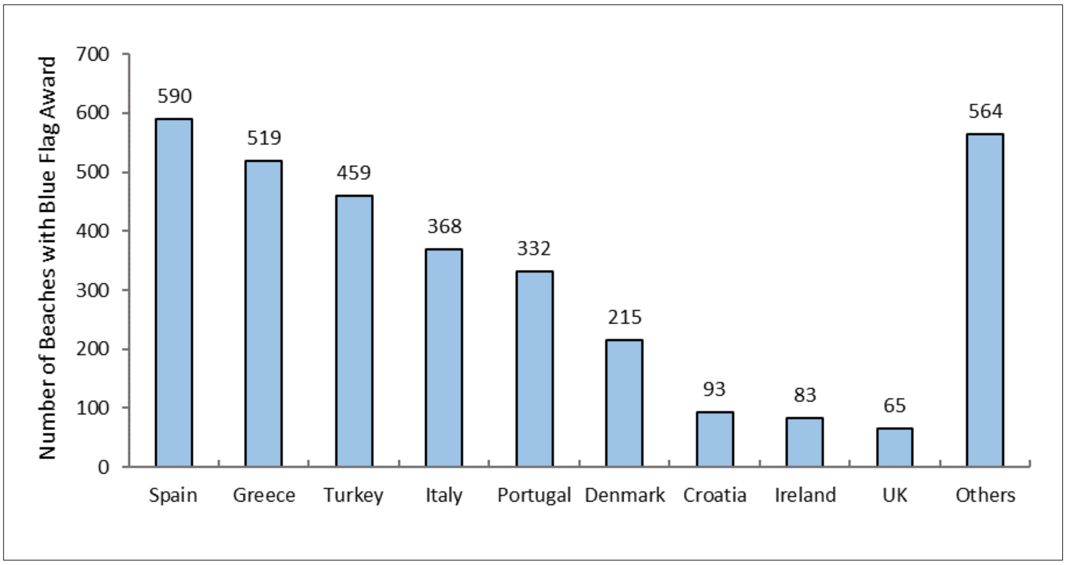


Figure 2.11. Top 10 Blue Flag Countries and Awarded Beach Amounts (TÜRÇEV, 2018)

2.4. Geostatistical Methods

2.4.1. General Overview of Geostatistical Methods

Spatial analysis is defined as a geographical analysis type which is seeking spatial expression to explain patterns of human behavior in terms of mathematics and geometry (Mayhew, 2009). In other words spatial analysis is used to manipulate the spatial information to interpret the original data in a different meaning from the original data (Bailey & Gatrell, 1995).

Spatial interpolation, on the other hand, is a kind of spatial analysis which is the process of creating a *statistical surface* as a result of estimation of values of points by using points with known values (Mitas & Mitasova, 2005). There are two main types of spatial interpolation approaches, namely geostatistical (kriging) and deterministic i.e. non-geostatistical approaches. In this part of the study, spatial interpolation techniques which are commonly used in water quality evaluation studies are going to be introduced briefly.

Unlike geostatistical methods, deterministic spatial interpolation techniques use mathematical functions rather than statistical analyses of sample points (Adhikary & Dash, 2017). Inverse distance weighting (IDW), natural neighbor interpolation (NNI), radial basis function (RBF) are some common spatial interpolation methods used to obtain prediction surfaces (Goush, Gelfand, & Mølhave, 2012).

Deterministic spatial interpolation methods are mostly used for prediction of physical properties of a region such as elevation (Goush, Gelfand, & Mølhave, 2012), groundwater levels (Ramkar & Yadav, 2018), temperature (Jahangir & Moghim, 2019), precipitation (Chen, et al., 2017) and so on. Although, in most of the cases with high data availability, deterministic methods give acceptable results, in prediction of spatial distributions of natural resources such as mine and petroleum, concentrations of chemicals, variation in soil properties or water quality geostatistical methods are preferred more than deterministic methods, since geostatistical approach uses statistical properties of relevant dataset, it is more useful for prediction purposes rather than deterministic methods (Shen, et al., 2019; Ding, Wang, & Zhuang, 2018). Also, prediction errors are also estimated as a result of geostatistical analysis which provides an advantage to measure performance of the prediction.

In 1950s, spatially correlated sample data obtained from South Africa's gold mines were assessed by the help of empirical statistical methods for prediction of ore grades, by a mining engineer named Daniel Krige (Oliver & Webster, 2014). In 1962, geostatistical methods were first formulized by Matheron, in the field of mining engineering and geology, with the purpose of determination of spatial distribution of gold ore in South African mines (Pawar, 2003). Matheron (1963) stated that classical statistical approaches became insufficient since they do not consider spatial variations.

In this study, geostatistical approach, i.e. kriging, is used for spatial interpolation purpose. Kriging is developed by mining geologists (Huisman & By, 2009) and took its name from Daniel Krige, a mining engineer, who studied the use of spatial interpolation techniques in determination of mine ore distributions (Oliver & Webster, 2014). Constitutively, kriging is an optimal prediction or estimation method used for determination of spatially varying environmental properties, including soil, vegetation, hydrologic and atmospheric properties (Fischer & Getis, 2010).

As a local estimation technique, kriging provides the best linear unbiased estimator (BLUE) of a characteristic in a specific location with an unknown value (Journel & Huijbregts, 1989). Following equation shows the general algorithm of BLUE (Bailey & Gatrell, 1995; Journel & Huijbregts, 1989):

$$Z(x_0) = \mu(x_0) + \sum_{i=1}^{n} \lambda_i [Z(x_i) - \mu(x_i)] \tag{2.1}$$

Here $Z(x_0)$ is the predicted value at an unknown sampling point x_0, λ_i is the kriging weights, $Z(x_i)$ is the observed value of each sampling point, $\mu(x_0)$ is the known stationary mean, i.e. mean of the data points used for interpolation of predicted location, and $\mu(x_i)$ is the mean of the dataset (Journel & Huijbregts, 1989; Bivand, Pebesma, & Rubio, 2008; Li & Heap, 2008). As a result of kriging estimation, a variogram, i.e. semivariogram, which is the core element of a geostatistical spatial interpolation application, is obtained (Journel A. G., 1989).

2.4.1.1. Variogram Analysis

Variogram, which is interchangeably used with “semivariogram” in this study, is a geostatistical tool which provides the spatial correlation of a parameter considering the measurement of the spatial continuity of that parameter, i.e. it defines semivariance as a function of distance and given by the following equation (Rudenno, 2012; Li & Heap, 2008):

$$\gamma(x_i, x_0) = \gamma(h) = \frac{1}{2n}\sum_{i=1}^{n}\{Z(x_i) - Z(x_0)\}^2 \qquad \text{where} \qquad x_0 = x_i + h \qquad (2.2)$$

Here $\gamma(x_i, x_0)$ is the semivariance between x_i and x_0 points, h is the lag distance, i.e. distance between x_i and x_0, $\gamma(h)$ is the semivariogram model and n is the number of sampling point pairs separated by distance h. Plot of $\gamma(h)$ against h gives the experimental variogram, which is the ordered set of semivariances (Li & Heap, 2008). Figure 2.12 shows a semivariogram model example.

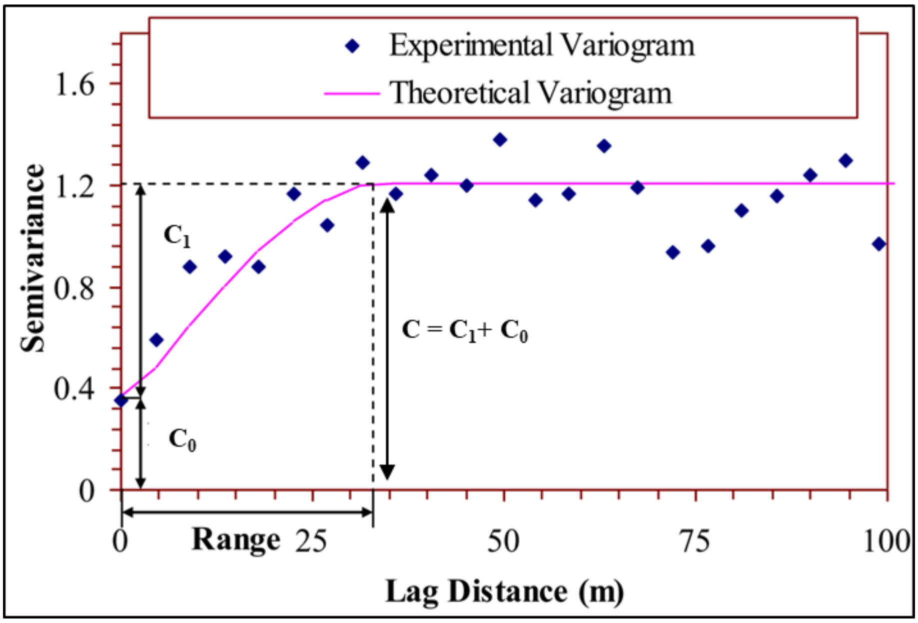


Figure 2.12. Example of a Semivariogram Model (Machiwal & Jha, 2014)

In Figure 2.12 C_1 is the partial sill, C_0 is the nugget and C is the sill, which is a typical example of bounded variogram with nugget (Machiwal & Jha, 2014). Upper-bound of the initial increase in a semivariogram model is called as the sill (Fischer & Getis, 2010), which is 1.2 in the given figure. The lag distance where the variogram reaches its sill point for the first time is named as range and defines the distance where larger than that distance spatial correlation becomes meaningless (Webster & Oliver, 2007). The difference between sill and nugget is called as the partial sill (ESRI, 2019a).

Journel and Huijbregts (1989) define the nugget as “the discontinuity of the variogram at the origin” and it is mainly caused by measurement errors (Li & Heap, 2008). In addition to measurement errors, nugget also occurs due to spatial sources of variation at distances smaller than the sampling intervals (ESRI, 2019a).

In addition to measurement errors, there are also directional components that can affect the output surface. Global trends and directional influences, i.e. anisotropy, are two types of directional components affecting the output surface produced by semivariogram model (ESRI, 2019b). Global trends are defined as an overriding process that affects all measurements in a deterministic manner (Johnston, Hoef, Krivoruchko, & Lucas, 2003). For example, when a smoke emission is modelled through a factory stack in a location with a prevailing wind in a specific direction, there is a global trend in the direction of wind. In some types of geostatistical methods, trend removal is required during analyses since global trends can usually be represented by mathematical expressions. But also, they should be added back just before predictions are completed (ESRI, 2019c).

Similar to global trends, anisotropy also represents the situation of change in spatial variation with direction (Webster & Oliver, 2007). However, unlike global trends, the reason causing the directional change in the modelled parameter is unknown in the case of anisotropy, i.e. there is no physical explanation of directional variation in the spatial property (Johnston, Hoef, Krivoruchko, & Lucas, 2003).

Figure 2.12 also shows the experimental and theoretical variograms. Experimental, or empirical, variogram refers to a discrete function defining measure of variability of distances between pairs of sampling points (US Department of Energy, 2018). On the other hand, theoretical variogram represents the variogram obtained after fitting the experimental variogram to a mathematical model (Li & Zhao, 2014). Although, spherical, exponential, circular, logarithmic function and power function models are widely used ones (Li & Zhao, 2014), the software used in this study ArcMap 10.0 offers more alternatives (Johnston, Hoef, Krivoruchko, & Lucas, 2003). Table 2.12 provides the equations of semivariogram models used in ArcMap 10.7 and Figure illustrates the some of the most common theoretical models.

Table 2.12. *Variogram Models and their Equations Provided in ArcMap 10.0 (Johnston, Hoef, Krivoruchko, & Lucas, 2003)*

Semivariogram Model	*Equation*
Circular	$\gamma(h;\ \theta) = \begin{cases} \frac{2\theta_s}{\pi}\left[\frac{\lVert h\rVert}{\theta_r}\sqrt{1-\left(\frac{\lVert h\rVert}{\theta_r}\right)^2} + arcsin\frac{\lVert h\rVert}{\theta_r}\right] for\ \ 0 \le \lVert h\rVert \le \theta_r \\ \theta_s \qquad for\ \theta_r < \lVert h\rVert \end{cases}$
Spherical	$\gamma(h;\ \theta) = \begin{cases} \theta_s\left[\frac{3}{2}\frac{\lVert h\rVert}{\theta_r} - \frac{1}{2}\left(\frac{\lVert h\rVert}{\theta_r}\right)^3\right] for\ \ 0 \le \lVert h\rVert \le \theta_r \\ \theta_s \qquad for\ \theta_r < \lVert h\rVert \end{cases}$
Tetraspherical	$\gamma(h;\ \theta) = \begin{cases} \frac{2\theta_s}{\pi}\left[arcsin\left(\frac{\lVert h\rVert}{\theta_r}\right) + \frac{\lVert h\rVert}{\theta_r}\sqrt{1-\left(\frac{\lVert h\rVert}{\theta_r}\right)^2} + \frac{2}{3}\frac{\lVert h\rVert}{\theta_r}\left(1-\left(\frac{\lVert h\rVert}{\theta_r}\right)^2\right)^{\frac{3}{2}}\right] for\ \ 0 \le \lVert h\rVert \le \theta_r \\ \theta_s \qquad for\ \theta_r < \lVert h\rVert \end{cases}$
Pentaspherical	$\gamma(h;\ \theta) = \begin{cases} \theta_s\left[\frac{15}{8}\frac{\lVert h\rVert}{\theta_r} - \frac{5}{4}\left(\frac{\lVert h\rVert}{\theta_r}\right)^3 + \frac{3}{8}\left(\frac{\lVert h\rVert}{\theta_r}\right)^5\right] for\ \ 0 \le \lVert h\rVert \le \theta_r \\ \theta_s \qquad for\ \theta_r < \lVert h\rVert \end{cases}$
Exponential	$\gamma(h;\ \theta) = \theta_s\left[1 - exp\left(-\frac{3\lVert h\rVert}{\theta_r}\right)\right]\ for\ all\ h$
Gaussian	$\gamma(h;\ \theta) = \theta_s\left[1 - exp\left(-3\left(\frac{\lVert h\rVert}{\theta_r}\right)^2\right)\right]\ for\ all\ h$
Rational Quadratic	$\gamma(h;\ \theta) = \theta_s\frac{19\left(\frac{\lVert h\rVert}{\theta_r}\right)^2}{1+19\left(\frac{\lVert h\rVert}{\theta_r}\right)^2}\ for\ all\ h$
Hole Effect	$\gamma(h;\ \theta) = \begin{cases} 0 \qquad for\ \ h = 0 \\ \theta_s\frac{1-sin(2\pi\lVert h\rVert/\theta_r)}{sin(2\pi\lVert h\rVert/\theta_r)}\ for\ h \ne 0 \end{cases}$
K-Bessel	$\gamma(h;\ \theta) = \theta_s\left[1 - \frac{(\Omega_{\theta_k}\lVert h\rVert/\theta_r)^{\theta_k}}{2^{\theta_d-1}\Gamma(\theta_k)}\right]K_{\theta_k}(\Omega_{\theta_k}\lVert h\rVert/\theta_r)\ for\ all\ h$
J-Bessel	$\gamma(h;\ \theta) = \theta_s\left[1 - \frac{2^{\theta_d}\Gamma(\theta_d+1)}{(\Omega_{\theta_d}\lVert h\rVert/\theta_r)^{\theta_d}}\right]J_{\theta_d}(\Omega_{\theta_d}\lVert h\rVert/\theta_r)\ for\ all\ h$
Stable	$\gamma(h;\ \theta) = \theta_s\left[1 - exp\left(-3\left(\frac{\lVert h\rVert}{\theta_r}\right)^{\theta_e}\right)\right]\ for\ all\ h$

In equations given in Table 2.12 θ_s refers to partial sill and θ_r is the range parameter. Also, in J-Bessel and K-Bessel models, J_{θ_d} refers to J-Bessel function and K_{θ_k} refers to modified Bessel function, $\Gamma(\theta_i)$ refers to gamma function expressed by Equation (2.3), in which i refers to d in J-Bessel and k in K-Bessel models.

$$\Gamma(y) = \int_{0}^{\infty} x^{y-1} \exp(-x)\, dx \tag{2.3}$$

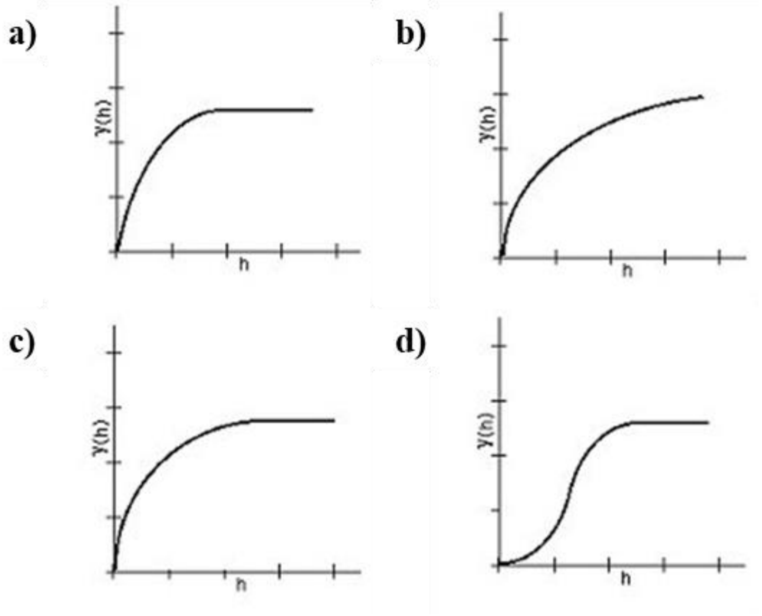


Figure 2.13. Illustration of Some widely used Theoretical Semivariogram models: a) Spherical, b) Exponential, c) Circular and d) Gaussian (Mokarram & Sathyamoorthy, 2016)

In selection of the semivariogram model, ME, MSE, RMSE, RMSSE and ASE are used as goodness-of-fit criteria, i.e. performance measurement, which are available in ArcMap 10.0 (ESRI, 2019e). Table 2.13 provides the equations of performance measurement criteria.

Table 2.13. *Performance Measurements Used in Geostatistics (Li & Heap, 2008)*

Measurement	*Equation**
ME	$ME = \frac{1}{N}\sum_{i=1}^{N}(p_i - o_i)$
MSE	$MSE = \frac{1}{N}\sum_{i=1}^{N}(p_{si} - o_{si})$
RMSE	$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(p_i - o_i)}$
RMSSE	$RMSSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(p_i - o_i)^2}$
ASE	$ASE = \sqrt{\sum_{i=1}^{N}\frac{1}{N}(p_i - (\sum_{i=1}^{N} p_i)/N)^2}$

* N: number of observations or samples, o: observed values, p: predicted values, p_s: standardized predicted values, o_s: standardized observed values.

In order to determine performance of the selected model, given equations are used. In addition to single values of ME, MSE, RMSE, RMSSE and ASE, relationship between them is also significant indicator of model performance (Isaaks & Srivastava, 1989; Goovaerts, 1997). Many studies adopting geostatistics as methodology use equations given in Table 2.13 for cross-validation purposes (Arétouyap, et al., 2016; Apaydın, Sönmez, & Yıldırım, 2004; Zuvala, Fišerová, & Marek, 2016; Knotters, Brus, & Voshaar, 1995).

Li and Heap (2014) state that, there is total of 38 spatial interpolation methods that are used in environmental studies and 20 of them are kriging-based methods. The variation in these methods are caused by the difference in the main algorithm and thus, variation in the semivariogram models (Deutsch & Journel, 1998). Table 2.14 provides the kriging based spatial interpolation methods.

Table 2.14. *Types of kriging methods widely used in environmental studies (Li & Heap, 2014)*

Univariate Kriging	*Multivariate Kriging*
	Universal kriging (UK)
	SK with varying local means (SKlm)
	Kriging with an external drift (KED)
Simple kriging (SK)	Simple cokriging (SCK)
Ordinary kriging (OK)	Ordinary cokriging (OCK)
Factorial kriging (FK)	Standardized OCK (SOCK)
Dual kriging (DuK)	Principle component kriging (PCK)
Indicator kriging (IK)	Co-located cokriging (CCK)
Disjunctive kriging (DK)	Kriging within strata (KWS)
Model-based kriging (MbK)	Multivariate factorial kriging (MFK)
	IK with an external drift (IKED)
	Indicator cokriging (ICK)
	Probability kriging (PK)

Univariate analysis considers a single dependent variable for an independent variable, which is location for spatial analyses most of the time (Wackernagel, 2003). On the other hand, in a multivariate analysis there are at least two dependent variables with a significant correlation for prediction of primary dependent variable at a specific location (Wackernagel, 2003; Dall'erba, 2009). In this study, ArcMap 10.7 software is used for kriging applications, therefore, types of kriging that are found in ArcMap 10.7 are going to be briefly explained.

2.4.1.2. Univariate Kriging Types

2.4.1.2.1. Simple Kriging

According to Bailey and Gatrell (1995), simple kriging (SK) is the earliest type of kriging and considers the Equation (2.3).

$$Z(x_0) = \mu(x_i) + \sum_{i=1}^{n} \lambda_i [Z(x_i) - \mu(x_i)] \tag{2.3}$$

Here $Z(x_0)$ is the predicted value at an unknown sampling point x_0, λ_i is the kriging weights, $Z(x_i)$ is the observed value of each sampling point and $\mu(x_i)$ is a known stationary mean (Li & Heap, 2008; Kanevski & Maignan, 2004). As can be seen from the above Equation, SK is a slightly modified version of Equation (2.1).

2.4.1.2.2. Ordinary Kriging

Ordinary kriging (OK) is known as the most robust and frequently used geostatistical method (Fischer & Getis, 2010; Li & Heap, 2011) and assumes that the correlation between two random variables is independent of both variables' positions and mainly is based on the spatial distance between them (Zuvala, Fišerová, & Marek, 2016). OK adopts the following algorithm (Deutsch & Journel, 1998):

$$Z(x_0) = \sum_{i=1}^{n} \lambda_i Z(x_i) \qquad \text{where} \qquad \sum_{i=1}^{n} \lambda_i = 1 \tag{2.4}$$

As can be seen from Equation (2.4) OK assumes that the mean of the variable do not show spatial trend, which causes mean to be eliminated and therefore is stationary (Bonham-Carter, 1994). Since the mean of the OK function is eliminated, it could be said that this method assumes that the modelled data is normally distributed (Isaaks & Srivastava, 1989). On the other hand, if only the semivariogram model is known, then the OK model can be expressed as a function of semivariogram, which is given in Equation (2.5) (Chilés & Delfiner, 2012):

$$\gamma(x_0) = \sum_{i=1}^{n} \lambda_i \gamma(x_i) - \mu(x_i) \qquad \text{where} \qquad \sum_{i=1}^{n} \lambda_i = 1 \tag{2.5}$$

2.4.1.2.3. Disjunctive Kriging

Oliver (2010) explains DK as a non-linear prediction method which is based on data transformation to indicator function regarding to a predefined threshold value, τ. DK was firstly developed by Georges Matheron in 1976 and provides local conditional probability estimations rather than direct predictions (Yates, Warrick, & Myers, 1986). Matheron (1976) formulizes DK by Equation (2.6).

$$Z(x_0) = \sum_{i=1}^{n} f_i[Y(x_i)] = \sum_{i=1}^{n} \sum_{k=0}^{\infty} f_{ik} H_k[Y(x_i)] \tag{2.6}$$

In the given equation, n is the number of samples, $f_i[Y(x_i)]$ is the function expressed as a series of multiplication of Hermite polynomials with a constant f_{ik} depending on i and k. As mentioned before, OK is applicable only when the dataset is normally distributed. For this purpose, DK is mostly used for spatial interpolation with a dataset that can be transformed into a normally distributed form using Hermite polynomials (Yates, Warrick, & Myers, 1986) which is defined by Equation 2.7.

$$H_k(y) = (-1)^k \exp\,[y^2/2]\,\frac{d^k(\exp[-y^2/2])}{dy} \tag{2.7}$$

In Equation 2.7, y is an independent variable and k is an integer given as $0 \rightarrow \infty$. Since DK adopts a more complicated mathematical approach, main disadvantage of this method is increasing computational time over linear estimators, such as OK or SK (Ortiz, Oz, & Deutsch, 2005).

2.4.1.2.4. Indicator Kriging

Indicator kriging (IK) is a non-parametric geostatistical method used to estimate the probability of exceeding or not exceeding of a specific threshold value at each estimation point (Kanevski & Maignan, 2004). Therefore, unlike OK and SK, IK provides probability maps, rather than prediction of parameters in unsampled regions (ESRI, 2019d). In IK applications each measured data at sampling points are transformed into binary system, i.e. 1 and 0, with respect to exceedance status of each data a defined threshold value (Journel A. , 1983). An example dataset distribution which is converted to binary values using a threshold is illustrated in Figure 2.14.

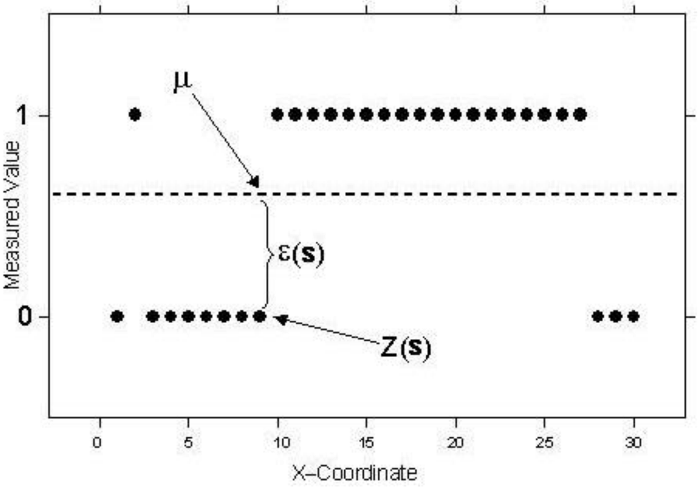


Figure 2.14. Illustration of an Example Dataset Conversion to Binary Values used in IK (ESRI, 2019d)

In Figure 2.14, μ is the mean of indicators, $\varepsilon(s)$ is the error of a single data point Equation (2.8) provides the mathematical expression of IK with threshold value τ, indicator value $I(x_i, \tau)$ at location x_i and measured value of $Z(x_i)$ (Olea, 2003; Oliver M. , 2010).

$$I(x_i, \tau) = \begin{cases} 0, & if\ Z(x_i) > \tau \\ 1, & if\ Z(x_i) \leq \tau \end{cases} \tag{2.8}$$

2.4.1.3. Multivariate Kriging Types

2.4.1.3.1. Cokriging

Cokriging is one of the significant examples of multivariate spatial analyses. Cokriging is usually used for the cases when there is a significant correlation between two different datasets and the number of observation points of primary dataset is less than secondary dataset (Isaaks & Srivastava, 1989; Wackernagel, 2003). Equation (3.9) shows the mathematical expression of cokriging estimations.

$$Z(x_0) = \sum_{i=1}^{n} \lambda_i Z(x_i) + \sum_{j=1}^{m} \omega_j U(y_j) \tag{2.9}$$

In Equation (2.9) ω_i refers to the weights of secondary dataset, $U(y_j)$ is the sampling result of the secondary dataset at location y_j. To obtain BLUE, the conditions given in Equation (2.10) should be satisfied for weights of both primary and secondary variable given in Equation (3.9) (Isaaks & Srivastava, 1989).

$$\sum_{i=1}^{n} \lambda_i = 1 \qquad \text{and} \qquad \sum_{j=1}^{m} \omega_j = 0 \tag{2.10}$$

The given conditions guarantee the unbiasedness of the obtained cokriging estimator. Cokriging estimations adopts covariance models instead of semivariogram models and there are multiple covariance models predicted for each dataset (Wackernagel, 2003). Equation (2.11) and (2.12) show the covariance functions for primary and secondary datasets, respectively (Isaaks & Srivastava, 1989).

$$Cov\{Z(x_0)Z(x_j)\} = \sum_{i=1}^{n} \lambda_i Cov\{Z(x_i)Z(x_j)\} + \sum_{i=1}^{m} \omega_i Cov\{U(y_i)Z(x_j)\} + \mu(x_i) \tag{2.11}$$

$$Cov\{Z(x_0)U(y_j)\} = \sum_{i=1}^{n} \lambda_i Cov\{Z(x_i)U(y_j)\} + \sum_{i=1}^{m} \omega_i Cov\{U(y_i)U(y_j)\} + \mu(y_j) \tag{2.12}$$

Where $j = [1, n]$ for Equation (2.11) and $j = [1, m]$ for Equation (2.12). Also, condition given in Equation (2.10) are also valid for Equation (2.11) and Equation (2.12).

2.4.1.3.2. Universal Kriging

Universal kriging (UK) is a common multivariate geostatistical technique used to estimate spatial means when the dataset has strong spatial trends (Kiš, 2016). UK is developed due to inability of models presuming the constancy of the means to characterize some attributes which have clear systematic variations, such as water depth near the shore, temperature in the upper part of the earth's crust, water table elevation in specific aquifer and other kinds of physical properties (Olea, 2003; Davis, 2002). Equation (2.13) provides the UK system (Olea, 2003; Kumar, 2007; Wackernagel, 2003).

$$\begin{cases} \sum_{i=1}^{n} \lambda_i \gamma(x_\alpha, x_i) + \sum_{j=1}^{L} \mu_j f_j(x_\alpha) = \gamma(x_\alpha, x_0) & \text{for } \alpha = 1, \dots, n \\ \sum_{i=1}^{n} \lambda_i f_j(x_\alpha) = f_j(x_0) & \text{for } j = 1, \dots, L \end{cases} \tag{2.13}$$

Where $\gamma(x_\alpha, x_i)$ is the semivariogram between two sampling points x_α and x_i, μ_j is the Lagrange multiplier associated with the j^{th} unbiased condition and $f_j(x)$ is a deterministic function. Universal kriging system can be solved either external drift or the semivariogram is known. External drift refers to a secondary variable which is directly influencing primary variable such as impact of elevation on temperature distribution (Wackernagel, 2003). Equation (2.14) expresses the external drift, $m(x)$, with non-zero coefficients a_j.

$$m(x) = \sum_{j=1}^{L} a_j f_j(x) \tag{2.14}$$

2.4.1.3.3. Probability Kriging

Similar to IK, probability kriging (PK) is also a non-parametric method used to determine the threshold exceedance probability of a specific region. Unlike IK, PK couples indicator values, i.e. binary values assigned to each sampling location, with exact measurement values and adopts the following equation (Deutsch & Journel, 1998; Adhikary P. P., Dash, Bej, & Chandrasekharan, 2011).

$$I(x_0;\tau)^* = \sum_{i=1}^{n} \lambda_i I(x_i;\tau) + \sum_{i=1}^{n} \lambda_{iu} U(x_i) \tag{2.15}$$

Where $I(x_0;\tau)^*$ is the PK estimator, $I(x_0;\tau)$ is the indicator value at location x_i with threshold τ, $U(x_i)$ is the uniform value, i.e. measured values at sampling locations, λ_i and λ_{iu} are weights of sampling points adopting unbiased conditions represented in Equation (2.16).

$$\sum_{i=1}^{n} \lambda_i = 1 \qquad \text{and} \qquad \sum_{i=1}^{n} \lambda_{iu} = 0 \tag{2.16}$$

There is no specific information on whether IK or PK is advantageous for prediction of exceedance probabilities. Properties of the relevant dataset is effective on deciding which method is more accurate. To evaluate the performance of the methods cross-validation should be conducted, which is going to be explained detailed in Chapter 3.

2.4.2. Geostatistical Methods used in Water Quality Analysis

Initially, geostatistical methods were used for mining applications or geological science, but then, it expanded through other fields such as environmental engineering, hydrology, archeology, ecology, agronomy and so on (Chilés & Delfiner, 2012; Lark, 2012). Other than determination of mine ore distributions or petroleum exploration works, today, geostatistical methods are also used to predict spatial distributions of contaminants through natural resources, such as soil (Dindaroğlu, 2014), groundwater (Rivest, Marcotte, & Pasquier, 2012) or surface waters (Boano, Revelli, & Ridolfi, 2005), spatial variations of groundwater levels (Theodoridou, Varouchakis, & Karatzas, 2017), soil properties (Lark, 2012; Brus, 2019) and so on. Currently it is also widely used in assessment of environmental data including water quality evaluation (Machiwal & Jha, 2014). Li and Heap (2014) state that environmental sciences and water resources are included in top 10 fields employing geostatistics.

In a study evaluating variation of groundwater salinity around Malwathu Oya cascade-I in Anuradhapura District, it was observed that that geostatistical methods give more accurate results rather than deterministic methods (Gunarathna, Nirmanee, & Kumari, 2016). Another study has used geostatistics as a validation measure for multivariate statistics for prediction of groundwater quality parameters, i.e. electrical conductivity, total dissolved solids, Ca^{2+}, Fe and total As, in Faridpur district of central Bangladesh based on selected 60 sampling points (Bodrud-Doza, et al., 2016). Similar to that study, Karami et al. (2018) also evaluated spatial distribution of seven groundwater quality parameters, namely electrical conductivity, total dissolved solids, sodium adsorption ratio, total hardness, Na^+, Cl^-, SO_4^{2-}. This study also showed that geostatistical methods are more accurate in comparison with deterministic methods for prediction of quality physico-chemical parameters. Rogowski (1983) evaluated groundwater quality around a coal mining site by geostatistical analysis. Similarly, Kayode et al. (2018) investigated health implications of municipal waste dumpsite related groundwater contamination nearby Oke-Afa, Oshodi/Isolo area of Lagos state, by geostatistical analysis.

Although, geostatistics used widely in evaluation of groundwater quality, it is also used for spatial analysis of surface water quality. A study analyzed total phosphorus distribution in the Yangtze River Estuary using four types of spatial interpolation methods including two deterministic (IDW and LPI) and two geostatistical method (OK and DK) (Liu, et al., 2014). This study also showed that geostatistical methods are more useful in prediction of pollution parameters. Beveridge et al. (2012) used spatial interpolation techniques to predict optimum locations for water quality monitoring around Lake Winnipeg. Similar to this study, Yenilmez et al. (2015) coupled kriging with kernel density estimation to minimize the number of active water quality monitoring stations in Porsuk Dam Reservoir. Distribution of dissolved oxygen concentration is predicted by kriging and as a result a better sampling network design is provided. A study conducted in a deep mesotrophic Lake Hancza also applied kriging for spatial interpolation of nutrients (N and P) and revealed that geostatistical methods are useful tools for water quality assessment (Łopata, et al., 2014). Islam et al. (2016) distribution of disinfection by-product concentrations along water distribution network of in Quebec with geostatistical methods. The results of study showed that geostatistics can give accurate results with limited data.

Geostatistical methods are also used to evaluate coastal and/or marine water quality. A study which was conducted in Charleston Harbor, an estuary on the coast of South Carolina, revealed that kriging is a useful method for modelling irregularly shaped regions such as estuaries and predicted salinity and dissolved oxygen concentrations higher in shorelines and lower at estuarine mouths, as expected (Rathbun, 1998).

Another study conducted in Kuwait Bay measured the adequacy of current monitoring network by geostatistical analysis (Al-Mutairi, AbaHussain, & El-Battay, 2015). The study revealed that current monitoring network is not able to represent the water quality pattern in the region. Murphy et al. (2010) compared three spatial interpolation methods, i.e. IDW, OK and UK, to model three physico-chemical water quality parameters, namely salinity, temperature and dissolved oxygen concentration in Chesapeake Bay. Similar to other studies measuring performance of geostatistical methods over deterministic methods, in this study, kriging methods again outperformed a deterministic spatial interpolation method, IDW. Another study involving coastal water quality assessed eutrophication process by geostatistically analyzing chlorophyll-a concentration over the coastline of Tien Yen Bay, a tropical shallow water (Ha, Koike, & Nhuan, 2014).

Geostatistical methods are also used to estimate the exceedance probability of a predetermined threshold/cutoff for a spatially varying parameter. Lee et al. (2008) conducted a study around Lanyang Plain and assessed effects of As on aquifers which were used as drinking, irrigation and aquaculture purposes. As a result, aquifers under the high risk of violating water quality standards was predicted and management options were recommended for them. Another study involving groundwater quality coupled kriging with natural background level concept to identify the areas with the same exceedance probability for groundwater quality criteria established by relevant institutions in Portugal and Italy (Ducci, et al., 2016). A study conducted in Puglia region/Italy used geostatistical methods to predict the exceedance probabilities of BWQ parameters for regulatory standards in the shoreline (Malcangio, Donvito, & Ungaro, 2018). Similarly, Jang (2018) assessed Taiwanese bathing sites regarding US EPA RWQC, by an indicator-based kriging method. The results of both studies discussed the regions with higher public health risks. Regarding these studies, IK is used in this study for assessment of critical BWQ sites around Turkey coastline.

CHAPTER 3

METHODOLOGY

3.1. Geostatistical Analysis used in This Study

This thesis aims to determine critical regions in terms of BWQ via a spatio-temporal analysis and discuss possible environmental stresses causing poor BWQ in relevant bathing sites. Although, in the Bathing Water Quality Control Regulation statistical approaches are underlined for data evaluation such as consideration of 90th and 95th percentiles of the dataset, in this study a spatial analysis method, called indicator kriging was used. The reason for choosing indicator kriging can be explained by two factors: (i) the ability to predict the BWQ of the non-monitored regions, (ii) the possibility of comparing BWQ with a threshold value rather than predicting the concentration of the parameter. Although, there were many locations monitored regularly (numbers given in Section 4), there are also bathing sites which are not monitored within the scope of the monitoring program of the Ministry of Health. For example, it is possible that a bathing site taken out of a monitoring program due to good BWQ status for a long period (Official Gazette Notice 26048, 2006; General Directorate of Public Health, 2008). The objective of this study is to determine the critical regions regardless of their monitoring status; monitored or non-monitored. Therefore, in order to assign the BWQ states of the non-monitored locations, a spatial interpolation method was used to estimate the BWQ of non-monitored areas based on the data collected for monitored locations. Since the objective is only to compare the BWQ data with the guideline value, indicator kriging provides an easy method (details given in Section 2.4). In order to be able to conduct both spatial and temporal analysis, the historical data collected over 25 years has been divided into 4 periods: (1) Before 2010, (2) 2010 – 2012, (3) 2013 – 2015 and (4) 2016 – 2018. These four periods were determined based on data availability and data quality. Since before 2010 number of data was limited and all available data was not useful due to some incorrect data entrance. After 2010, in order to evaluate temporal variation in BWQ remaining 9 years were divided into 3 equal periods, each composed of 3 years. Mean values for each geostatistical analysis period at each monitoring station was calculated. To this purpose, geostatistics were used to determine the critical bathing regions in each geostatistical analysis period and critical regions were classified based on threshold exceedance probabilities.

First of all, quality control was performed for the existing BWQ data, which was obtained from General Directorate of Public Health. Primary criteria for deciding whether a single data point must be eliminated or not is to compare the values of TC and FC parameters. Since FC is a subset of TC, it is not reasonable to have FC concentrations higher than TC. Thus, samples satisfying the condition FC > TC were eliminated from the data set. Number of eliminated data for each coastal region is provided in Figure 3.10.

After quality control, eliminated data was explored by general statistics. Historical change in the number of BWQ measurements, variation in the concentrations of BWQ parameters, change in number exceeding samples, change in the single point maximum measured concentrations, and histogram analysis was conducted for each BWQ parameter and coastal zone. Figure 3.1 shows the steps of methodology applied in this study.

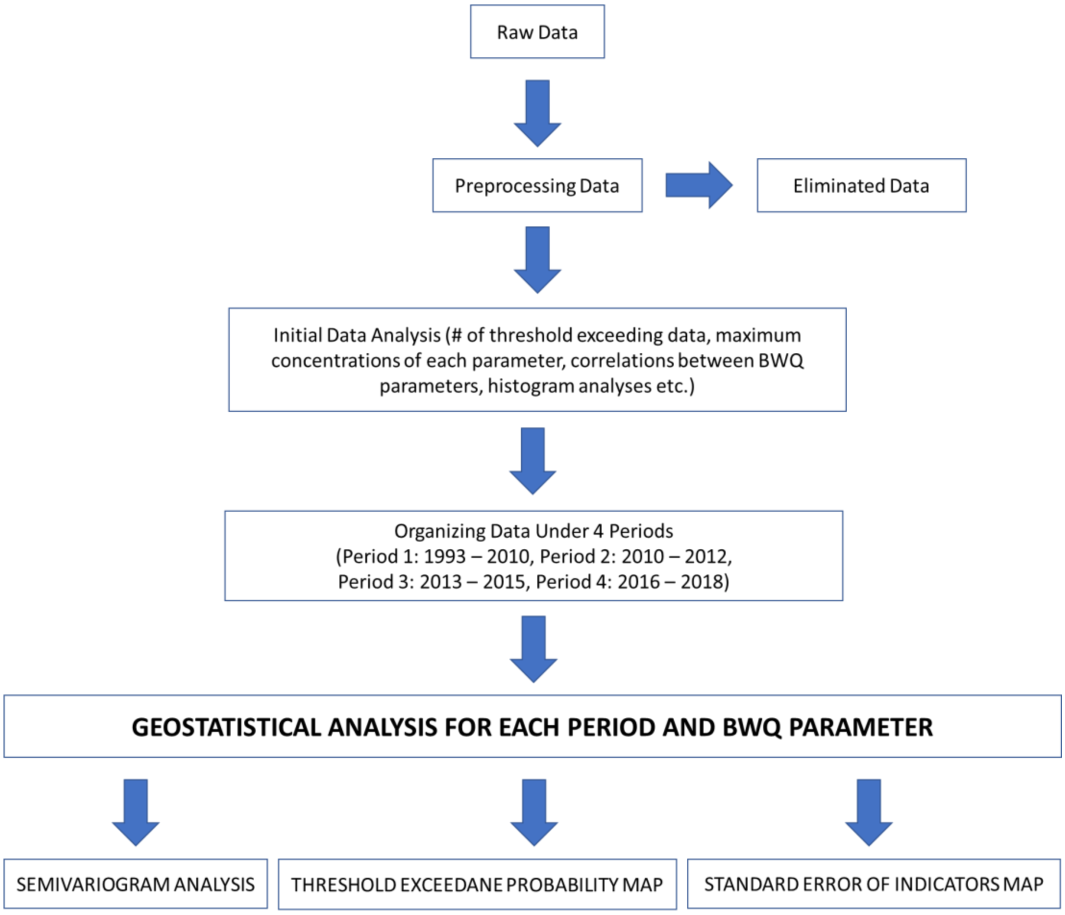
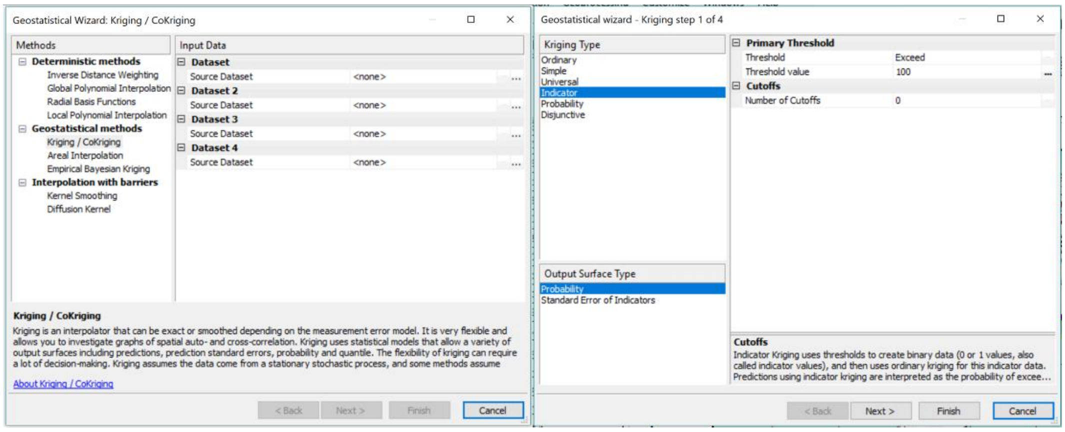


Figure 3.1. Illustration of Methodology used in this Study

For GA, a GIS software ArcMap 10.0 was used. In ArcMap 10.0, Geostatistical Wizard is used for spatial interpolation applications. Geostatistical Wizard is found in Geostatistical Analyst expansion of the software. “The Geostatistical Wizard is a dynamic set of pages that is designed to guide you through the process of constructing and evaluating the performance of an interpolation model.” (ESRI, 2018). In Geostatistical Wizard, there are geostatistical, deterministic and barrier including interpolation methods (Töreyen, Özdemir, & Kurt, 2010). In Geostatistical Wizard, there is six types of geostatistical methods; OK, SK, UK, IK, PK and DK. Figure 3.2 shows the method selection screen of ArcMap 10.7 Geostatistical Wizard.



Dataset
Source Dataset <none>
Dataset 2
Source Dataset <none>
Dataset 3
Source Dataset <none>
Dataset 4
Source Dataset <none>

Kriging / CoKriging

Kriging is an interpolator that can be exact or smoothed depending on the measurement error model. It is very flexible and allows you to investigate graphs of spatial auto- and cross-correlation. Kriging uses statistical models that allow a variety of output surfaces including predictions, prediction standard errors, probability and quantile. The flexibility of kriging can require a lot of decision-making. Kriging assumes the data come from a stationary stochastic process, and some methods assume

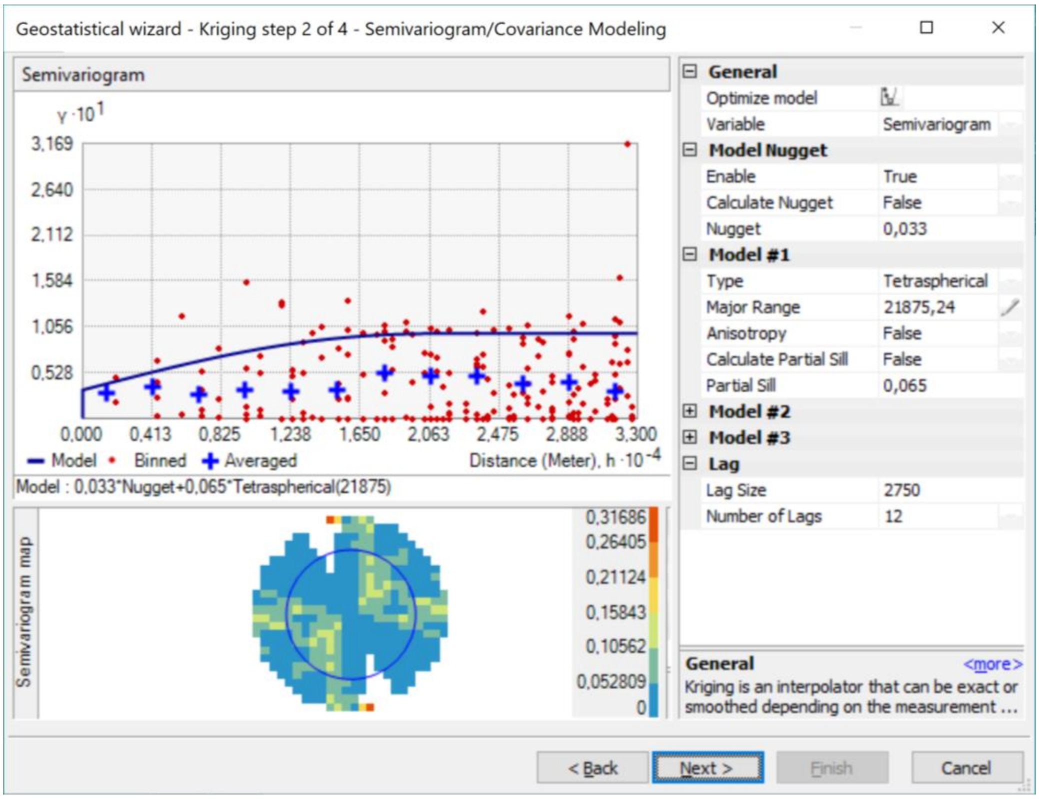
Primary Threshold
Threshold Exceed
Threshold value 100
Cutoffs
Number of Cutoffs 0

Cutoffs

Indicator Kriging uses thresholds to create binary data (0 or 1 values, also called indicator values), and then uses ordinary kriging for this indicator data. Predictions using indicator kriging are interpreted as the probability of excee…

Figure 3.2. ArcMap 10.7 Geostatistical Wizard Method Selection Screens

IK was used in this study and for IK, initially a threshold value must be selected. The analysis was conducted using three BWQ parameters that are being monitored in Turkey, namely TC, FC and FS (Table 2.7). In this study, the regulatory criteria listed in TR Bathing Water Quality Control Regulation for each BWQ parameter was selected as threshold value for IK. These are 500 cfu/100 mL for TC and 100 cfu/100 mL for FS and FC/ After method is selected as IK and threshold value was set, semivariogram analysis was conducted. Figure 3.3 provides the semivariogram analysis screen of the software.



Geostatistical wizard - Kriging step 2 of 4 - Semivariogram/Covariance Modeling

Model : 0,033*Nugget+0,065*Tetraspherical(21875)

General
- Optimize model
- Variable: Semivariogram

Model Nugget
- Enable: True
- Calculate Nugget: False
- Nugget: 0,033

Model #1
- Type: Tetraspherical
- Major Range: 21875,24
- Anisotropy: False
- Calculate Partial Sill: False
- Partial Sill: 0,065

Model #2

Model #3

Lag
- Lag Size: 2750
- Number of Lags: 12

General <more>

Kriging is an interpolator that can be exact or smoothed depending on the measurement ...

Figure 3.3. ArcMap 10.7 Geostatistical Wizard Semivariogram Analysis Screen

In the given screen, first of all, model type was selected and then the model was optimized using the “Optimize Model” option. Nugget, range and partial sill values can either be set manually or estimated automatically by the software. In this study, initially all values were estimated automatically by the software and if the cross-validation process does not give acceptable results, only the nugget value was changed. This process was repeated until acceptable cross-validation results were achieved.

Cross-validation was conducted through 2 steps. First step was based on the estimation of prediction errors, i.e. ME, MSE, RMSE, ASE and RMSSE, which are provided in Table 2.13. Figure 3.4 shows the expected relation between performance measurement parameters of a best-fit model.

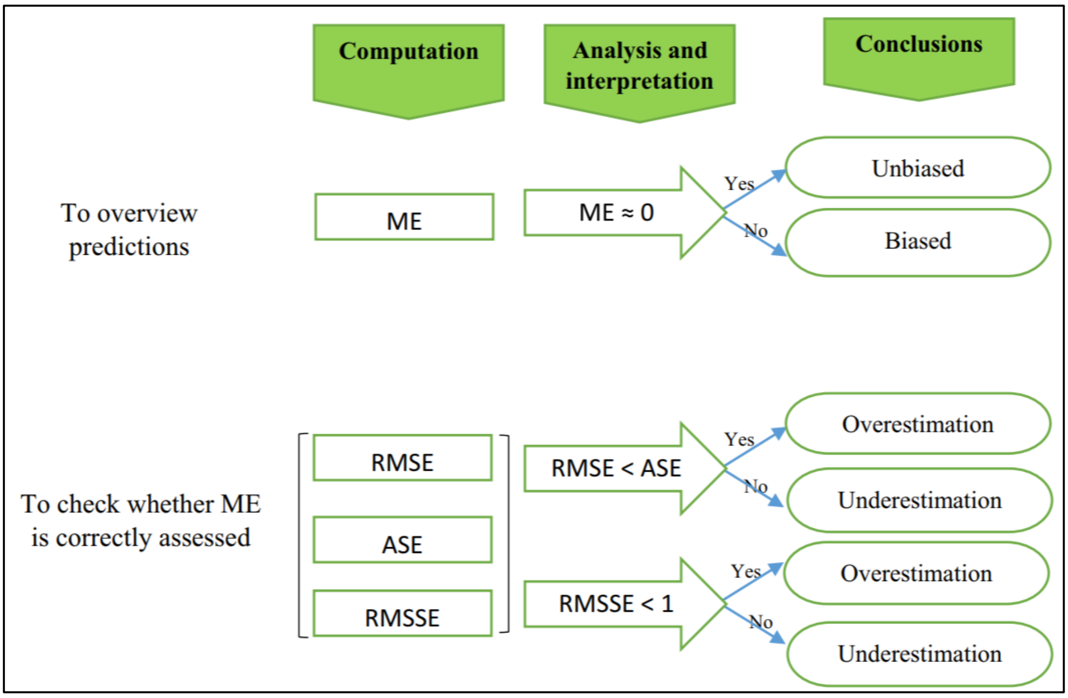
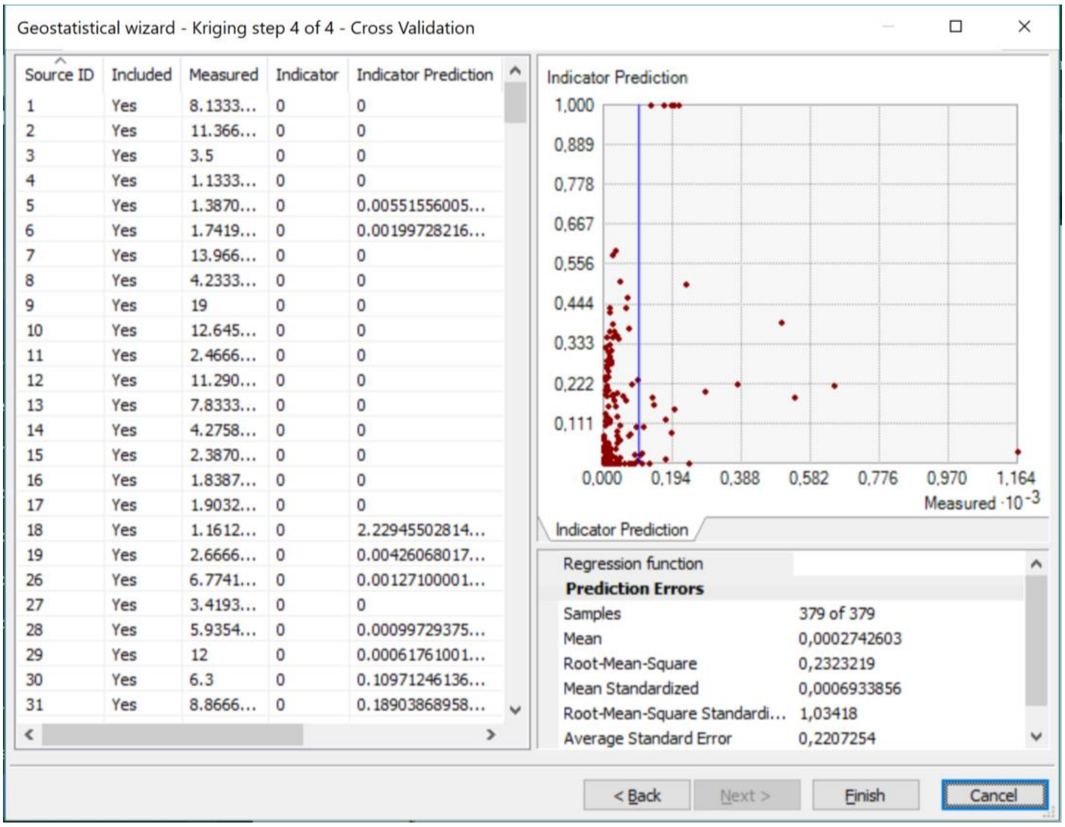


Figure 3.4. Model Selection Criteria (Arétouyap, et al., 2016)

Second step of cross-validation was “Indicator Prediction” which is also prepared by the software. “Indicator Prediction” results were assessed to compare the exceedance probability values with measurement values. Figure 3.5 provides the cross-validation screen in ArcMap 10.7 including a sample Indicator Prediction graph. In the graph shown in the figure, red dots provide exceedance probability versus measured data results and blue line provides the threshold which was set manually at the beginning of the analysis.



Geostatistical wizard - Kriging step 4 of 4 - Cross Validation

Source ID	Included	Measured	Indicator	Indicator Prediction
1	Yes	8.1333...	0	0
2	Yes	11.366...	0	0
3	Yes	3.5	0	0
4	Yes	1.1333...	0	0
5	Yes	1.3870...	0	0.00551556005...
6	Yes	1.7419...	0	0.00199728216...
7	Yes	13.966...	0	0
8	Yes	4.2333...	0	0
9	Yes	19	0	0
10	Yes	12.645...	0	0
11	Yes	2.4666...	0	0
12	Yes	11.290...	0	0
13	Yes	7.8333...	0	0
14	Yes	4.2758...	0	0
15	Yes	2.3870...	0	0
16	Yes	1.8387...	0	0
17	Yes	1.9032...	0	0
18	Yes	1.1612...	0	2.22945502814...
19	Yes	2.6666...	0	0.00426068017...
26	Yes	6.7741...	0	0.00127100001...
27	Yes	3.4193...	0	0
28	Yes	5.9354...	0	0.00099729375...
29	Yes	12	0	0.00061761001...
30	Yes	6.3	0	0.10971246136...
31	Yes	8.8666...	0	0.18903868958...

Regression function	
Prediction Errors	
Samples	379 of 379
Mean	0,0002742603
Root-Mean-Square	0,2323219
Mean Standardized	0,0006933856
Root-Mean-Square Standardi...	1,03418
Average Standard Error	0,2207254

Figure 3.5. ArcMap 10.7 Geostatistical Wizard Cross Validation Screen

This process helps to assess whether the measurement points with high exceedance probabilities also have high concentrations, i.e. threshold exceeding concentrations. According to this assessment, if a point with high concentration has lower exceedance probability, this indicates that most of the neighbors used to predict that point's exceedance probability has lower concentrations and lower exceedance probabilities.

As a result of analysis, two types of geostatistical surfaces were obtained, (i) probability surface and (ii) standard error of indicators surface. Probability surfaces are usually used when there is a specific value of interest, such as a national regulatory criterion for a pollutant. On the other hand, standard error of indicators surface provides standard errors of the expected value of the indicator variable, which is either 1 or 0; i.e. it is the standard error of the probability that the threshold value is exceeded (ESRI, 2019e). Figure 3.6 provides the GA steps conducted in this study.

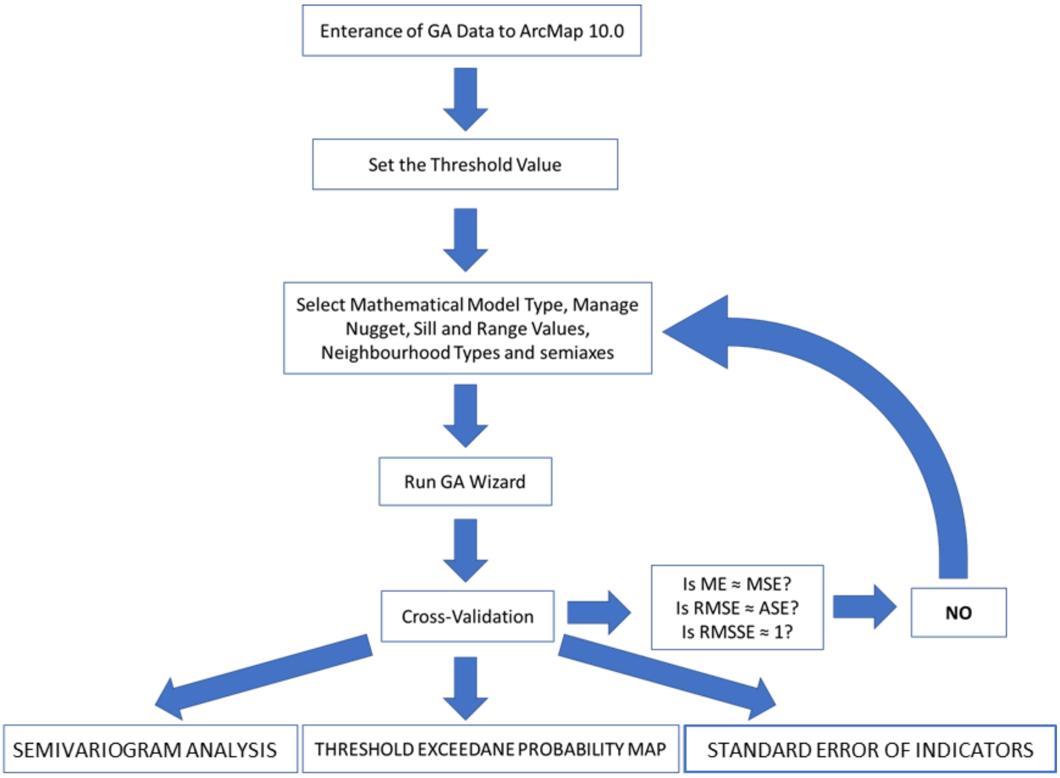


Figure 3.6. Steps of GA

3.2. Determination of Critical Regions along a Coastal Zone

As outputs of GA two maps are generated, namely, threshold exceedance probability maps and standard error of indicators maps. The critical regions are defined based on the probability of exceedance of threshold in a given area. The criteria set for designating an area as "highly critical" is used to designate a region is highly polluted with fecal sources and contains problematic areas in terms BWQ. The set criterion for "highly critical" region is:

- Threshold exceedance probability is > 90% for at least 3 times in the last 2 periods

This is applicable to Marmara and Black Sea regions of Turkey. In order to assign a bathing site as critical in a region; two tables were generated for each region. One of them shows the bathing sites that show >90% exceedance probability in a given period based on each BWQ parameter. The second table shows the frequency of observation of >90% exceedance probability in a given bathing site by summing up the occurrences for all three parameters without any segmentation. In this table, all periods and the last two periods are shown, separately, which enables the determination of (i) critical regions and (ii) the temporal BWQ status of a bathing site. Further discussion of this evaluation is given in Chapter 4.

On the other hand, if a region is in relatively better position in terms of BWQ, then a less strict criteria is set for that particular region and the region is named as “moderately critical”. As the objective is not only to compare the regions of Turkey with each other but also to provide a within-region comparison of BWQ status, it is important to determine regions with different levels of criticality. Therefore, “moderately critical” criterion can be stated as:

- Threshold exceedance probability is > 90% for at least 3 times in the last 2 periods

In regions such as Mediterranean, BWQ shows much better profile and thus, even a small depletion in BWQ in these regions may cause significant side effects. Decrease in tourism income and increase in number of people concerning from bathing water related illnesses are the most significant examples for this situation. Therefore, much lower exceedance probability value, i.e. 70%, is set for “less critical” regions. The less critical regions are determined by the following criterion:

- Threshold exceedance probability is > 70% for at least 3 times in the last 2 periods

3.3. Study Area and Available Data

Turkey is a Mediterranean country having coasts to three international and one inland seas. As mentioned in Chapter 2.2.3 BWQ monitoring applications has initiated in 1993 still continue. In northern region of the country, it has coast to Black Sea, in southern region Mediterranean Sea is located and western region has coast to Aegean Sea (Figure 3.7). Also, there is an inner sea, named Marmara Sea, provides a transition between Black Sea and Aegean Sea. Turkey has also high potential of inland waters, which are also used for recreational purposes. Van, Hazar, Burdur, Eğirdir, Beyşehir and Sapanca lakes are some of the important inland waters those are also used for recreational purposes and have beaches around them.

Figure 3.7. BWQ Monitoring stations in Turkey

There are 5 monitoring purposes identified by General Directorate of Public Health for BWQ assessment, namely, bathing water monitoring, Blue Flag, pollution monitoring, pollution research and complaint. These purposes are explained briefly below (General Directorate of Public Health, 2008). Regardless of the purpose of monitoring, the three parameters given in Table 2.7 are monitored and in some cases additional parameters such as pH, color, heavy metals, mineral oils and so on are monitored (Official Gazette Notice 26048, 2006). In this thesis, data evaluation covers only these three parameters; TC, FC and FS bacteria concentration as BWQ parameters.

- Bathing water monitoring: Most of the monitoring stations are in service to serve to this purpose. Depending on the monitoring results recorded by these stations, fate of beaches located nearby those monitoring stations are determined, i.e. beaches can continue their activities, or any leisure activity should be banned.
- Blue Flag: Blue flag certificate may be given to the beach if it satisfies the criteria given in Table 2.11.

- Pollution monitoring: These monitoring stations are usually located on river mouths or nearby direct wastewater and/or WWTP discharge locations. The main purpose of these stations is to investigate the health risks.
- Pollution Research: This is related to the research studies which may aim to determine the reasons of fecal pollution in a polluted bathing site.
- Complaint: These monitoring applications are conducted when/if public reports to health centers with bathing water related illnesses or public complaints.

In this study, each coastal zone is geostatistically assessed. The coastal zones, namely Black Sea, Marmara Sea, Aegean Sea and Mediterranean Sea, used in this study are shown in Figure 3.8.

Figure 3.8. Coastal Zones of Turkey (General Directorate of Public Health, 2008)

In Section 2.3, it is reported 25 years of historical data of BWQ parameters is available for the coastline of Turkey. In order to analyze the samples collected from the coastline for related BWQ parameters a monitoring station is needed and the number of monitoring stations along the coast of Mediterranean Sea, Aegean Sea, Black Sea and Marmara Sea has been changing (Figure 3.9). Before 2010, BWQ monitoring stations were dominated by Mediterranean and Aegean coastal lines, however, after 2009 a drastic increase in monitoring stations along the country was observed. Figure 3.9 shows the change in the number of BWQ monitoring stations for each coastal zone between 1993 – 2018.

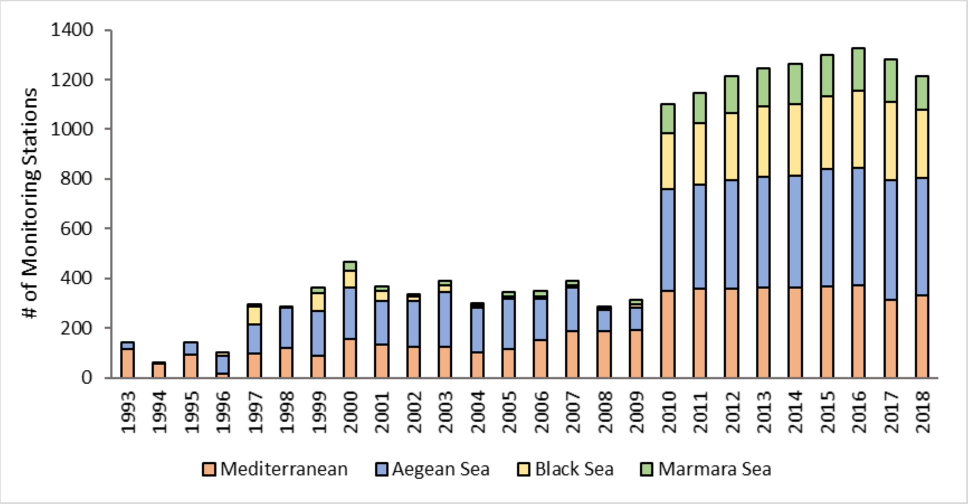
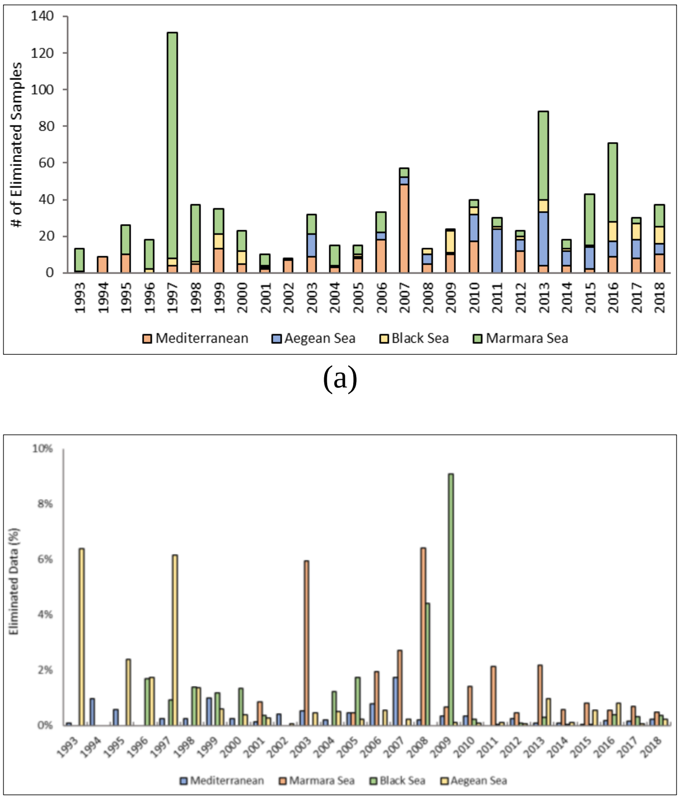


Figure 3.9. The Change in the Number of BWQ Monitoring Stations in Turkey Coastline

In order to conduct GA, the first step is the pre-processing of the collected BWQ data. The main objective of this pre-processing step is to assess the quality of the data. In this study, major criteria to evaluate that if the data is correct or there is a possibility of measurement error is to check the difference between TC and FC parameters. As stated in Chapter 2.1, FC is a sub-group of TC and therefore concentration of FC should always be lower than or equal to TC. Therefore, data points which were not satisfying this condition has been eliminated. Figure 3.10 shows the change in the number of eliminated samples between 1993 and 2018. It was observed that the Marmara Sea region had the highest number of unreliable data in comparison to other regions. As can be seen from Figure 3.10, at any year the eliminated samples did not go beyond 10 %.



(a)

(b)

Figure 3.10. The Change (a) in the Number of Eliminated BWQ Samples and (b) in the Percentage of Eliminated Samples

Municipal Wastewater Treatment Plant Locations

Wastewater discharges are one of the main causes of fecal contamination frequently observed in bathing sites (WHO, 2001; Hassan, 2003; Gavio, Palmer-Cantillo, & Mancera, 2010). Therefore, discharge locations of municipal wastewater treatment plants, urban wastewater treatment plants and/or direct discharges are examined as a possible environmental stress on bathing sites. The discharge criteria for municipal WWTPs is provided in Water Pollution Control Regulation (Appendix B). As shown in Table B-3 there is no discharge criteria available for microbiological parameters which are examined for BWQ in this study, i.e. total coliform, fecal coliform and fecal streptococci. In order to reduce the concentration of these BWQ parameters the presence of disinfection unit is significant. However, unfortunately with the available information provided by the Ministry we were unable to differentiate WWTPs with a disinfection unit and locate them on the map.

Deep Sea Discharge Systems

Deep sea discharge systems are defined as “a piece of engineering structures designed to convey industrial and/or domestic effluent into ambient waters as a means of reducing the impact of (treated or untreated) anthropogenic waste to acceptable levels to the receiving environment.” Botelho, et al. (2016). Therefore, unlike WWTPs, deep sea discharge systems discharge wastewater in a way that no depletion would be observed through receiving body environment, i.e. bathing waters. The reason behind this situation is that a preliminary and primary treatment processes should be applied the wastewater before it reaches to deep sea discharge system. After that dilution dynamics and disinfection capability of the marine environment treats wastewater during deep sea discharge operation. Discharge criteria published in Water Pollution Control Regulation is provided in Appendix B, Table B-4. Discharge locations of WWTPs are obtained from Provincial Environmental Status Reports of each province (General Directorate of EIA, Permission and Audit, 2019).

Population Data

Household based population data is obtained from Turkish Statistical Institute (TÜİK) (TÜİK, 2018). The data is used to assess a possible correlation between the population and human originated fecal pollution in bathing sites. According to previous studies, densely populated areas may have a high impact on poor BWQ (Malcangio, Donvito, & Ungaro, 2018; Kelly, et al., 2018).

Locations of Marinas

Marinas are also indicated as important fecal pollution sources for bathing sites due to sewage discharges (European Commission, 2007). Although, marinas are not as effective as combined sewer overflows, domestic animals, seeping septic tanks and population density on fecal pollution, especially in holidays when boating activities are frequent, marinas are potential fecal pollution sources on bathing sites (US EPA, 2015). McAllister et al. (1996), recorded that for recreational waters around marinas are violated FC criteria most of the time. Therefore, in this study, location of marinas is used as a discussion tool. Although, marinas and their septic tanks including all urinal and fecal wastes generated from yachts or ships evaluated as a “possible” reason of fecal pollution, according to Annex IV of “The International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978 (MARPOL 73/78)”, for which Turkey has been also a counterparty, forbids the wastewater discharges through marine environment closer than 12 miles to coasts (International Maritime Organization, 2003). Locations of marinas were obtained from Chamber of Shipping (Chamber of Shipping, 2019).

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Bathing Water Quality Assessment around Mediterranean Region

Mediterranean region constitutes the southern part of Turkey coastline. It has a 1,600 km of coastline (Turkish Marine Environment Protection Association, 2019). Salinity of Turkish Mediterranean is ranged between 39.0 – 39.1 PSU in winter and 39.5 – 40.0 PSU in summer, which indicated high levels of salinity (Tuğrul, Yücel, & Akçay, 2016). Turkish Mediterranean region also shows the Mediterranean climatic conditions with a warm winter and hot summers (Lionello, 2012). Therefore, bathing season in the region starts earlier than other coastal regions of Turkey. General Directorate of Public Health stated that for Mediterranean Sea bathing season starts on 1st of May and ends on 30th of October (General Directorate of Public Health, 2008).

Mediterrenean coastline of Turkey has the lowest number of cities located nearby the seaside, i.e. Antalya, Mersin, Adana and Hatay, currently, yet it has the second highest number of BWQ monitoring stations with a total of 470 (General Directorate of Public Health, 2018). Antalya is one of the most popular tourism destination of Turkey and the world, therefore, in addition to local tourists, Antalya and thus Mediterranean region hosts quite a high number of foreign tourists each bathing season. According to 2018 General Assessment Report on Tourism, Antalya takes the first place in Turkey for hosting the highest number of domestic and international tourists (Republic of Turkey Ministry of Culture and Tourism, 2019).

Mersin is also an important tourism destination of Turkey with natural and cultural assets, and high potential of beach tourism (MTSO, 2019). Mersin coasts also hosts several endangered species, i.e. *Caretta Caretta* and Mediterranean monk seal in their breeding periods (Mersin Regional Directorate of Nature Conservation and National Parks , 2014; Governorship of Mersin, 2018). Compared to Antalya and Mersin, Adana and Hatay provinces are not preferred as much for recreational activities. The reason is their close proximity to other cities. For example, Mersin and Adana are located close to each other and climatic conditions are more favorable for bathers, in bathing seasons bathers and/or local people of Adana travel to Mersin for recreational activities. In this section, first of all dataset used for GA in the Mediterranean region will be explored by some basic statistics and then GA results will be discussed.

4.1.1. Exploratory Data Analysis for Mediterranean Coastline

BWQ monitoring has been initiated in 1993 in the Mediterranean region. Although, at first, monitoring activities was limited with Antalya, the number of monitoring stations were increased year by year (Figure 3.9). Figure 4.1 provides change in the number of measurements in bathing seasons and all other periods including bathing season (1st of May and ends on 30th of October).

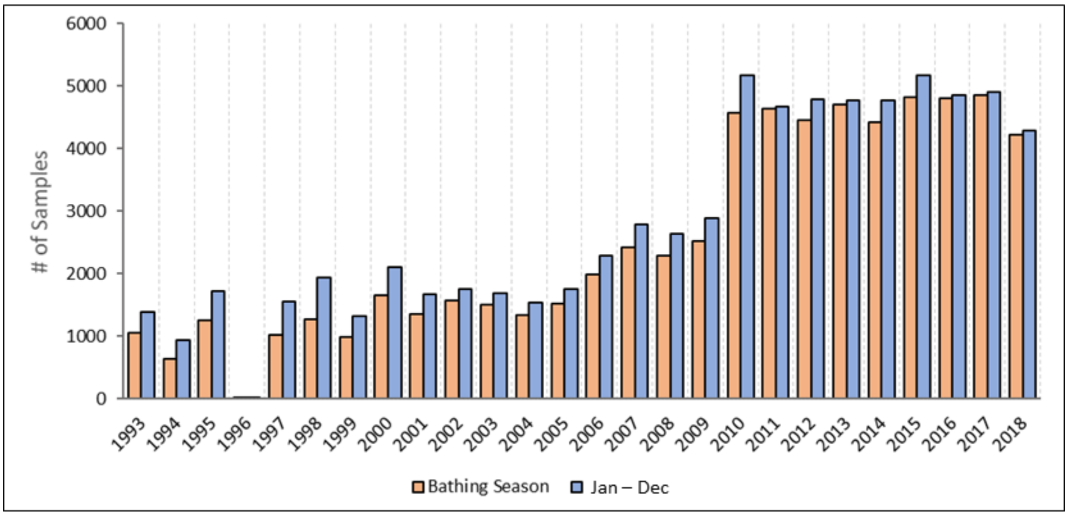


Figure 4.1. The Change in the Number of BWQ Measurements in the Mediterranean Region

Mediterranean region has the longest period of BWQ monitoring with 25 years of measurements and also it is the coastline where the number of BWQ monitoring stations per coastal distance is highest. Figure 4.1 shows that the number of monitoring stations in Mediterranean coastline is increased by each year. Especially after 2010, similar to other coastal zones of Turkey, i.e. Aegean, Black Sea and Marmara, a drastic increase has been observed in the number of BWQ measurements.

Mediterranean coastline also has the second highest number of beaches which holds a Blue Flag which comes after the Aegean coasts. The fact that there is quite a high number of Blue Flags (a total of 210) indicated the good standing of Mediterranean beaches of Turkey in terms of BWQ (TÜRÇEV, 2018). Figure 4.2 provides the change in the concentrations of BWQ parameters in all bathing sites located in the Mediterranean coastline in between years 1993 and 2018. There are a small number of locations with poor BWQ in Mediterranean coastline, and most of the measurements, the analysis results satisfy the relevant regulation.

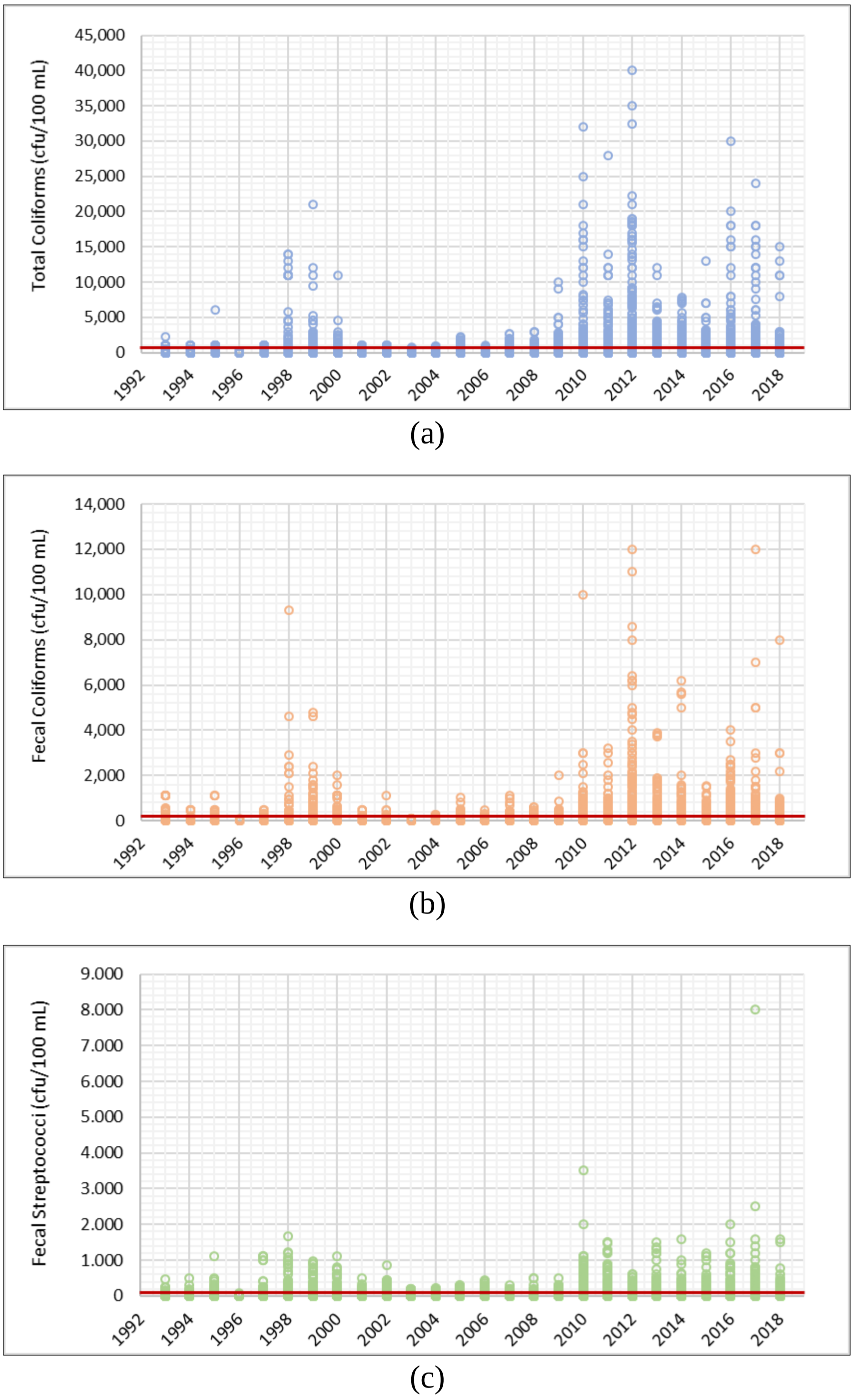


Figure 4.2. The Variation in the Concentrations of (a) TC (b) FC (c) FS over the cycle of 1993 – 2018 in the Mediterranean Coastline[6]

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[6] Circles represents the measured data, and red line shows the regulatory limit for good quality, which refers to 500 cfu/100 mL for TC, 100 cfu/100 mL for both FC and FS.

Figure 4.2 shows that after 2010, the number of exceedances especially for TC and FC were increased, yet, one should keep in mind that both the number of monitoring stations (Figure 3.9) and the number of collected samples for BWQ monitoring (Figure 4.1) were increased after 2010. In order to account for this change the percentage of samples that are exceeding the regulatory limits are reported in Figure 4.3 for each parameter.

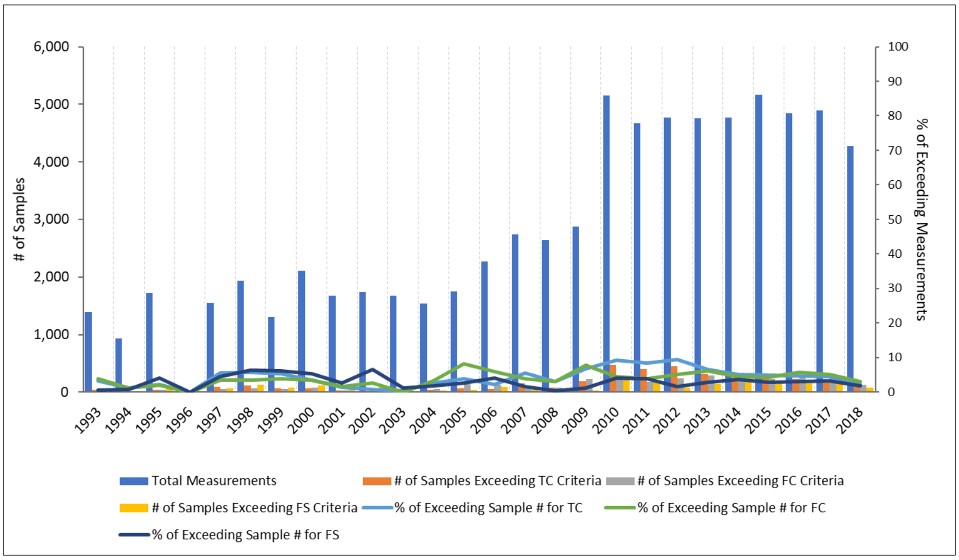


Figure 4.3. Number of Threshold Exceeding Measurements in Mediterranean Coastline

In Figure 4.3, the number exceedances were determined by comparing the measured data with the guideline value given in Table 2.7. Over the past 26 years of measurements along the Mediterranean coastline, the number of samples which exceeded the regulatory limits was not above 10% (Figure 4.3). After 2013 the percentage of exceeding observations has decreased year by year for both TC and FC. The possible reason lying behind this situation is that in 2010 BWQ monitoring recordings became more systematic as a part of EU integration process and in 2012, Ministry of Health started sharing BWQ analysis results freely with public online via Bathing Waters Monitoring System (General Directorate of Public Health, 2019). This is an indication that public awareness and perception is an important leading factor for improvement of BWQ (Pendleton, Martin, & Webster, 2001; Shepherd, 2014; Duvat,

2012) . The single sample maximum concentrations of each BWQ parameter in between years 1993 and 2018 is reported in Figure 4.4. The single sample maximum concentrations of TC ranged between 240 and 40,000, with 12 single sample maximum concentrations that are exceeding 10,000 cfu/100 mL.

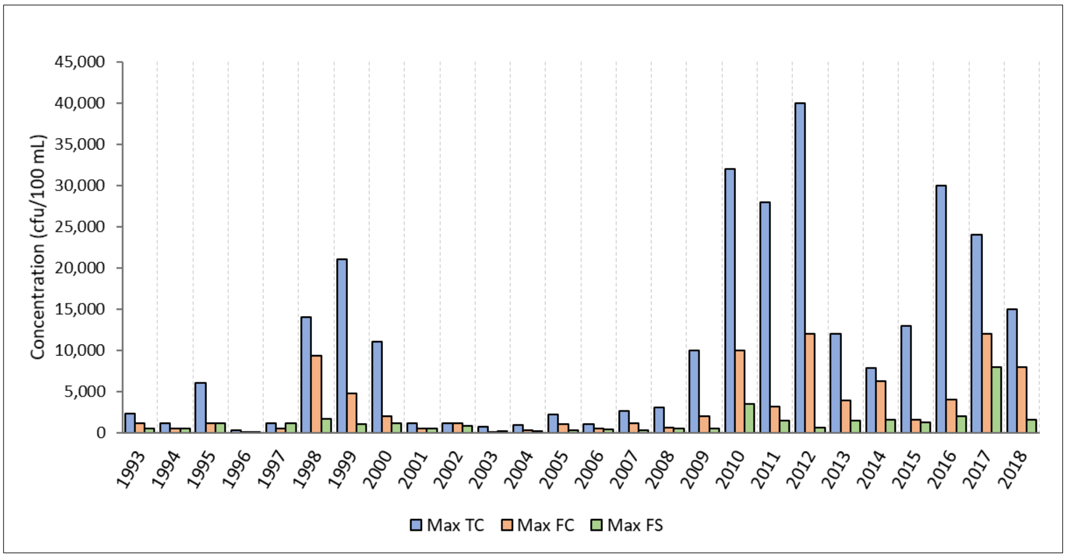


Figure 4.4. The Change in the Single Sample Maximum Concentrations of BWQ Parameters in the Mediterranean Coastline over the years 1993 - 2018

Figure 4.3 shows the percentage of exceedances decreased after 2013, however, according to Figure 4.4 after 2013 the single sample maximum concentrations became extremely high due to the widening of monitoring activities in river mouths with the purpose of “pollution monitoring”. These points may indicate fecal pollution caused by wastewater discharges. As the TC concentration of treated domestic sewage ranges between 10^4 - 10^5 cfu/100 mL (Vargas, Moreira, Spricigo, & José, 2013). BWQ monitoring stations which are opened for the reason of pollution monitoring definitely helps the determination of the impacts of WWTPs on BWQ. Figure 4.5 provides number of monitoring stations with respect to their purpose of monitoring.

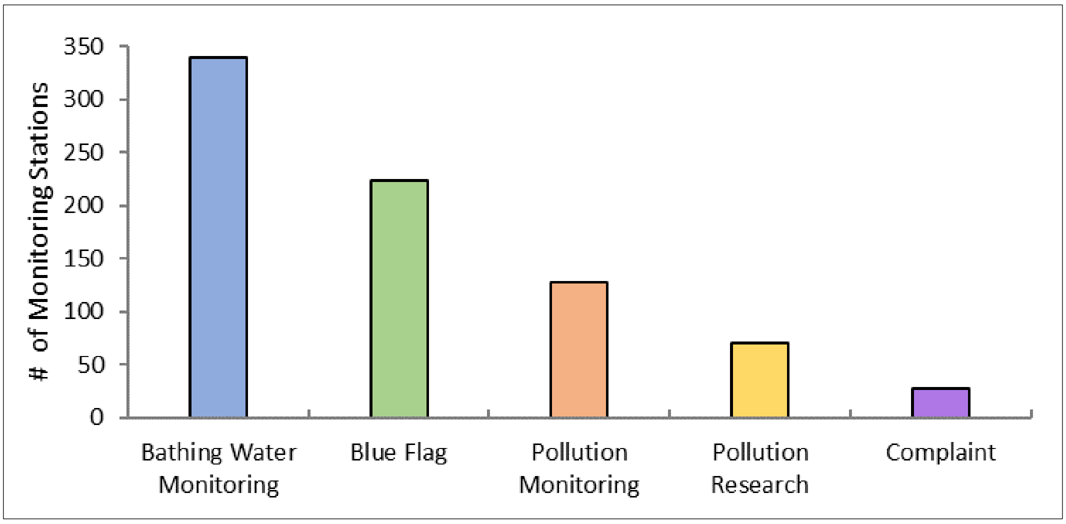
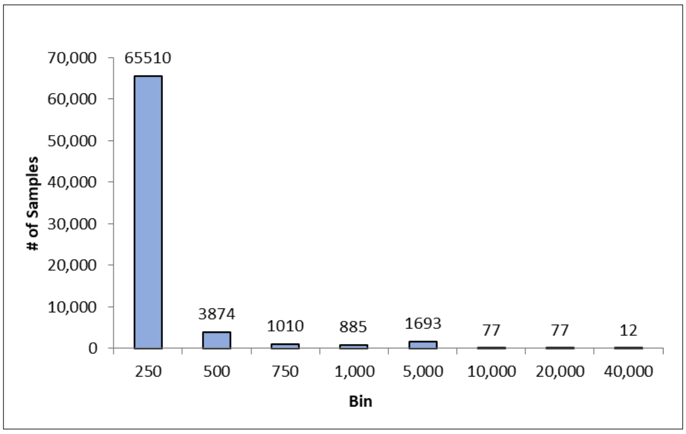
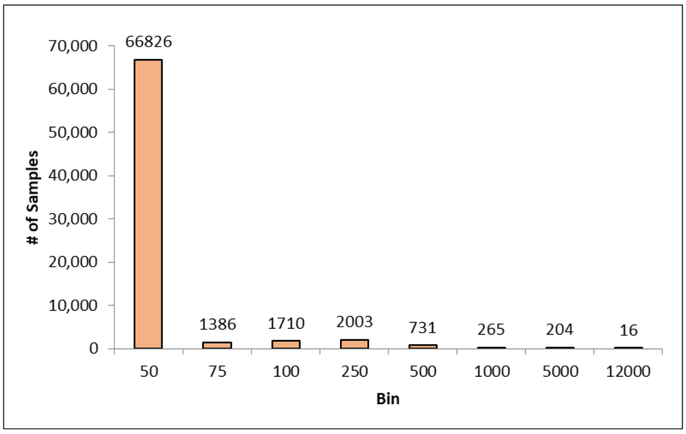


Figure 4.5. Number of Monitoring Stations for Different Purposes in Mediterranean Region

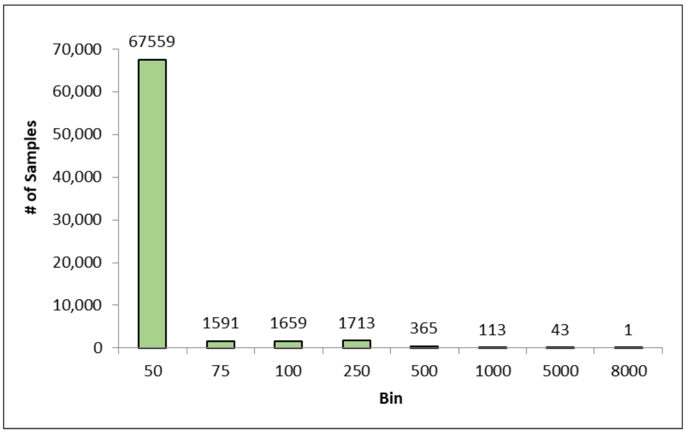
Please note that one beach can be monitored regarding more than one purpose which may have led to counting a beach more than once in Figure 4.5. Although, single sample maximum concentrations for each parameter increased after 2010, when the whole dataset is evaluated, it is observed that the number of samples satisfying the BWQ criteria represents the majority of the entire dataset for each BWQ parameter. Figure 4.6 provides the histograms for all BWQ parameters for 25 years period.



(a)



(b)



(c)

Figure 4.6. Histograms of (a) TC (b) FC and (c) FS concentrations in Mediterranean Region

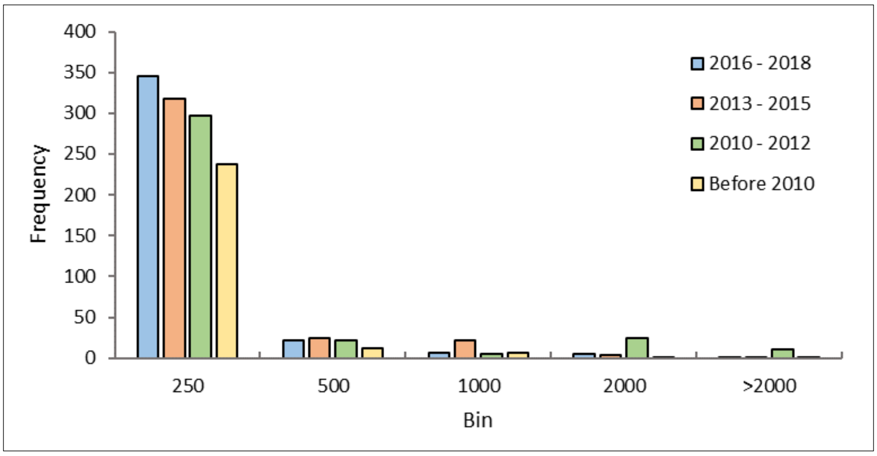
According to Figure 4.6, 94.7%, 93.2% and 94.5% of samples satisfy BWQ criteria for TC, FC and FS, respectively. Table 4.1 provide general statistics of the dataset used in GA for the Mediterranean region.

Table 4.1. *General Statistics of the GA Dataset of Mediterranean Region*

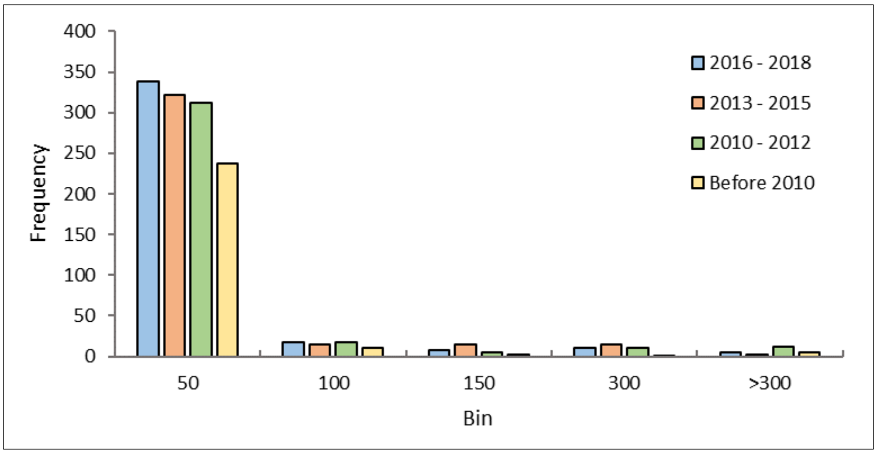
Parameter	*TC*	*FC*	*FS*
Total number of measurements	73,138	73,125	73,035
Maximum value (cfu/100 mL)	40,000	12,000	8,000
Minimum value (cfu/100 mL)	0	0	0
Mean (cfu/100 mL)	140.2	25.7	16.1
Standard Deviation (cfu/100 mL)	706.4	176.2	66.5

4.1.2. Geostatistical Analysis of BWQ Data of the Mediterranean Coastline

Mediterranean region has the second largest number of monitoring stations. In this study, for Mediterranean region, total of 470 monitoring stations are used for GA, but this number is different for each study period. During GA all monitoring stations were taken into consideration and data analysis was conducted over 4 periods, i.e. 2016 – 2018, 2013 – 2015, 2010 – 2012 and before 2010. GA is conducted using the average values calculated for each period. The average of all samples collected in these 4 GA periods, i.e. before 2010, 2010 – 2012, 2013 – 2015 and 2016 – 2018, were also calculated for comparison purposes. Figure 4.10 shows the histograms of GA dataset for each period.



(a)



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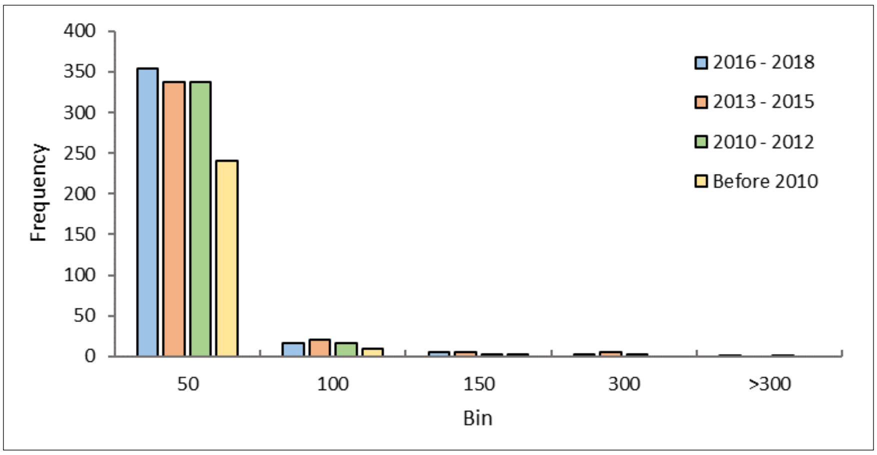


(c)

Figure 4.7. Histogram of GA Dataset for (a) TC (b) FC and (c) FS concentrations over different GA periods in the Mediterranean Region

As can be seen from Figure 4.10, most of the data used for GA for each period is below the threshold values considered in analyses. Therefore, it is expected to observe a good BWQ around Mediterranean coastline and thus, lower exceedance probabilities near bathing beaches. Table 4.2 shows the model parameters estimated by GA.

Table 4.2. *Values of Model Parameters for IK in Mediterranean Region between 1993 - 2018*

Parameter	*Model*	*Range (m)*	*Nugget*	*Lag Size (m)*	*Partial Sill*	*Nugget/Sill Ratio*
TC	Tetraspherical	45,255	0.012	3,771	0.016	0.429
FC	Circular	44,084	0.028	3,771	0.030	0.483
FS	Rational Quadratic	49,006	0.009	3,771	0.004	0.682

Based on nugget values and cross-validation results best-fit models were selected for each parameter. Table 4.2 shows the model parameters used in IK. In the case of TC tetraspherical provided the best-fit to the semivariogram, whereas rational quadratic model was chosen for the FS parameter and circular model was chosen for the FC parameter. The nugget values of TC and FS are very close to each other (0.012 and 0.009), and FC has a nugget value greater than those two parameters. This is an indication of more random data distribution in FC parameter. Regarding nugget to sill ratios it is observed that in Mediterranean region moderate spatial dependency is valid since these values are ranged between 25 – 75% (Essington, 2004).

Lag sizes were selected as the same for each BWQ parameter as each monitoring station measures all three parameters. Range values, which indicate the distance where there is no autocorrelation, for all three parameters are about 45 kilometers and after those distances there is no more spatial correlation between monitoring stations. Figure 4.8 shows the semivariograms of BWQ parameters for 1993 – 2018 BWQ sampling results, for which the model parameters were given in Table 4.2.

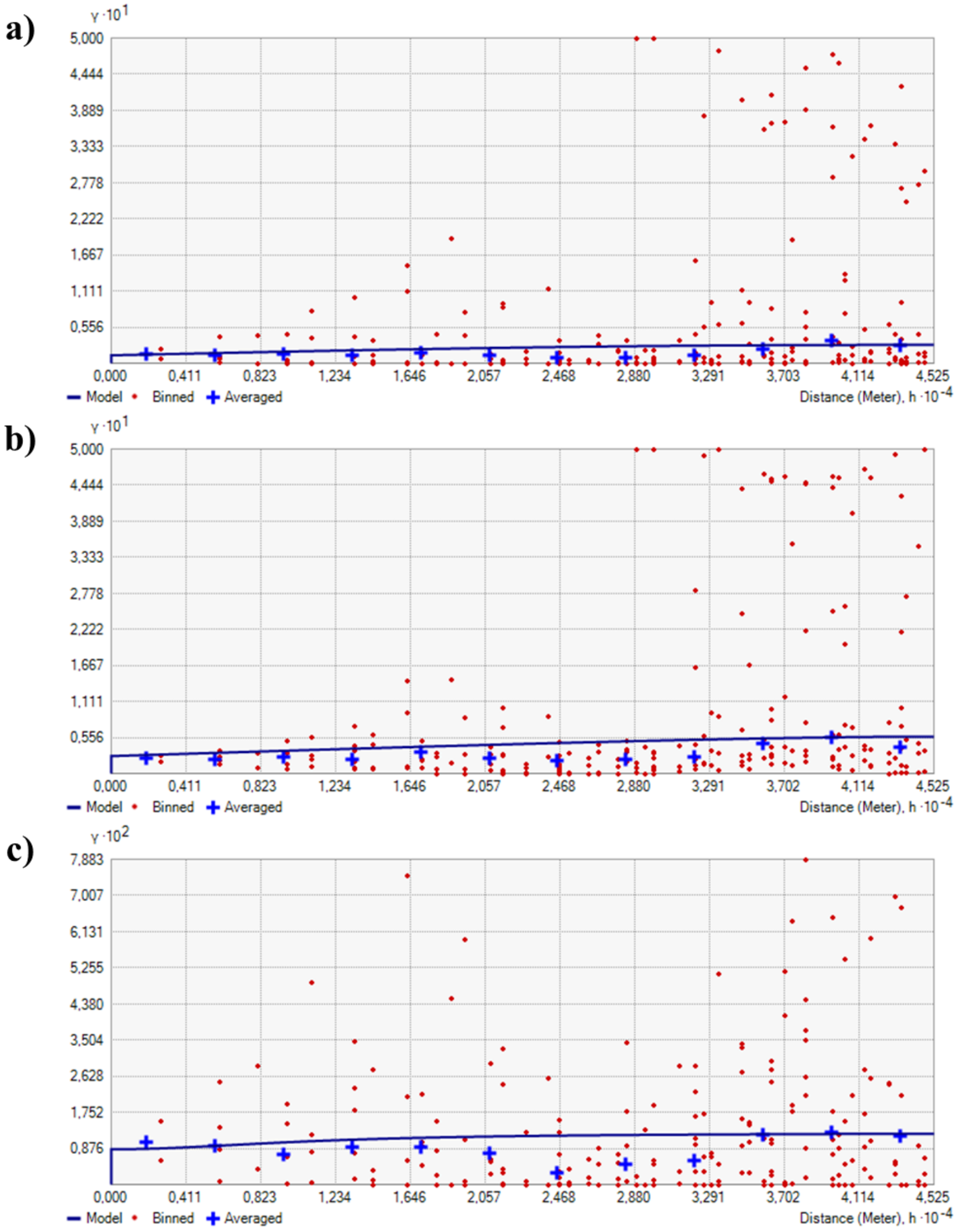


Figure 4.8. Semivariograms of a) TC, b) FC and c) FS in Mediterranean Region between 1993 – 2018

To measure the quality of GA results, cross validation was performed. In this study, first, “Indicator Prediction” results were assessed to compare the exceedance probability values with measurement values. This process helps to observe if the measurement points with high exceedance probabilities also have high concentrations, i.e. threshold exceeding concentrations, or vice versa. According to this assessment, if a point with high concentration has lower exceedance probability, this indicates that most of the neighbors used to predict that point's exceedance probability has lower concentrations and lower exceedance probabilities. Figure 4.9 shows the indicator predictions for all three BWQ parameters.

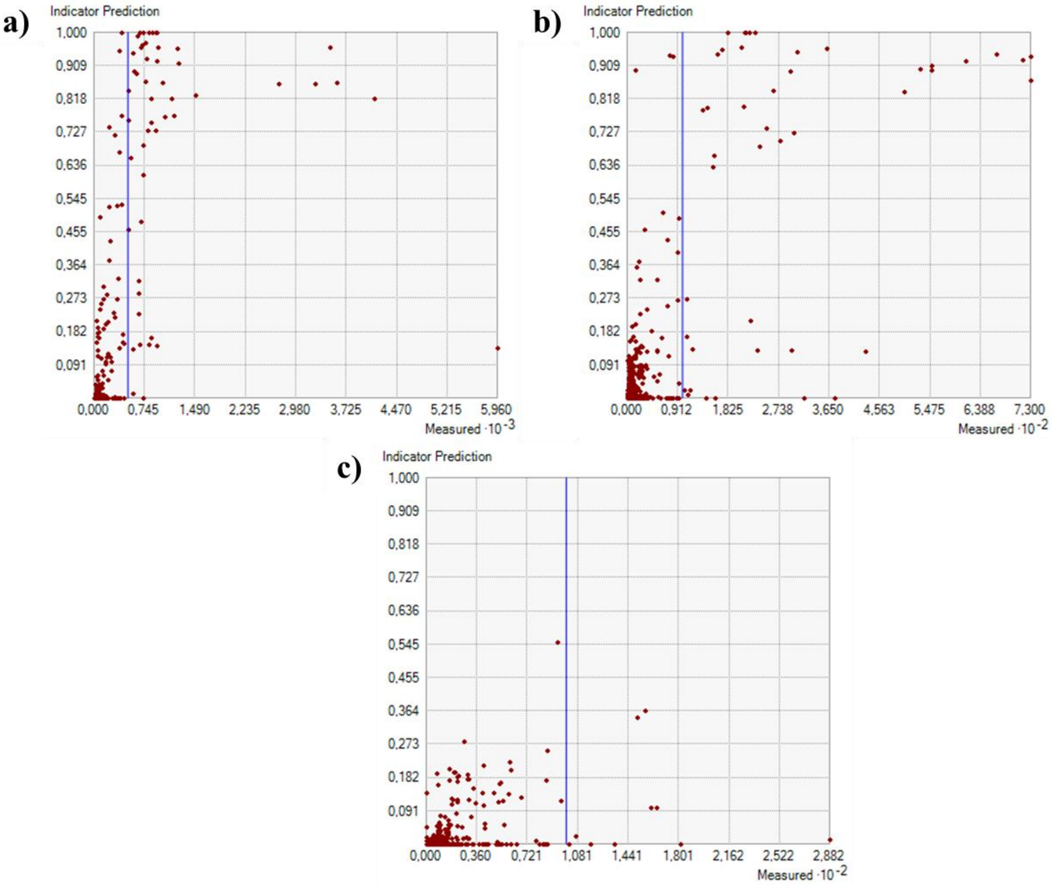


Figure 4.9. Indicator Predictions for a) TC, b) FC and c) FS for Mediterranean Region between 1993 – 2018

According to Figure 4.9, although there are some outliers in each parameters' dataset, for most measurement points exceedance probabilities are correlated with measurement results. Therefore, first step of cross validation shows that the prediction results are acceptable. The second step of cross validation involves estimation and comparison of prediction errors, i.e. comparison of measured values with predicted values. For this purpose, 5 types of error estimations (RMSE, ASE, ME, MSE and RMSSE) were conducted. Table 4.3 shows the cross-validation results of GA between 1993 – 2018.

Table 4.3. *Cross Validation Results for Mediterranean Region*

Parameter	*RMSE*	*ASE*	*ME*	*MSE*	*RMSSE*
TC	0.190	0.123	-0.0007	-0.006	1.468
FC	0.199	0.178	-0.00003	-0.002	1.096
FS	0.149	0.020	-0.0001	-0.002	1.474

Table 4.3 represents that for each parameter, ME values are almost zero and therefore it could be commented that predictions are unbiased. To check if the ME is correctly evaluated, firstly, relation between ASE and RMSE is assessed. For all BWQ parameters, RMSE and ASE values are closer to each other, but, for all parameters, RMSE values are a bit higher than ASE values which indicate that there may be an underestimation for some regions (Arétouyap, et al., 2016). Similar to RMSE and ASE relation, RMSSE values are also used to evaluate whether the ME prediction is correct or not. Since for each parameter RMSSE values are closer to one, although, all of them are a bit higher, predictions are acceptable. RMSSE values also indicate that there may be underestimation since RMSSE values are a bit greater than 1. Depending on these results, exceedance probability maps are obtained and 3rd step of cross validation takes place, namely, standard error of indicators maps. Figure 4.10, Figure 4.11 and Figure 4.12 provides the exceedance probability and standard error of indicators maps for Mediterranean region considering GA dataset between 1993 – 2018. Critical zones are identified by numbers and the designated areas by the numbers are given in Table 4.4.

Table 4.4. *Designated Areas in Exceedance Probability Maps of Mediterranean Region*

Bathing Site Number	*Designated Area*
1	River Mouth of Orontes
2	İskenderun Bay
3	River Mouth of Ceyhan
4	River Mouth of Seyhan

Bathing Site Number	*Designated Area*
5	River Mouth of Limonlu Creek
6	River Mouth of Göksu
7	Gazipaşa
8	Center of Mersin

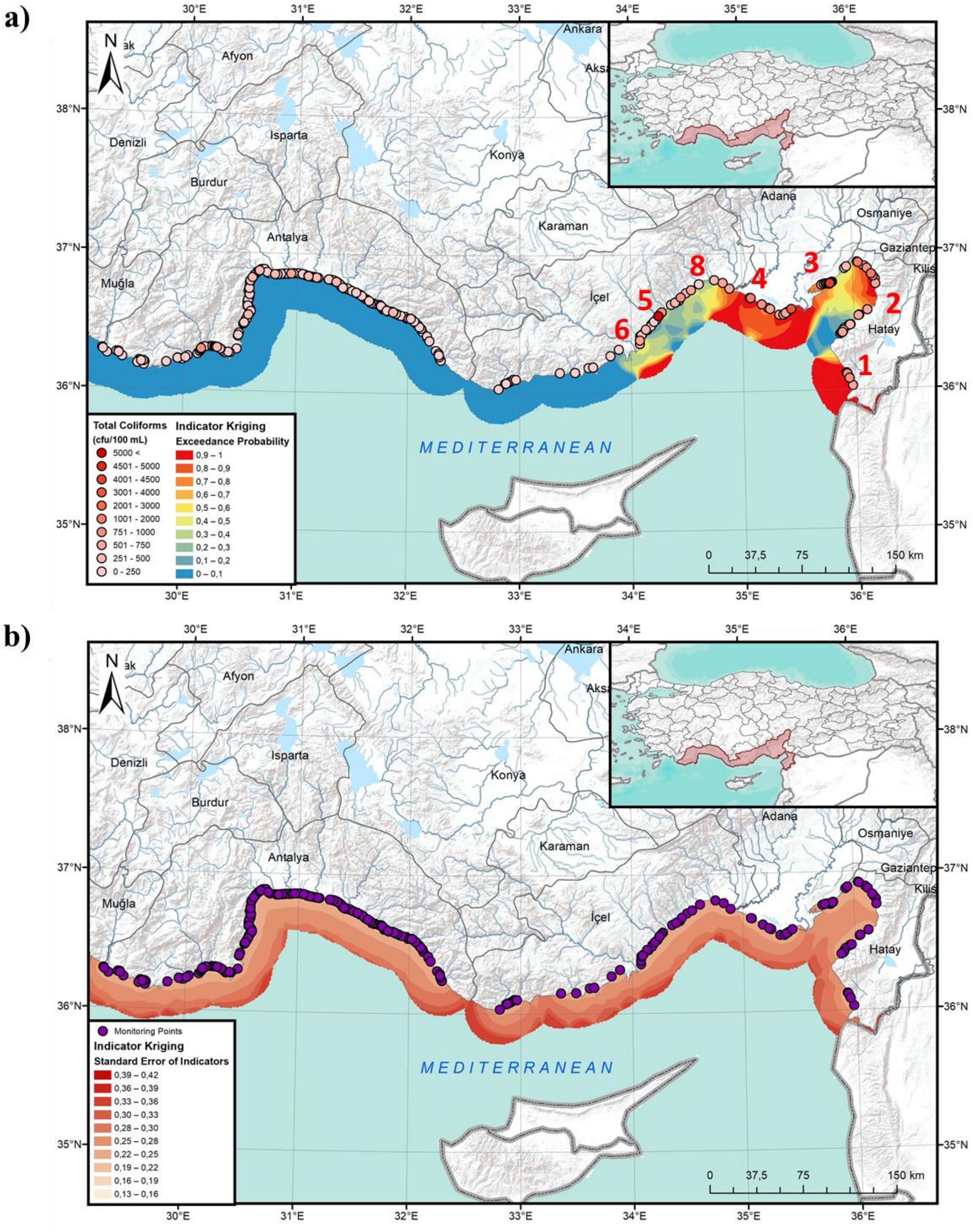


Figure 4.10. a) Exceedance Probability and b) Standard Error of Indicators Maps of Mediterranean Region over years 1993 – 2018 for TC

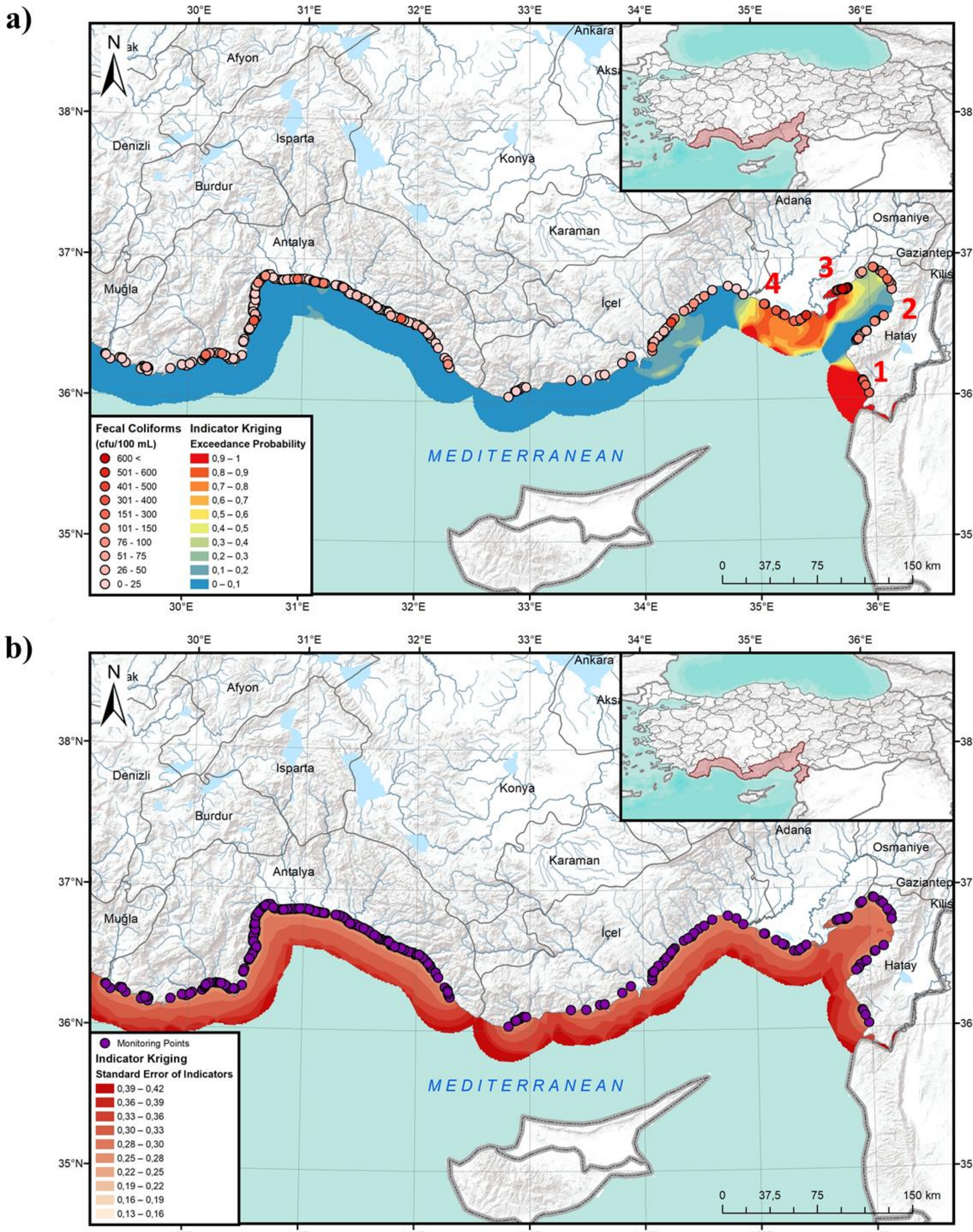


Figure 4.11. a) Exceedance Probability and b) Standard Error of Indicators Maps of Mediterranean Region over years 1993 – 2018 for FC

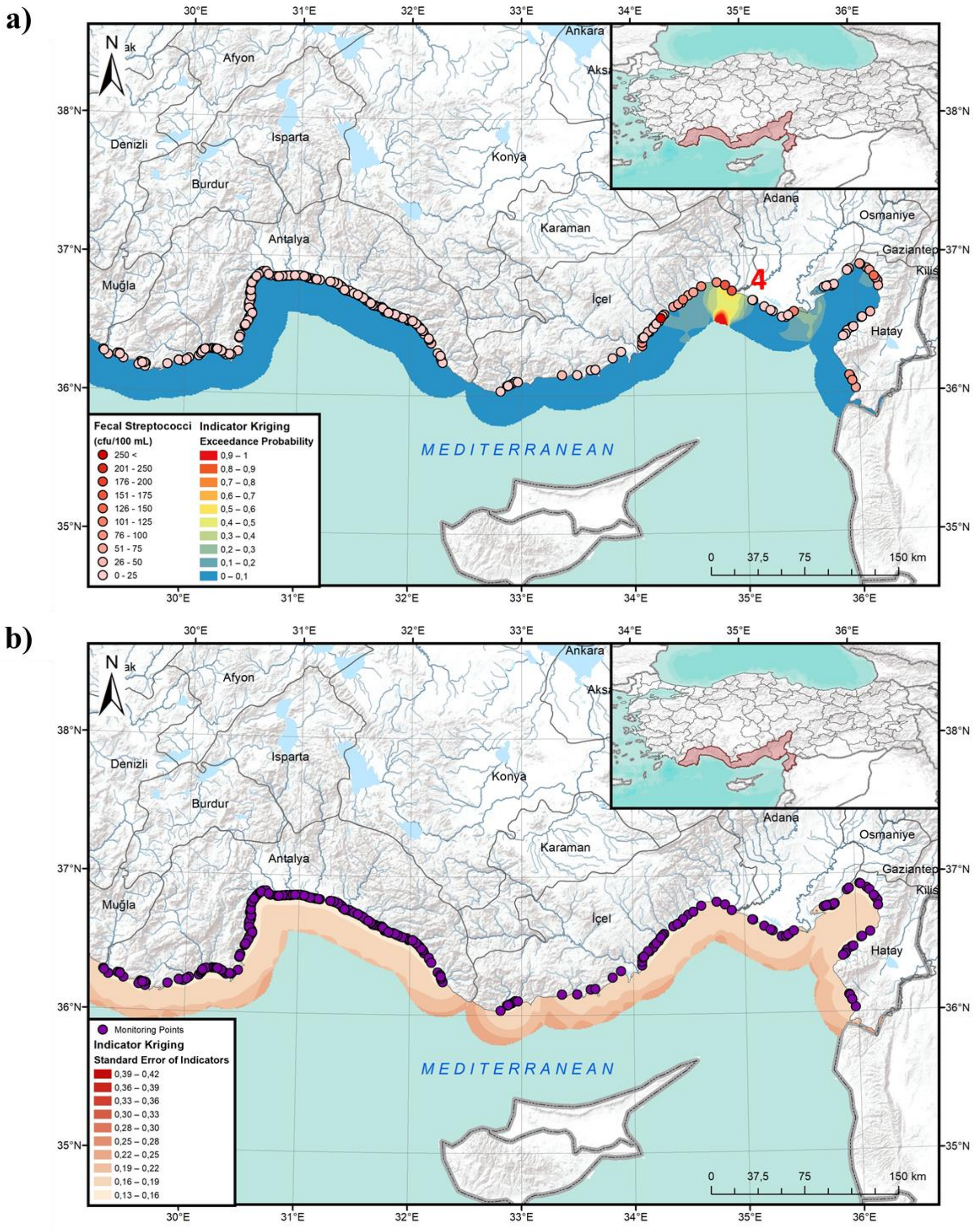


Figure 4.12. a) Exceedance Probability and b) Standard Error of Indicators Maps of Mediterranean Region over years 1993 – 2018 for FS

Figure 4.10, Figure 4.11 and Figure 4.12 gives a general overview of BWQ over years 1993 – 2018. To examine the critical areas in Mediterranean coastline, analyses considering smaller time intervals were also conducted. But figures given above show that most of the time, eastern part of the coastline draws more critical picture in terms of all BWQ parameters. TC and FC have more monitoring stations exceeding the regulatory criteria, however, for FS the number of monitoring stations exceeding threshold value is not that much. Therefore, FS shows more optimistic scenario. To identify the causes of poor BWQ, GA is also conducted for four periods. Table 4.5 provides the model parameters for each BWQ parameter and GA period.

Table 4.5. *Values of Model Parameters for IK in Mediterranean Region*

Parameter_Period*	*Model*	*Range (m)*	*Nugget*	*Lag Size (m)*	*Partial Sill*	*Nugget/Sill** Ratio*
TC_1	Gaussian	45,252	0.017	3,771	0.014	0.548
FC_1	Gaussian	305,808	0.027	3,771	0.105	0.205
FS_1	Hole Effect	45,252	0.011	3,771	0.004	0.733
TC_2	Hole Effect	25,020	0.008	3,771	0.003	0.727
FC_2	Exponential	198,000	0.017	3,771	0.031	0.354
FS_2	Exponential	26,600	0.005	3,771	0.002	0.714
TC_3	Exponential	45,252	0.029	3,771	0.009	0.711
FC_3	Gaussian	41,532	0.028	3,771	0.021	0.571
FS_3	Circular	45,252	0.011	3,771	0.009	0.550
TC_4	Exponential	31,585	0.022	3,771	0.011	0.667
FC_4	Exponential	45,252	0.030	3,771	0.018	0.625
FS_4	Exponential	22,043	0.017	3,771	0.007	0.708

* Period Number 1: Before 2010, 2: 2010 – 2012, 3: 2013 - 2015, 4: 2016 – 2018
**Sill = Nugget + Partial Sill

Nugget values range between 0.004 and 0.030 for each period, and for all periods nugget value for FS semivariogram is lower than others, which points out that the semivariance for FS observations are lower. Depending on these model parameters, semivariogram models are obtained separately for each parameter and for each period. Cross-validation results for each BWQ parameter in each period is provided in Table 4.6.

Table 4.6. *Cross Validation Results for Mediterranean Region*

Parameter_Period*	*RMSE*	*ASE*	*ME*	*MSE*	*RMSSE*
TC_1	0.182	0.137	-0.002	-0.009	1.247
FC_1	0.190	0.169	-0.002	-0.012	1.085
FS_1	0.156	0.110	-0.002	-0.012	1.301
TC_2	0.143	0.096	0.0001	0.0005	1.412
FC_2	0.182	0.142	0.0009	0.004	1.260
FS_2	0.116	0.074	0.0004	0.004	1.532
TC_3	0.195	0.177	0.0002	0.0002	1.081
FC_3	0.225	0.176	-0.0006	-0.003	1.254
FS_3	0.179	0.113	0.0008	0.003	1.529
TC_4	0.179	0.165	-0.0007	-0.003	1.089
FC_4	0.226	0.190	-0.00009	-0.0006	1.171
FS_4	0.157	0.144	0.0003	0.002	1.098

*Period Number 1: Before 2010, 2: 2010 – 2012, 3: 2013 - 2015, 4: 2016 – 2018

Cross-validation results shown in Table 4.6 validates unbiasedness of analyses since ME values are almost zero for each parameter at each GA period. However, for all analyses RMSE values are a bit higher than ASE values, i.e. 6.6% at most, and RMSSE values are higher than 1, the cross-validation results point out that there is an underestimation of spatial variety. The possible reason lying behind this situation is that the number of monitoring stations is very low around Adana and Hatay coasts, i.e. total of 56 stations are representing 270 km of 1,600 km total coastline. Also, along Antalya and Mersin coastlines, there is total of 395 monitoring stations showing high spatial variety. Although, RMSSE values which are closer to 1 is an identification of better prediction, depending on dataset, several studies state that higher or lower values may also be acceptable. In addition to these, RMSSE values become closer to 1 and RMSE and ASE values become closer to each other in 2016 – 2018 period which indicates that spatial correlation between measurements has improved.

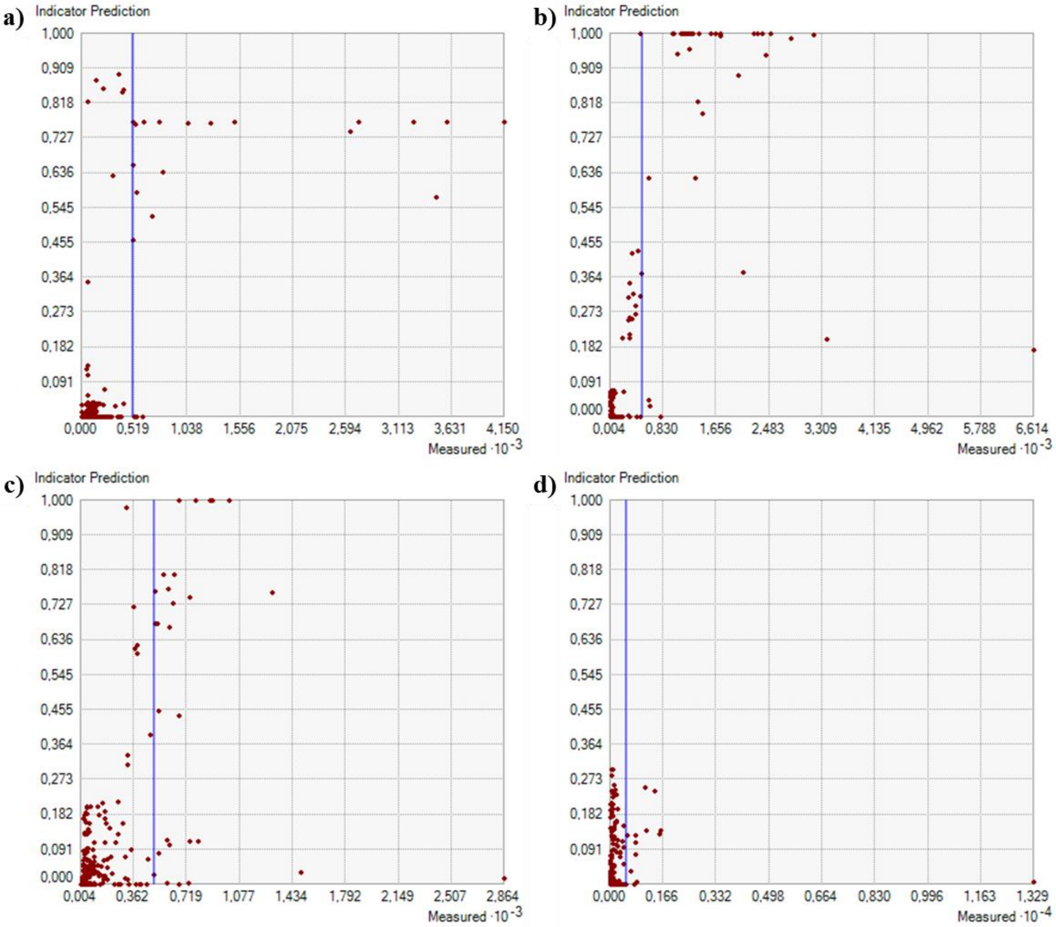


Figure 4.13. Indicator Predictions of TC for Mediterranean Region between a) 1993 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

Figure 4.13 shows that, recently, i.e. between 2016 - 2018, indicator predictions, therefore, exceedance probabilities are mostly lower than 40%. However, before 2016, indicator predictions increased up to 1, which identifies that insufficient BWQ become an areal appearance rather than a point-wise outlier.

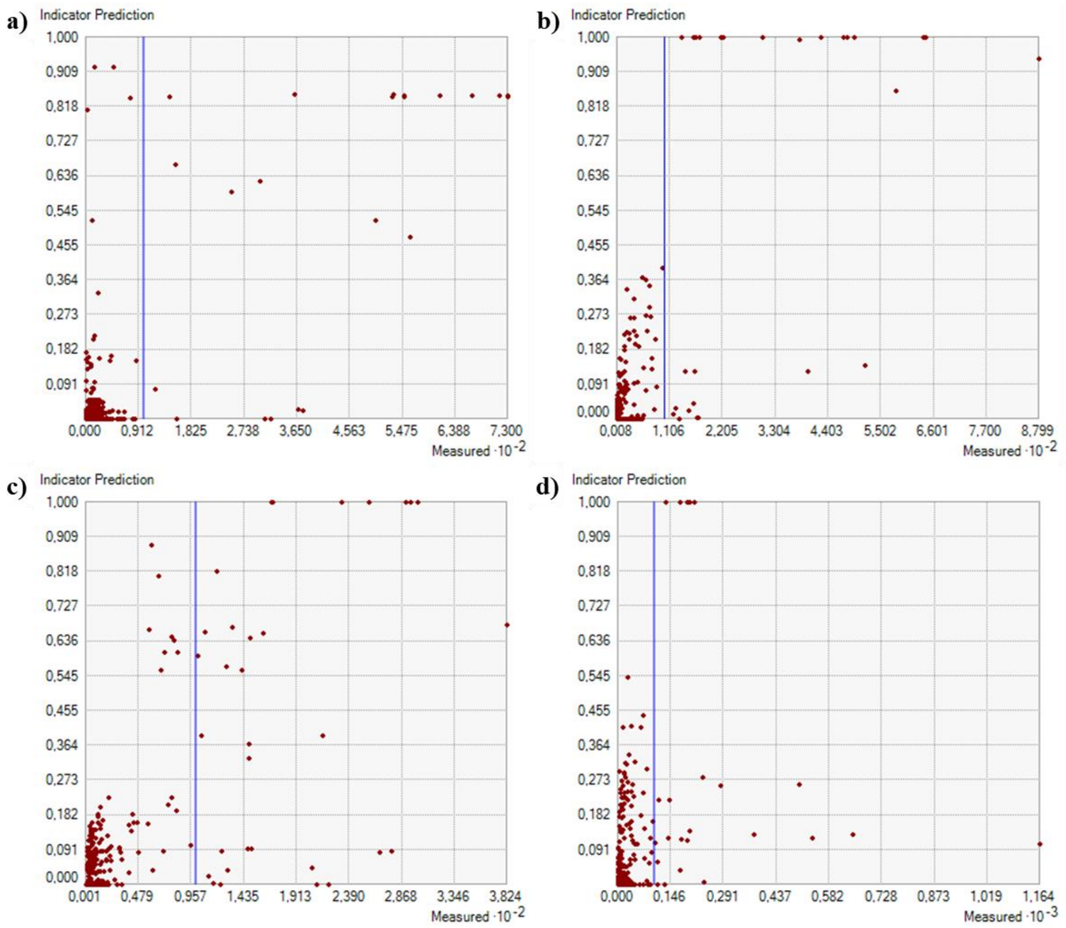


Figure 4.14. Indicator Predictions of FC for Mediterranean Region between a) 1993 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

On the other hand, for FC, exceedance probabilities are higher for more sampling point in each period. Higher exceedance probabilities are also observed in between 2016 – 2018 in consideration of FC. But, also for 2016 – 2018 period, some extremely high FC concentrations are paired with lower exceedance probabilities. This indicates that those outliers show different behavior than their neighbors. The best case is predicted in 2013 – 2015 period, when the highest concentration is 3,824 cfu/100 mL.

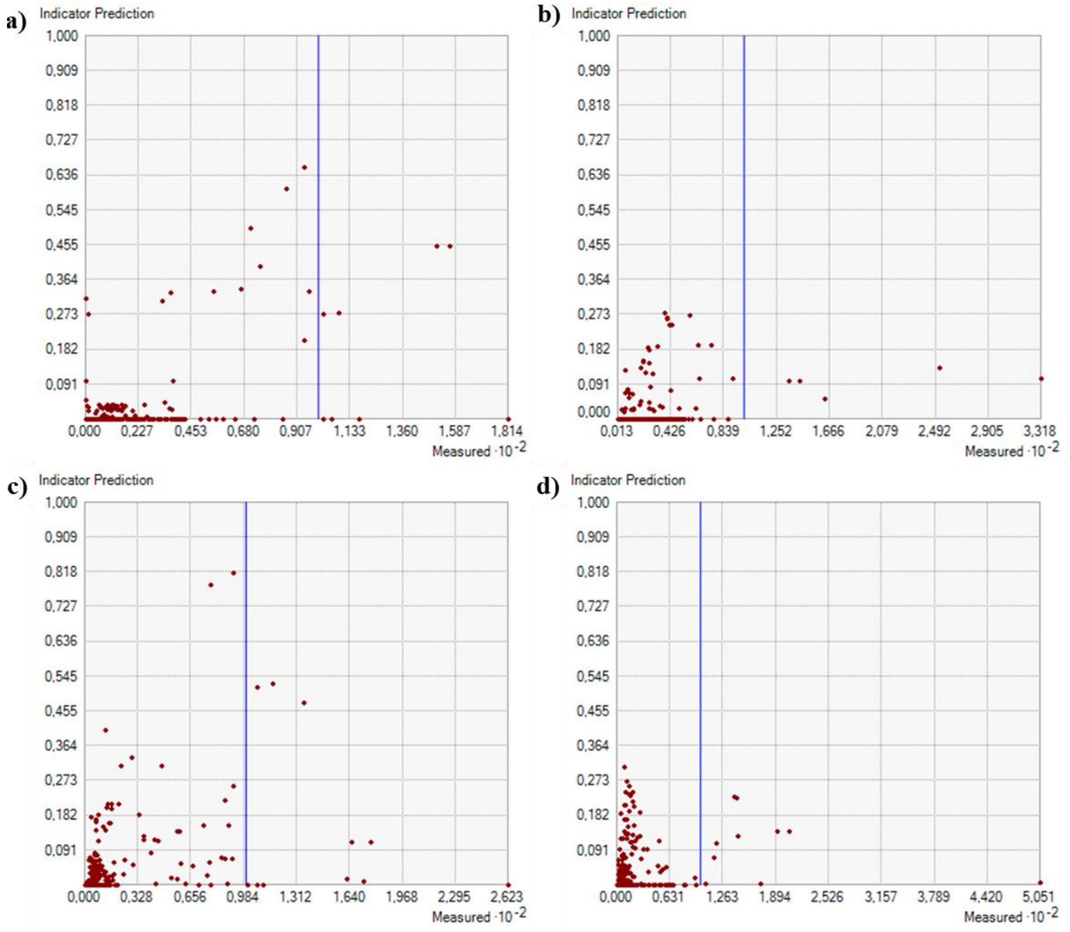


Figure 4.15. Indicator Predictions of FS for Mediterranean Region between a) 1993 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

For FS, highest exceedance probabilities are observed before 2010 and between 2013 – 2015 with values closer to 90%. Unlike FC and TC, FS has satisfactory measurements for most of the monitoring stations between 2016 – 2018, which identifies that fecal pollution is mostly caused by human sources within this period. As exceedance in terms of FS parameter indicates that fecal pollution in the region is animal originated.

As a result of IK analyses exceedance probability maps were obtained for each period for all three BWQ parameters. From Figure 4.16 to Figure 4.27 threshold exceedance probabilities for 1993 – 2010, 2010 – 2012, 2013 – 2015 and 2016 – 2018 periods are shown, respectively.

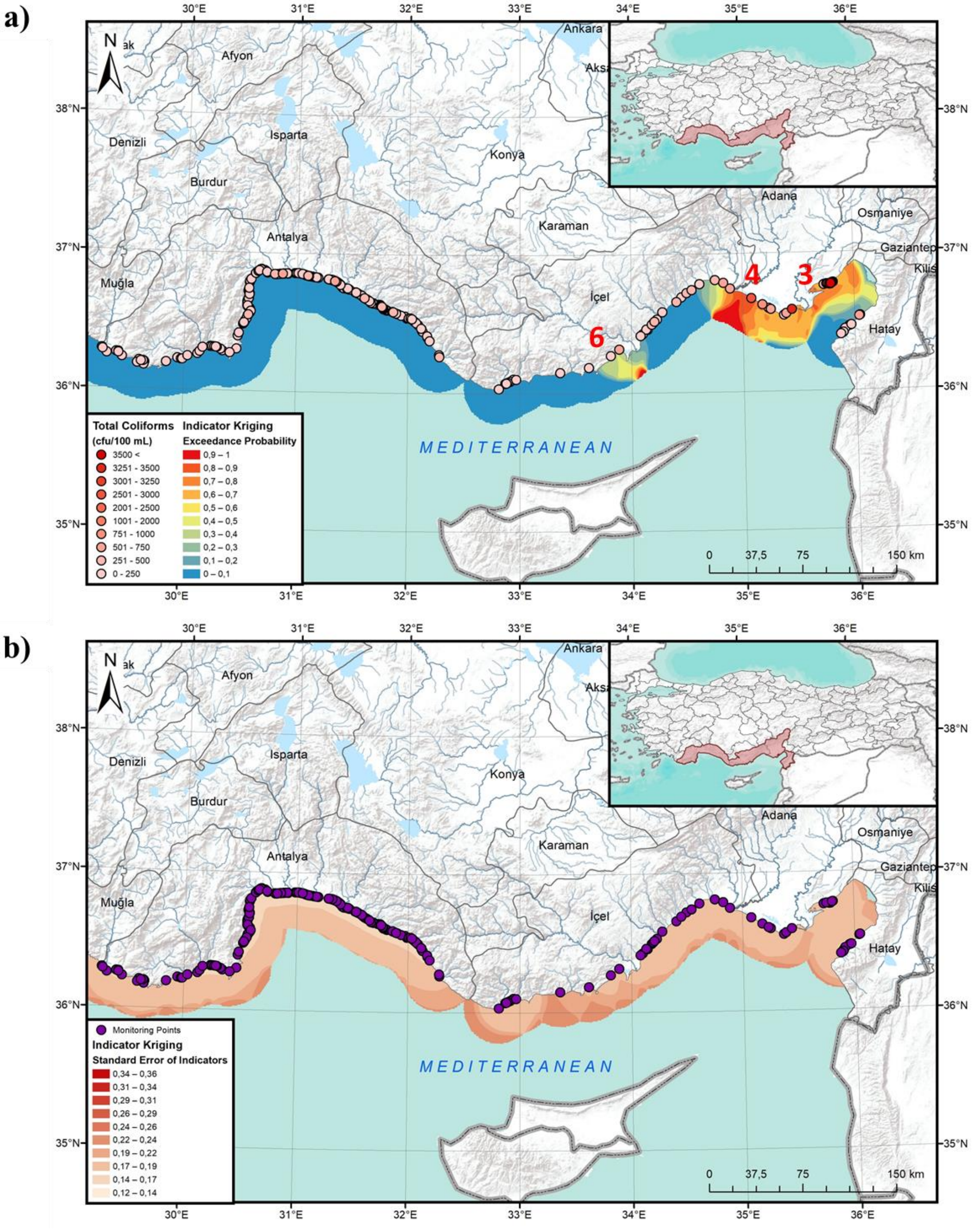


Figure 4.16. a) Exceedance probability and b) standard error maps generated for Mediterranean Region before 2010 for TC (GA period 1)

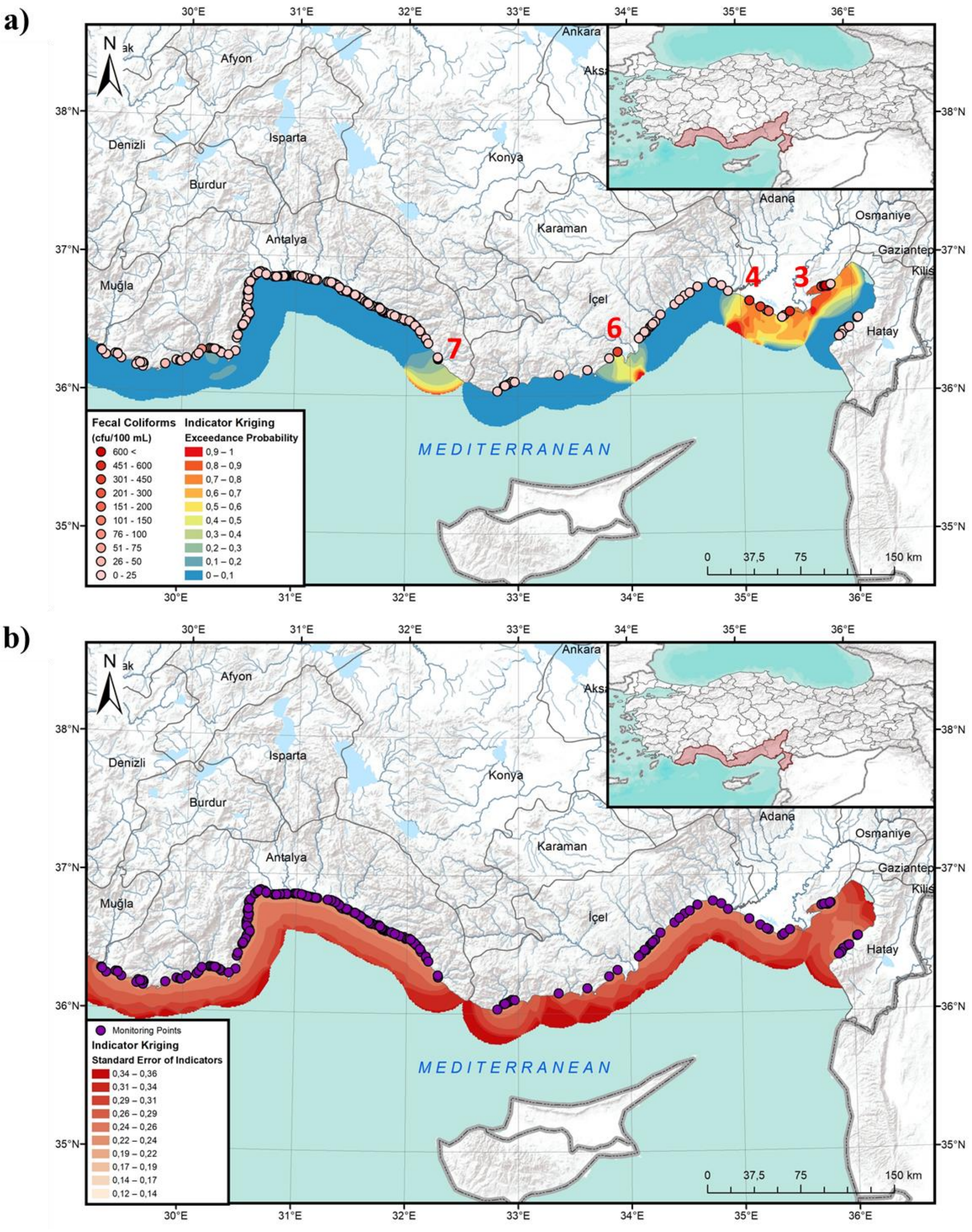
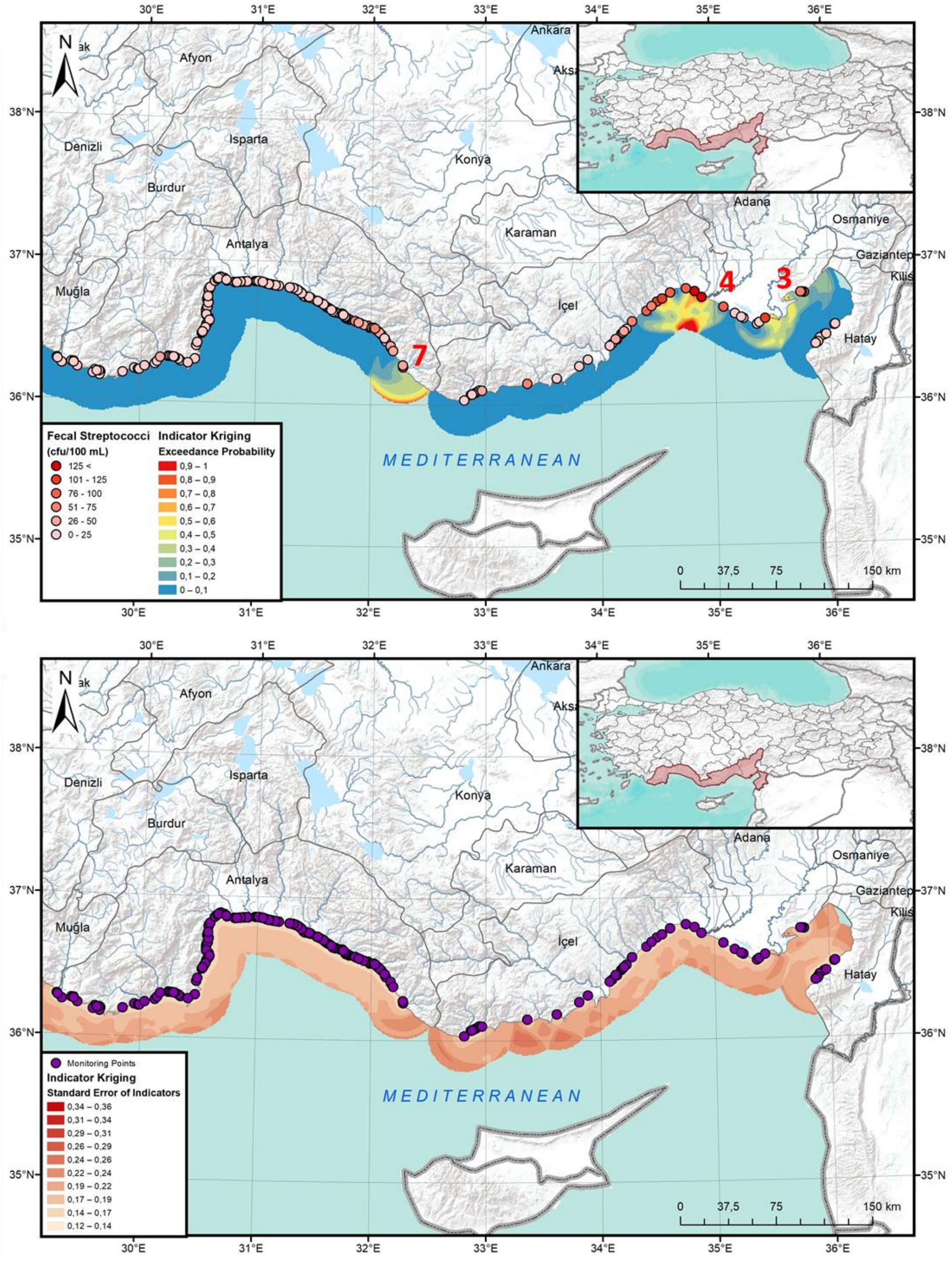


Figure 4.17. a) Exceedance probability and b) standard error maps generated for Mediterranean Region before 2010 for FC (GA period 1)

a)



b)

Figure 4.18. a) Exceedance probability and b) standard error maps generated for Mediterranean Region before 2010 for FS (GA period 1)

Before 2010 nearby river mouths of Seyhan (4) and Ceyhan (3) show critical pattern in terms of all three BWQ parameters. Also, FC and FS show poor BWQ near Gazipaşa (7). Mouth of Göksu River/Mersin (6) also shows higher exceedance probabilities for TC (Figure 4.16) and FC criteria (Figure 4.17). Therefore, during this period, pollution sources on rivers formed the major environmental stresses on bathing sites in the Mediterranean region. Locations of river mouths are provided in Appendix C. The error maps show TC and FS has lower errors, ranged between 12 –22 %, in comparison to FC (error range 24 – 36%). The exceedance probabilities show correlation with measurement results of monitoring stations in most of the bathing site for all BWQ parameters.

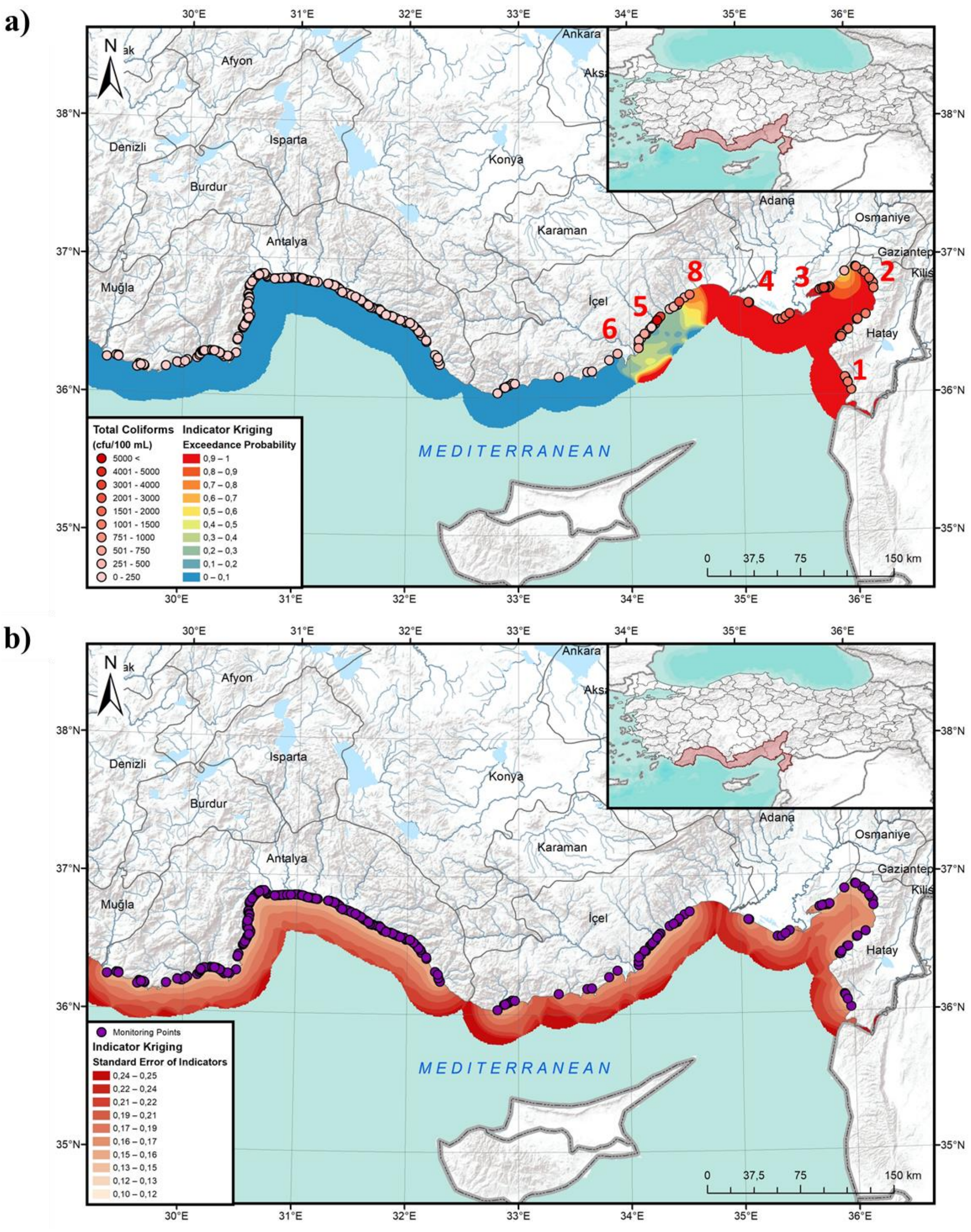


Figure 4.19. a) Exceedance probability and b) standard error maps generated for Mediterranean Region in 2010-2012 Period for TC (GA period 2)

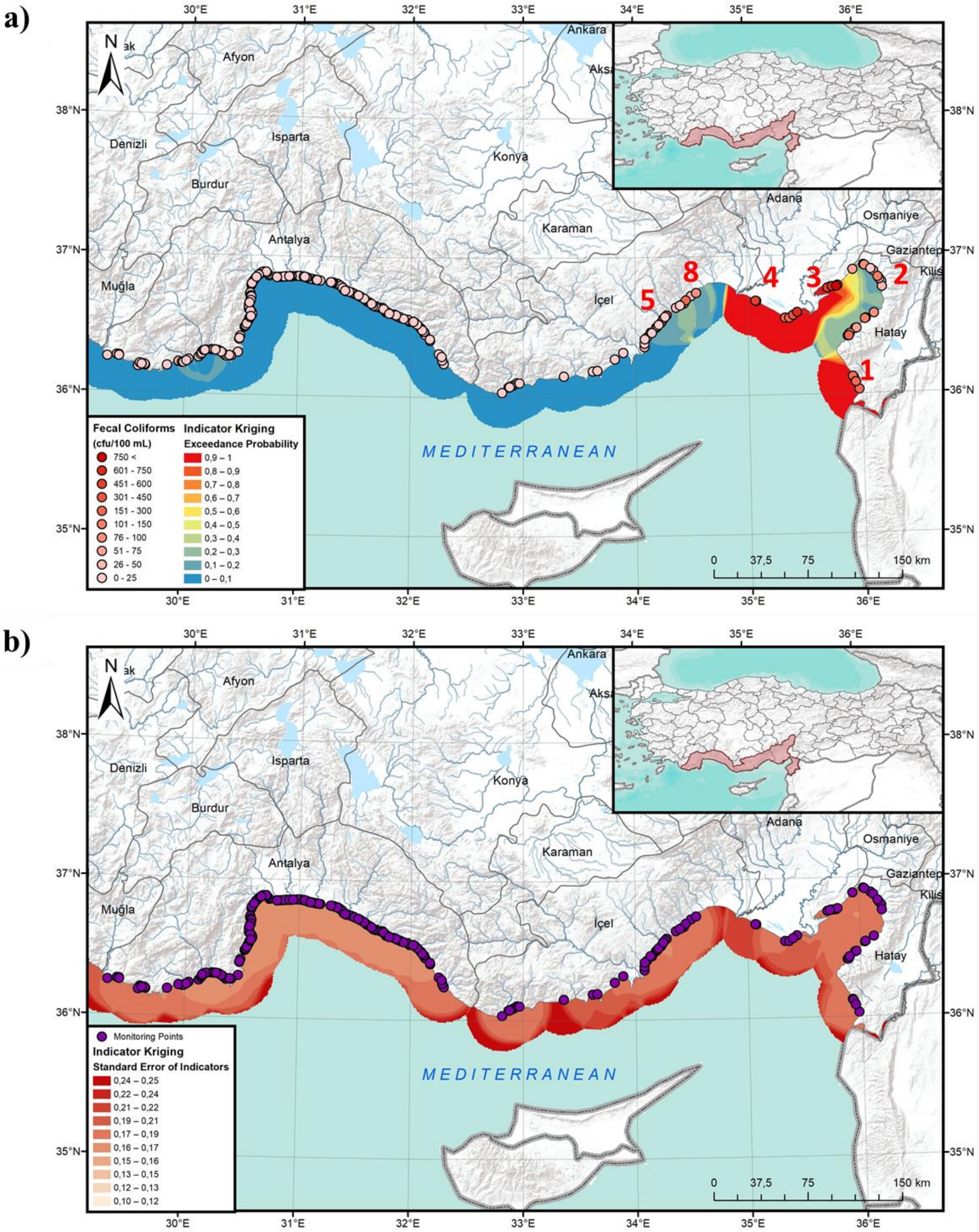


Figure 4.20. a) Exceedance probability and b) standard error maps generated for Mediterranean Region in 2010-2012 Period for FC (GA period 2)

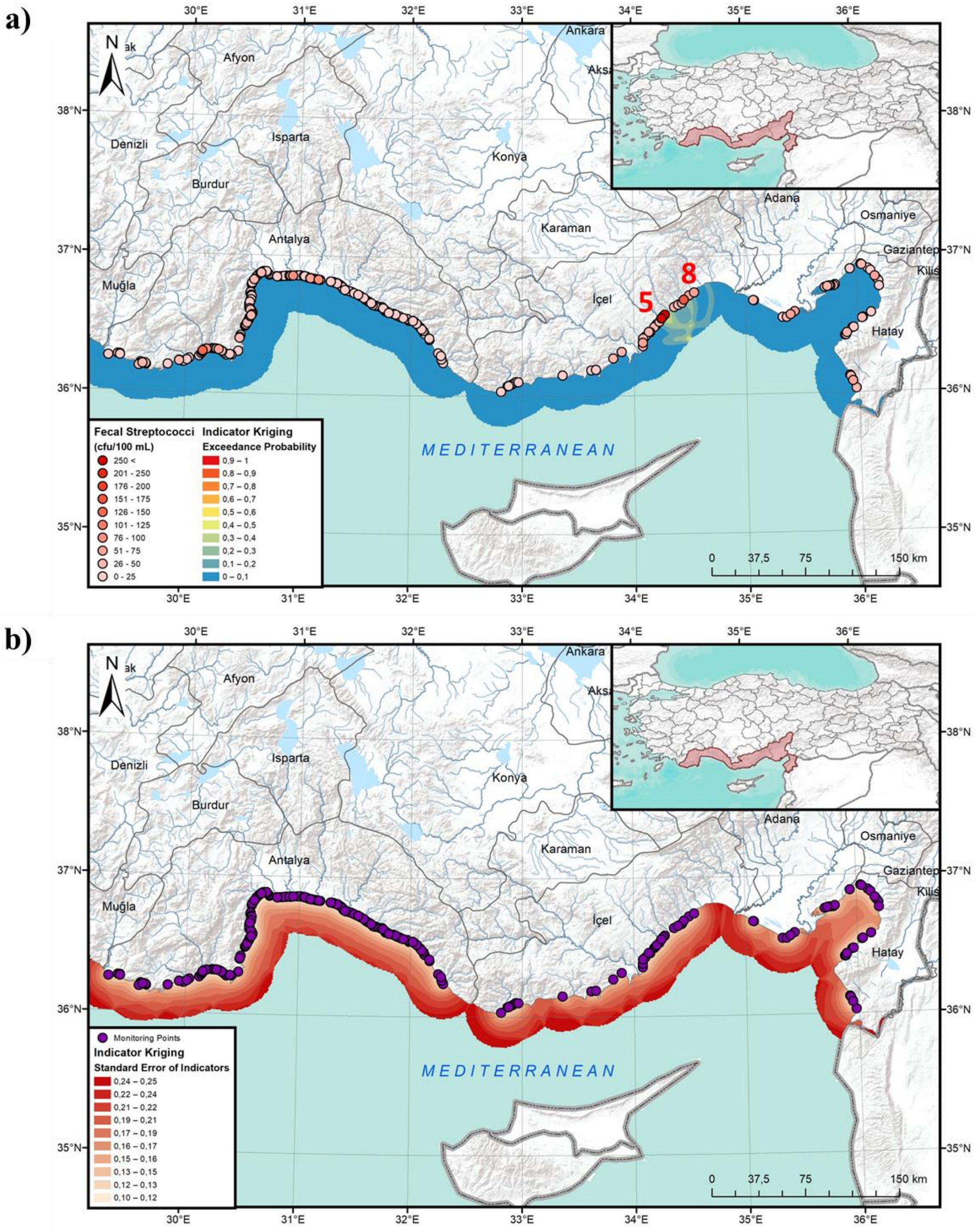


Figure 4.21. a) Exceedance probability and b) standard error maps generated for Mediterranean Region in 2010-2012 Period for FS (GA period 2)

For 2010 – 2012 period, Seyhan (4), Ceyhan (3), Orontes (1) river mouths and İskenderun Bay (2) show exceedance probabilities above 80% with respect to TC and FC, Göksu River mouth (6) shows poor quality in terms of TC. Additionally, river mouth of Limonlu Creek (5) and center of Mersin (8) with high population density do not satisfy regulatory criteria in all three parameters. For FS, highest exceedance probability is observed in mouth of Limonlu Creek (5) and center of Mersin (8) with 40%. However, the other five regions, i.e. Seyhan (4), Ceyhan (3), Orontes (1), Göksu (6) river mouths and İskenderun Bay (2) are not identified as critical region in terms of FS criteria. This clearly indicates that all three BWQ parameters must be measured in order to fully assess BWQ of a coastline. Table 4.7 shows the average concentrations of BWQ parameters in Adana and Hatay coasts between 2010 – 2012 years.

Table 4.7. *Average Values of BWQ Parameters in Adana and Hatay Monitoring Stations between 2010 - 2012*

Monitoring Point	*BWQ Parameters (cfu/ 100 mL)*			*FC/FS Ratio*
	TC_{ave}	FC_{ave}	FS_{ave}	
Adana_1	2429.0	879.9	35.8	24.6
Adana_2	2371.1	638.7	51.2	12.5
Adana_3	2817.4	381.2	28.1	13.6
Adana_4	1721.3	494.2	31.7	15.6
Adana_5	1292.2	222.4	23.9	9.3
Adana_6	462.7	67.5	12.1	5.6
Adana_7	1916.3	234.5	46.6	5.0
Adana_8	1651.1	302.6	56.0	5.4
Adana_9	3172.9	644.0	33.7	19.1
Adana_10	2514.2	478.9	19.0	25.2
Adana_11	2253.7	473.5	25.5	18.6
Adana_12	1995.6	581.4	21.1	27.6
Adana_13	2292.9	425.6	36.1	11.8
Hatay_1	1000.8	163.2	41.2	4.0
Hatay_2	1276.1	171.0	43.8	3.9
Hatay_3	1165.1	217.0	42.7	5.1
Hatay_4	1259.4	163.9	53.5	3.1
Hatay_6	1266.7	63.2	18.7	3.4
Hatay_7	1443.6	82.4	36.7	2.3
Hatay_8	1194.9	94.8	23.8	4.0
Hatay_9	978.4	134.0	34.7	3.9
Hatay_10	1235.9	38.5	14.1	2.7
Hatay_11	1105.0	45.6	14.9	3.1
Hatay_12	1046.6	10.6	1.3	8.1
Hatay_13	1242.3	73.7	16.1	4.6
Hatay_14	1718.8	130.6	59.0	2.2
Hatay_15	1365.4	81.6	27.6	3.0

Table 4.7 shows there is a significant difference between FC and FS concentrations in the critical regions. As stated in Chapter 2, FC/FS values greater than 4 refers to strong evidence of human originated fecal pollution and smaller than 0.75 indicates that there is a strong evidence of animal origin fecal pollution (Gerba & Pepper, 2004). When FC/FS ratio is calculated and analyzed according to Gerba and Pepper's (2004) classification, nearby Hatay and Adana coasts there is a strong evidence that the pollution is human originated. Therefore, during this period the source of contamination could be originating from domestic wastewater discharges, yet this needs to be evaluated further.

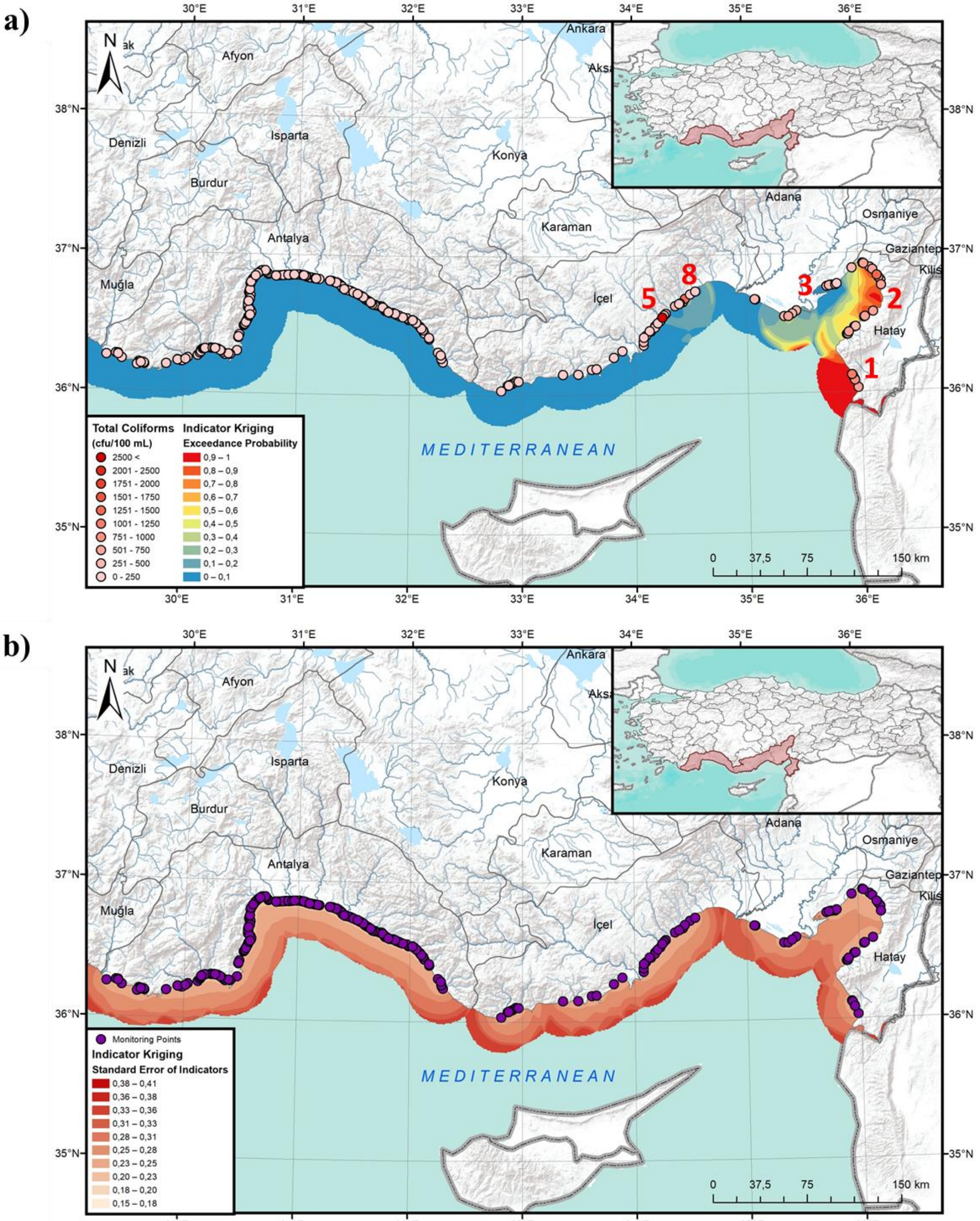


Figure 4.22. a) Exceedance probability and b) standard error maps generated for Mediterranean Region in 2013-2015 Period for TC (GA period 3)

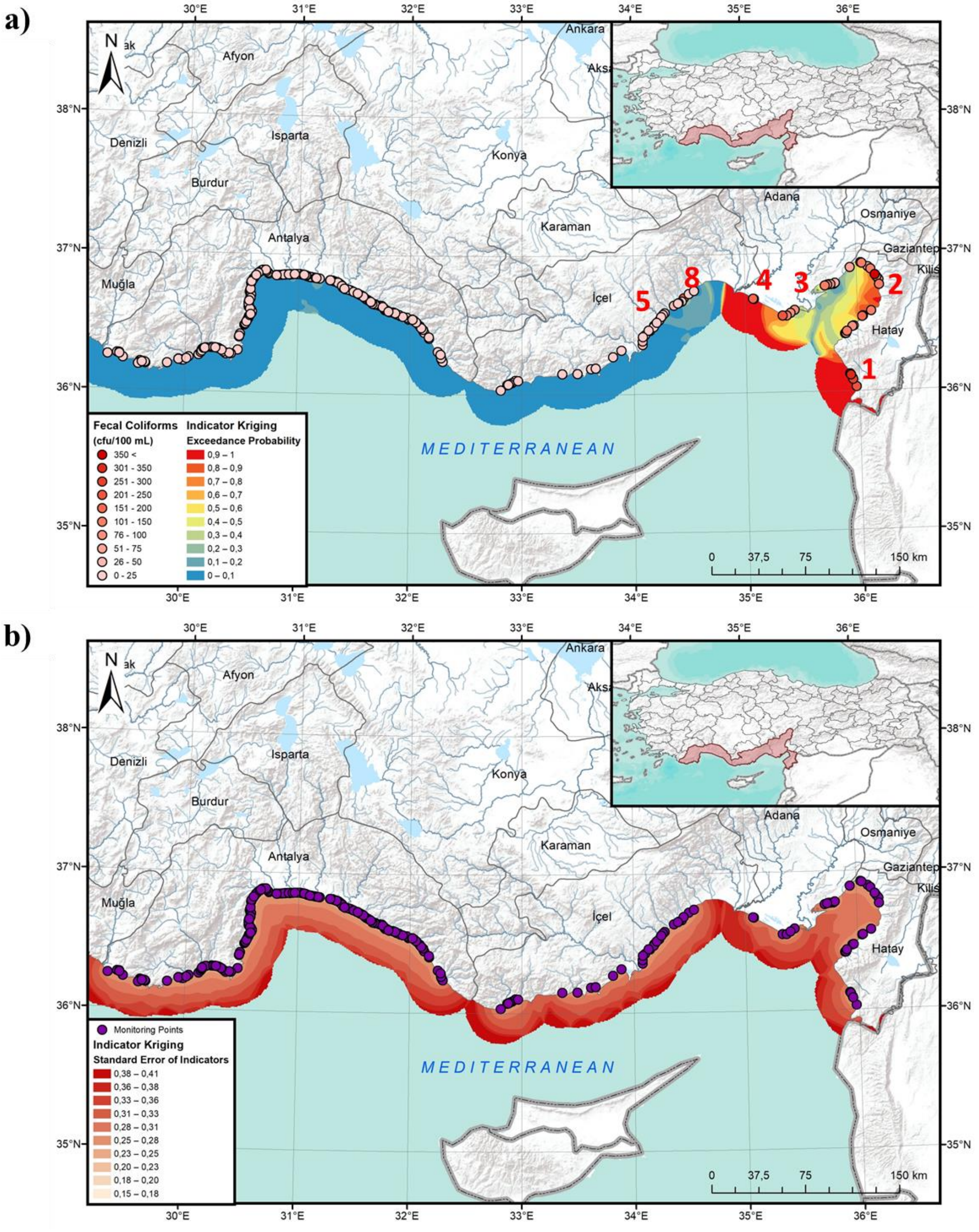


Figure 4.23. a) Exceedance probability and b) standard error maps generated for Mediterranean Region in 2013-2015 Period for FC (GA period 3)

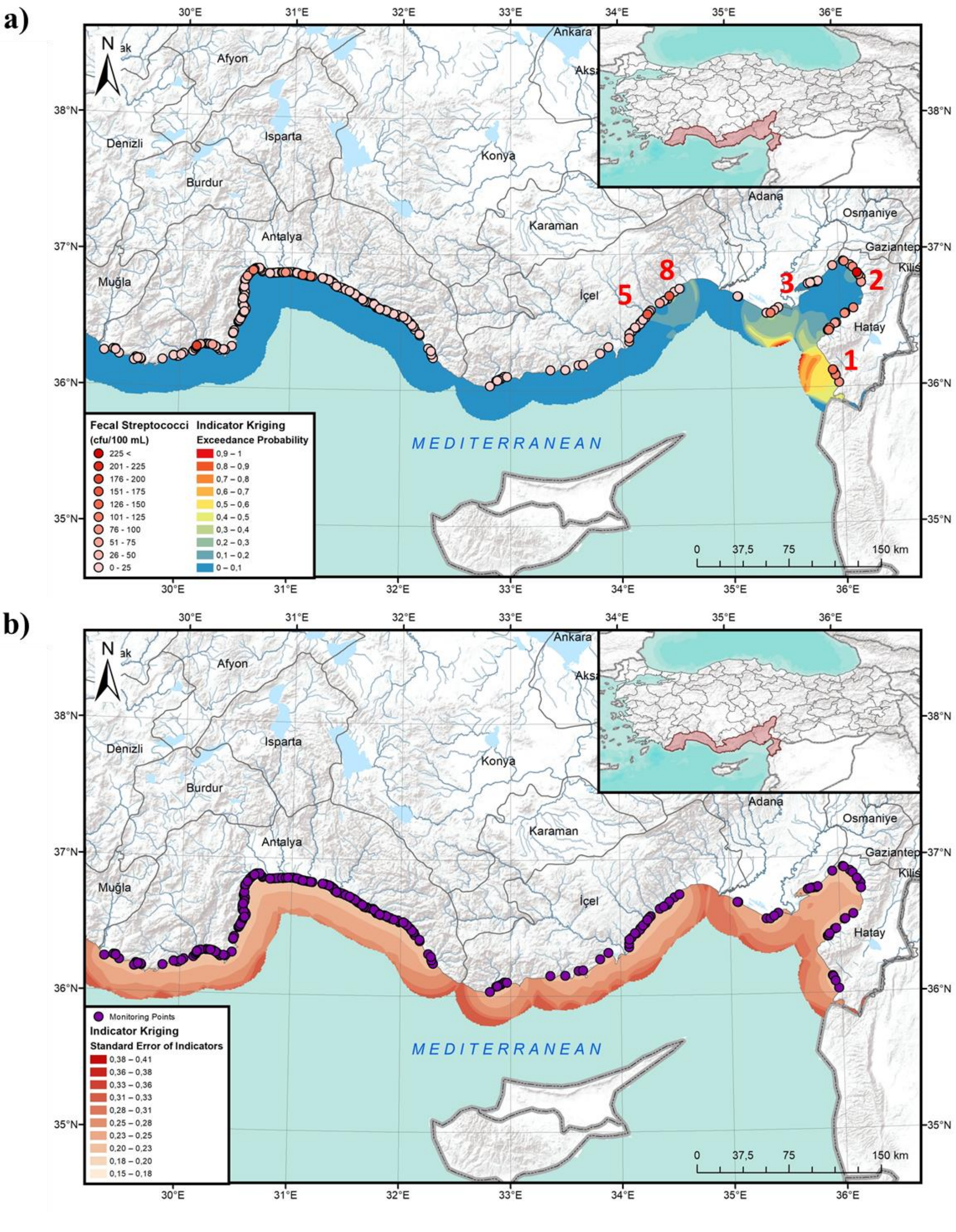


Figure 4.24. a) Exceedance probability and b) standard error maps generated for Mediterranean Region in 2013-2015 Period for FS (GA period 3)

For 2013 – 2015 period, Orontes river mouth (1) show critical appearance for all three parameters. Additionally, İskenderun Bay (2) also show high threshold exceedance probability in terms of TC and FC. Seyhan (4) and Ceyhan (3) river mouths were also identified as critical region in terms of FC. Similar to 2016 – 2018 period, there is a small possibility of threshold exceedance for all BWQ parameters nearby river mouth of Limonlu Creek (5). During this period, the difference of standard error of indicators is higher among different parameters. For FS, spatial variation of errors is lower, however, FC showed higher error in all monitoring points.

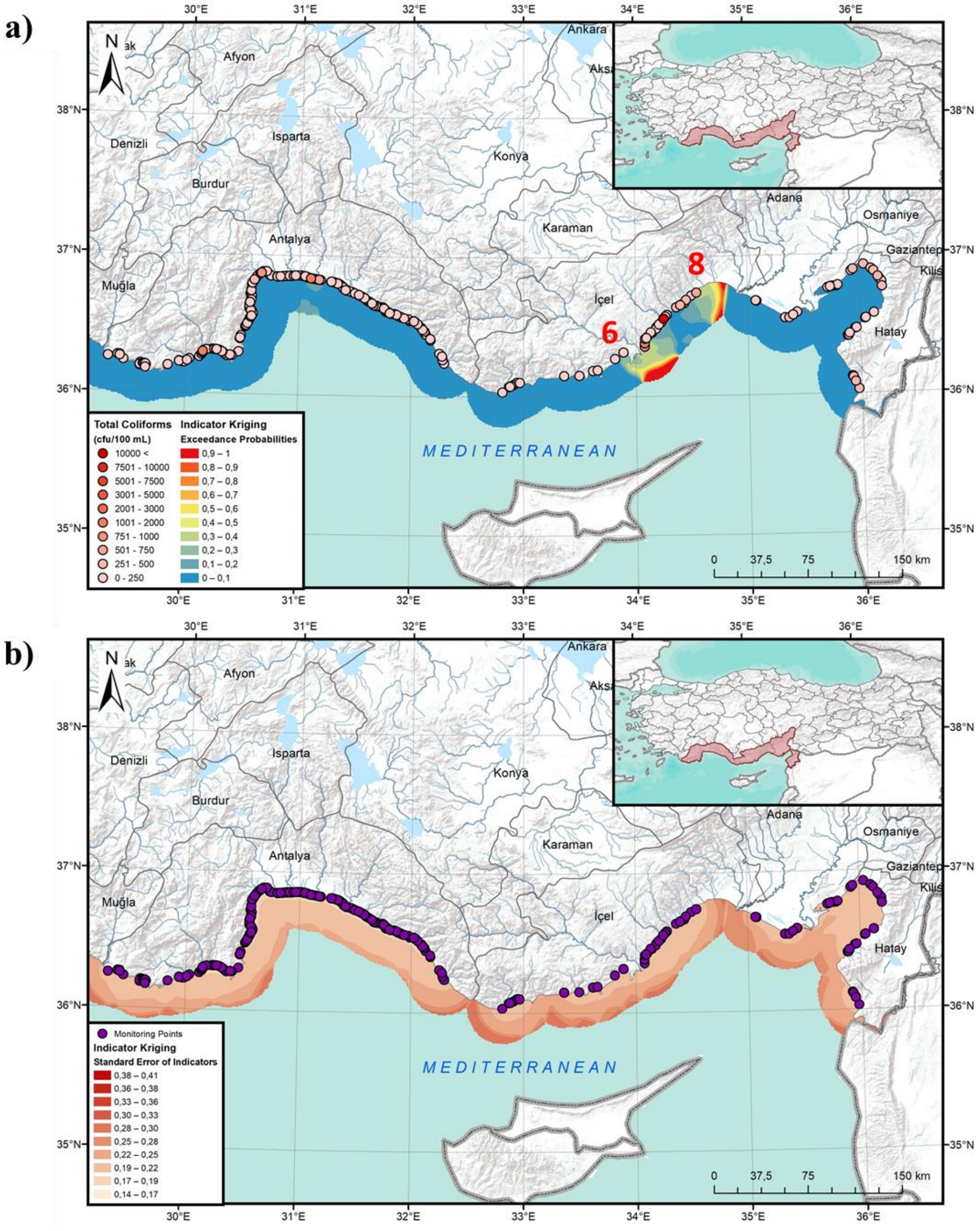


Figure 4.25. a) Exceedance probability and b) standard error maps generated for Mediterranean Region in 2016 – 2018 for TC (GA period 4)

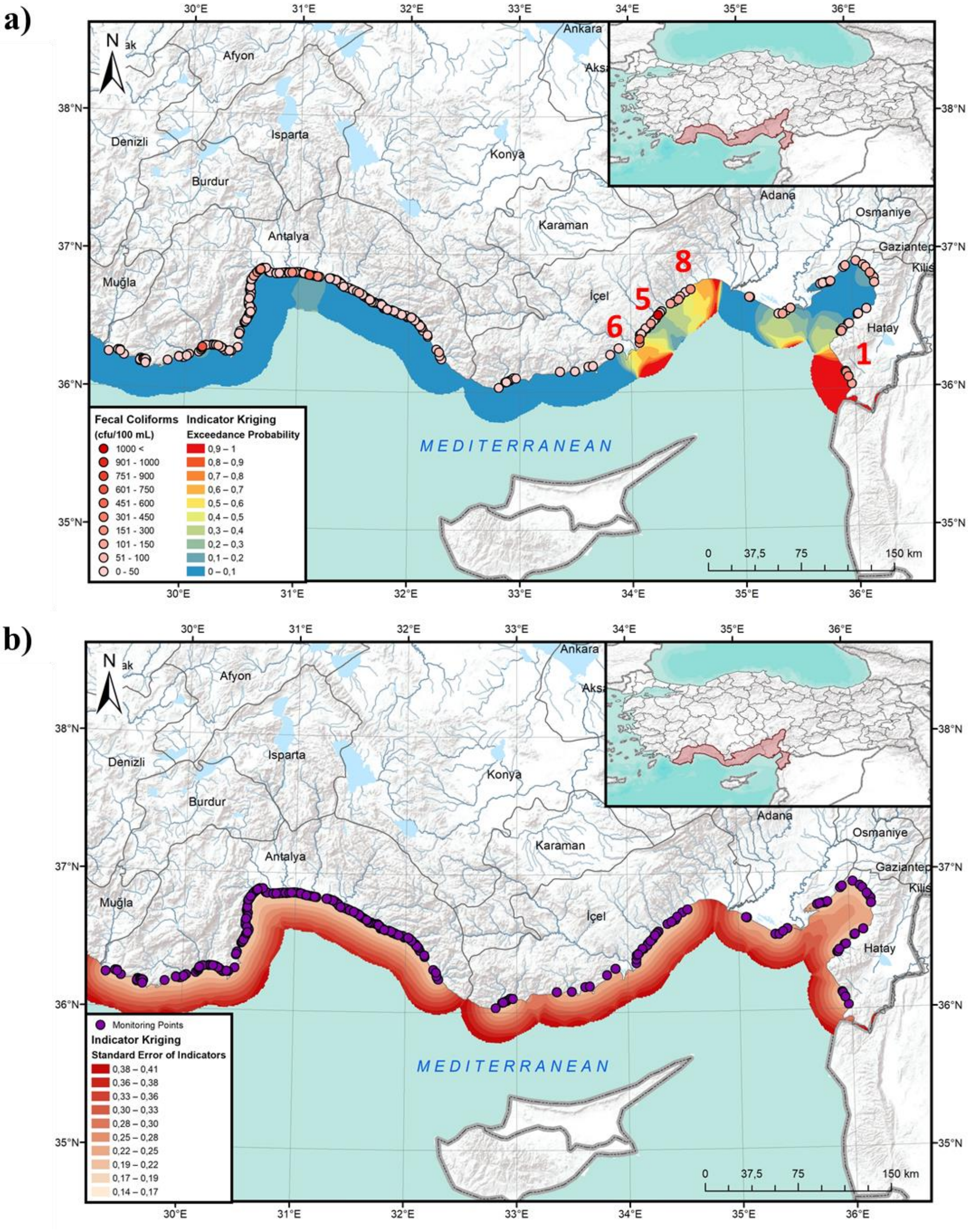


Figure 4.26. a) Exceedance probability and b) standard error maps generated for Mediterranean Region in 2016 – 2018 for FC (GA period 4)

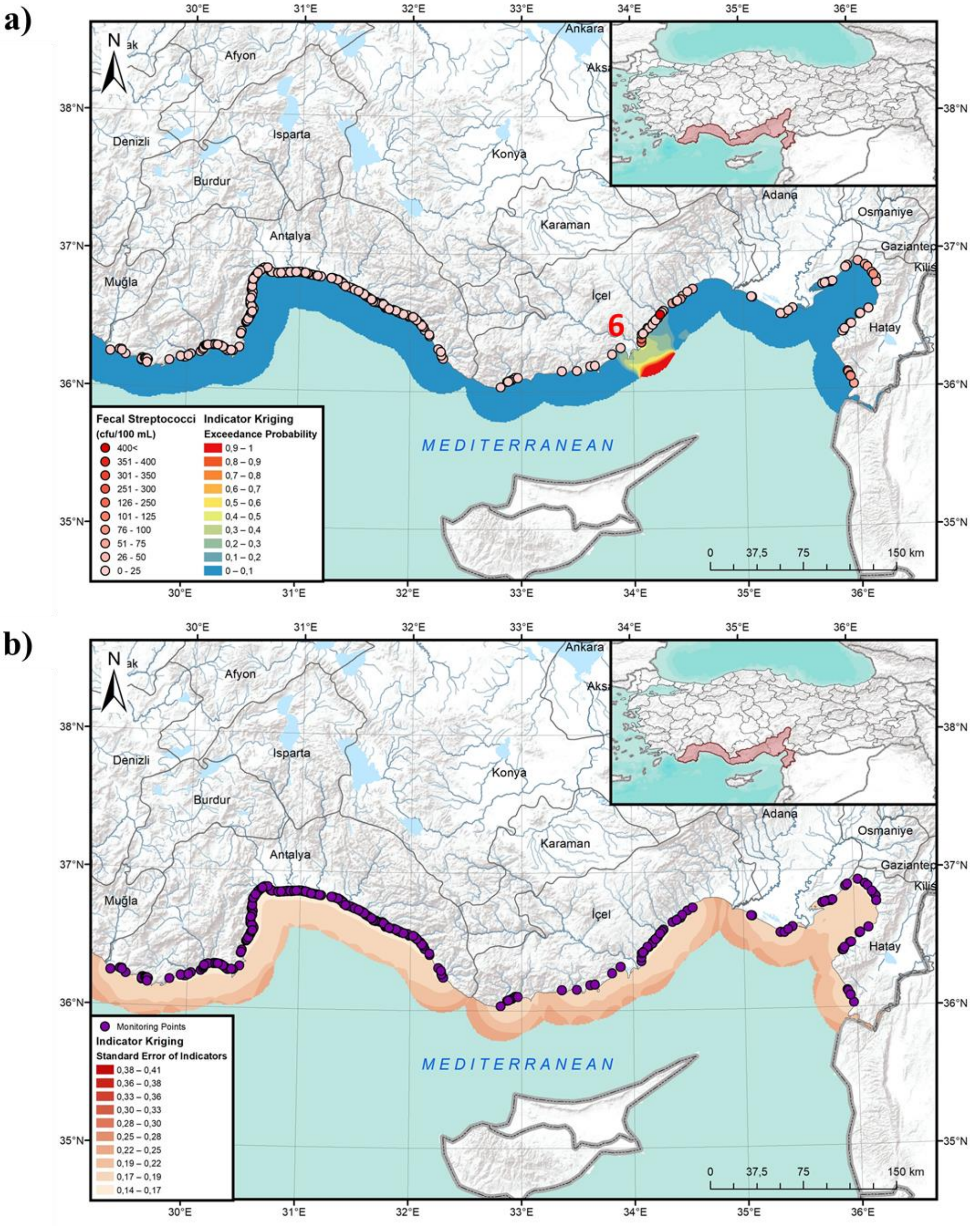


Figure 4.27. a) Exceedance probability and b) standard error maps generated for Mediterranean Region in 2016 – 2018 for FS (GA period 4)

For 2016 – 2018 period, Göksu river mouth (6) shows critical quality in terms of all BWQ parameters which creates the requirement of assessment of possible stresses on BWQ in that region. Also, river mouth of Limonlu Creek (5) and city center of Mersin

(8), where there is a high population density and increased number of socio-economic activities, i.e. trade, industry, product transfer through Mersin Harbour and so on, show higher exceedance probability in terms of both TC and FC. In addition to Mersin coasts (5 – 6 – 8), Orontes river mouth (1), i.e. Samandağ/Hatay coasts, also showed critical behavior only in FC, although, the other two parameters satisfy the BWQ criteria. The difference in behavior of all three BWQ parameters is that between 2016 – 2018, the mean value of the BWQ measurements at each monitoring point exceeds the threshold for FC parameter, on the other hand, averages of TC and FS measurements are not exceeding but very close to threshold values. Table 4.8 shows the averages of BWQ parameters in 2016 – 2018 period for this region.

Table 4.8. *Average Values of BWQ Parameters in Samandağ/Hatay in 2016 – 2018 Period*

Monitoring Point	*BWQ Parameters (cfu/ 100 mL)*		
	TC_{ave}	FC_{ave}	FS_{ave}
Hatay_1	386.96	130.92	50.38
Hatay_2	456.74	189.93	93.74
Hatay_3	485.48	211.93	62.00
Hatay_4	481.30	196.74	66.93
Hatay_5	431.59	170.22	80.56

When cross validation results, i.e. standard error of indicators, are compared for this period, the standard errors for the area closer to the coastline was ranged between 14% – 17% for TC and FS, and 17% – 19% for FC. The standard error increases moving away from the coast towards the open sea. This is the indication of that the sampling points were numerically sufficient for the assessment of BWQ. For FS, semivariances are lower which means that less variation is observed in closer monitoring points which can be observed from Figure 4.27. Because of that standard error of indicators are lower for FS. On the other hand, FC has high variety in concentrations of closer monitoring stations which leads an increase in standard error of indicators. Because of that standard error of indicators are lower for FS. On the other hand, FC has high variety in concentrations of closer monitoring stations which leads an increase in standard error of indicators.

As stated in Chapter 4.1, wastewater treatment plants are significant sources of fecal pollution. Therefore, wastewater discharges are evaluated in the scope of this study. Figure 4.28 shows the wastewater discharge points and threshold exceedance probabilities for FC in 2016 – 2018.

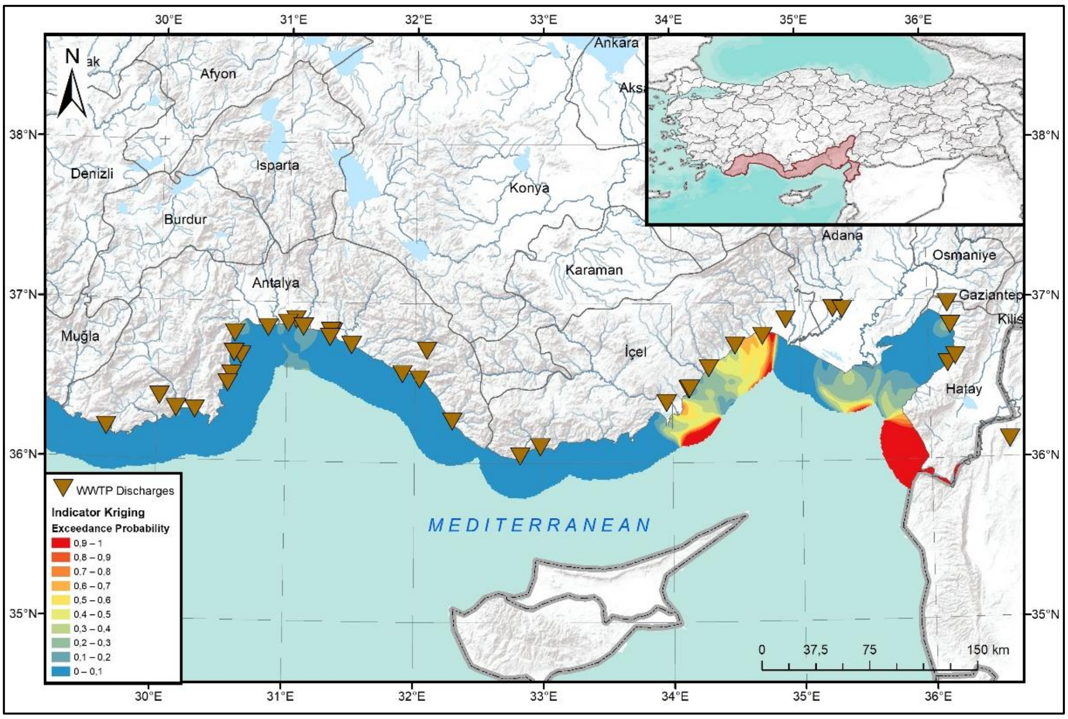


Figure 4.28. WWTP Discharge Locations in Mediterranean Region embedded in FC Exceedance Probability Map (Antalya Provincial Directorate of Environment and Urbanization, 2018; Mersin Provincial Directorate of Environment and Urbanization, 2018; Adana Provincial Directorate of Environment and Urbanization, 2018; Hatay Provincial Directorate of Environment and Urbanization, 2018)

As shown in Figure 4.28, especially in eastern coasts of Mersin, wastewater treatment plants are effective on BWQ. However, in Antalya coasts, WWTPs do not show an influence on BWQ. The possible reason of this difference is that all of the WWTPs that are found in coastal districts of Antalya, except Serik, has deep sea discharge systems. In Serik/Antalya, where the exceedance probability has ranged between 40 – 50%, there are lots of tourism facilities and has total daily wastewater discharge of 75,700 m^3, which involves the 9% of total wastewater generation (Antalya Provincial Directorate of Environment and Urbanization, 2018). Also, three largest WWTPs, with total capacity 630,000 m^3/day, are located in the city center and have deep sea discharge systems. Other WWTPs are smaller and serving to lower populations.

There is also a relationship between the fecal pollution and local population density. Densely populated locations are more likely to have fecal pollution (WHO, 2010). Another significant indicator of fecal pollution is population density. Densely populated locations are more alike to have fecal pollution. Figure 4.29 provides the information on local population density in Mediterranean coastline and comparison of this with BWQ.

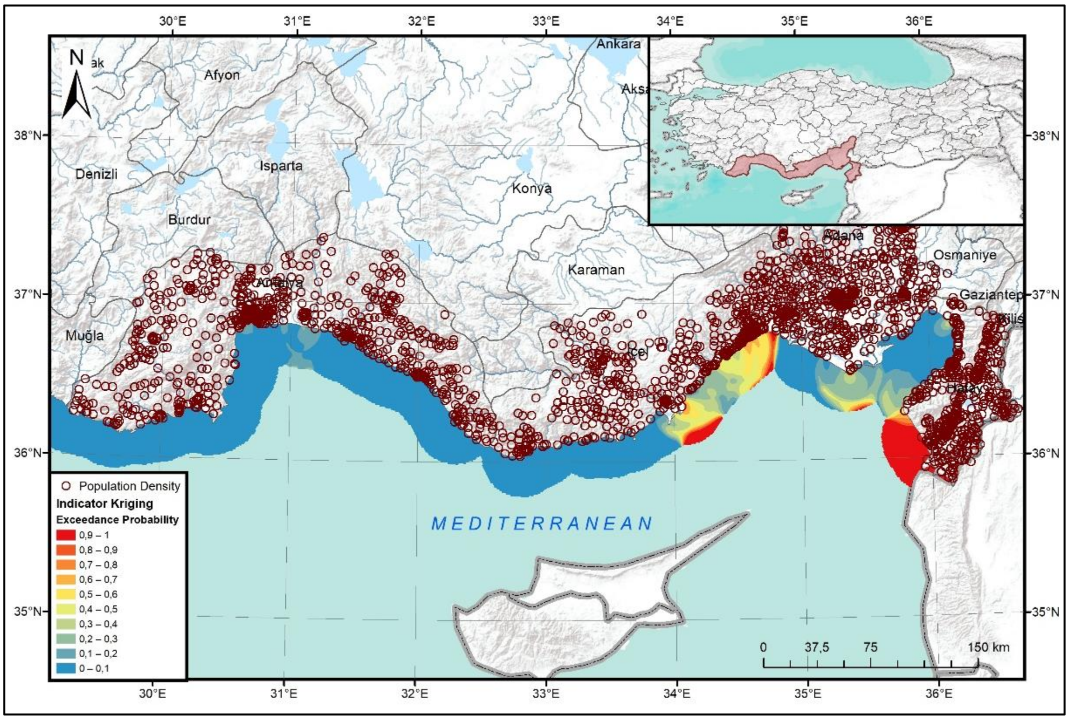


Figure 4.29. Population Density Along Mediterranean Region embedded in FC Exceedance Probability Map (Adapted from: TÜİK, 2018)

The given figure shows that the regions with high population densities except the center of Antalya has poor BWQ, which supports the idea of higher threshold exceedance probabilities is caused by human originated fecal pollution.

The ways that how marinas contribute to fecal contamination in bathing sites were stated in Chapter 4.1. Thus, locations of marinas and critical BWQ areas are also compared in this study. Figure 4.30 shows the locations of marinas in Mediterranean coastline and indicates that there is low impact of marinas in Antalya, since 5 out of 7 of the marinas have Blue Flag awards. On the other hand, in Mersin, marina which is located in Erdemli district is operated by municipality and marina that is found in Yenişehir, i.e. city center of Mersin, coast also has Blue Flag award. Therefore, there is no strong evidence that the fecal pollution and poor BWQ is caused by marinas in Mediterranean.

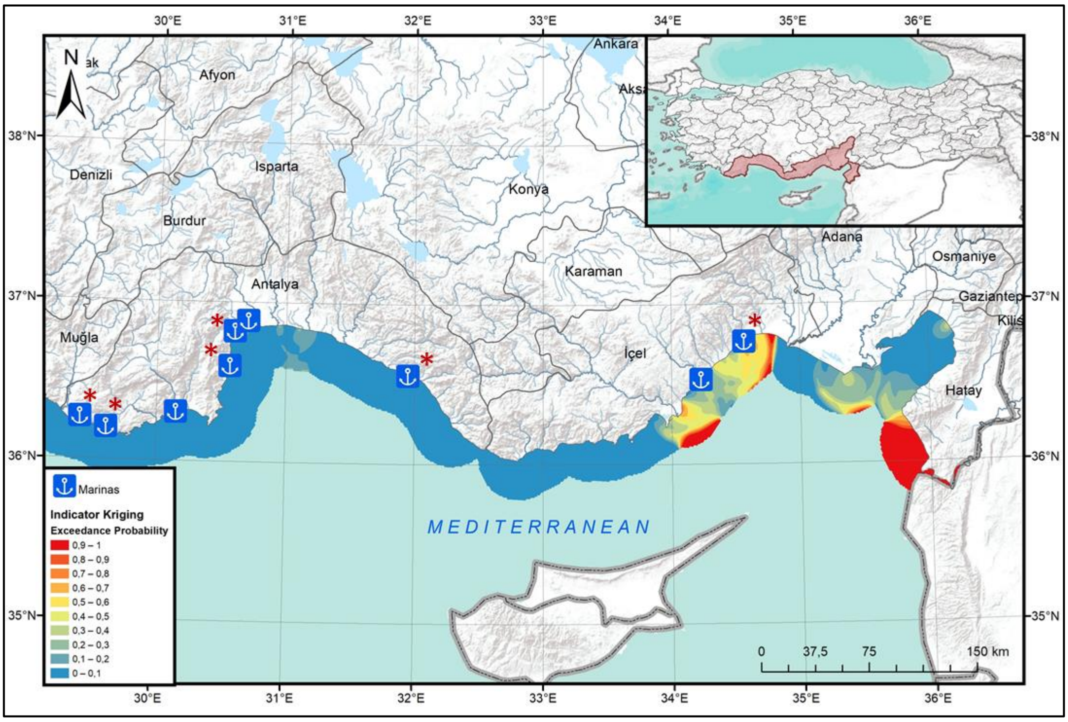


Figure 4.30. Location of Marinas in Mediterranean Coasts embedded in FC Exceedance Probability Map (Chamber of Shipping, 2019)

4.1.3. Concluding Remarks for Mediterranean Region

- Mediterranean region is one of the most popular tourism regions of Turkey since it covers Antalya which is a preferred tourism direction for both national and international tourists.
- There is total of 470 monitoring stations in Mediterranean region for all GA periods.

- Number of monitoring stations per length of coastline is much higher in western part of the region, where is more popular in terms of tourism activities, and thus in western part analyses become more accurate.
- For all GA periods semivariograms show moderate spatial dependency regarding nugget/sill ratios.
- Hatay coast, where Orontes (1) river discharges, shows critical appearance in terms of TC and FC parameters in each GA period (Table 4.9). In Table 4.10, BWQ improvements and depletions along Mediterranean coastline is summarized for 25 years.
- Decision-makers should take action for Orontes River mouth in the region.

Table 4.9. *Coastal areas with >70% threshold exceedance probability in the Mediterranean Region*

Period	*TC*	*FC*	*FS*
Before 2010	4-3	4-3	-
2010 – 2012	1-2-3-4-8	1-4-3	-
2013 – 2015	1-2	1-2-4	-
2016 – 2018	-	1-8	-

- For more recent periods, an improvement in BWQ along Mediterranean coastline was observed, especially near Adana and Hatay coasts.
- All three BWQ parameters show similar patterns in Mediterranean coastline for most of the GA periods.
- Cross-validation results point out an underestimation of spatial variation for all GA period since sampling point numbers and continuity show variety along all coastline.
- Discharge locations of WWTPs show correlation with exceedance probabilities of FC between 2016 – 2018, which indicates that WWTPs are effective on insufficient BWQ in the region.
- There is no strong evidence investigated as marinas have a negative impact on BWQ in this region.

Table 4.10. *The frequency of observation of >70% threshold exceedance probability in a given coastal area* in Mediterranean region*

Regions**	*Designated Areas*	*All Periods*	*Last Two Period*
1	River Mouth of Orontes	5	3
2	İskenderun Bay	3	2
3	River Mouth of Ceyhan	4	-
4	River Mouth of Seyhan	5	1
5	River Mouth of Limonlu Creek	-	-
6	River Mouth of Göksu	-	-
7	Gazipaşa	-	-
8	Center of Mersin	2	1

**Coastal Areas are designated with a number.*
*** Table 4.4 shows the designated areas.*

Based on the data analysis stated in Section 3.2 using Table 4.10 above River Mouth of the Orontes is determined as the critical BWQ site for Mediterranean region.

4.2. Bathing Water Quality Assessment around Aegean Region

Aegean region constitutes the western part of Turkey coastline with 2,805 km of length (Turkish Marine Environment Protection Association, 2019). Salinity of Aegean Sea shows high variety since it provides a transitional sea between Black Sea and Mediterranean (Velaoras, et al., 2013). At the exit of Dardanelles, Aegean Sea has a low salinity of 23 – 28 PSU (Velaoras, et al., 2013) and in southern part, around Cretan Sea, it shows similar salinity values with eastern Mediterranean that is average of 39 PSU (Theocharis, Nittis, Kontoyiannis, Papageorgiou, & Balopoulos, 1999). Bathing season in the Aegean Sea starts on 1st of June and ends on 30th of September (General Directorate of Public Health, 2008).

Aegean region has the highest number of BWQ monitoring stations with a total of 671 (General Directorate of Public Health, 2018). Muğla is one of the most popular tourism direction of Turkey covering Bodrum, Marmaris, Datça, Fethiye and others. Tourism investments are at high levels at this location with high number of 5 starred hotels. According to 2018 General Assessment Report on Tourism, Muğla is determined as one of the cities hosting the highest numbers of domestic and international tourists (Republic of Turkey Ministry of Culture and Tourism, 2019).

Other cities located in the coastline of Aegean Sea, namely Çanakkale, Balıkesir, İzmir and Aydın, are also significant tourism destinations of Turkey with natural and cultural assets, and high potential of beach tourisms. In this section, first dataset used for GA in the Aegean region will be analyzed by some basic statistics and then GA results will be discussed.

4.2.1. Exploratory Data Analysis for Aegean Coastline

BWQ monitoring has been initiated in 1993 in Aegean region. Although, at first, monitoring activities was limited with Kuşadası, number of monitoring stations increased year by year (Figure 3.9). Covering Muğla, which has the most important tourism areas in Turkey, i.e. Bodrum, Marmaris, Datça, Fethiye and so on, was also effective in this increase. Figure 4.31 provides change in the number of measurements between 1993 and 2018.

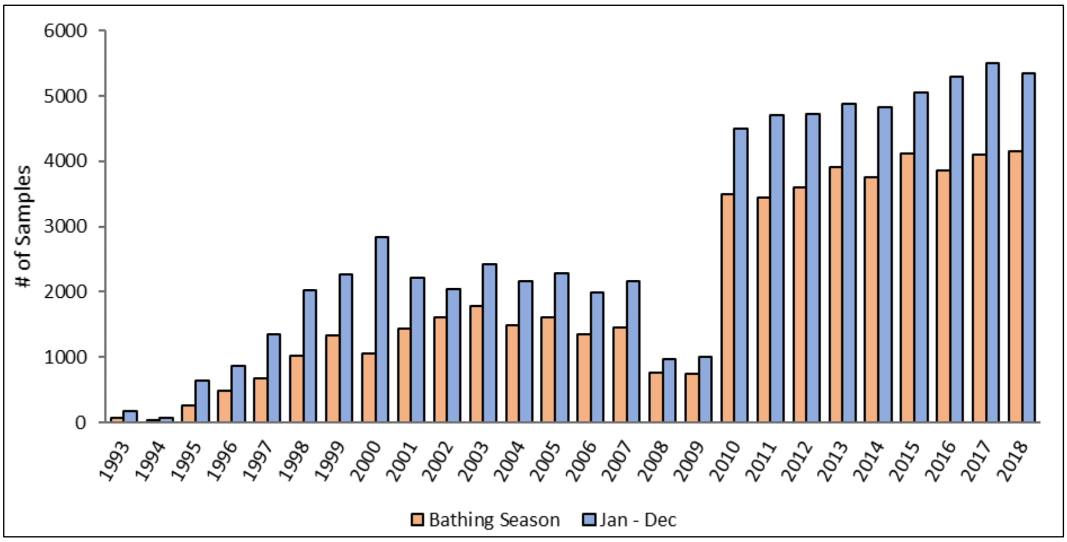
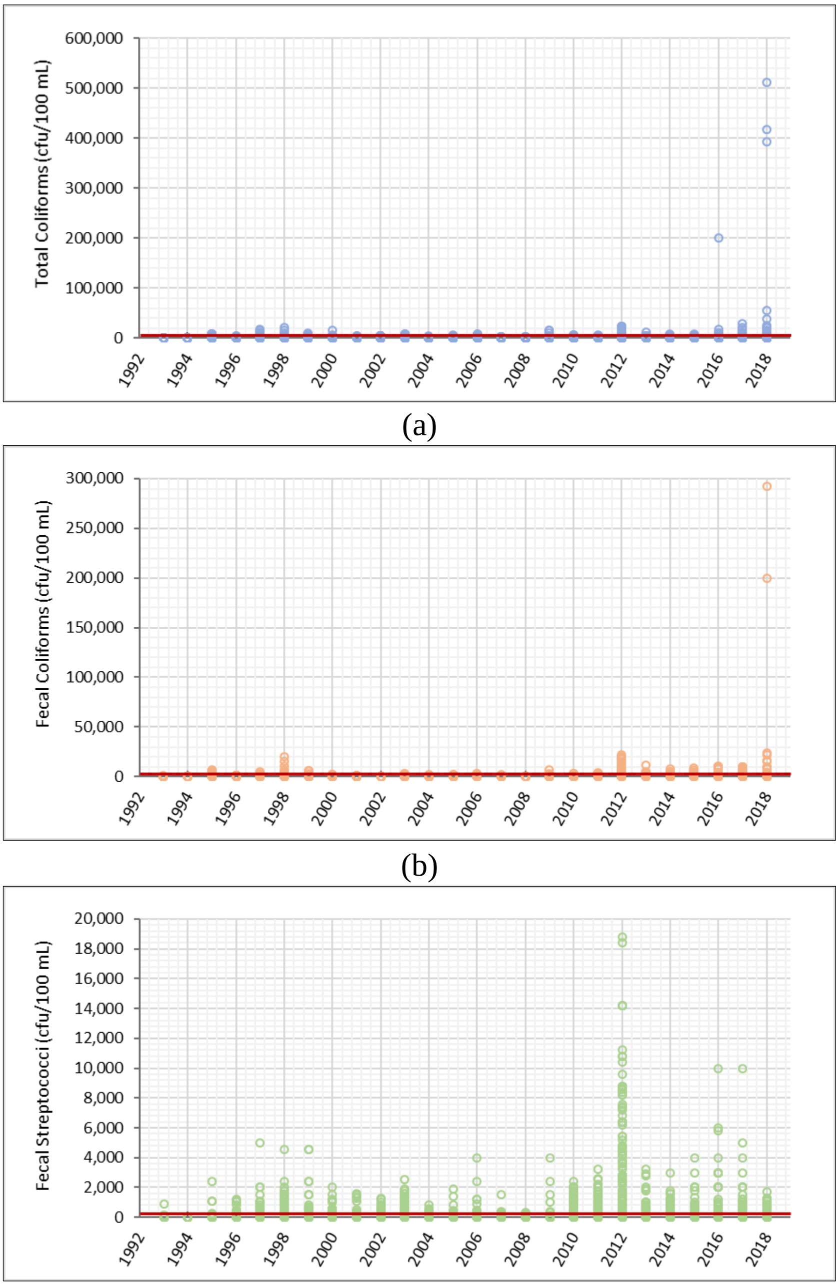


Figure 4.31. Change in BWQ Measurements in Aegean Region between 1993 – 2018

In addition to Mediterranean region, Aegean region also has the longest period of BWQ monitoring with 25 years of measurement results and also, similar to Mediterranean coastline, the number of BWQ monitoring stations per coastal distance is high in the region. Especially after 2010, similar to other bathing regions, a drastic increase is observed in the number of measurements. Therefore, GA is more reliable in this region and in later periods.

Aegean coastline also has the highest number of Blue Flag awarded beaches, i.e. 46.1% of all Blue Flagged beaches in Turkey, which is a testimony of the good BWQ in the region (TÜRÇEV, 2018). Most of the monitoring points are still under observation related to Blue Flag monitoring actions. Although, there are locations with poor BWQ in Aegean coastline, in most of the measurements, results satisfy the relevant regulation. Figure 4.32 provides the annual change in BWQ parameters in all bathing sites located in Aegean coastline.



(a)

(b)

(c)

Figure 4.32. The Variation in the Concentrations of (a) TC (b) FC (c) FS over the cycle of 1993 – 2018 in the Aegean Coastline[7]

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[7] Circles represents the measured data, and red line shows the regulatory limit for good quality, which refers to 500 cfu/100 mL for TC, 100 cfu/100 mL for both FC and FS.

Figure 4.32 shows that each year most of the data satisfy the BWQ requirements. Red lines in the figure represent regulatory criteria for each parameter. After 2010, especially for TC and FC, concentrations in monitoring points are increased, although, at the same time number of monitoring stations and samples also increased as can be seen from Figure 3.9 and Figure 4.31, respectively. Thus, the percentage of the number of samples that are exceeding the threshold is provided in Figure 4.33.

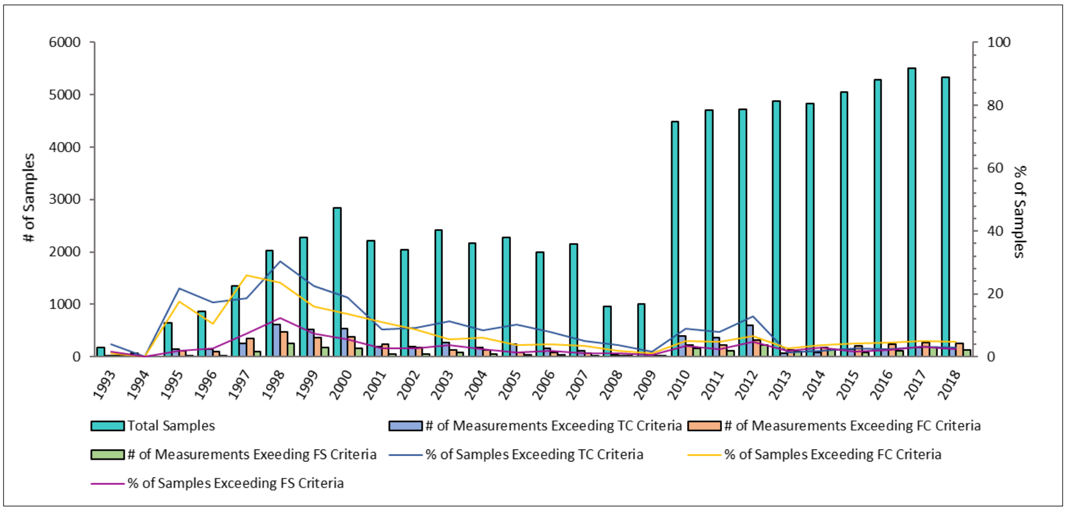


Figure 4.33. Number of Threshold Exceeding Measurements in Aegean Region

Figure 4.33 shows that after 2010 total number of measurements drastically increased, however, there is not a significant change in the number of exceeding samples. Moreover, after 2012 percentage of exceeding observations has decreased year by year. The possible reason lying behind this situation is that in 2010 BWQ monitoring recordings become more systematic and in 2012, BWQ results were shared with public from Bathing Waters Monitoring System. Similar trend was also observed in the Mediterrenean region. Figure 4.34 shows the single sample maximum concentrations of each BWQ parameter in between years 1993 and 2018.

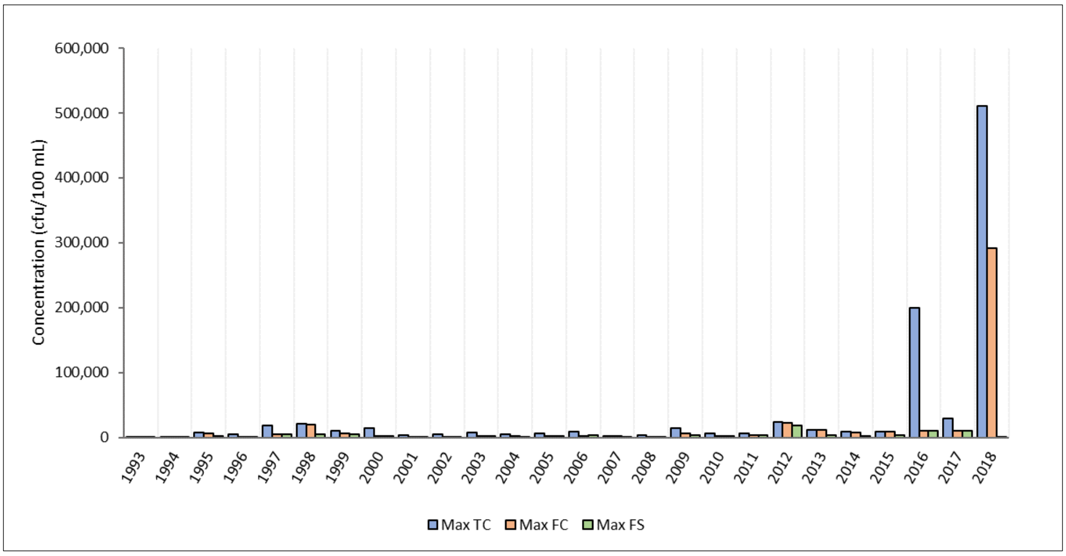


Figure 4.34. Change in Maximum Concentrations of BWQ Parameters in Aegean Region between 1993 – 2018

Even though the percentage of exceedances decreases after 2010 (Figure 4.33) measured single sample maximum concentrations became extremely high due to widening of monitoring activities. For example, river mouths currently are being monitored for the purpose of "pollution monitoring". Also, it is observed that in 2016 and 2018 TC concentration reached to extremely high values (511,000 cfu/100 mL) which points out that there may be a soil disposal/or soil related pollution source in the sampled bathing site, especially in 2016, because FC contributes to half of this measurement and other source of TC is soil related coliforms (An, Kampbell, & Breidenbach, 2002). Figure 4.35 provides the number of monitoring stations with respect to their purpose of monitoring.

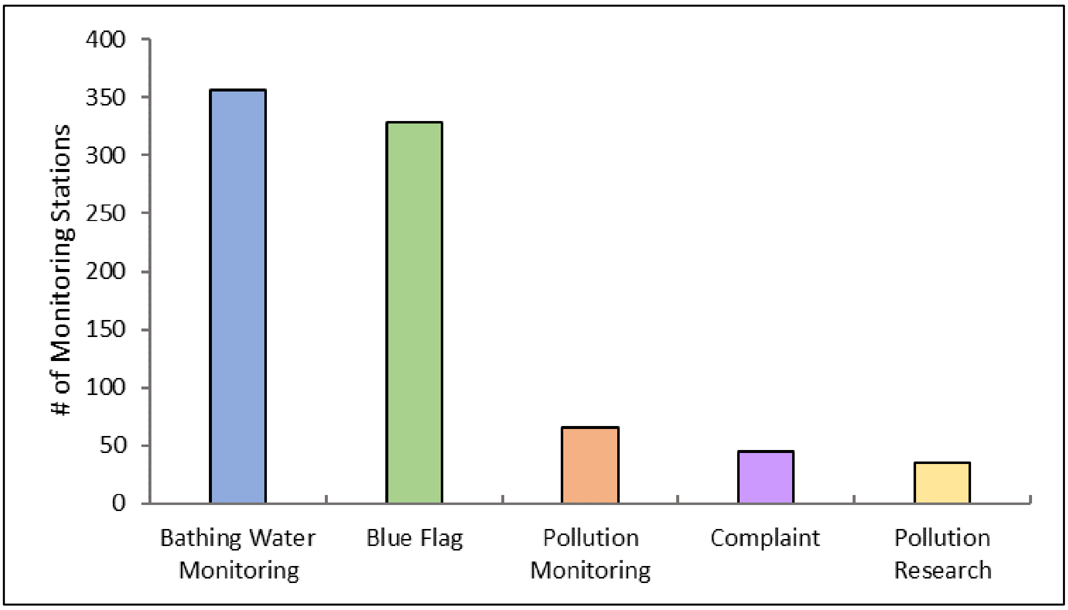
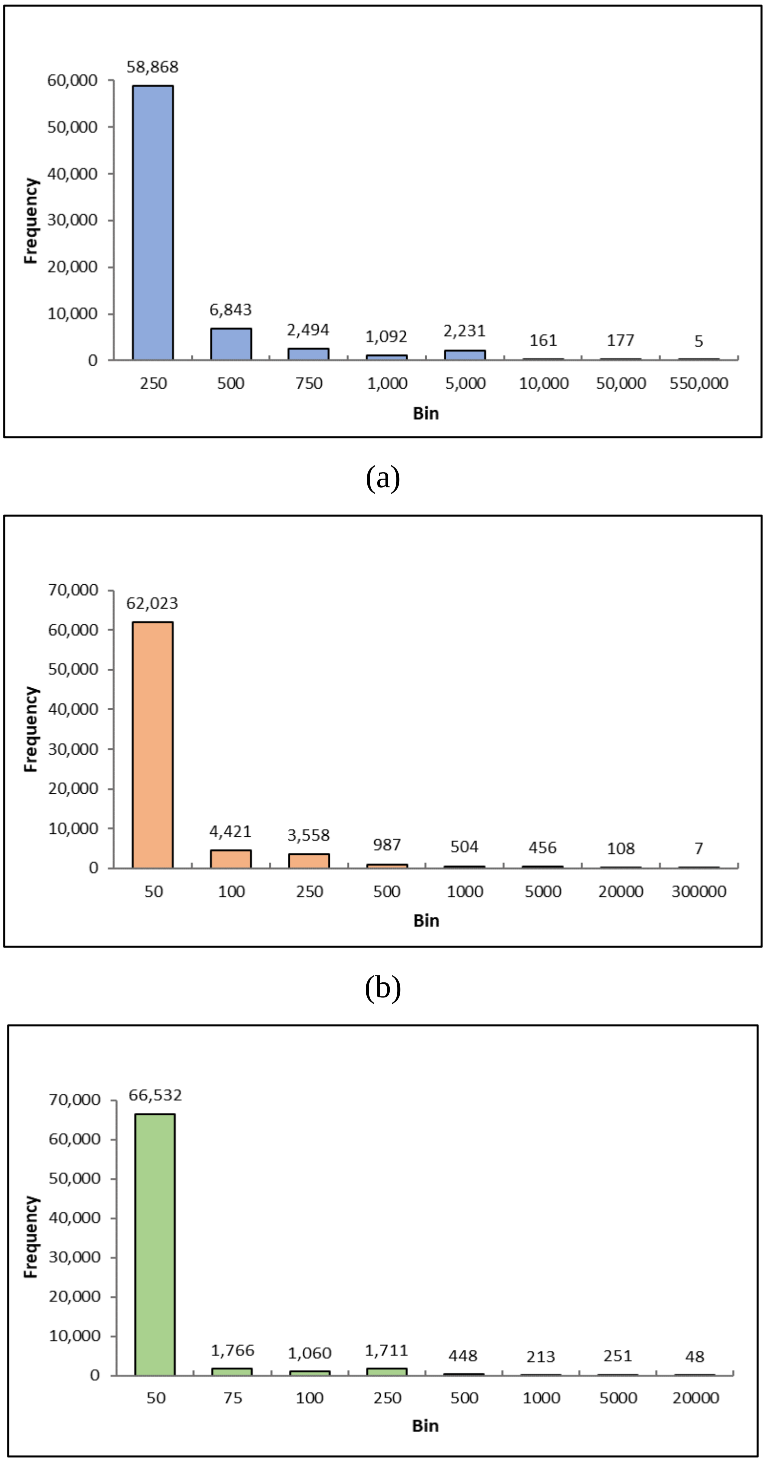


Figure 4.35. Number of Monitoring Stations for Different Purposes in Aegean Region

Please note that one beach can be monitored regarding more than one purpose which may have led to counting a beach more than once in Figure 4.35. Although, single sample maximum concentrations for each parameter increased after 2010, when the whole dataset is evaluated, it is observed that the number of samples satisfying the BWQ criteria represents the majority of the entire dataset for each BWQ parameter. Figure 4.36 provides the histograms for all BWQ parameters for 25 years period.



(a)

(b)

(c)

Figure 4.36. Histograms of (a) TC (b) FC and (c) FS concentrations in Aegean Region

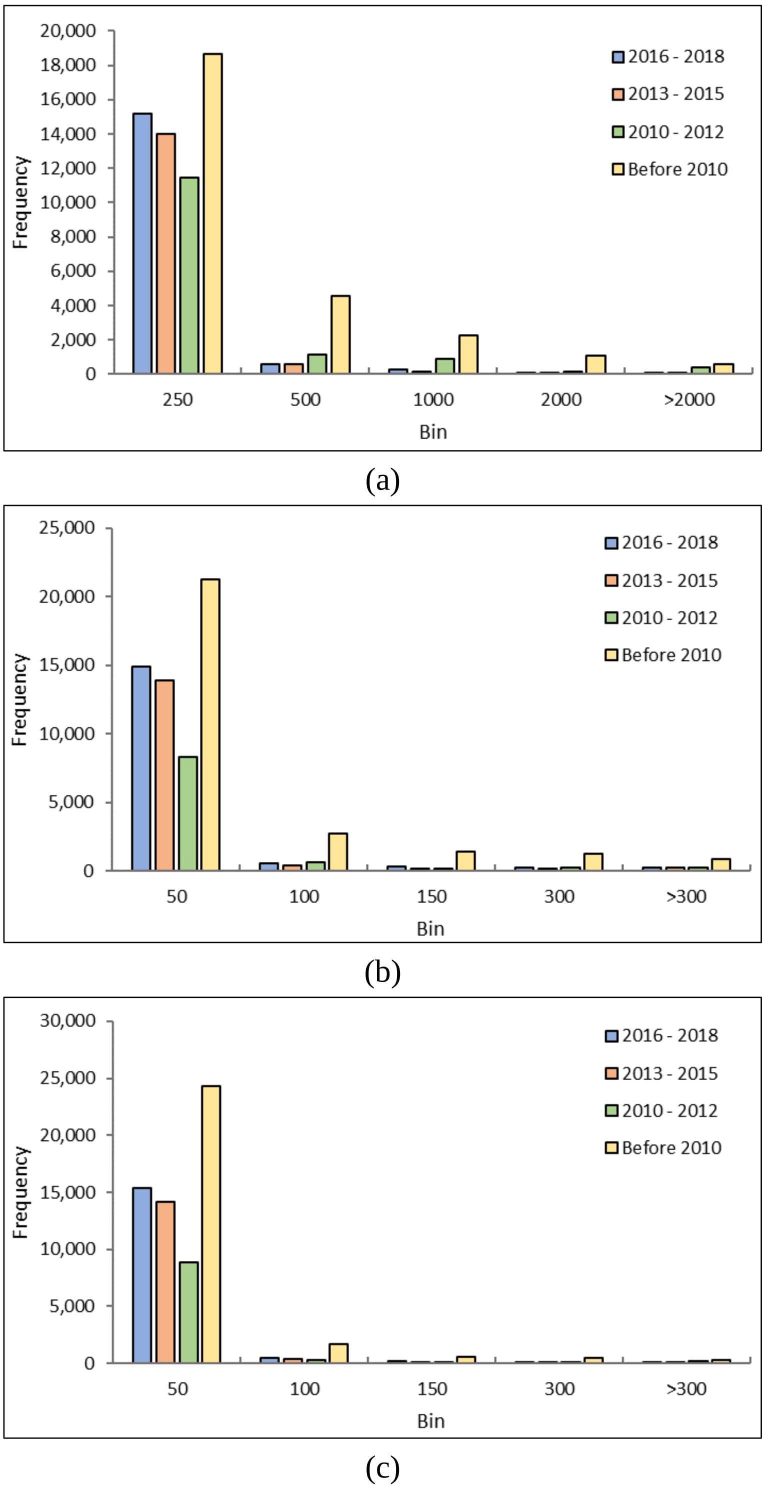
According to Figure 4.36, 90.9%, 92.0% and 95.7% of samples satisfy BWQ criteria for TC, FC and FS, respectively. Table 4.11 provide general statistics of the dataset used in GA for the Aegean region.

Table 4.11. *General Statistics of the GA Dataset of Aegean Region*

Parameter	*TC*	*FC*	*FS*
Total number of measurements	71,879	72,070	72,035
Maximum value (cfu/100 mL)	511,000	292,000	18,800
Minimum value (cfu/100 mL)	0	0	0
Mean (cfu/100 mL)	238	59	27
Standard Deviation (cfu/100 mL)	3,109	1,392	273

4.2.2. Geostatistical Analysis of BWQ Data of the Aegean Coastline

Aegean coastline has the largest amount of monitoring points. In this study, for Aegean region, total of 671 monitoring stations are used for GA, but this number is different for each study period. During GA all monitoring stations were taken into consideration and data analysis was performed over 4 separate periods, i.e. 2016 – 2018, 2013 – 2015, 2010 – 2012 and before 2010. The average of all samples collected in these 4 GA periods, i.e. before 2010, 2010 – 2012, 2013 – 2015 and 2016 – 2018, were calculated. GA is conducted using the average values calculated for each period. Figure 4.10 shows the histograms of GA dataset for each period.



(a)

(b)

(c)

Figure 4.37. Histogram of GA Dataset for a) TC (b) FC and (c) FS concentrations over different GA periods in the Aegean Region

As can be seen from Figure 4.37, most of the data used for GA for each period is below the threshold values considered in analyses. Therefore, it is expected to observe a good BWQ along the Aegean coastline and thus, lower exceedance probabilities near bathing beaches. As a comparison, the mean data of the complete data collection period covering the time slot between 1993 – 2018 was also subjected to GA. Table 4.12 shows the model parameters estimated by GA for this duration (1993 – 2018).

Table 4.12. *Values of Model Parameters for IK in Aegean Region between 1993 - 2018*

Parameter	*Model*	*Range (m)*	*Nugget*	*Lag Size (m)*	*Partial Sill*	*Nugget/Sill* Ratio*
TC	K-Bessel	48,000	0.001	4,000	0.075	0.013
FC	J-Bessel	34,000	0.058	4,000	0.023	0.716
FS	Hole Effect	42,000	0.035	4,000	0.016	0.686

*Sill = Nugget + Partial Sill

Table 4.12 shows that, K-Bessel, J-Bessel and hole effect models were chosen due to low nugget values for TC, FC and FS, respectively. Nugget/sill ratio is below 25% for TC, which indicates that there is a strong spatial dependency for this parameter, whereas for FC and FC these values are ranged between 25 – 75% underlining that in Aegean region, FC and FS data used in analyses show moderate spatial dependency (Essington, 2004). FC has the highest nugget and partial sill values which indicates that the data points are distributed non-homogeneously. Lag sizes are selected as the same for each BWQ parameter since monitoring stations are the same for each BWQ parameters. Range values, on the other hand, show that spatial correlations become meaningless at distances longer than 48,000, 34,000 and 42,000 meters for TC, FC and FS, respectively. Figure 4.43 shows the semivariograms of BWQ parameters for 1993 – 2018 BWQ sampling results and visualizes Table 4.12.

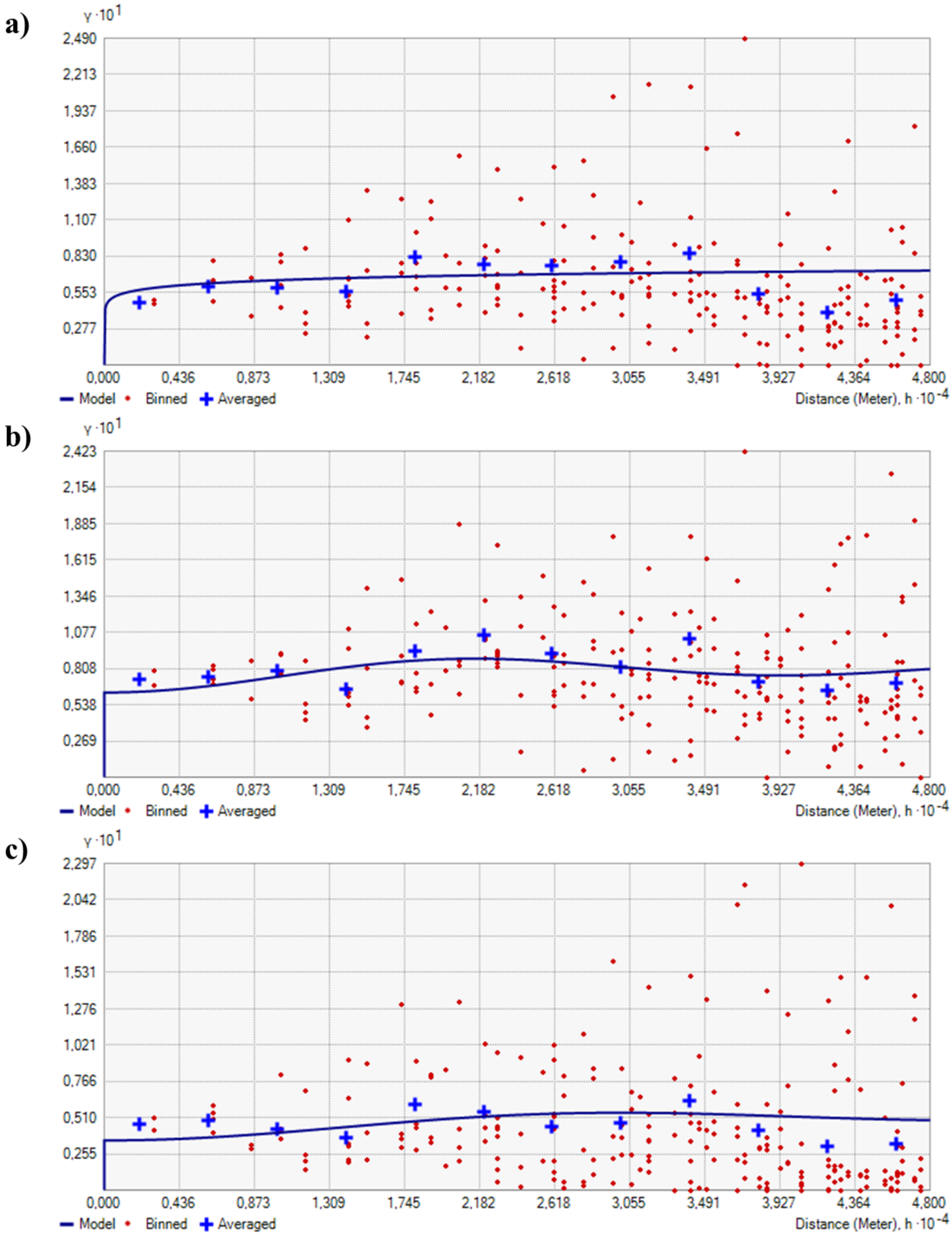


Figure 4.38. Semivariograms of a) TC, b) FC and c) FS in Aegean Region between 1993 – 2018

“Indicator Prediction” results were assessed to compare the exceedance probability values with measurement values. This process helps to observe if the measurement points with high exceedance probabilities also have high concentrations, i.e. threshold exceeding concentrations. According to this assessment, if a point with high concentration has lower exceedance probability, this indicates that most of the neighbors used to predict that point's exceedance probability has lower concentrations and lower exceedance probabilities. Figure 4.39 shows the indicator predictions for all three BWQ parameters.

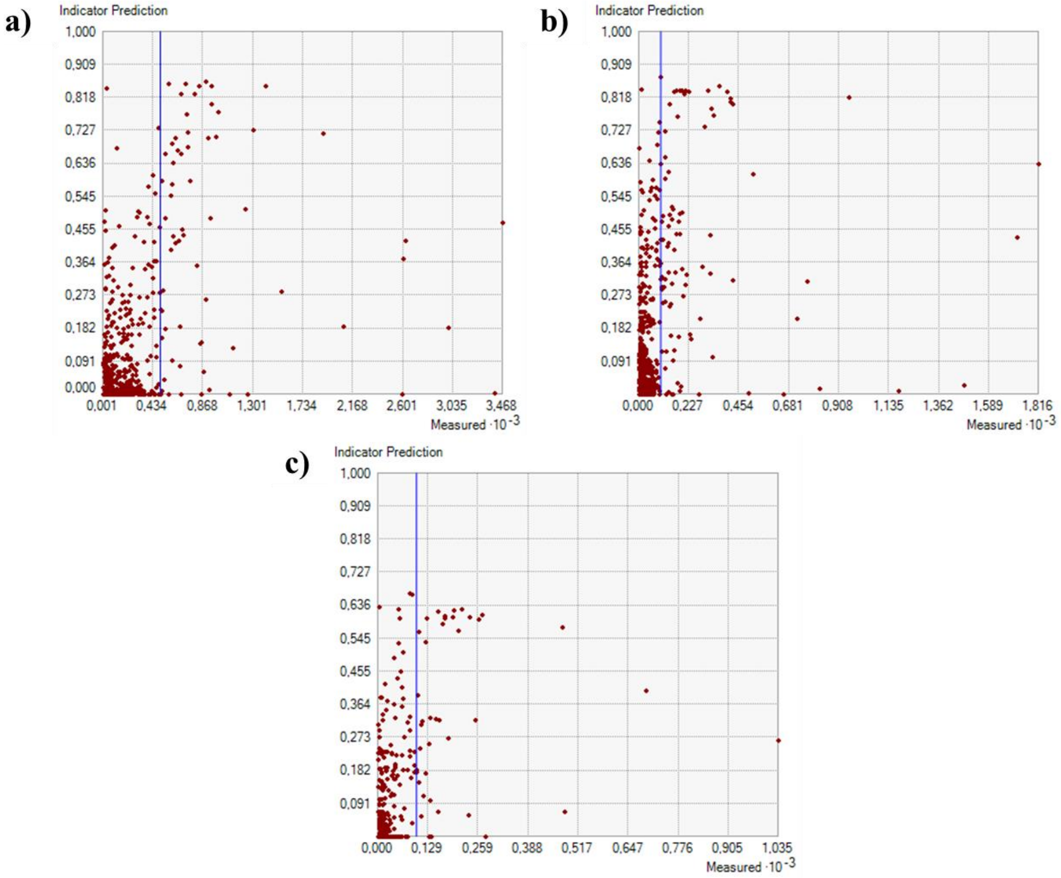


Figure 4.39. Indicator Predictions for a) TC, b) FC and c) FS for Aegean Region between 1993 – 2018

According to Figure 4.39, although there are some outliers in each parameters' dataset, for most measurement points exceedance probabilities are correlated with measurement results. Therefore, first step of cross validation shows that the prediction results are acceptable. The second step of cross validation involves estimation and comparison of prediction errors, i.e. comparison of measured values with predicted values. For this purpose, 5 types of error estimations (RMSE, ASE, ME, MSE and

RMSSE) were conducted. Table 4.13 shows the cross-validation results of GA between 1993 – 2018.

Table 4.13. *Cross Validation Results for Aegean Region*

Parameter	*RMSE*	*ASE*	*ME*	*MSE*	*RMSSE*
TC	0.253	0.247	0.0007	0.001	1.015
FC	0.308	0.255	-0.0003	0.0002	1.199
FS	0.208	0.197	0.0002	0.0006	1.072

Table 4.13 represents that for each parameter, ME values are almost zero and therefore it could be commented that predictions are unbiased. To check if the ME is correctly evaluated, firstly, relation between ASE and RMSE is assessed. For all BWQ parameters, RMSE and ASE values are closer to each other (with a difference of at most 2.2%), but, for all parameters, RMSE values are slightly higher than ASE values which indicate that there may be an underestimation for some regions (Arétouyap, et al., 2016). Similar to RMSE and ASE relation, RMSSE values are also used to evaluate whether the ME prediction is correct or not. Since for each parameter RMSSE values are closer to 1, although, all of them are a bit higher, predictions are acceptable. RMSSE values also indicate that there may be underestimation since RMSSE values are a bit greater than 1. Depending on these results, exceedance probability maps were obtained. The 3rd step of cross validation is the production of standard error of indicators maps. Figure 4.40, Figure 4.41 and Figure 4.42 provides the exceedance probability and standard error of indicators maps for Aegean region considering GA dataset between 1993 – 2018. Critical zones are identified by numbers and the designated areas by the numbers are given in Table 4.14.

Table 4.14. *Designated Areas in Exceedance Probability Maps of Aegean Region*

Bathing Site Number	*Designated Area*
1	Edremit Gulf
2	Center of Çanakkale
3	Enez/Edirne
4	İzmir Gulf

Bathing Site Number	*Designated Area*
5	Dardanelles
6	Ayvalık/Balıkesir
7	Gökçeada/Çanakkale
8	Didim/Aydın
9	Fethiye/Muğla
10	Çeşme/İzmir

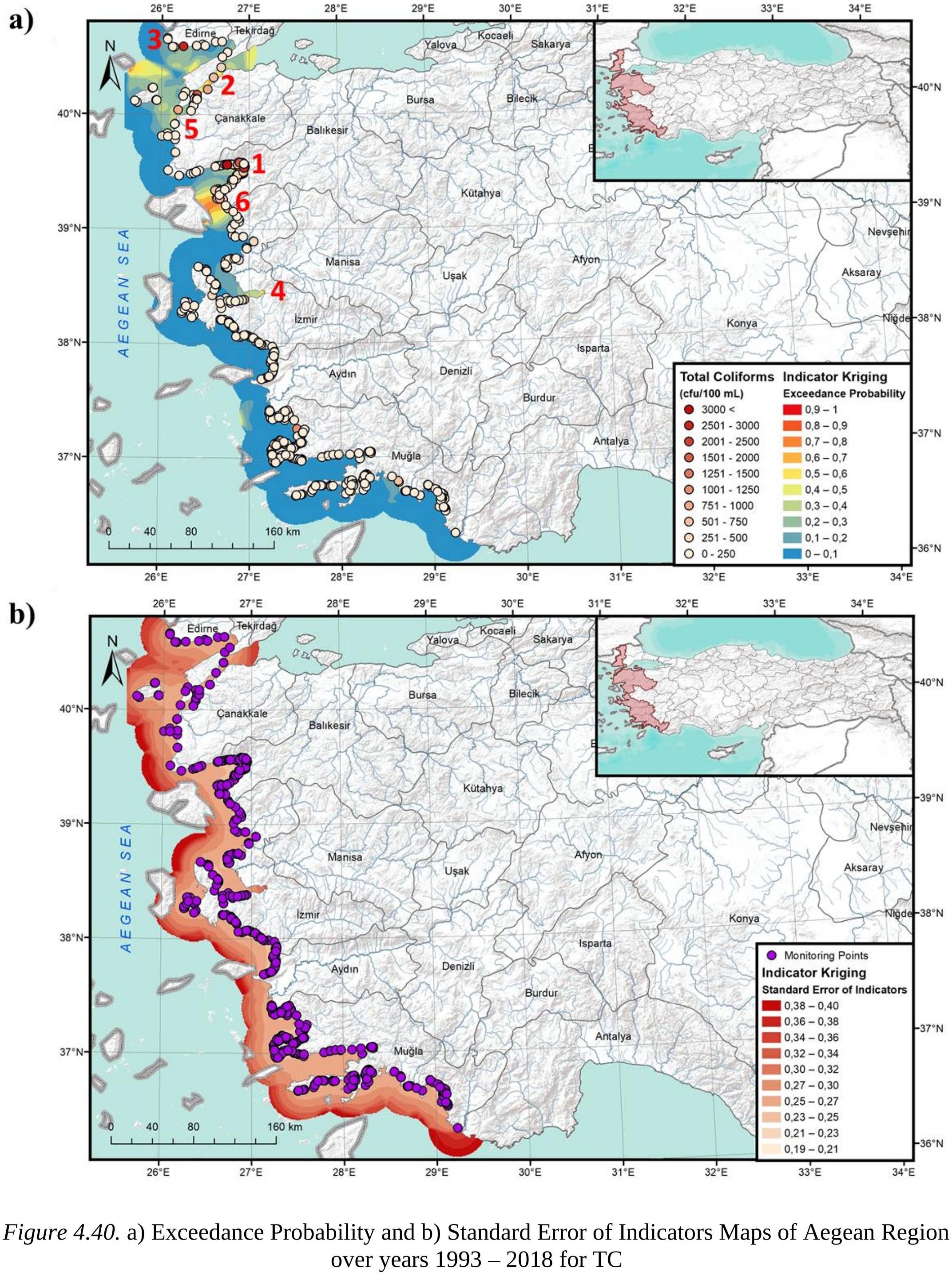


Figure 4.40. a) Exceedance Probability and b) Standard Error of Indicators Maps of Aegean Region over years 1993 – 2018 for TC

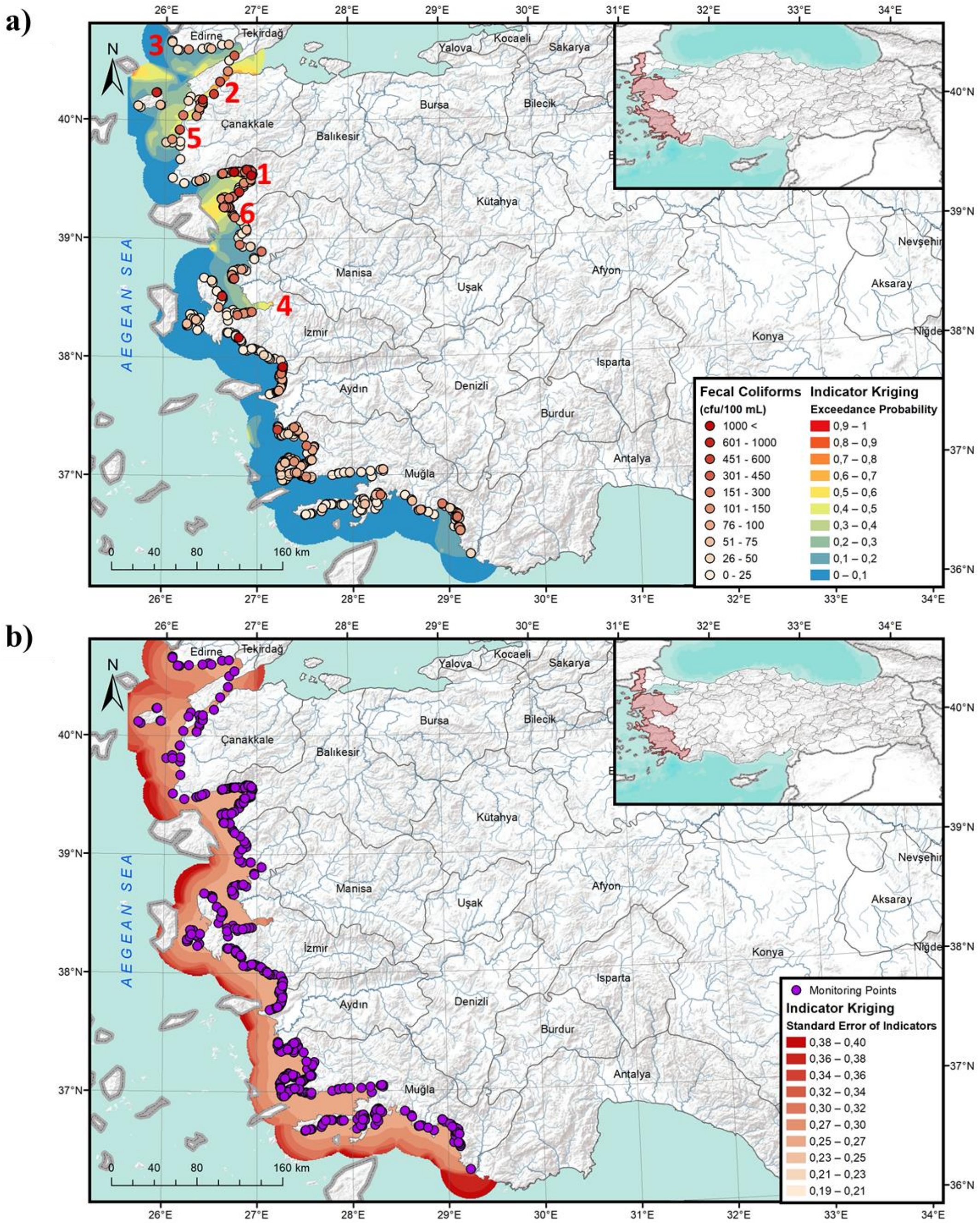


Figure 4.41. a) Exceedance Probability and b) Standard Error of Indicators Maps of Aegean Region over years 1993 – 2018 for FC

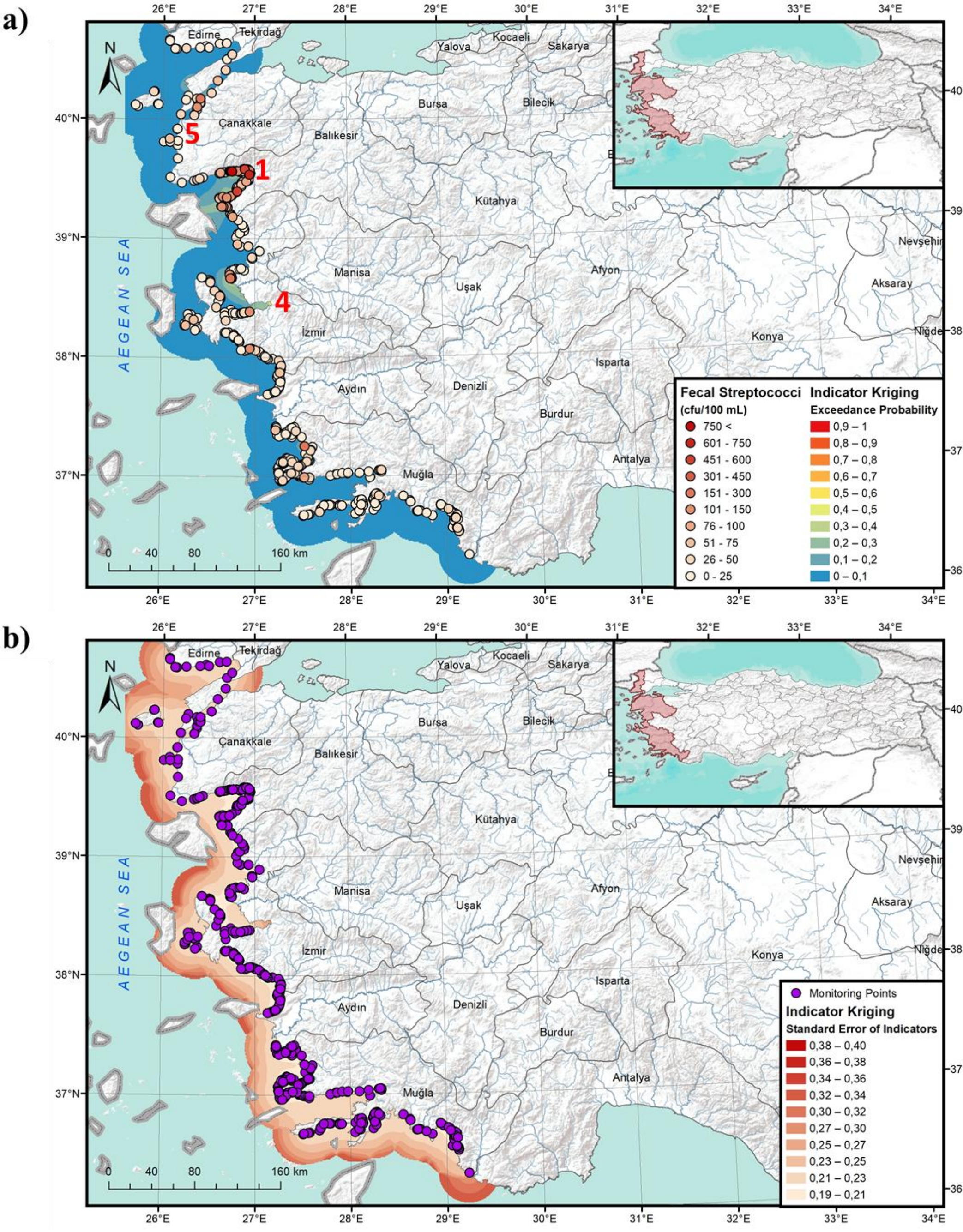


Figure 4.42. a) Exceedance Probability and b) Standard Error of Indicators Maps of Aegean Region over years 1993 – 2018 for FS

Figure 4.40, Figure 4.41 and Figure 4.42 gives a general overview of BWQ over years 1993 – 2018. To examine the critical areas in Aegean coastline, analyses considering smaller time intervals were also conducted. But figures given above show that most of the time, Edremit (1) and İzmir (4) gulfs draw more critical picture by means of all BWQ parameters. Also, TC and FC show poor BWQ in Dardanelles (5). FC and FS have more monitoring stations exceeding the regulatory criteria, however, for TC the number of monitoring stations exceeding threshold value is not that much. Therefore, TC shows more optimistic scenario. To identify the causes of poor BWQ, GA is also conducted for four periods. Table 4.15 provides the model parameters for each BWQ parameter and GA period.

Table 4.15. *Values of Model Parameters for IK Analysis in Aegean Region*

Parameter_Period*	*Model*	*Range (m)*	*Nugget*	*Lag Size (m)*	*Partial Sill*	*Nugget/Sill** Ratio*
TC_1	J-Bessel	32,427	0.068	4,000	0.042	0.618
FC_1	Gaussian	48,000	0.103	4,000	0.045	0.696
FS_1	Circular	46,330	0.029	4,000	0.012	0.707
TC_2	Spherical	30,617	0.022	4,000	0.028	0.440
FC_2	Hole Effect	31,490	0.026	4,000	0.027	0.491
FS_2	Hole Effect	32,370	0.038	4,000	0.017	0.691
TC_3	Hole Effect	37,200	0.006	4,000	0.003	0.667
FC_3	Exponential	48,000	0.023	4,000	0.011	0.676
FS_3	Stable	48,000	0.010	4,000	0.007	0.588
TC_4	Tetraspherical	73,851	0.021	4,000	0.008	0.724
FC_4	Exponential	38,200	0.038	4,000	0.020	0.655
FS_4	Gaussian	48,000	0.017	4,000	0.007	0.708

* Period Number 1: Before 2010, 2: 2010 – 2012, 3: 2013 – 2015, 4: 2016 – 2018
**Sill = Nugget + Partial Sill

There is no specific pattern observed in nugget values given in Table 4.15 by means of BWQ parameters, however, nugget values are higher for dataset between 2016 – 2018 and before 2010, which indicates that in those periods semivariances are higher, i.e. closer locations show high variation in measurements. Also, for all periods nugget to sill ratios are ranged between 25 – 75%, indicating that spatial dependency in this region is at the moderate level for each BWQ parameters. Cross-validation results for each BWQ parameter in each period is provided in Table 4.16.

Table 4.16. *Cross Validation Results for Aegean Region*

Parameter_Period*	*RMSE*	*ASE*	*ME*	*MSE*	*RMSSE*
TC_1	0.304	0.286	-0.004	-0.009	1.056
FC_1	0.347	0.336	-0.002	-0.004	1.034
FS_1	0.191	0.182	-0.0003	-0.002	1.063
TC_2	0.184	0.172	0.0007	0.003	1.090
FC_2	0.180	0.179	0.002	0.009	1.030
FS_2	0.201	0.210	0.0008	0.003	0.974
TC_3	0.094	0.083	0.0003	0.003	1.177
FC_3	0.178	0.166	0.0002	0.0007	1.096
FS_3	0.129	0.129	0.0009	0.006	1.015
TC_4	0.183	0.153	0.0003	0.002	1.198
FC_4	0.253	0.216	0.0006	0.002	1.178
FS_4	0.143	0.136	-0.00008	-0.001	1.069

*Period Number 1: Before 2010, 2: 2010 – 2012, 3: 2013 – 2015, 4: 2016 – 2018

Table 4.16 shows that GA results are reliable since all error values are acceptable. It was indicated in Chapter 3 that ME and MSE should be closer to zero, which is a valid situation for each parameter at each period. Smaller RMSE identifies more accurate results. Since most of the RMSE values, except for TC and FC assessments before 2010, are lower than 0.3, the model predictions give closer results to measured values (Veerasamy, et al., 2011).

Another kind of cross validation that is conducted in this study is to compare indicator predictions with measured data, i.e. average BWQ concentrations at each sampling point. In addition to error estimations, Figure 4.43, Figure 4.44 and Figure 4.45 provides the indicator predictions at each data point, for TC, FC and FS, respectively.

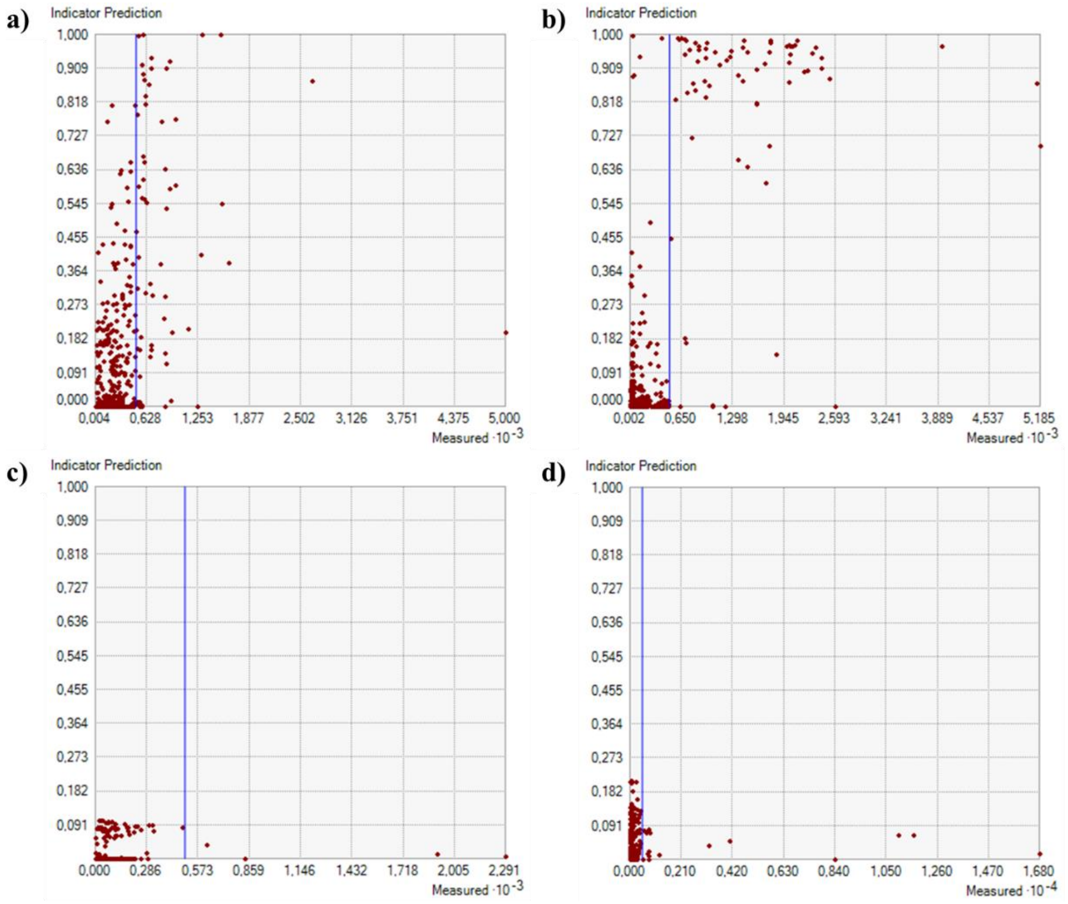


Figure 4.43. Indicator Predictions of TC for Aegean Region between a) 1993 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

Figure 4.43 shows that, in more recent periods, indicator predictions, therefore, exceedance probabilities are mostly lower than 30%, whether, measured values at sampling points are higher than threshold value for TC parameter or not. However, for 2010 – 2012 and before 2010, indicator predictions increased up to 1, which identifies that insufficient BWQ become an areal appearance rather than a point-wise outlier.

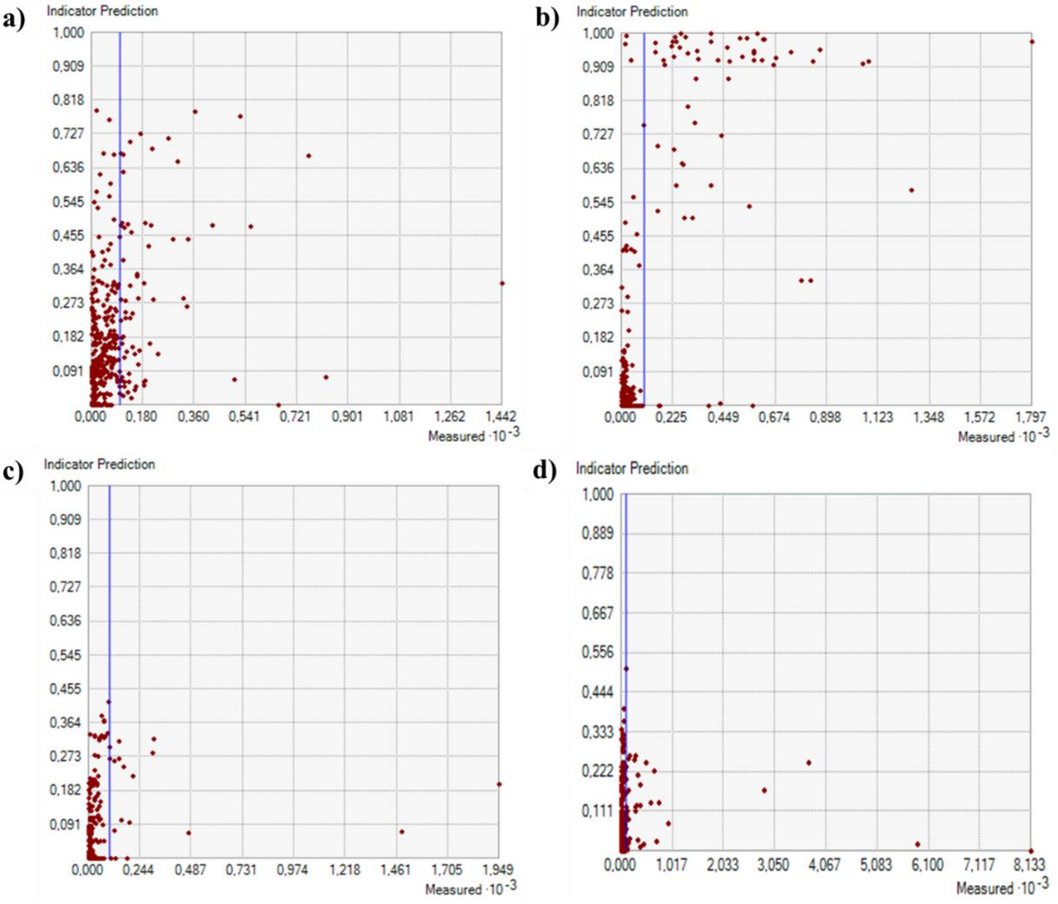


Figure 4.44. Indicator Predictions of FC for Aegean Region between a) 1993 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

Similar to TC concentrations, Figure 4.44 shows that, in more recent periods, exceedance probabilities, therefore, exceedance probabilities are low in most of the monitoring points. The highest exceedance probability values are approximately 65% for two monitoring points out of than 40%, although, measured values at some sampling points violates threshold value for FC parameter. However, for 2010 – 2012, indicator predictions increased up to 1, which identifies that insufficient BWQ become an areal appearance rather than a point-wise outlier, especially between 2010 – 2012.

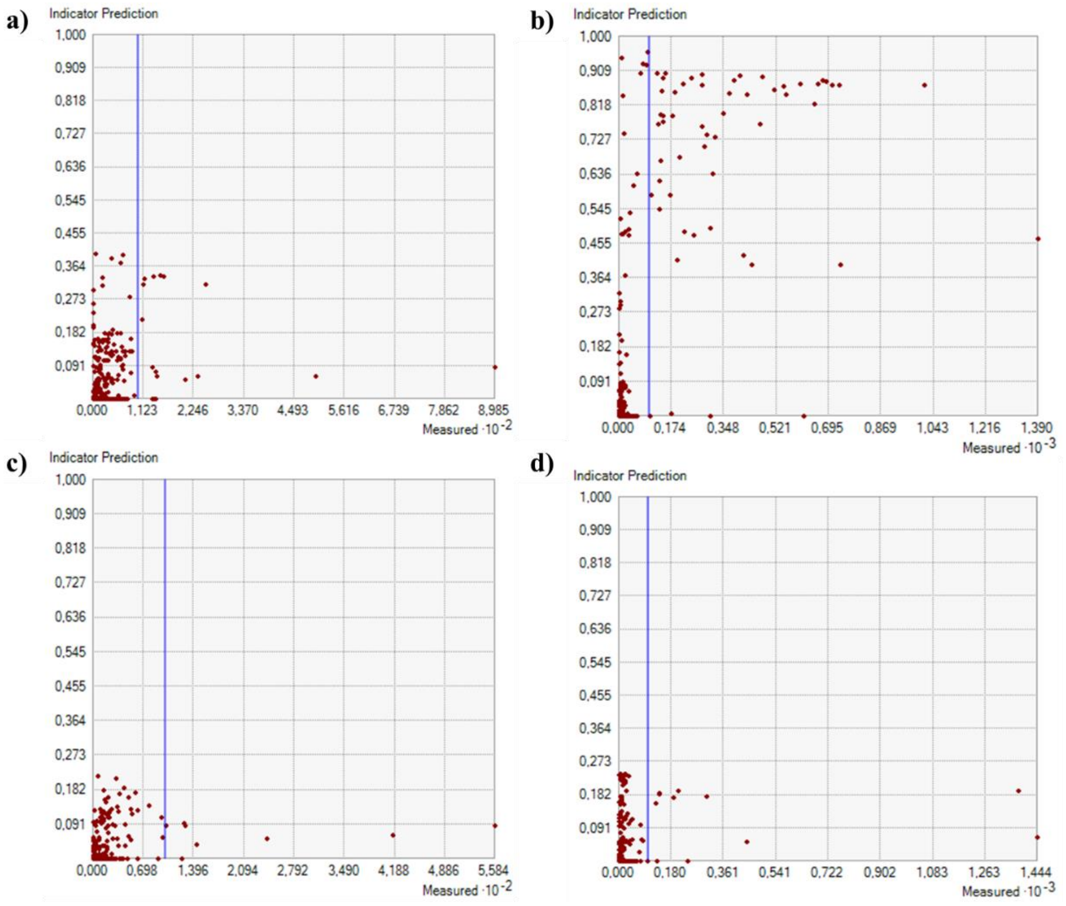


Figure 4.45. Indicator Predictions of FS for Aegean Region between a) 1993 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

Indicator prediction results of FS show similar appearance to both TC and FC predictions as shown in Figure 4.45. The highest exceedance probability values are approximately 20% for more current periods, although, measured values at some sampling points are extremely higher than threshold value for FS parameter. However, similar to FC analyses, for 2010 – 2012 indicator predictions increased up to 1, which identifies that insufficient BWQ become an areal appearance rather than a point-wise outlier 2010 – 2012.

As a result of IK analyses, exceedance probability maps and for cross validation standard error of indicators maps were obtained for each period for all three BWQ parameters. From Figure 4.46 to show threshold exceedance probabilities for 2016 –

2018, 2013 – 2015, 2010 – 2012 and 1993 – 2010 periods, respectively, for each BWQ parameter.

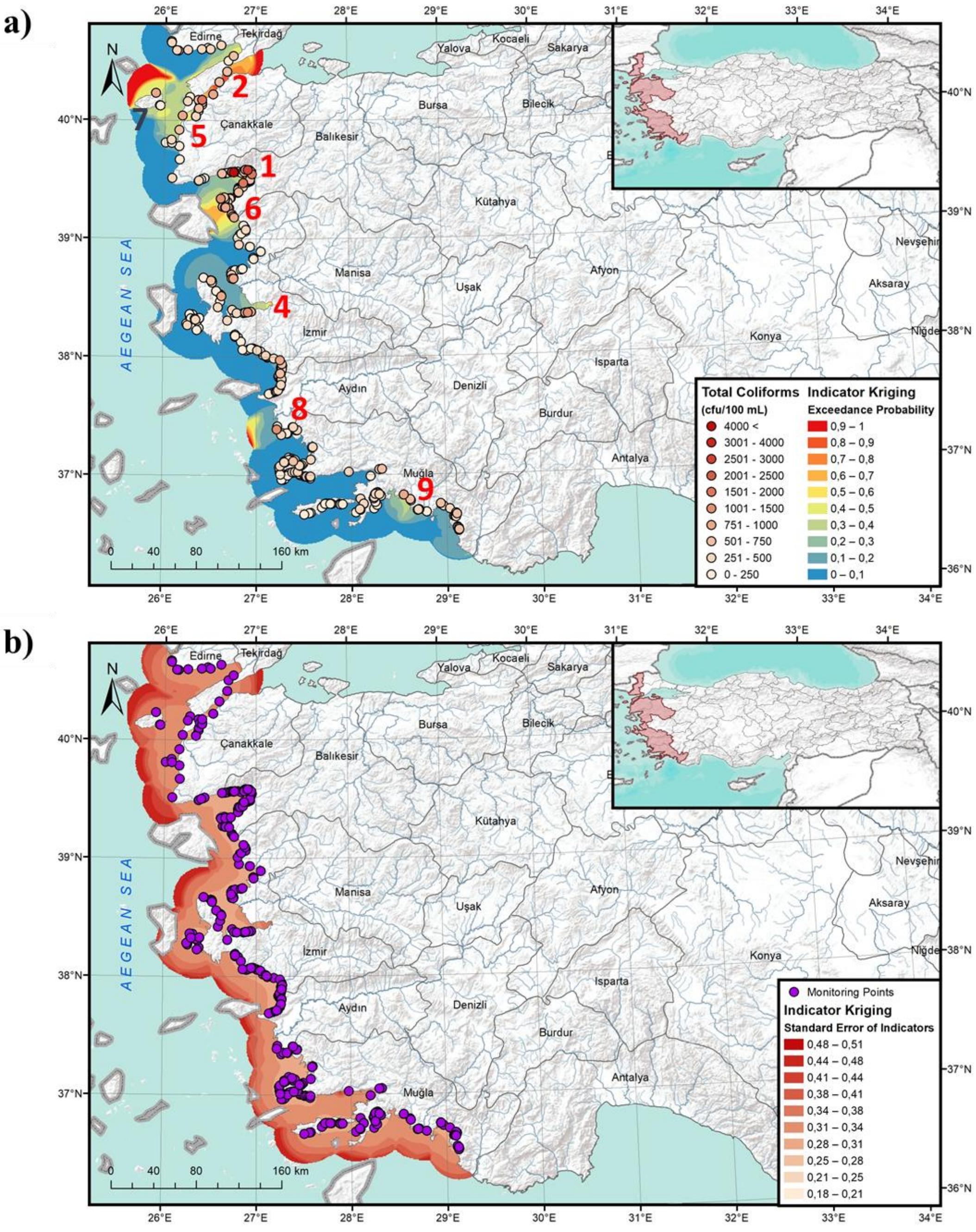


Figure 4.46. a) Exceedance probability and b) standard error maps generated for Aegean Region before 2010 for TC (GA period 1)

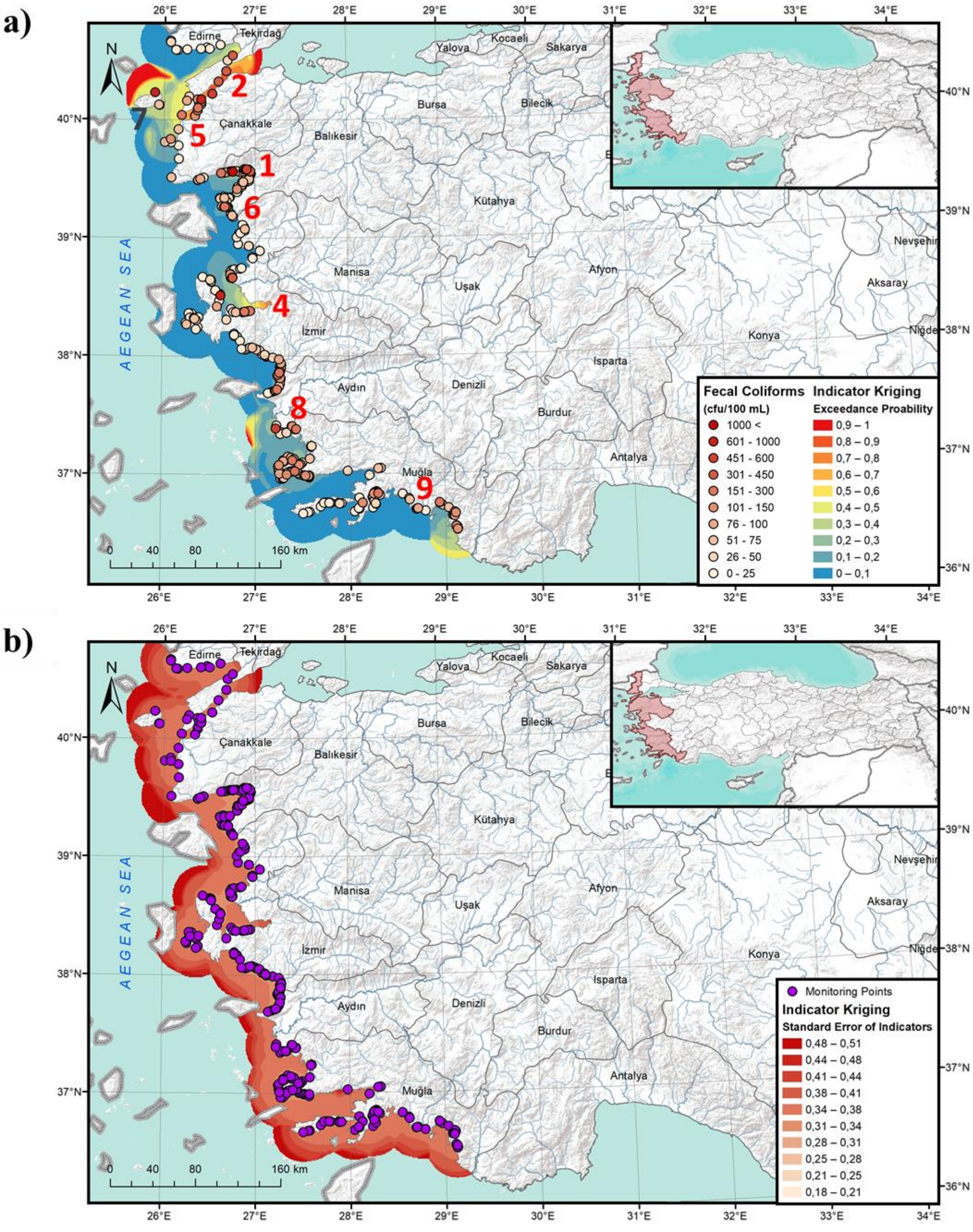


Figure 4.47. a) Exceedance probability and b) standard error maps generated for Aegean Region before 2010 for FC (GA period 1)

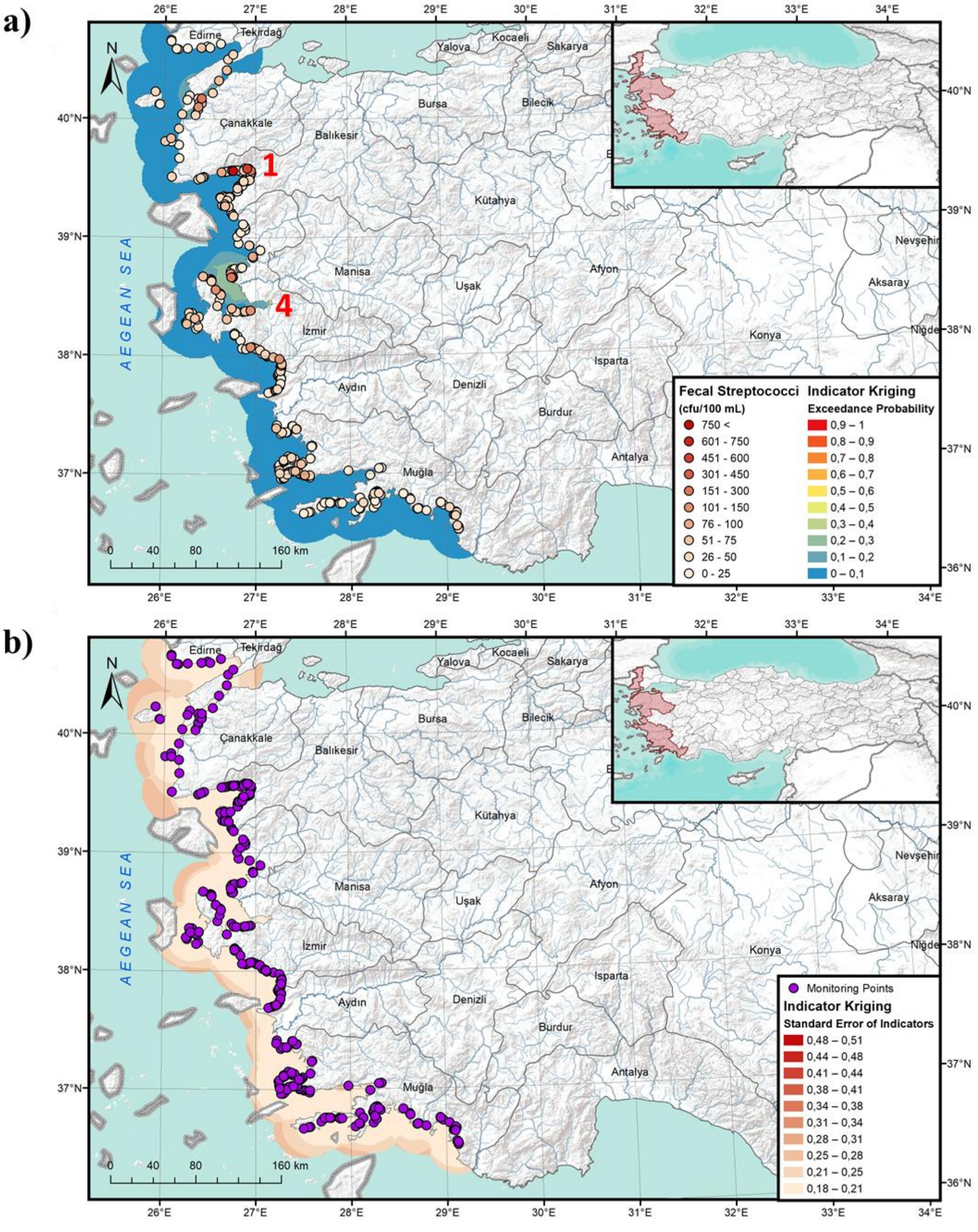


Figure 4.48. a) Exceedance probability and b) standard error maps generated for Aegean Region before 2010 for FS (GA period 1)

Before 2010, critical regions by means of BWQ become more widespread. This period involves 16 years average for each monitoring point which lowers the reliability of the analysis in this period. But, monitoring applications were limited before 2010, therefore consideration of this period as a whole is an optimal approach for this kind of dataset. For this period, even though, TC and FC shows similar patterns, FS provides lower concentrations and thus, better BWQ.

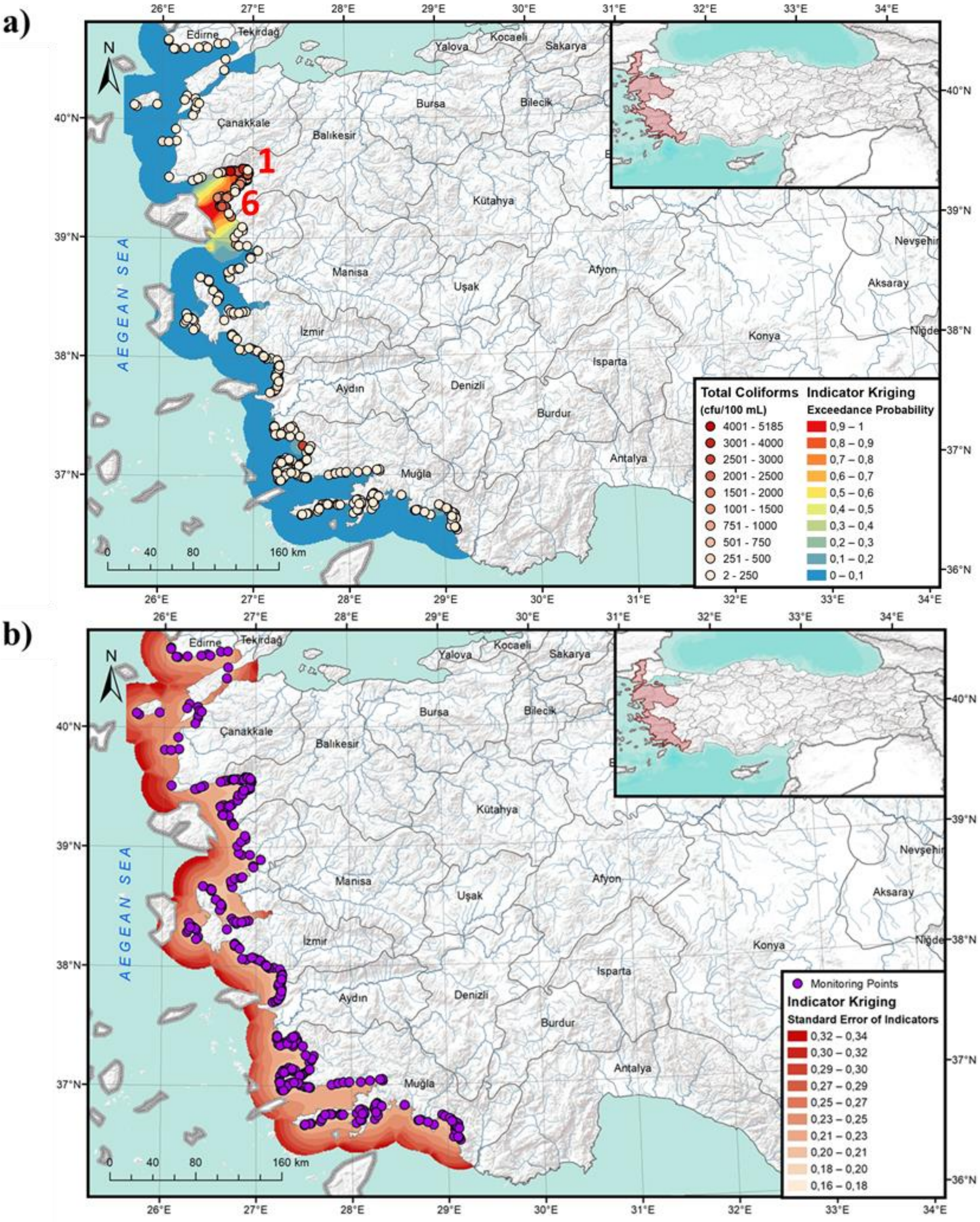


Figure 4.49. a) Exceedance probability and b) standard error maps generated for Aegean Region between 2010 – 2012 for TC (GA period 2)

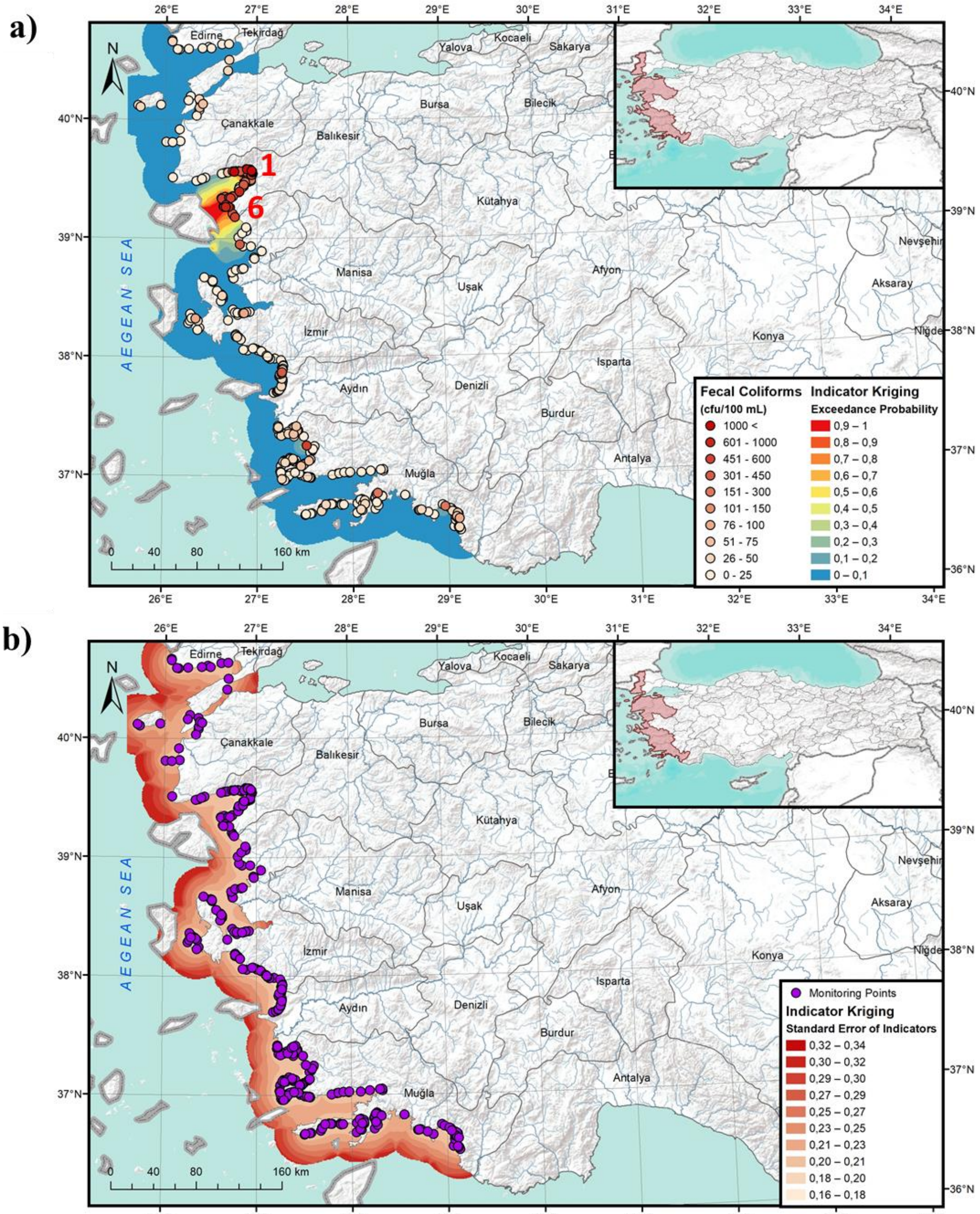


Figure 4.50. a) Exceedance probability and b) standard error maps generated for Aegean Region between 2010 – 2012 for FC (GA period 2)

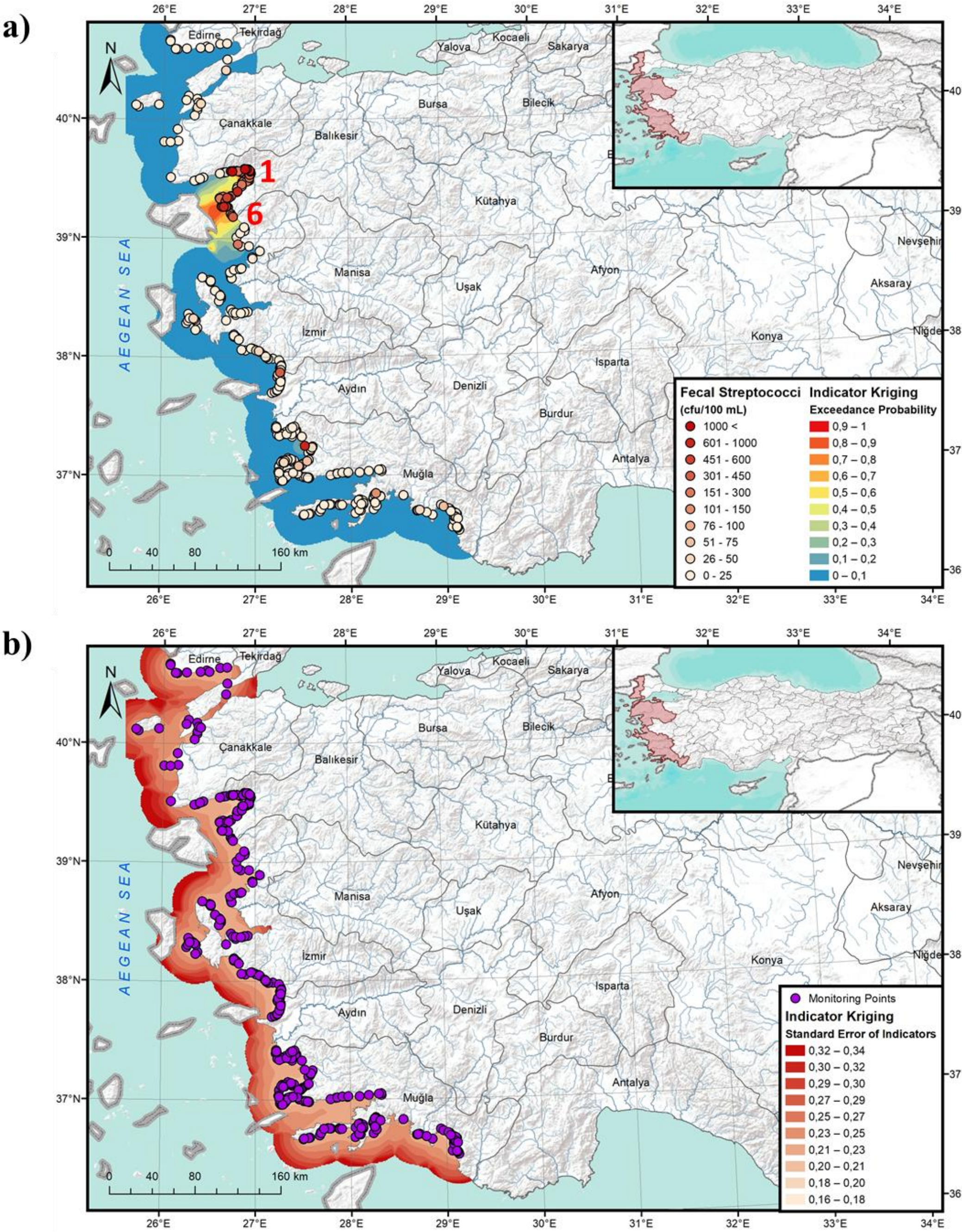


Figure 4.51. a) Exceedance probability and b) standard error maps generated for Aegean Region between 2010 – 2012 for FS (GA period 2)

Between 2010 and 2012, Edremit Gulf (1) and Ayvalık/Balıkesir (6) coastlines show highly insufficient BWQ and high values of exceedance probabilities by means of all three BWQ parameters. Therefore, it could be commented that in this region, BWQ is improved after 2012. One of the main reasons of this improvement is development of BWQ monitoring network and elimination of environmental stresses on bathing sites. In 2012 and 2013, three WWTPs put into operation (Balıkesir Provincial Directorate of Environment and Urbanization, 2018) and after that it can be observed from the figures provided above that BWQ has improved.

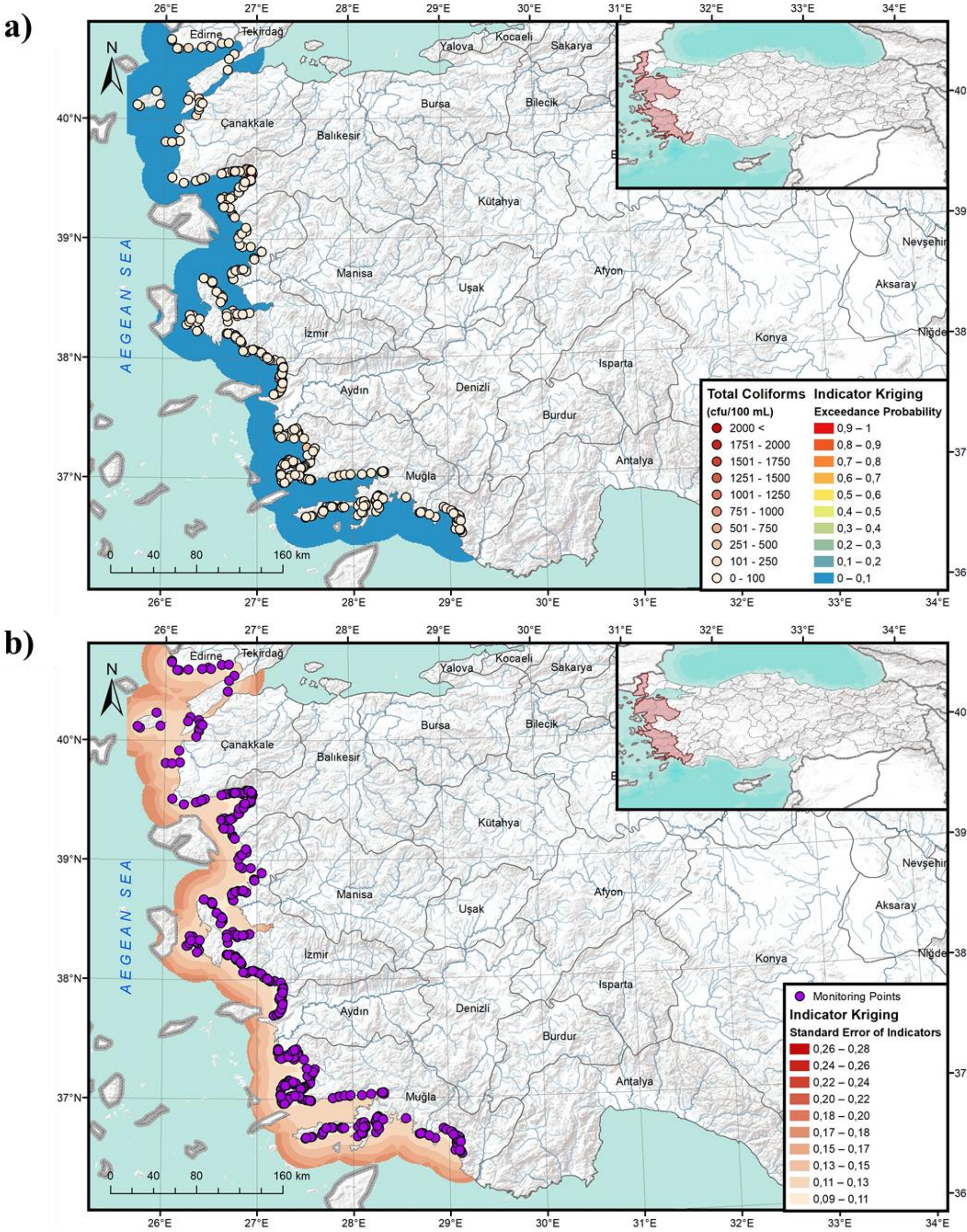


Figure 4.52. a) Exceedance probability and b) standard error maps generated for Aegean Region between 2013 – 2015 for TC (GA period 3)

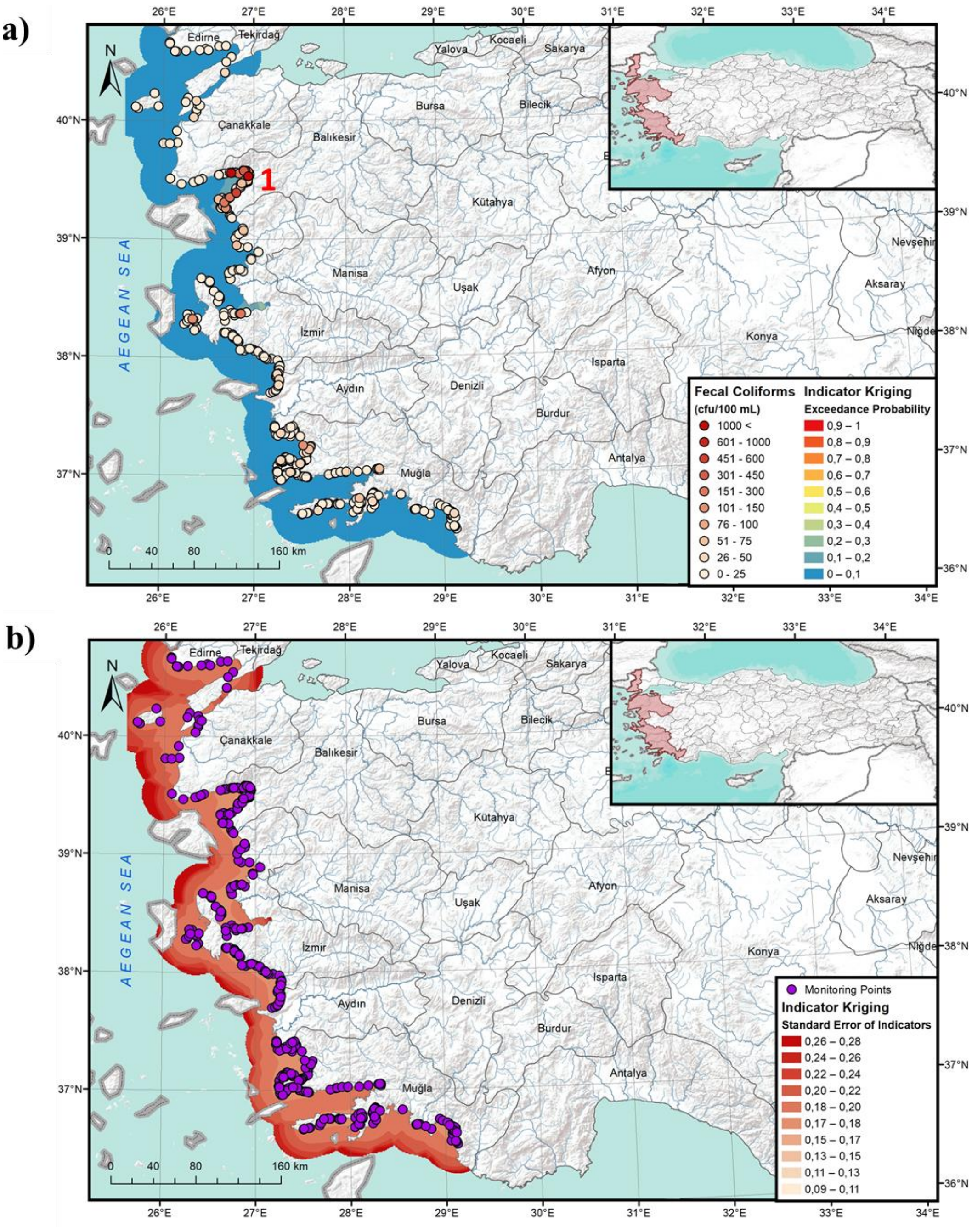


Figure 4.53. a) Exceedance probability and b) standard error maps generated for Aegean Region between 2013 – 2015 for FC (GA period 3)

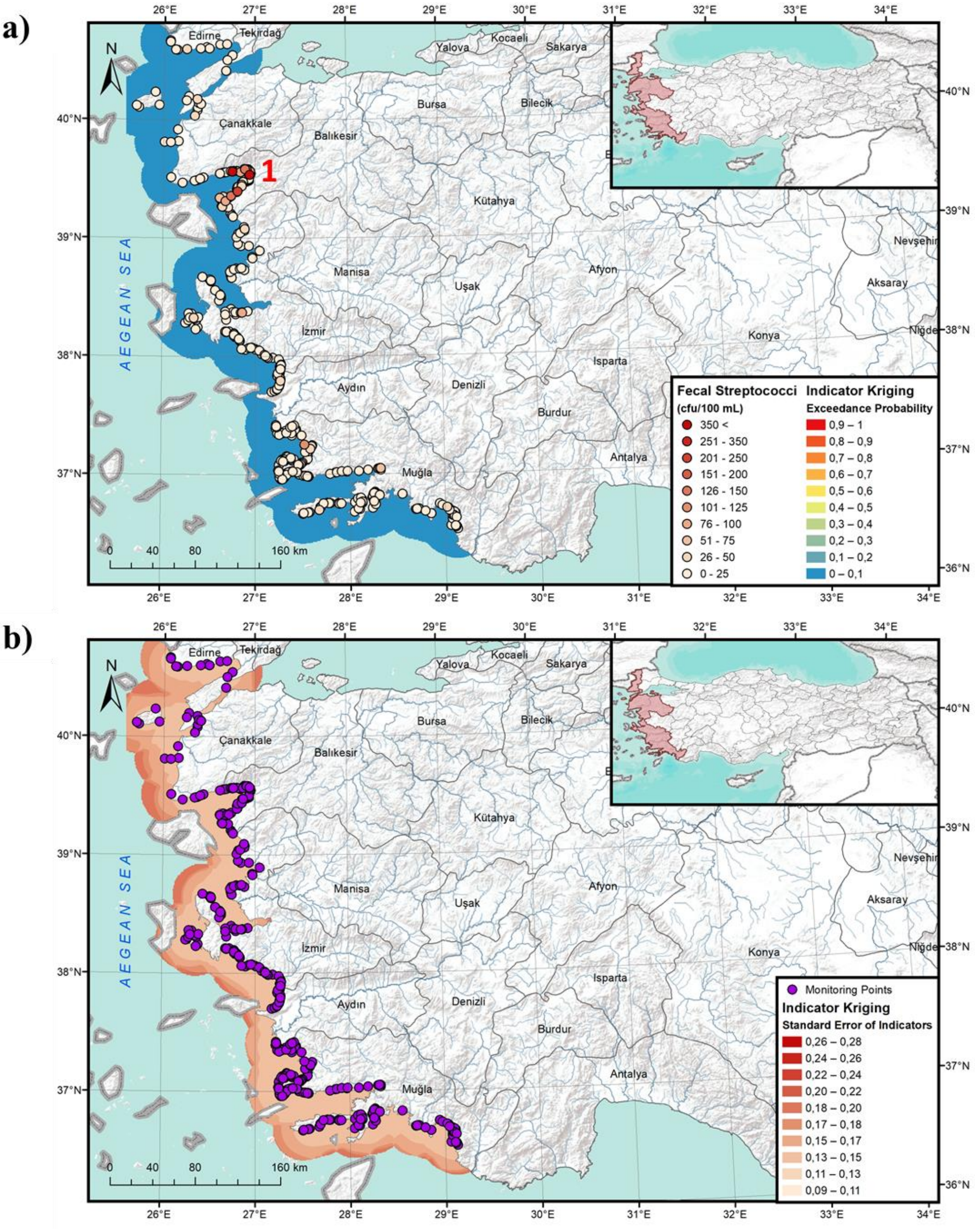


Figure 4.54. a) Exceedance probability and b) standard error maps generated for Aegean Region between 2013 – 2015 for FS (GA period 3)

For all three BWQ parameters, similar to 2016 – 2018 period, Edremit Gulf (1) also shows insufficient BWQ between 2013 – 2015. The reason is same with the 2016 – 2018 period, since same pollution stresses also exist in 2013 – 2015 period. Table 4.17

provides the 3 years averages for BWQ parameters in the region and FC/FS ratios for each monitoring station at Edremit Gulf.

Table 4.17. *FC/FS Ratios in Edremit Gulf between 2013 – 2015*

Monitoring Point	*BWQ Parameters (cfu/ 100 mL)*			*FC/FS*
	TC_{ave}	FC_{ave}	FS_{ave}	
Edremit_1	233	102	62	1.65
Edremit_2	112	93	36	2.58
Edremit_3	103	52	21	2.45
Edremit_4	323	141	102	1.39
Edremit_5	292	124	124	1.01
Edremit_6	112	60	15	4.07
Edremit_7	61	30	18	1.65
Edremit_8	124	48	34	1.39
Edremit_9	181	70	32	2.18
Edremit_10	222	62	43	1.44
Edremit_11	122	107	41	2.59
Edremit_12	41	21	15	1.42
Edremit_13	72	39	14	2.85
Edremit_14	91	36	14	2.65
Edremit_15	22	11	10	1.07
Edremit_16	35	24	11	2.13
Edremit_17	41	28	12	2.42
Edremit_18	221	183	90	2.03
Edremit_19	318	143	58	2.46
Edremit_20	295	207	94	2.20
Edremit_21	159	74	21	3.56
Edremit_22	249	163	54	3.03
Edremit_23	488	302	128	2.37
Edremit_24	620	307	126	2.43
Edremit_25	61	26	22	1.16
Edremit_26	177	79	53	1.49
Edremit_27	1,908	1,489	417	3.57
Edremit_28	212	121	49	2.45
Edremit_29	178	90	77	1.18

Although, all FC/FS ratio values are close to each other, ratios with greater than or equal to 2 have the majority in the monitoring points. Therefore, it could be commented that pollution sources are mostly human originated but there is also fecally contaminated locations caused by animal wastes from farms.

Cross validation results for exceedance probability maps show that TC shows more reliable results and FC shows the worst case, although, it is acceptable. For TC, semivariances are lower which means that less variation is observed in closer monitoring points. Because of that standard error of indicators are lower for FS. On the other hand, similar to 2016 – 2018 period, FC has high variety in concentrations of closer monitoring stations which leads an increase in standard error of indicators between 2013 – 2015.

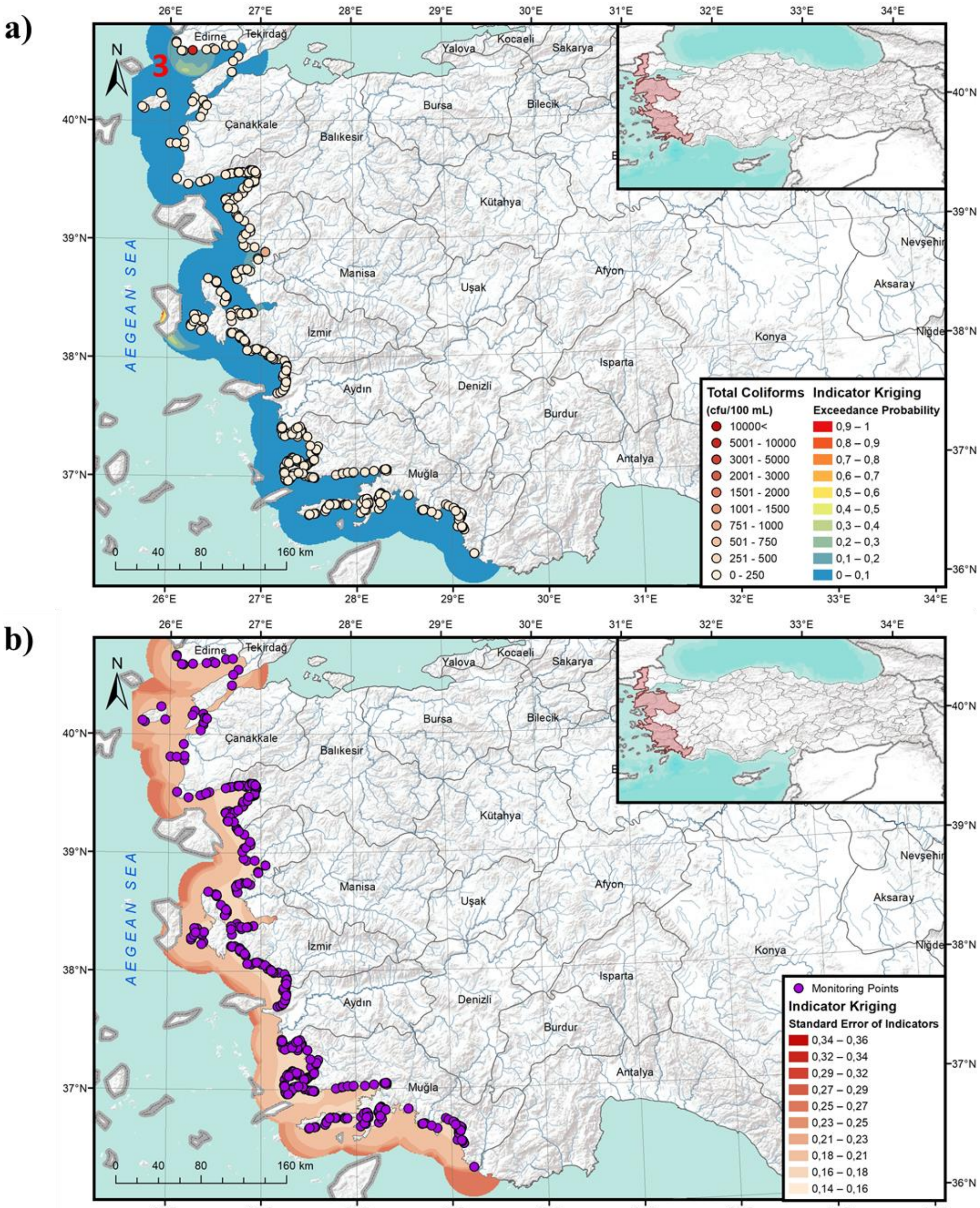


Figure 4.55. a) Exceedance probability and b) standard error maps generated for Aegean Region between 2016 – 2018 for TC (GA period 4)

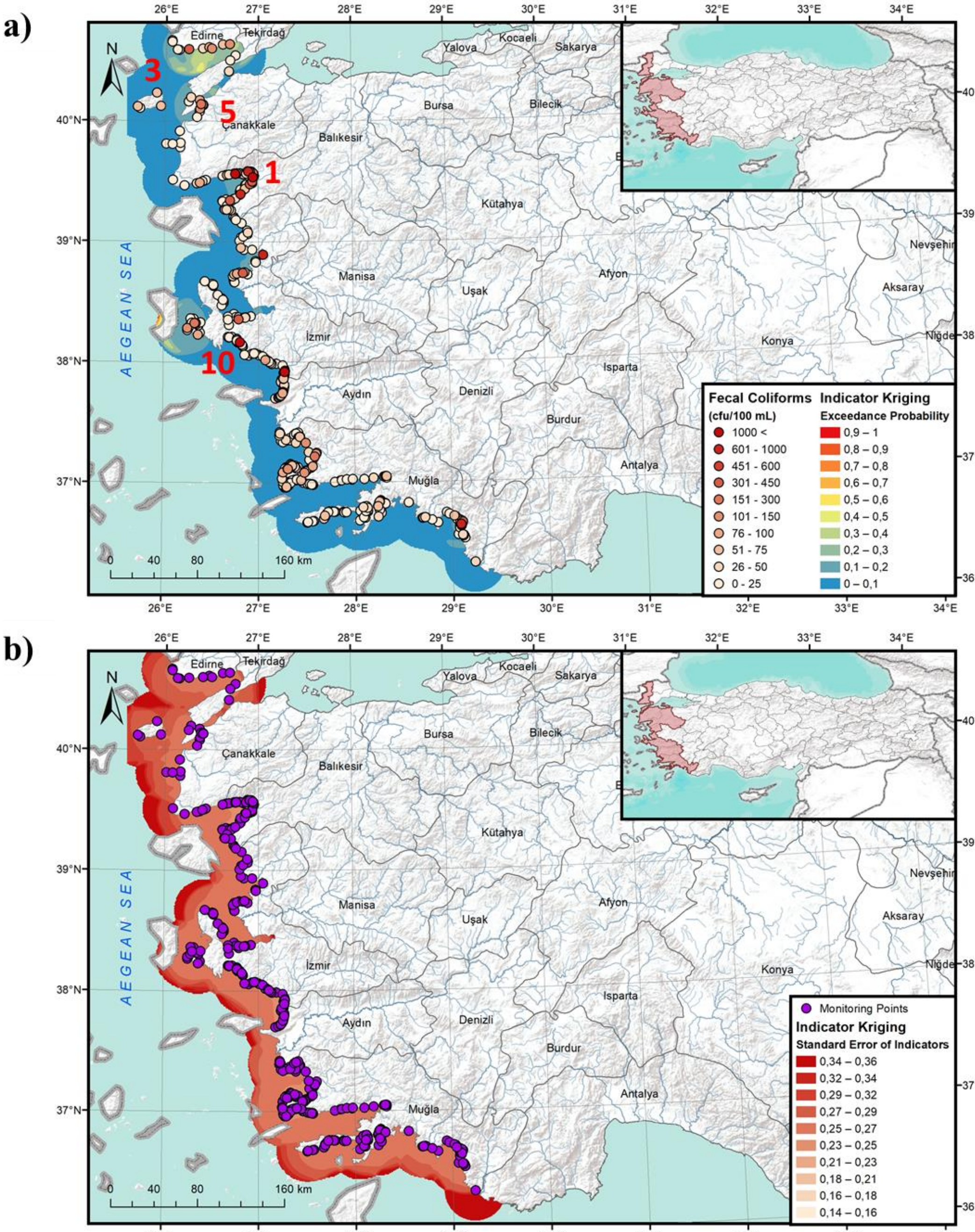


Figure 4.56. a) Exceedance probability and b) standard error maps generated for Aegean Region between 2016 – 2018 for FC (GA period 4)

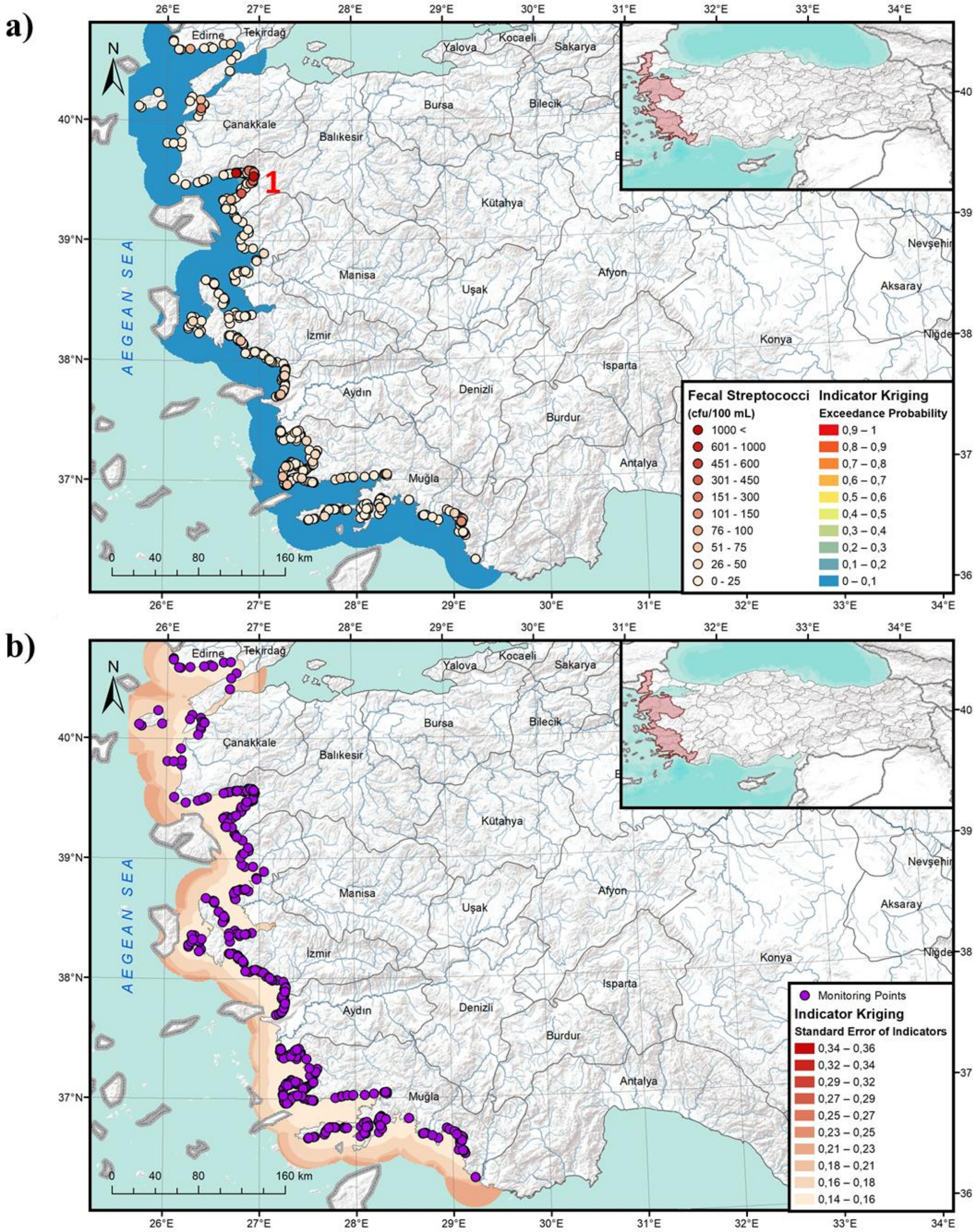


Figure 4.57. a) Exceedance probability and b) standard error maps generated for Aegean Region between 2016 – 2018 for FS (GA period 4)

For 2016 – 2018 period, Edremit Gulf (1) shows critical appearance by means of all BWQ parameters. The main reason for this situation is that there are lots of discrete creeks in the area which flow through urban regions, especially seasonal residential areas. Although, there is no strong evidence proving that there is a direct wastewater discharges through those rivers in this region, Balıkesir Provincial Environmental Situation Report states that direct discharges from summerhouses involve significant environmental stress on those creeks which lead to fecal contamination in bathing sites (Balıkesir Provincial Directorate of Environment and Urbanization, 2018). In addition to Edremit Gulf (1) and its surroundings, Enez/Edirne (3) coasts also show critical behavior by means of TC and FC. The reason causing this situation is that between 2016 – 2018, a single monitoring point dominates the region by means of TC and FC, and also, FS concentration is very close to regulatory criteria. Table 4.18 shows the three-year averages of BWQ parameters in 2016 – 2018 period for this region.

Table 4.18. *Average Concentrations of BWQ Parameters in Enez/Edirne between 2016 – 2018*

Monitoring Point	*BWQ Parameters (cfu/ 100 mL)*		
	TC_{ave}	FC_{ave}	FS_{ave}
Enez_1	8403	365	99
Enez_2	106	21	13
Enez_3	72	11	16
Enez_4	315	279	40

In addition to these, there are also some poor BWQ regions by means of only FC or FS parameters. Near Çeşme/İzmir (10) and Fethiye/Muğla coastlines, FC shows higher exceedance probability. On the other hand, at the Aegean outlet of Dardanelles, indicators are higher for FS. The regions with insufficient BWQ near Çeşme (10) and Fethiye coastlines are very close to central regions, which indicates that fecal pollution is due to high population density. To understand the reason why FS concentrations are higher at the outlet of Dardanelles FC/FS ratios should be assessed. FC/FS ratios for the relevant region is provided in Table 4.19.

Table 4.19. *FC/FS Ratios in Dardanelles between 2016 – 2018*

Monitoring Point	BWQ Parameters (cfu/ 100 mL)			FC/FS
	TC_{ave}	FC_{ave}	FS_{ave}	
ÇanakkaleCenter_1	58	22	28	0.77
ÇanakkaleCenter_2	26	6	9	0.65
ÇanakkaleCenter_3	759	119	235	0.51
ÇanakkaleCenter_4	43	10	15	0.70
ÇanakkaleCenter_5	97	54	43	1.25
Eceabat_1	36	27	17	1.60
Eceabat_2	15	9	2	5.45
Eceabat_3	61	12	16	0.75
Eceabat_4	148	81	73	1.11

Table 4.19 shows that in most of the monitoring points in the region FC/FS ratio is smaller than 2 and in some locations it is smaller than 0.7, which indicates that the predominant origin of the fecal pollution in the area is animal wastes.

When cross validation results for exceedance probability maps are compared for this period, FS shows more reliable results and FC shows the worst case, although, it is acceptable. For FS, semivariances are lower which means that less variation is observed in closer monitoring points. Because of that standard error of indicators are lower for FS. On the other hand, FC has high variety in concentrations of closer monitoring stations which leads an increase in standard error of indicators. In addition to these, as expected, in the regions closer to monitoring points, i.e. coastline, show lower errors compared with further regions.

As stated in Chapter 4.1, wastewater treatment plants are significant fecal pollution sources. Therefore, wastewater discharges are evaluated in the scope of this study. Figure 4.58 shows the wastewater discharge points and threshold exceedance probabilities for FC in 2016 – 2018.

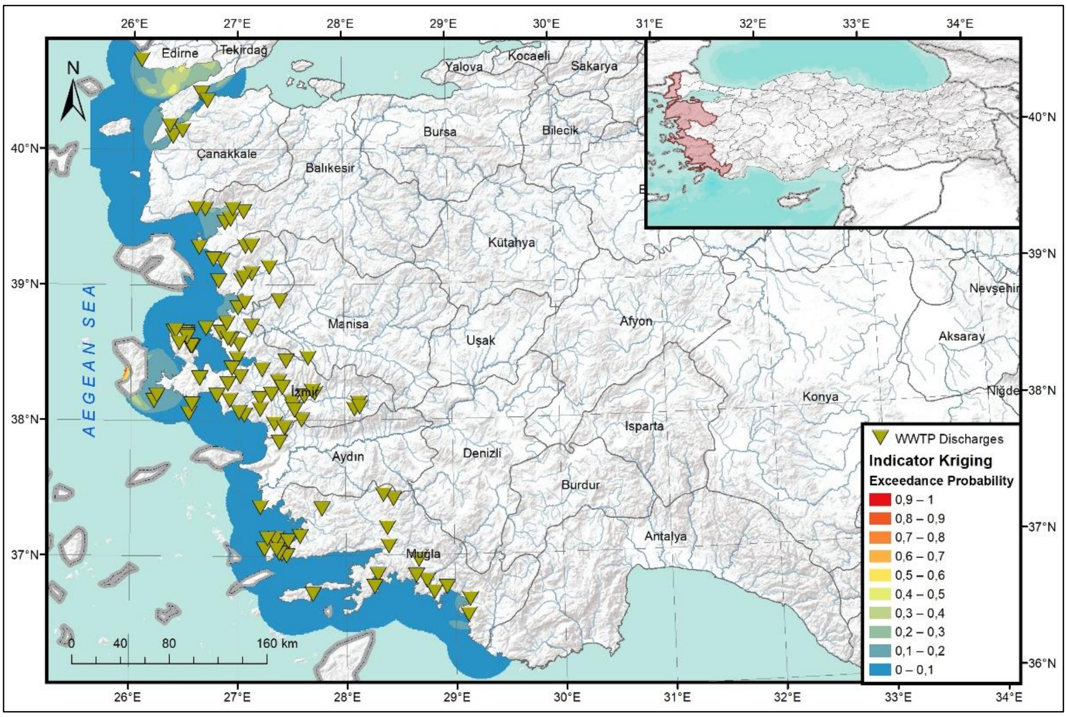


Figure 4.58. WWTP Dischage Locations in Aegean Region embedded in FC Exceedance Probability Map for GA Period 4 *(Balıkesir Provincial Directorate of Environment and Urbanization, 2018; Çanakkale Provincial Directorate of Environment and Urbanization, 2018; İzmir Provincial Directorate of Environment and Urbanization, 2018; Muğla Provincial Directorate of Environment and Urbanization, 2018; Aydın Provincial Directorate of Environment and Urbanization, 2018)*

As shown in Figure 4.58, especially in western region of Edirne and Gallipoli Semi-island, wastewater treatment plants have negative impact on BWQ. However, near Muğla coasts, WWTPs do not show an influence on BWQ. The possible reason of this difference is that the most significant and prestigious tourism points Bodrum, Marmaris, Datça, Fethiye and so on are located in Muğla and efficiencies of WWTPs are higher in this region. Since deterioration in BWQ will cause the cancellation of Blue Flag award, WWTP performances are highly important near Muğla coasts.

As mentioned before, one of the most significant environmental stress on Edremit Gulf is summerhouses and seasonal variation in population. Although, after initiation of WWTPs in 2012 improvement in BWQ is observed, exceedance probability is estimated in a range of 20 – 50% in the region.

In İzmir coastline, bathing sites around İzmir Gulf, Aliağa and Çeşme show critical appearance. For Aliağa, it can be discussed that WWTPs are effective on BWQ, but for Çeşme deep sea discharge system is active. In İzmir Gulf, the WWTP which has the largest capacity in İzmir discarges treated water into sea. This WWTP carries all wastewater load of central İzmir, therefore, fecal pollution in this area is also related with population density which is shown in Figure 4.59.

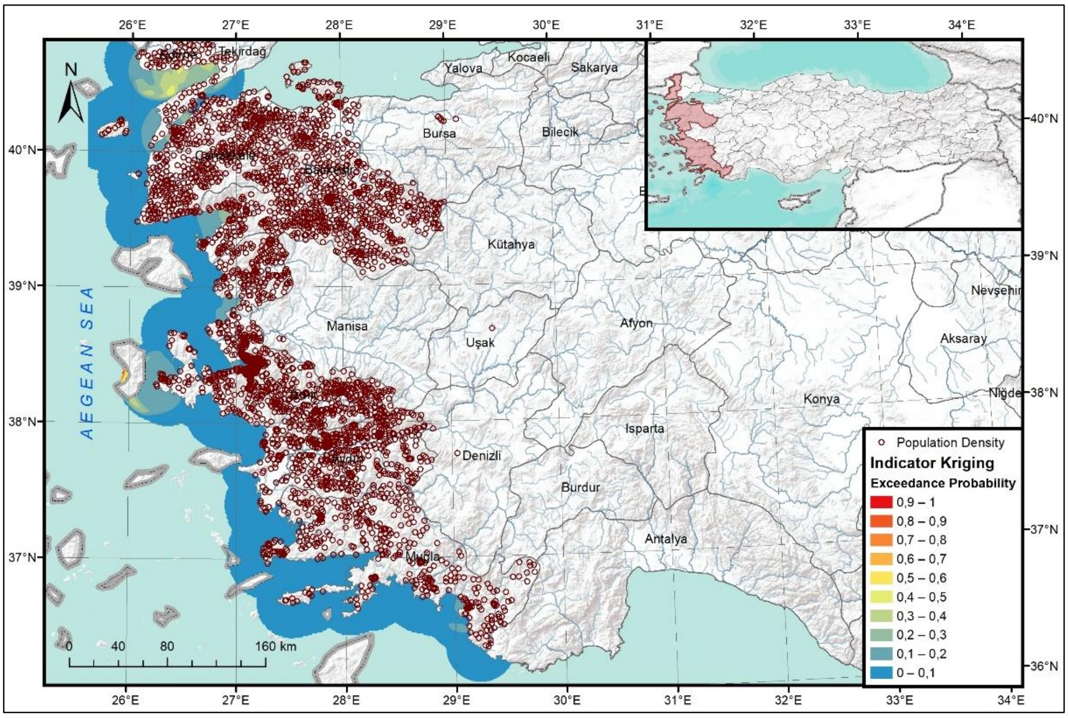


Figure 4.59. Population Density Along Aegean Region embedded in FC Exceedance Probability Map for GA Period 4 (Adopted from: TÜİK, 2018)

The given figure shows that the regions with poor BWQ have high population densities, which supports the idea of higher threshold exceedance probabilities is caused by human originated fecal pollution. This figure is also correlated with locations of WWTPs since increase in population density leads increase in wastewater load of WWTPs. Therefore, population densities validate the relationship between critical bathing sites and WWTPs.

As previously specified marinas are known as an important pollution sources in bathing sites. Figure 4.60 shows the locations of marinas in Aegean coastline and indicates that there is not a strong evidence that proves the negative impacts of marinas on bathing sites around Aegean coasts.

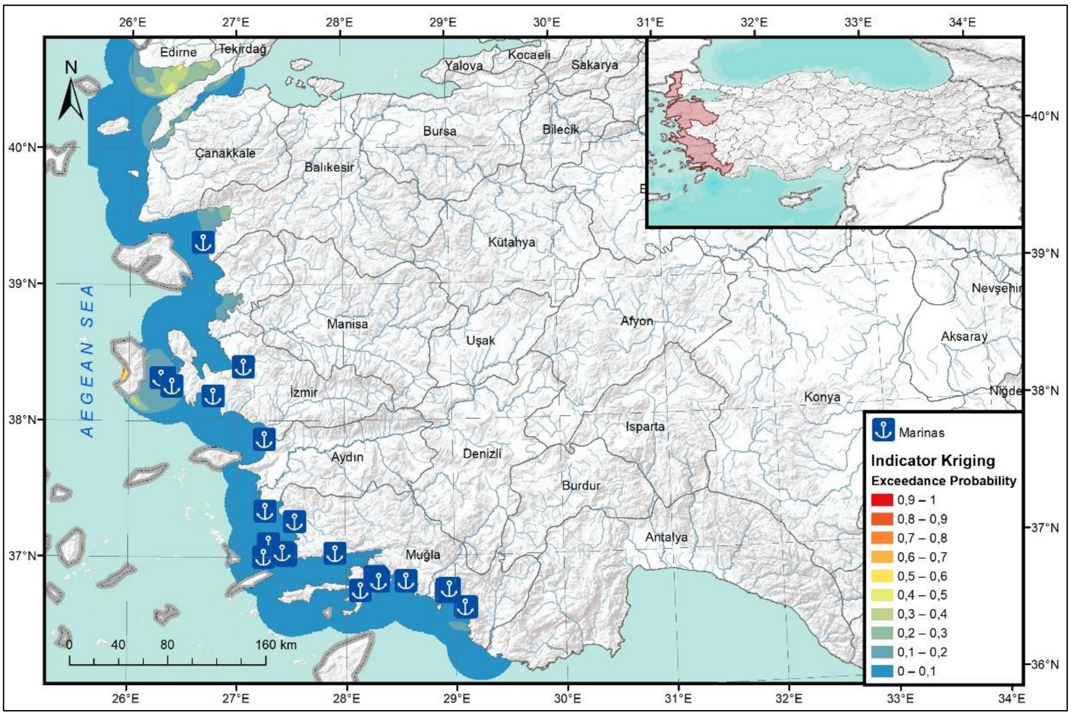


Figure 4.60. Location of Marinas in Aegean Coasts embedded in FC Exceedance Probability Map for GA Period 4 *(Chamber of Shipping, 2019)*

The only existing marina in Balıkesir, 3 out of 5 marinas in İzmir, all marinas in Aydın and 7 out of 23 marinas in Muğla have Blue Flag awards. Therefore, causes of fecal contamination near Balıkesir and İzmir cannot be related to marinas. However, 2 marinas located in southern region of Fethiye do not have Blue Flag awards, and also there is no other environmental stresses are investigated in that area. Thus, marinas are considered as an influencing factor on BWQ in southern Fethiye.

4.2.3. Concluding Remarks for Aegean Region

- Similar to Mediterranean region, Aegean region is also a significant area for mass tourism in Turkey. Unlike Mediterranean region, beach tourism is expanded through all coastline rather than focused on a part of the coastal zone.
- Aegean region has the largest number of monitoring stations with 671 for all GA periods.

- For all GA periods semivariograms show moderate spatial dependency regarding nugget/sill ratios which confirms that spatial analysis is meaningful in the region.
- Aegean region shows good BWQ profile since no critical bathing site is determined as a result of the analysis (Table 4.20).
- After 2012 improvement in BWQ in bathing sites of Edremit Gulf (1) and Ayvalık (6) were observed due to WWTP installation (Table 4.20).

Table 4.20. *Coastal areas with >70% threshold exceedance probability in the Aegean Region*

Period	*TC*	*FC*	*FS*
Before 2010	1-2-6-7	1-2-4-7	-
2010 – 2012	1-6	1-6	1-6
2013 – 2015	-	-	-
2016 – 2018	-	1	-

- For more recent periods, an improvement in BWQ along Aegean coastline was observed due to WWTP installation.
- Enez/Edirne (3) and Çeşme/İzmir (10) are two bathing areas which became insufficient in terms of BWQ due to increase in exceedance probabilities up to 30-40% in later periods.

Table 4.21. *The frequency of observation of >70% threshold exceedance probability in a given coastal area* in Aegean region*

Regions**	*Designated Areas*	*All Periods*	*Last Two Periods*
1	Edremit Gulf	6	1
2	Center of Çanakkale	2	-
3	Enez/Edirne	-	-
4	İzmir Gulf	1	-
5	Dardanelles	-	-
6	Ayvalık/Balıkesir	4	-
7	Gökçeada/Çanakkale	2	-
8	Didim/Aydın	-	-
9	Fethiye/Muğla	-	-
10	Çeşme/İzmir	-	-

**Coastal Areas are designated with a number.*
*** Table 4.14 shows the designated areas.*

Based on the data analysis stated in Section 3.2 using Table 4.21 above, no critical BWQ site is determined for Aegean region.

4.3. Bathing Water Quality Assessment around Marmara Region

Marmara Sea constitutes an inland sea which provides a transitional water between Black Sea and Aegean Sea. In northeast part of the region, it is connected to Black Sea by Bosphorus and in southwest part it is connected to Aegean Sea by Dardanelles. Marmara Sea coastline has the length of 930 km, which increases up to 1,200 km when straits are included (Turkish Marine Environment Protection Association, 2019). Salinity of Marmara Sea is about 38 PSU in deeper parts and 28 PSU near surface, which indicated that Marmara Sea shows both Black Sea and Aegean Sea like behavior in terms of salinity (Chiggiato, et al., 2012). Marmara region mostly shows similar climatic conditions with Black Sea and Northern Aegean regions (Unal, Kindap, & Karaca, 2003), therefore, bathing seasons within the region shows similarity with those neighbor coastal zones. General Directorate of Public Health stated that for Marmara Sea bathing season starts on 15th of June and ends on 15th of September (General Directorate of Public Health, 2008).

Marmara region has the lowest number of monitoring stations with 219 observation points (General Directorate of Public Health, 2018). Regular monitoring applications along all coastline were started after 2010. Before 2010 monitoring stations were denser in southern and eastern parts of the coastal zone, where Çanakkale, Balıkesir, Bursa, Kocaeli and Yalova are located.

For touristic reasons, indeed, Marmara is not the first place which comes to mind compared with Mediterranean and Aegean regions. Yet, it still provides a place for recreational demands of locals especially because of busy work schedules in the region. 6 cities, namely İstanbul, Kocaeli, Yalova, Bursa, Balıkesir, Çanakkale and Tekirdağ have coasts to Marmara Sea. In this section, first dataset used for GA in the Marmara region will be explored by some basic statistics and then GA results will be presented and discussed. It is important to note that the biggest metropolitan city of Turkey, Istanbul, with its 15 million population is located in this region.

4.3.1. Exploratory Data Analysis for Marmara Coastline

BWQ monitoring has started in Marmara region in 1997. At first, monitoring activities were limited to Çanakkale, the number of monitoring stations were increased year by year (Figure 3.9). Figure 4.59 provides the change in the number of measurements in bathing seasons and all year.

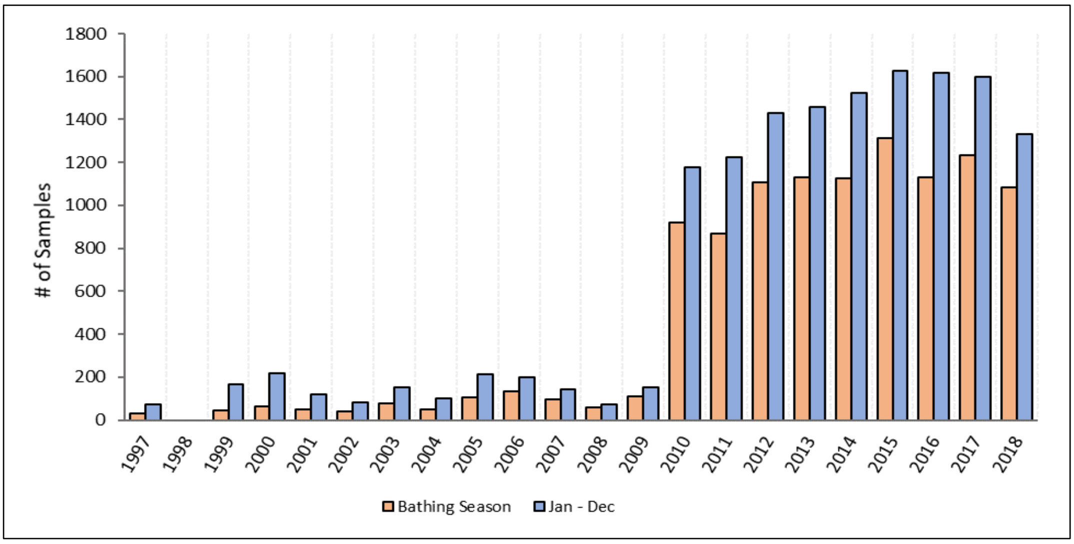
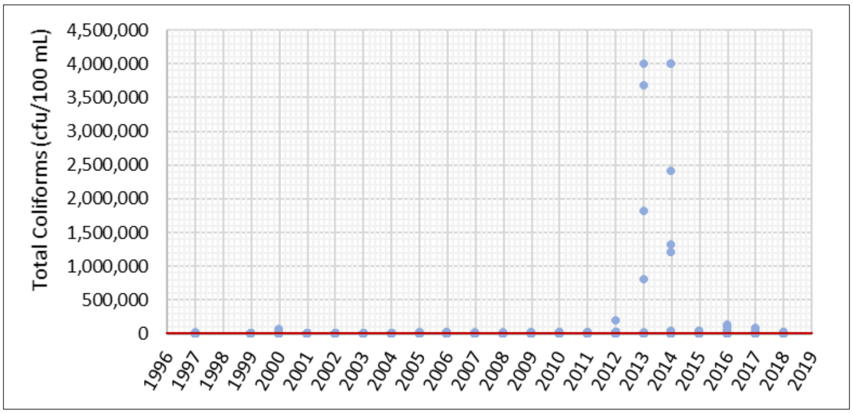
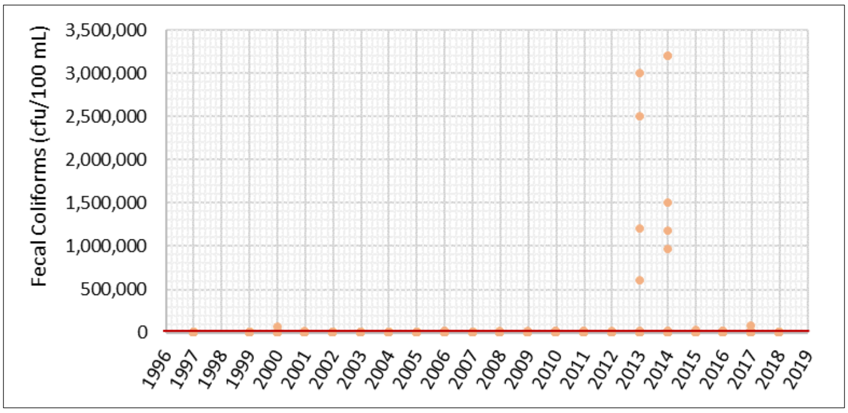


Figure 4.61. The Change in the Number of BWQ Measurements in the Marmara Region

In Marmara region, monitoring stations are located more sparsely in comparison to Mediterranean and Aegean regions. Figure 4.59 shows that the number of monitoring stations in Marmara coastline is increased by each year. Especially after 2010, similar to other coastal zones of Turkey, i.e. Mediterranean, Aegean and Black Sea, a drastic increase has been observed in the number of BWQ measurements. Marmara is the region with the lowest number of Blue Flag awarded beaches (TÜRÇEV, 2018). Compared to other coastal zones, the highest concentrations for each BWQ parameter was observed in Marmara region. Figure 4.62 provides the change in the concentrations of BWQ parameters in all bathing sites located in the Marmara Sea coastline in between years 1997 and 2018. Although, most the samples satisfy the relevant regulatory criteria, the number of locations with poor BWQ is not negligible.



(a)



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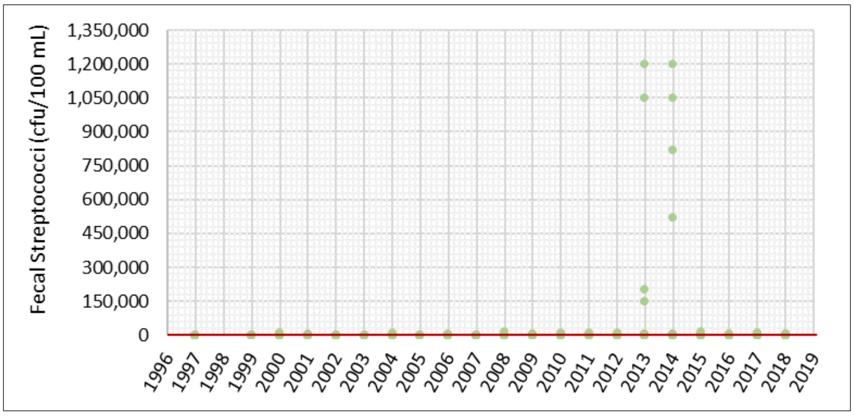

(c)

Figure 4.62. The Variation in the Concentrations of (a) TC (b) FC (c) FS over the cycle of 1997 – 2018 in the Marmara Coastline[8]

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[8] Circles represents the measured data, and red line shows the regulatory limit for good quality, which refers to 500 cfu/100 mL for TC, 100 cfu/100 mL for both FC and FS.

Figure 4.62 shows that after 2010, the number of exceedances for all BWQ parameters were increased, yet, one should keep in mind that both the number of monitoring stations (Figure 3.9) and the number of collected samples for BWQ monitoring (Figure 4.59) were increased after 2010. Also, the maximum concentrations for each parameter are extremely higher than other regions' maximum concentration values, thus, Figure 4.62 do not represent each measurement value clearly. In order to account for this change the percentage of samples that are exceeding the regulatory limits are reported in Figure 4.63 for each parameter.

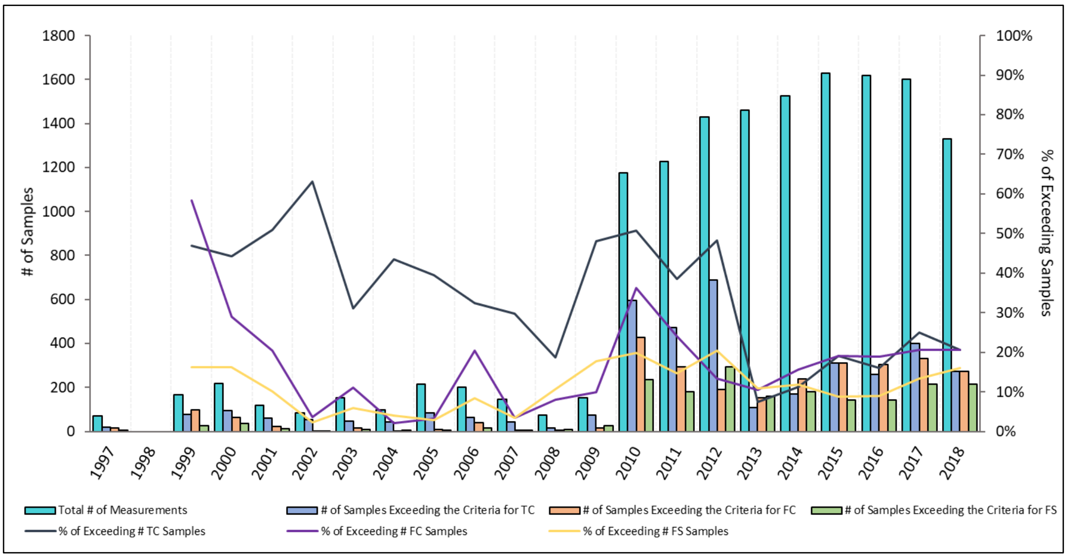


Figure 4.63. Number of Threshold Exceeding Measurements in Marmara Sea Coastline

Over the past 21 years of measurements along the Marmara Sea coastline, especially in earlier years, the number of samples which exceeded the regulatory limits were quite high (Figure 4.63). After 2012 the percentage of exceeding observations has decreased year by year for all BWQ parameters. Yet, by 2013 an increasing trend was observed for TC and FC and by 2016 the increasing trend was also observed in FS criteria. The single sample maximum concentrations of each BWQ parameter in between years 1997 and 2018 is reported in Figure 4.64. The single sample maximum concentrations of TC ranged between 3400 and 4,000,000 cfu/100 mL, with 14 single sample maximum concentrations that are exceeding 10,000 cfu/100 mL. Figure 4.64 depicts that the highest concentrations for all BWQ parameters were observed in 2013 and 2014.

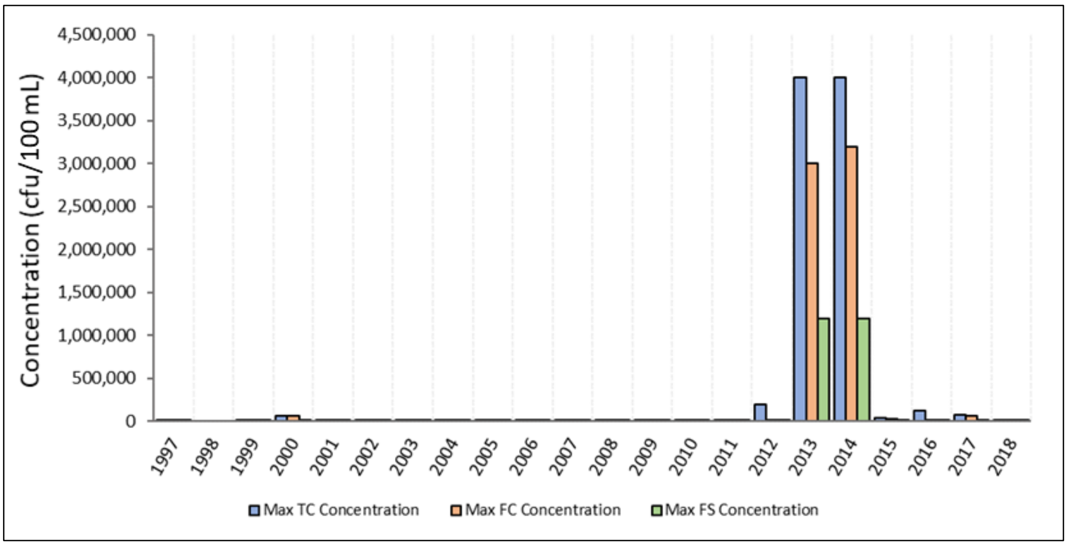


Figure 4.64. The Change in the Single Sample Maximum Concentrations of BWQ Parameters in the Marmara Sea Coastline over the years 1997 - 2018

Note that for 2013 and 2014, for all three BWQ parameters very extreme values are observed (Figure 4.64). Therefore, it is highly possible that these values can dominate a specific bathing area, although the rest of the monitoring stations show better quality. Figure 4.65 provides the number of monitoring stations with respect to their purpose of monitoring.

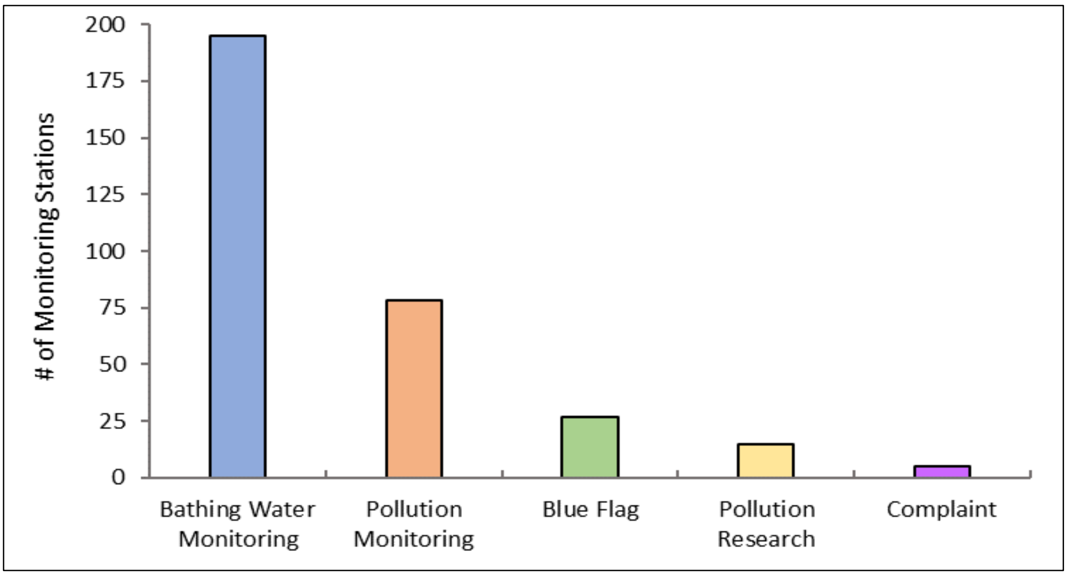
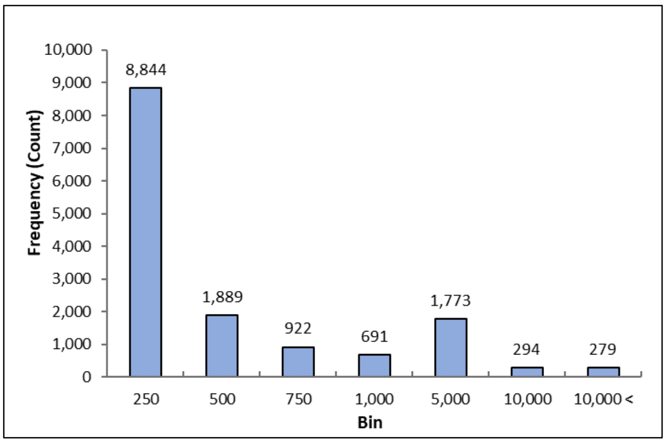
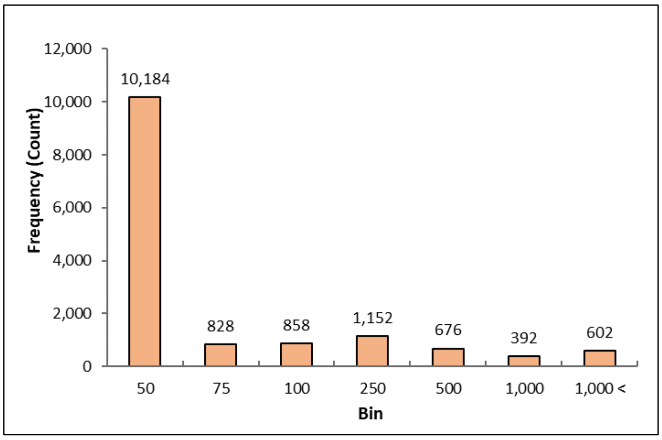


Figure 4.65. Number of Monitoring Stations for Different Purposes in Marmara Region

Please note that one beach can be monitored regarding more than one purpose which may have led to counting a beach more than once in Figure 4.65. Although, single sample maximum concentrations for each parameter increased after 2010, when the whole dataset is evaluated, it is observed that the number of samples satisfying the BWQ criteria represents the majority of the entire dataset for each BWQ parameter. The histograms presented in Figure 4.66 illustrates the distribution of all BWQ parameters for 21 years of period.



(a)



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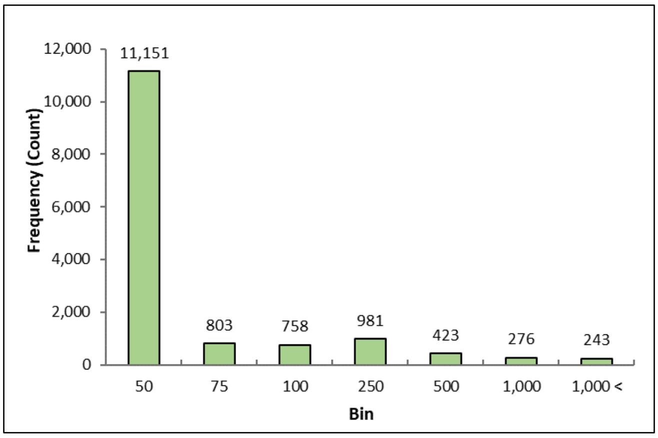


(c)

Figure 4.66. Histograms of (a) TC (b) FC and (c) FS concentrations in Marmara Region over the years 1997 - 2018

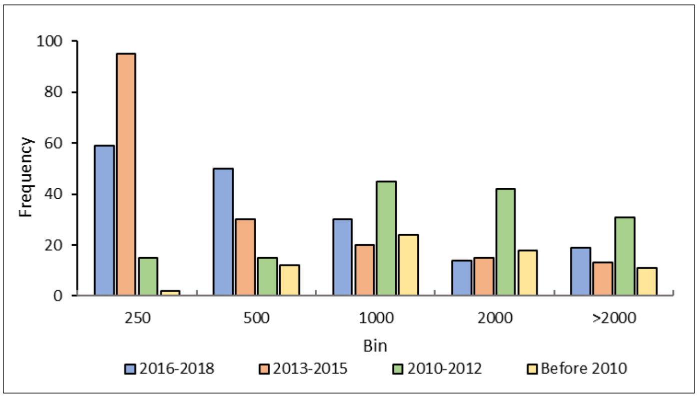
According to Figure 4.66, 73.1%, 80.8% and 86.9% of samples satisfy BWQ criteria for TC, FC and FS, respectively. Table 4.22 provide general statistics of the dataset used in GA for the Marmara region.

Table 4.22. *General Statistics of the GA Dataset of Marmara Region* over the years 1997 - 2018

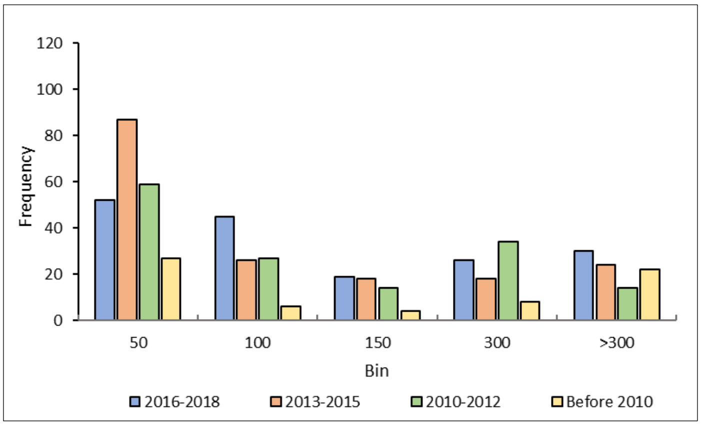
Parameter	*TC*	*FC*	*FS*
Total number of measurements	14,692	14,692	14,635
Maximum value (cfu/100 mL)	4,000,000	3,200,000	1,200,000
Minimum value (cfu/100 mL)	0	0	0
Mean (cfu/100 mL)	2,441.5	1,360.7	508.8
Standard Deviation (cfu/100 mL)	71,223.5	53,523.1	20,398.0

4.3.2. Geostatistical Analysis of BWQ Data of the Marmara Coastline

Marmara region has the lowest amount of monitoring points. In this study, for Marmara region, total of 219 monitoring stations are used for GA, but this number is different for each study period. During GA all monitoring stations were taken into consideration and data analysis was conducted over 4 periods, i.e. 2016 – 2018, 2013 – 2015, 2010 – 2012 and before 2010. The average of all samples collected in these 4 GA periods, i.e. before 2010, 2010 – 2012, 2013 – 2015 and 2016 – 2018, were calculated. GA is conducted using the average values calculated for each period. Figure 4.67 shows the histograms of GA dataset for each period.



(a)



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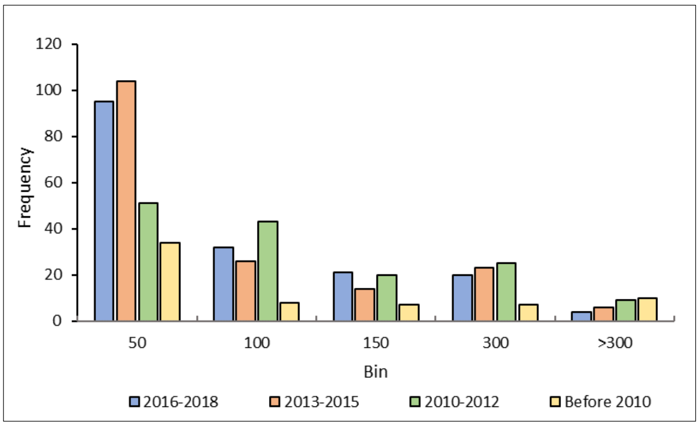


(c)

Figure 4.67. Histogram of GA Dataset for a) TC (b) FC and (c) FS concentrations over different GA periods in the Marmara Region

Data distribution shows variation among each GA period. Most of the data used for GA for each period is below the threshold values considered in analyses (Figure 4.67).

However, especially in more recent periods, BWQ observations are centered upon higher concentrations. Therefore, it is expected to observe a poor BWQ around Marmara Sea coastline and thus, higher exceedance probabilities near bathing beaches. Table 4.23 shows the model parameters estimated by GA.

Table 4.23. *Values of Model Parameters for IK in Marmara Region between 1997 - 2018*

Parameter	*Model*	*Range (m)*	*Nugget*	*Lag Size (m)*	*Partial Sill*	*Nugget/Sill* Ratio*
TC	Exponential	64,558	0.110	5,000	0.142	0.437
FC	Exponential	29,532	0.170	5,000	0.060	0.730
FS	Exponential	30,181	0.160	5,000	0.068	0.702

*Sill = Nugget + Partial Sill

Exponential model is chosen for all parameters due to low nugget values compared to other models. Nugget/sill ratios are ranged between 25 – 75% for each BWQ parameter which indicates that in Marmara region, data used in analyses show moderate spatial dependency (Essington, 2004). Lag sizes are selected as the same for each BWQ parameter since monitoring stations are the same for each BWQ parameters. Range values, on the other hand, show that spatial correlations become meaningless at distances longer than 64,558, 29,532 and 30,181 meters for TC, FC and FS, respectively. Figure 4.68 shows the semivariograms of BWQ parameters for 1997 – 2018 BWQ sampling results and visualizes Table 4.23.

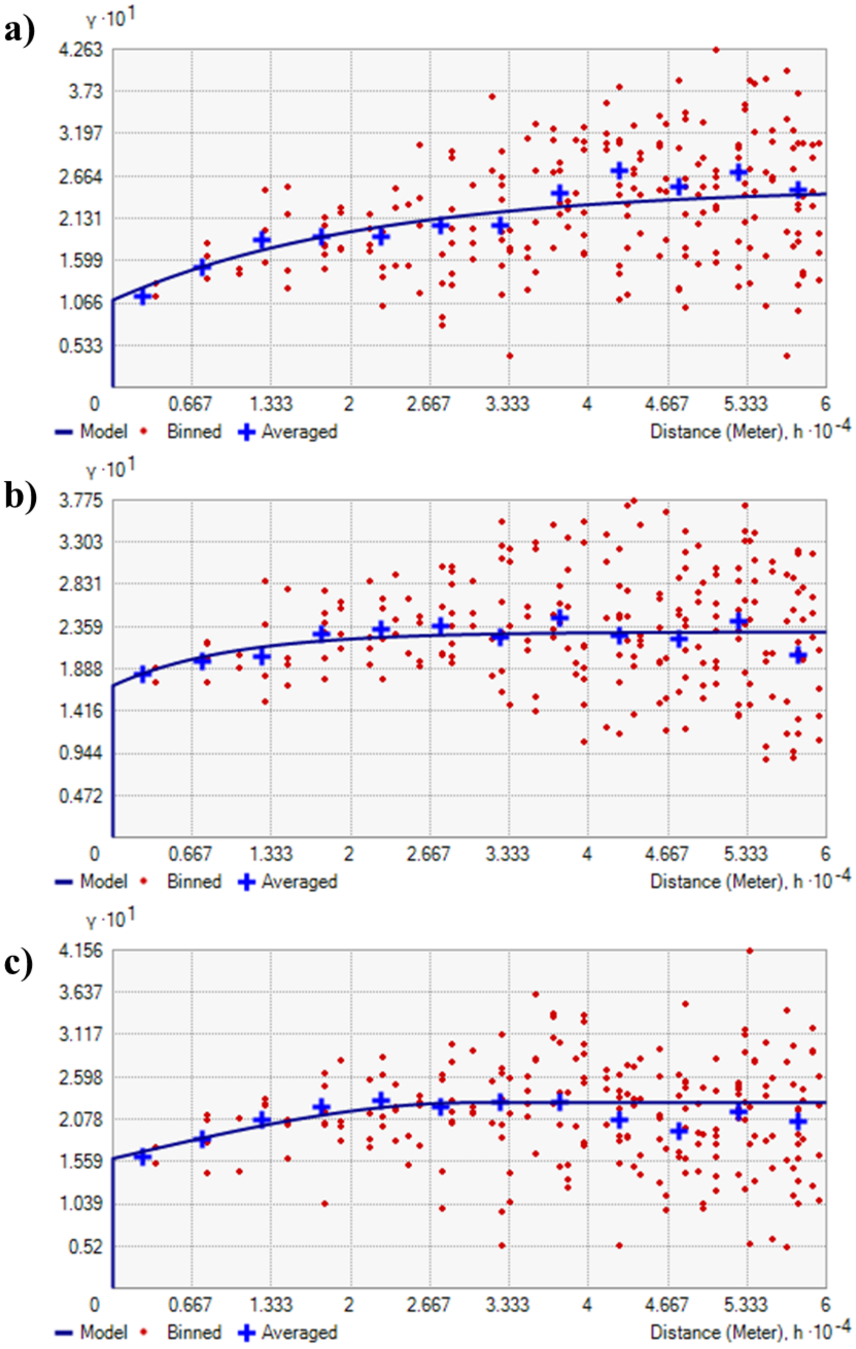


Figure 4.68. Semivariograms of a) TC, b) FC and c) FS in Marmara Region between 1997 – 2018

“Indicator Prediction” results were also assessed to compare the exceedance probability values with measurement values. This process helps to observe if the measurement points with high exceedance probabilities also have high concentrations, i.e. threshold exceeding concentrations, or vice versa. According to this assessment, if a point with high concentration has lower exceedance probability, this indicates that most of the neighbors used to predict that point's exceedance probability has lower concentrations and lower exceedance probabilities. Figure 4.69 shows the indicator predictions for all three BWQ parameters.

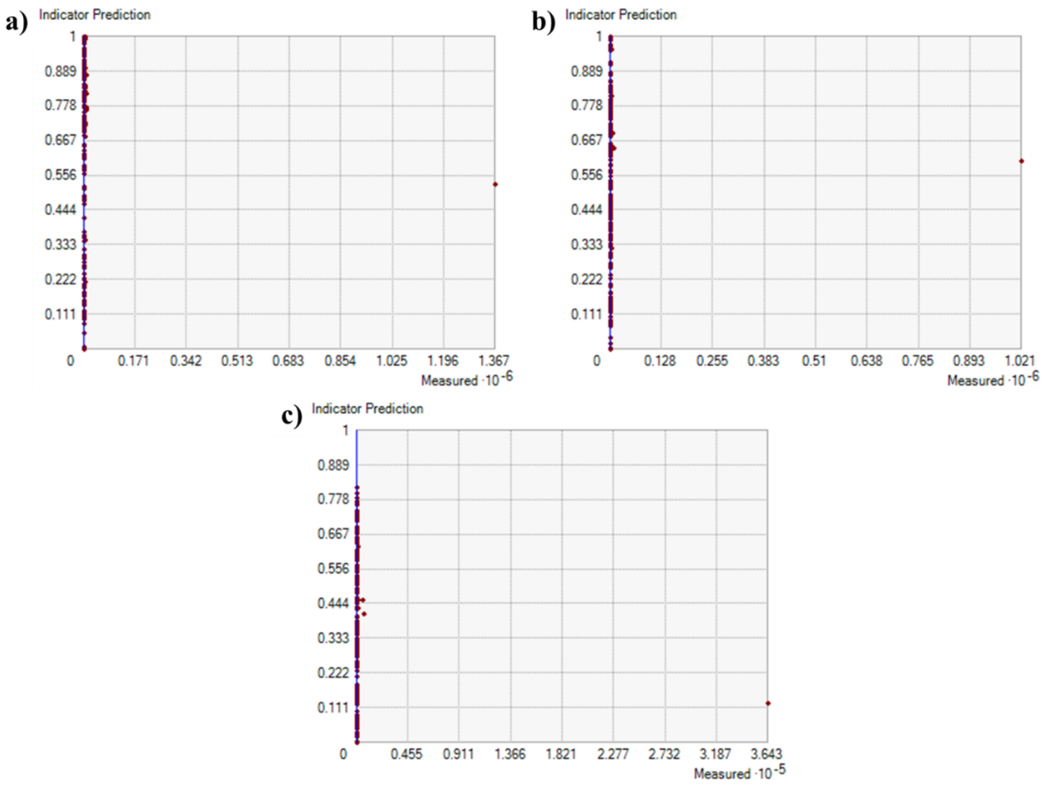


Figure 4.69. Indicator Predictions for a) TC, b) FC and c) FS for Marmara Region between 1997 – 2018

Figure 4.69 provide a good representation since there are some observed values which are extremely higher than regulatory criteria. Therefore, blue line indicating threshold value is almost overlapped with y-axis. Thus, second step of cross-validation is more indicative for Marmara region. The second step of cross validation involves estimation and comparison of prediction errors, i.e. comparison of measured values with predicted values. Table 4.24 shows the cross-validation results of GA between 1997 – 2018.

Table 4.24. *Cross-validation Results for Marmara Region*

Parameter	*RMSE*	*ASE*	*ME*	*MSE*	*RMSSE*
TC	0.387	0.391	-0.006	-0.009	0.997
FC	0.459	0.466	-0.010	-0.013	0.979
FS	0.449	0.446	-0.014	-0.024	1.004

Table 4.24 represents that for each parameter, ME values are almost zero and therefore it could be commented that predictions are unbiased. For all BWQ parameters, RMSE and ASE values are closer to each other, which eliminates the possibility of under/overestimation (Arétouyap, et al., 2016). Since for each parameter RMSSE values are closer to 1, predictions are seemed to be acceptable. Depending on these results, exceedance probability maps were obtained and 3rd step of cross validation takes place, namely, standard error of indicators maps. Figure 4.70, Figure 4.71 and Figure 4.72 provides the exceedance probability and standard error of indicators maps for Marmara region considering GA dataset between 1997 – 2018. Critical zones are identified by numbers and the designated areas by the numbers are given in Table 4.25.

Table 4.25. *Designated Areas in Exceedance Probability Maps of Marmara Region*

Bathing Site Number	*Designated Area*
1	Bosphorus
2	İzmit Bay
3	Mudanya/Bursa
4	Erdek/Balıkesir
5	Dardanelles
6	Marmaraereğlisi
7	Marmara Island
8	Çorlu/Tekirdağ
9	Biga/Çanakkale and Gönen/Balıkesir
10	Büyükçekmece/İstanbul
11	Tuzla/İstanbul

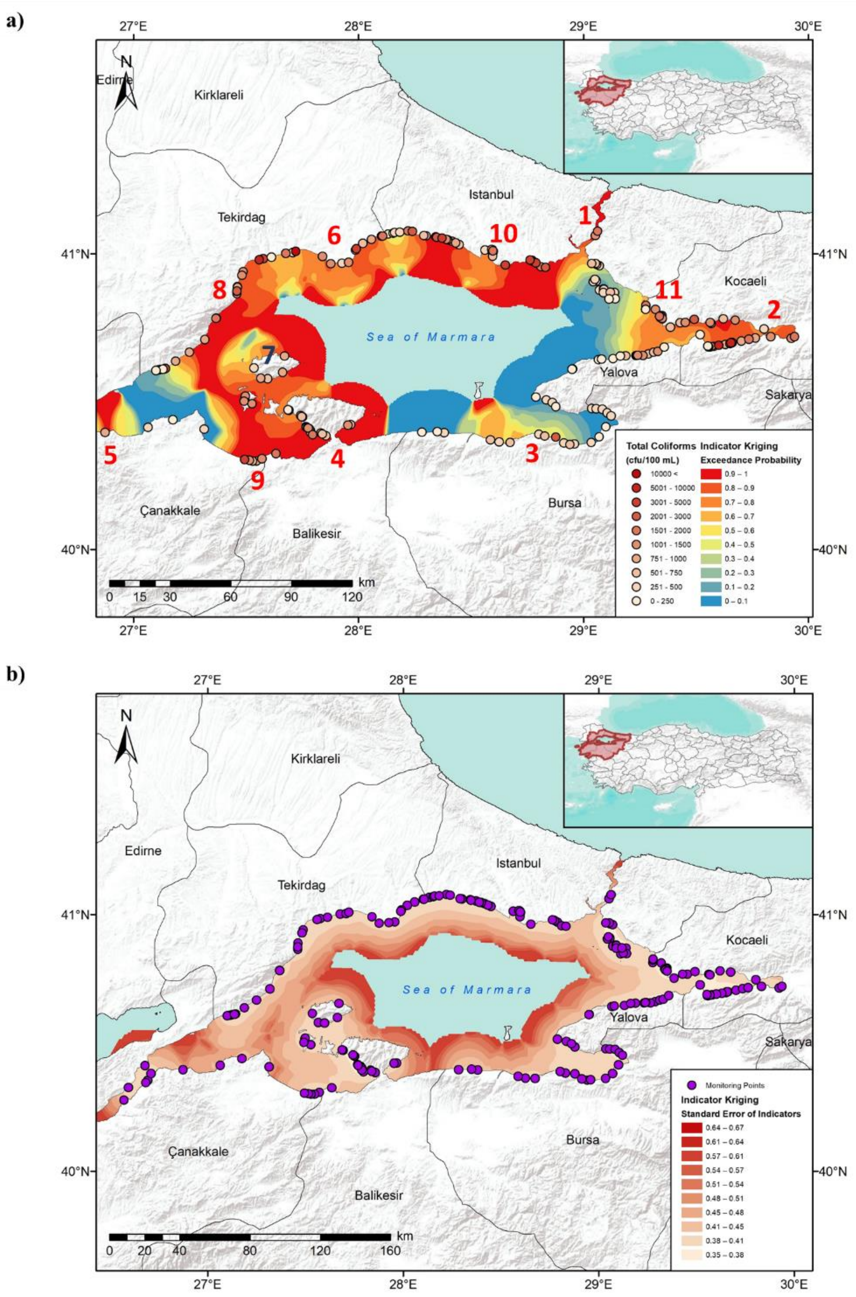


Figure 4.70. a) Exceedance Probability and b) Standard Error of Indicators Maps of Marmara Region over years 1997 – 2018 for TC

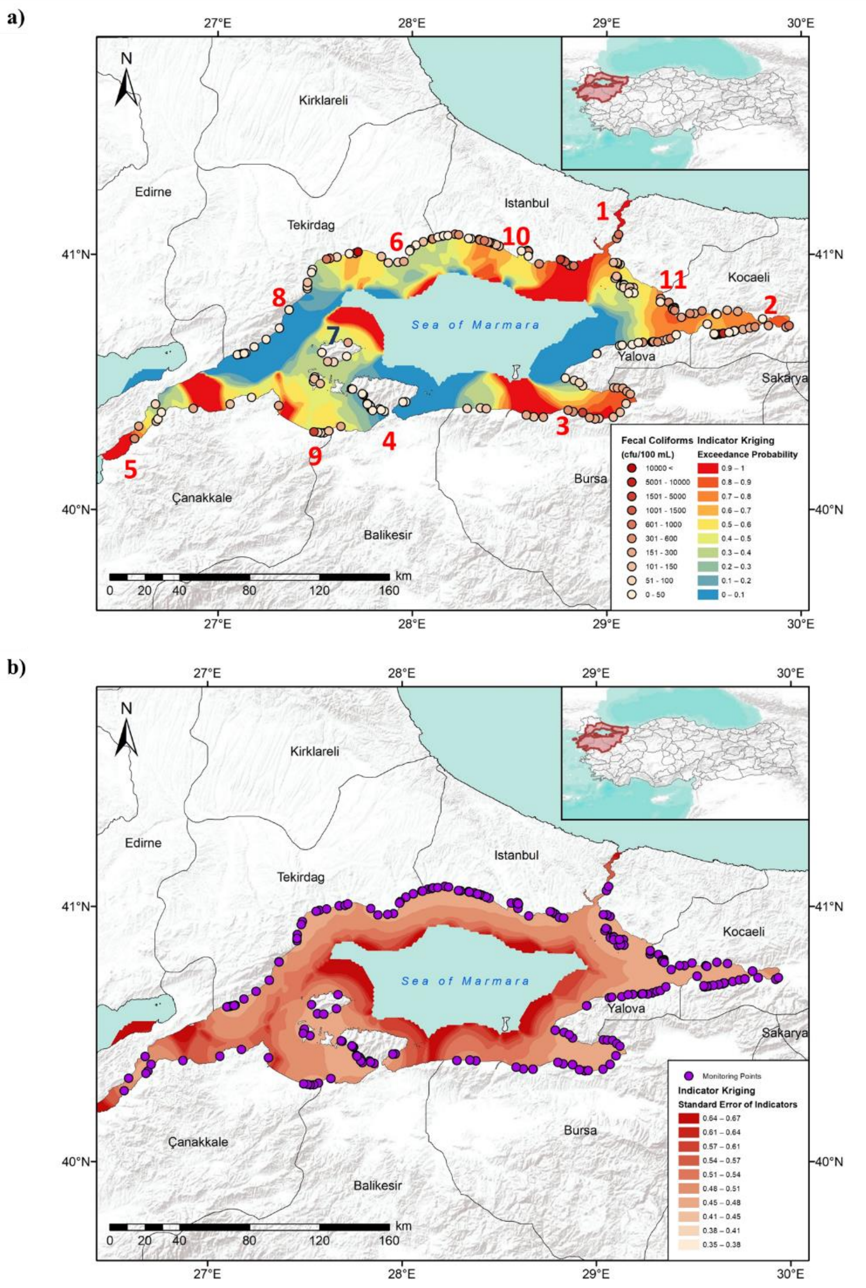


Figure 4.71. a) Exceedance Probability and b) Standard Error of Indicators Maps of Marmara Region over years 1997 – 2018 for FC

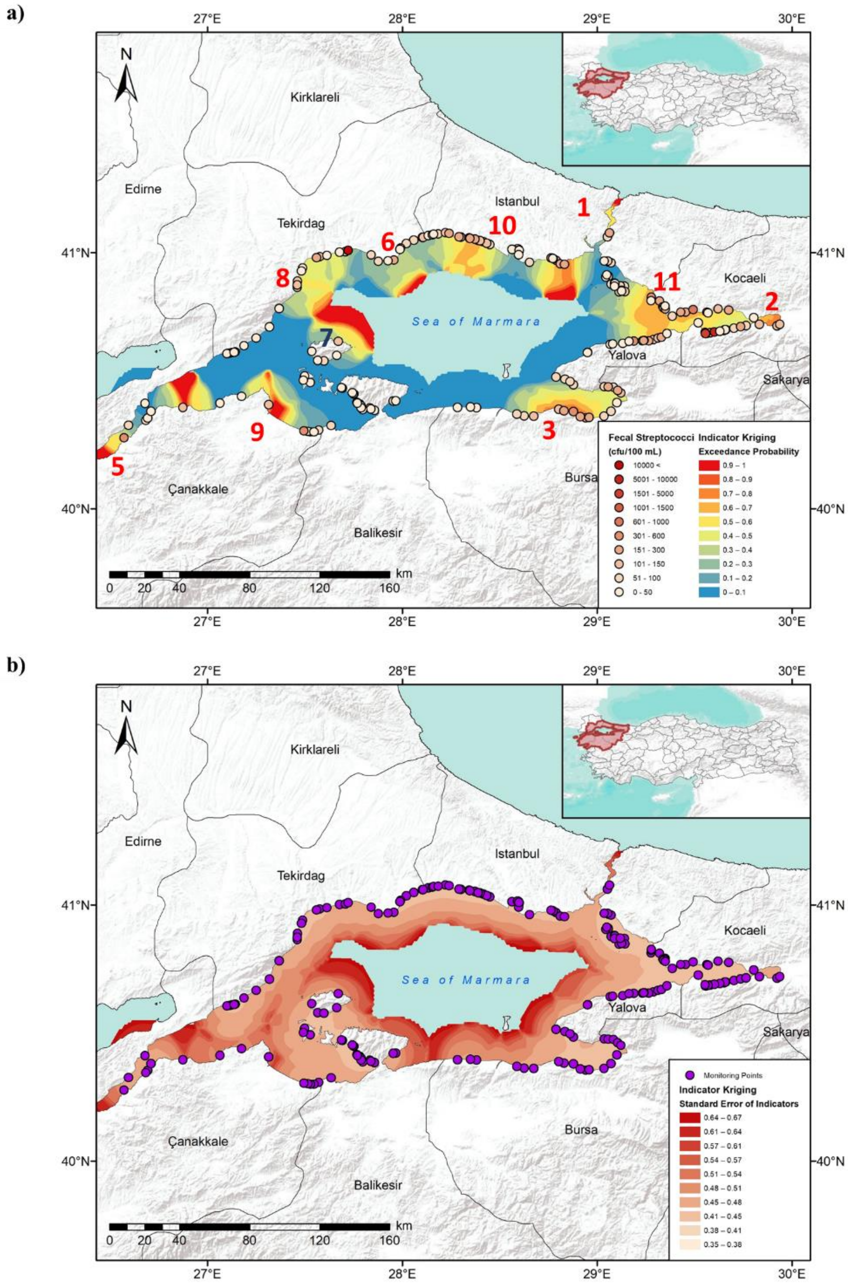


Figure 4.72. a) Exceedance Probability and b) Standard Error of Indicators Maps of Marmara Region over years 1997 – 2018 for FS

Figure 4.70, Figure 4.71 and Figure 4.72 gives a general overview of BWQ over years 1997 – 2018. To examine the critical areas in Marmara coastline, analyses considering smaller time intervals were also conducted. But figures given above show that most of the time poor BWQ is present along Marmara coastline. Since the number of stations with high exceedance probability is lower in parameter FS, it shows a more optimistic scenario, in comparison with TC and FC. There are at least 9 regions at which all three parameters regulatory limits were exceeded. To identify the causes of poor BWQ and have a closer look at the situation, GA was also conducted separately for four periods. Table 4.26 provides the model parameters for each BWQ parameter and GA period.

Table 4.26. *Values of Model Parameters for IK Analysis in Marmara Region*

Parameter_ Period*	*Model*	*Range (m)*	*Nugget*	*Lag Size (m)*	*Partial Sill*	*Nugget/Sill** Ratio*
TC_1	Spherical	47,476	0.050	5,000	0.169	0.228
FC_1	Exponential	41,455	0.083	5,000	0.110	0.430
FS_1	Circular	60,000	0.100	5,000	0.130	0.435
TC_2	Gaussian	43,446	0.061	5,000	0.094	0.0392
FC_2	Hole Effect	26,371	0.110	5,000	0.110	0.500
FS_2	Exponential	72,948	0.175	5,000	0.070	0.714
TC_3	Circular	23,867	0.119	5,000	0.100	0.543
FC_3	Tetraspherical	16,507	0.126	5,000	0.108	0.539
FS_3	Exponential	17,381	0.097	5,000	0.093	0.511
TC_4	Stable	192,434	0.010	5,000	0.264	0.365
FC_4	Stable	39,349	0.048	5,000	0.213	0.184
FS_4	Circular	40,774	0.155	5,000	0.052	0.748

*Period Number 1: Before 2010, 2: 2010 – 2012, 3: 2013 – 2015, 4: 2016 – 2018
**Sill = Nugget + Partial Sill

There is no specific pattern observed in nugget or sill values given in Table 4.26 in terms of BWQ parameters, however, when nugget to sill ratios are examined, it is observed that for FC and FS, nugget/sill ratios are between 25 – 75%, indicating that there is a moderate spatial dependency. On the other hand, for TC, before 2010 and for FC between 2016 and 2018 nugget to sill ratios are smaller than 25% and therefore, spatial dependency was found out as strong in these periods (Essington, 2004). For all periods nugget values for FS are greater than other periods' nugget values which indicates that measurement errors are higher for FS. Depending on these model parameters, semivariogram models are obtained separately for each parameter and for each period. Cross-validation results for each BWQ parameter in each period is provided in Table 4.27.

Table 4.27. *Cross Validation Results for Marmara Region*

Parameter_Period*	*RMSE*	*ASE*	*ME*	*MSE*	*RMSSE*
TC_1	0.308	0.290	-0.015	-0.027	1.042
FC_1	0.374	0.358	-0.019	-0.033	0.971
FS_1	0.398	0.369	-0.005	-0.008	1.034
TC_2	0.297	0.276	-0.001	-0.008	1.083
FC_2	0.403	0.395	0.0006	-0.0006	1.063
FS_2	0.469	0.471	-0.006	-0.012	0.997
TC_3	0.388	0.405	-0.004	-0.004	0.964
FC_3	0.430	0.441	-0.004	-0.005	0.980
FS_3	0.403	0.401	-0.003	-0.006	1.009
TC_4	0.413	0.442	0.003	0.005	0.942
FC_4	0.419	0.435	0.004	0.004	0.992
FS_4	0.400	0.436	0.0009	0.003	0.938

*Period Number 1: Before 2010, 2: 2010 – 2012, 3: 2013 – 2015, 4: 2016 – 2018

Cross-validation results shown in Table 4.27 validates the possibility of presence of higher measurement errors for FS in each period since RMSE values are higher for FS in most periods. Also, when ASE and RMSE values are compared, it is observed as prediction of errors are correct because difference between them is at most 3.6%. Another kind of cross validation that is conducted in this study is to compare indicator predictions with measured data, i.e. average BWQ concentrations at each sampling point. Figure 4.73, Figure 4.74 and Figure 4.75 provides the indicator predictions at each data point, for TC, FC and FS, respectively.

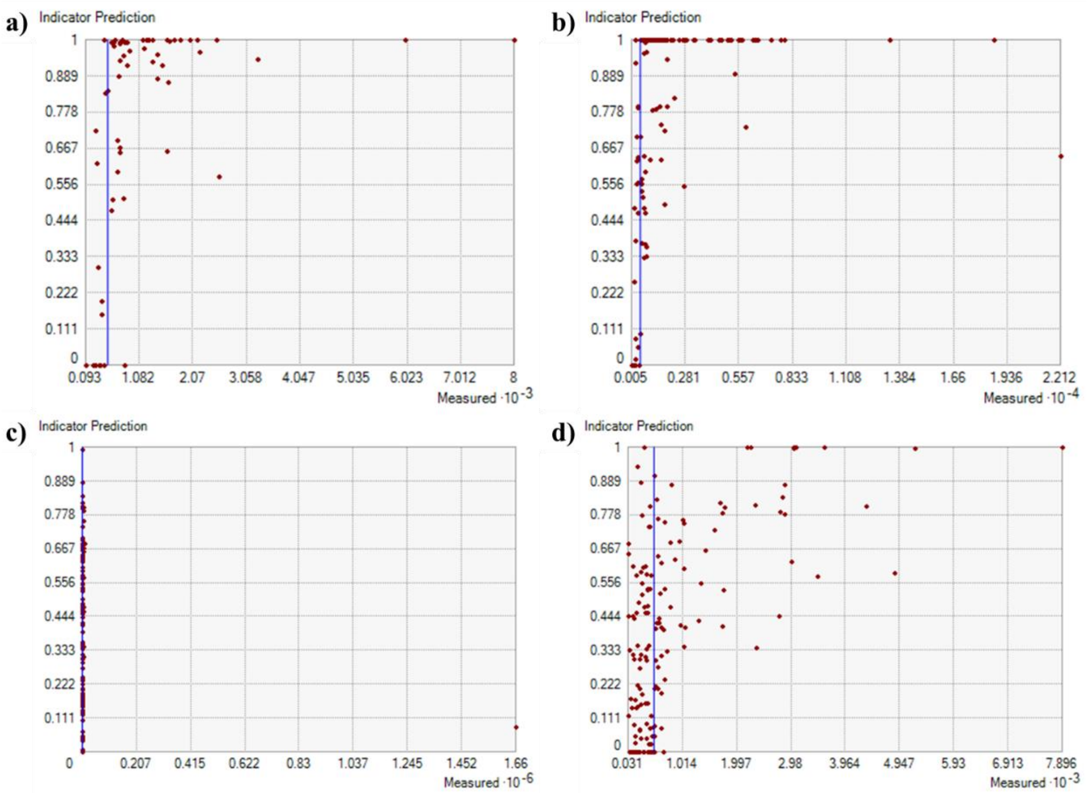


Figure 4.73. Indicator Predictions of TC for Marmara Region between a) 1997 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

Figure 4.73 shows that, between 2016 - 2018, TC indicator predictions, thus, exceedance probabilities are higher than 90%. This indicates that there is high levels of fecal pollution in Marmara region which may pose risk on environment and health of bathers using Marmara Sea for recreational purposes.

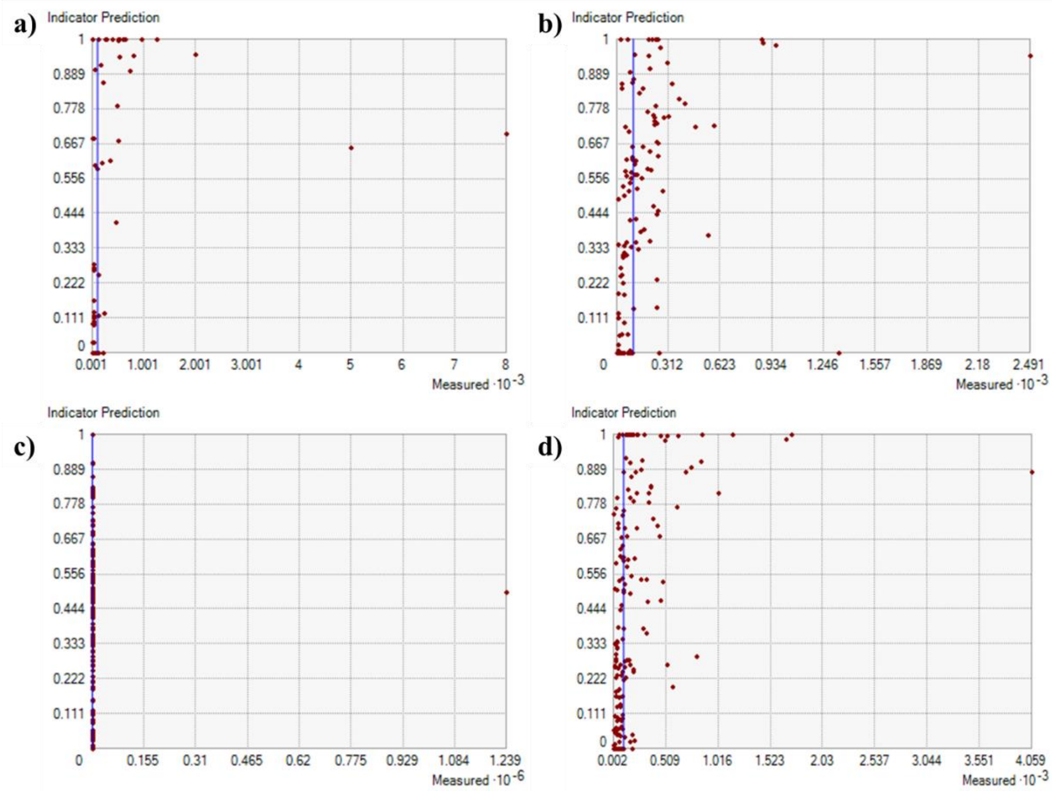


Figure 4.74. Indicator Predictions of FC for Marmara Region between a) 1997 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

On the other hand, by means of FC, Figure 4.74 shows that, especially between 2016 – 2018, i.e. GA Periods 4, exceedance probabilities are mostly higher than 90%, which indicates that there is high levels of fecal pollution creates risk on Marmara Sea environment and health of bathers using Marmara Sea for recreational purposes. This situation was also illustrated in Figure 4.67, in which there is no measurements below 100 cfu/100 mL and the lowest FC concentrations were 100 cfu/100 mL, i.e. overlapping the threshold value.

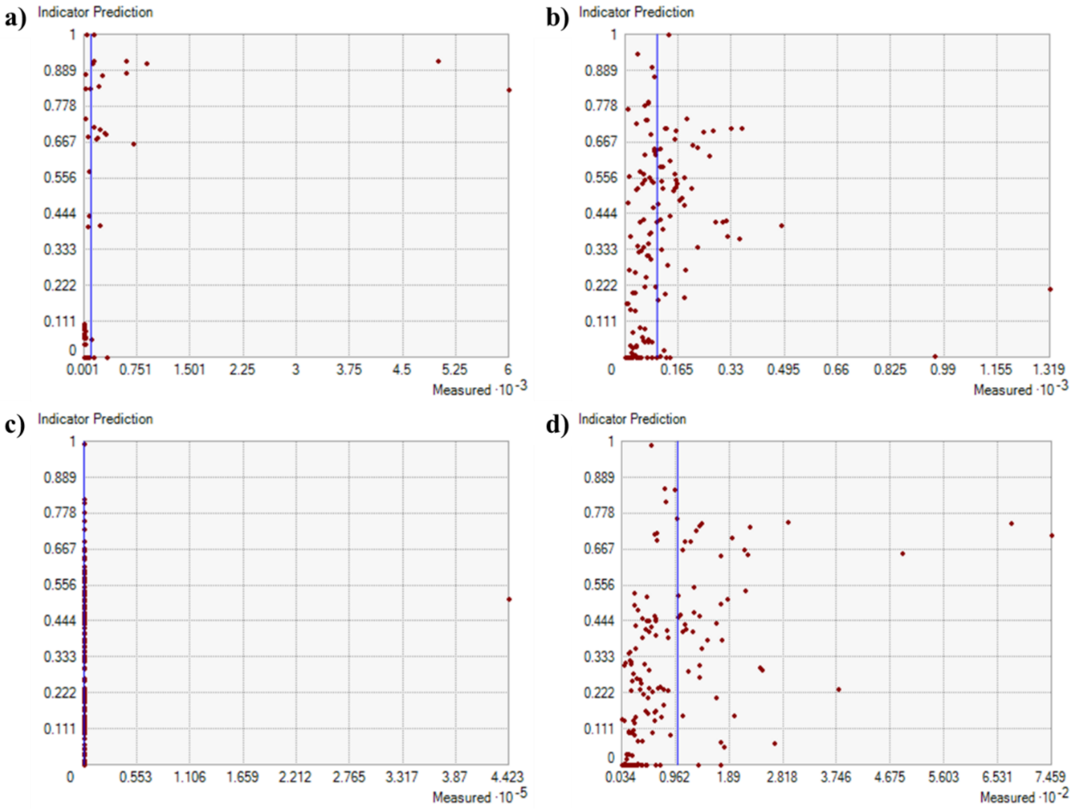


Figure 4.75. Indicator Predictions of FS for Marmara Region between a) 1997 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

Unlike TC and FC, FS shows more variety in terms of exceedance probabilities. Figure 4.75 shows that, especially between 2016 – 2018, exceedance probabilities related with measured values, i.e. higher exceedance probabilities have higher measured values and vice versa. As a result of IK analyses exceedance probability maps were obtained for each period for all three BWQ parameters. From Figure 4.76 to Figure 4.87 threshold exceedance probabilities for 1997 – 2010, 2010 – 2012, 2013 – 2015 and 2016 – 2018 periods are shown, respectively.

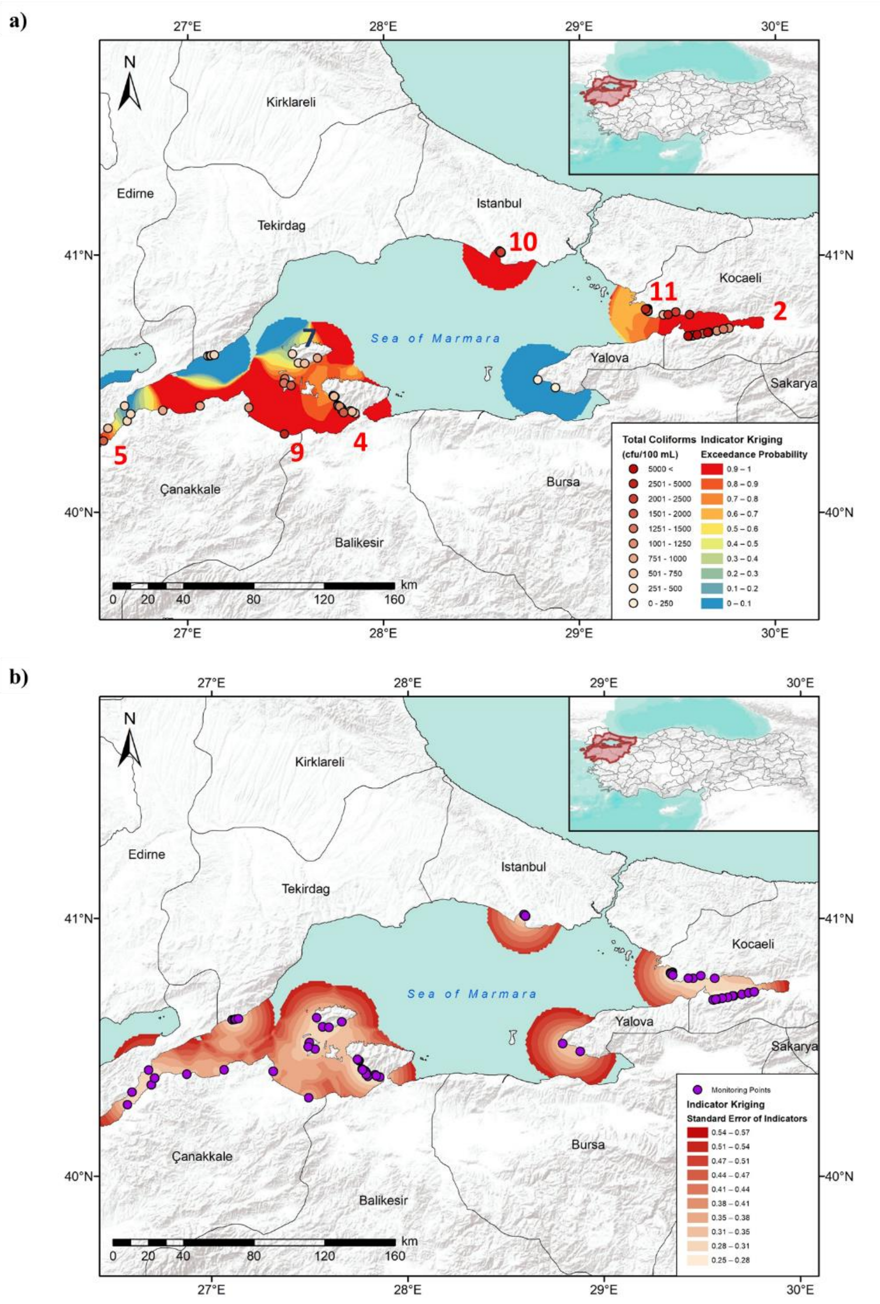


Figure 4.76. a) Exceedance probability and b) standard error maps generated for Marmara Region before 2010 for TC (GA period 1)

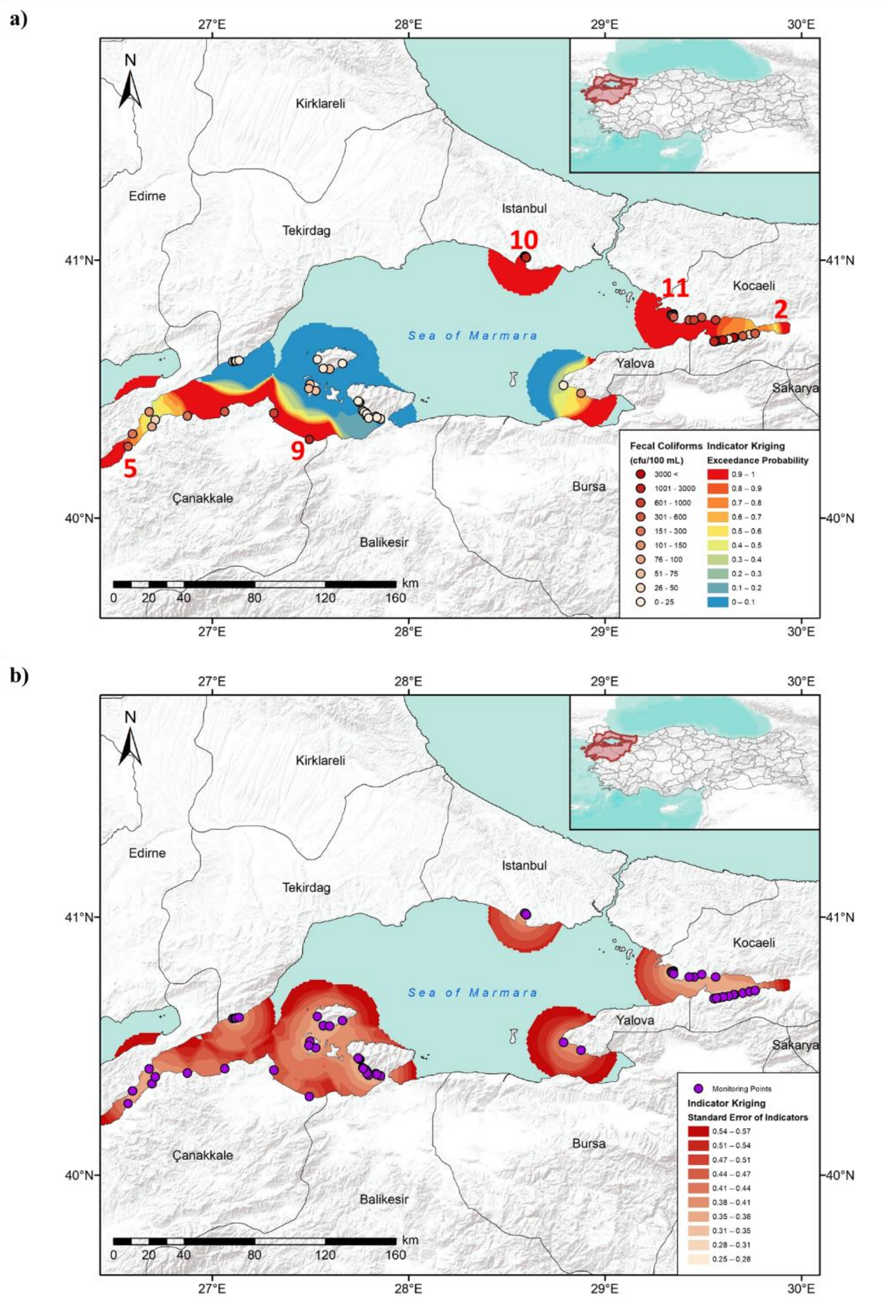


Figure 4.77. a) Exceedance probability and b) standard error maps generated for Marmara Region before 2010 for FC (GA period 1)

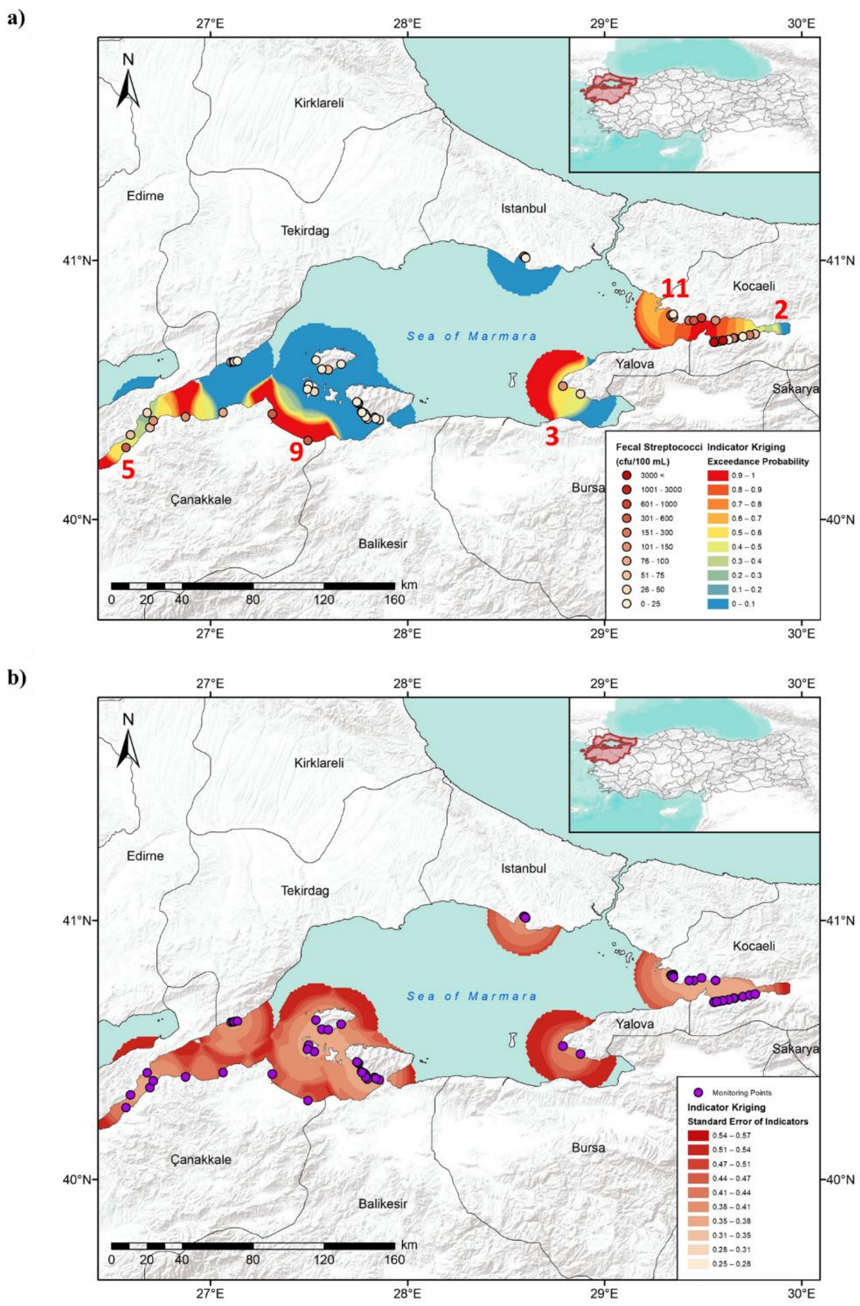


Figure 4.78. a) Exceedance probability and b) standard error maps generated for Marmara Region before 2010 for FS (GA period 1)

Before 2010, the spatial data is not representative for whole Marmara Sea coastline, i.e. there is no monitoring stations in some areas such as Tekirdağ, Bosphorus and Bursa, therefore, GA results are illustrated discretely as can be seen from Figure 4.76,

Figure 4.77 and Figure 4.78. İzmit Bay (2), Gönen/Balıkesir and Biga/Çanakkale (9), Tuzla/İstanbul (11) and Dardanelles (5) have high threshold exceedance probabilities in terms of all three parameters. Also, TC and FC show poor BWQ near Büyükçekmece/İstanbul (10). The error maps show TC and FS has lower errors, ranged between 25 – 41%, in comparison to FC (error range 41 – 57%). However, in this study standard errors of locations that are closer to coastline, i.e. monitoring stations, was considered since purpose of these analyses is to assess the bathing sites.

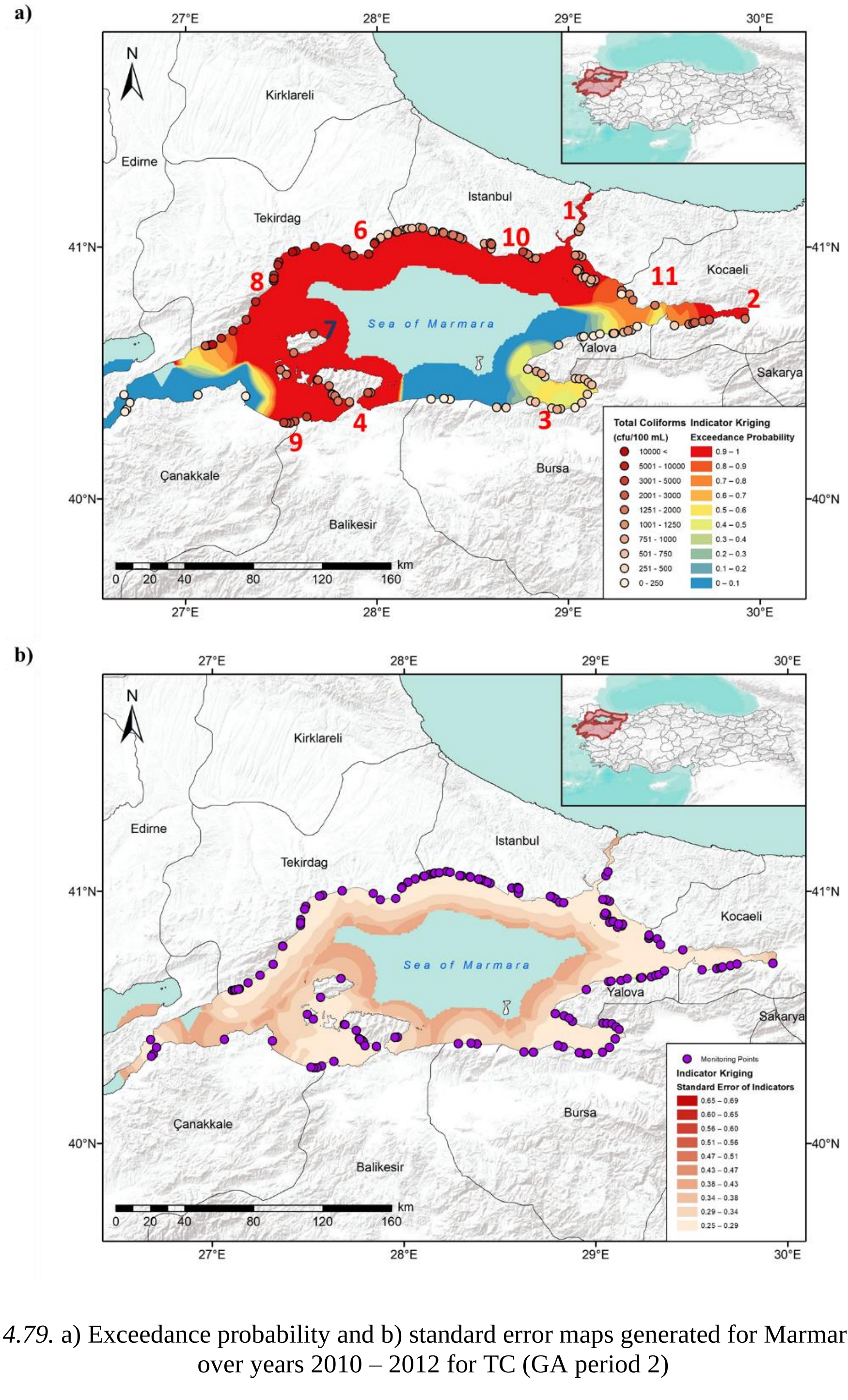


Figure 4.79. a) Exceedance probability and b) standard error maps generated for Marmara Region over years 2010 – 2012 for TC (GA period 2)

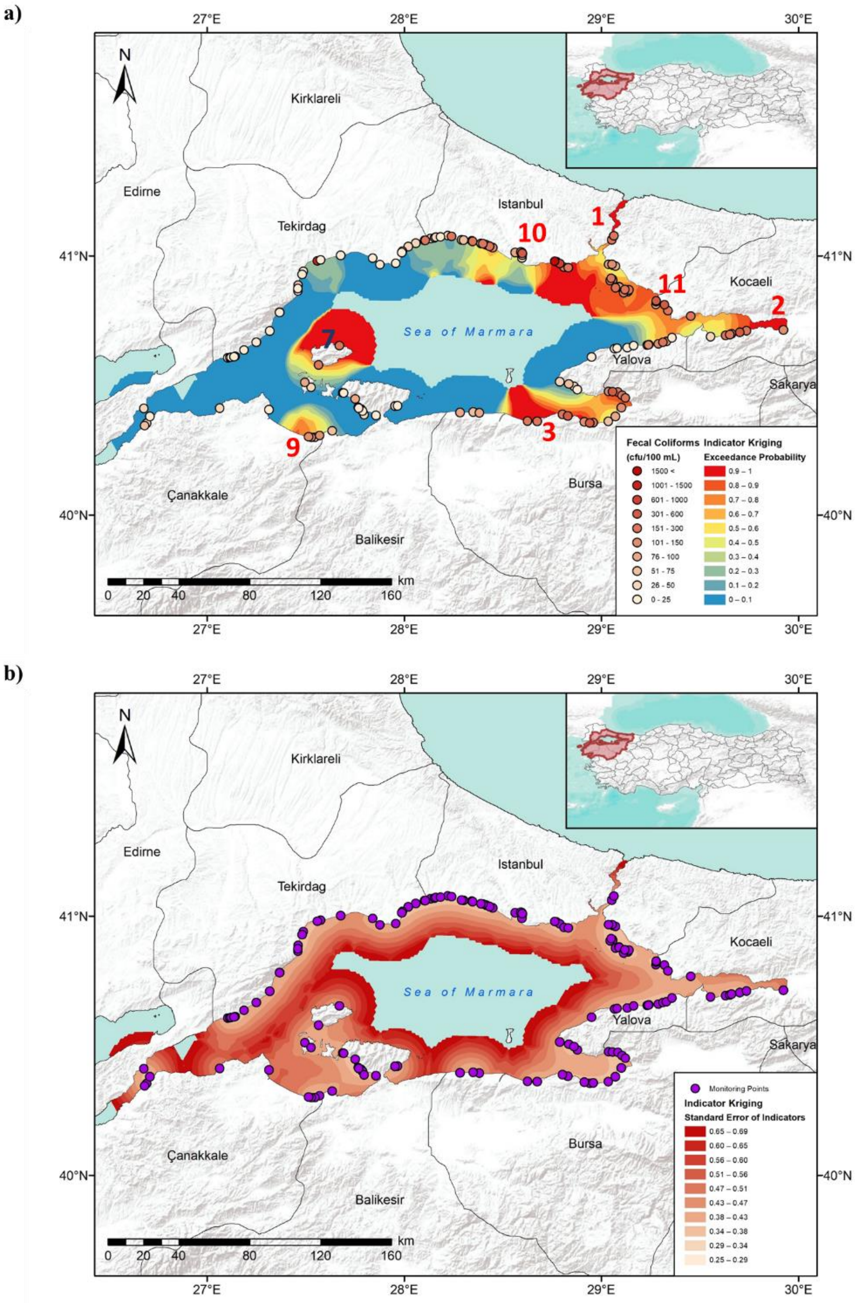


Figure 4.80. a) Exceedance probability and b) standard error maps generated for Marmara Region over years 2010 – 2012 for FC (GA period 2)

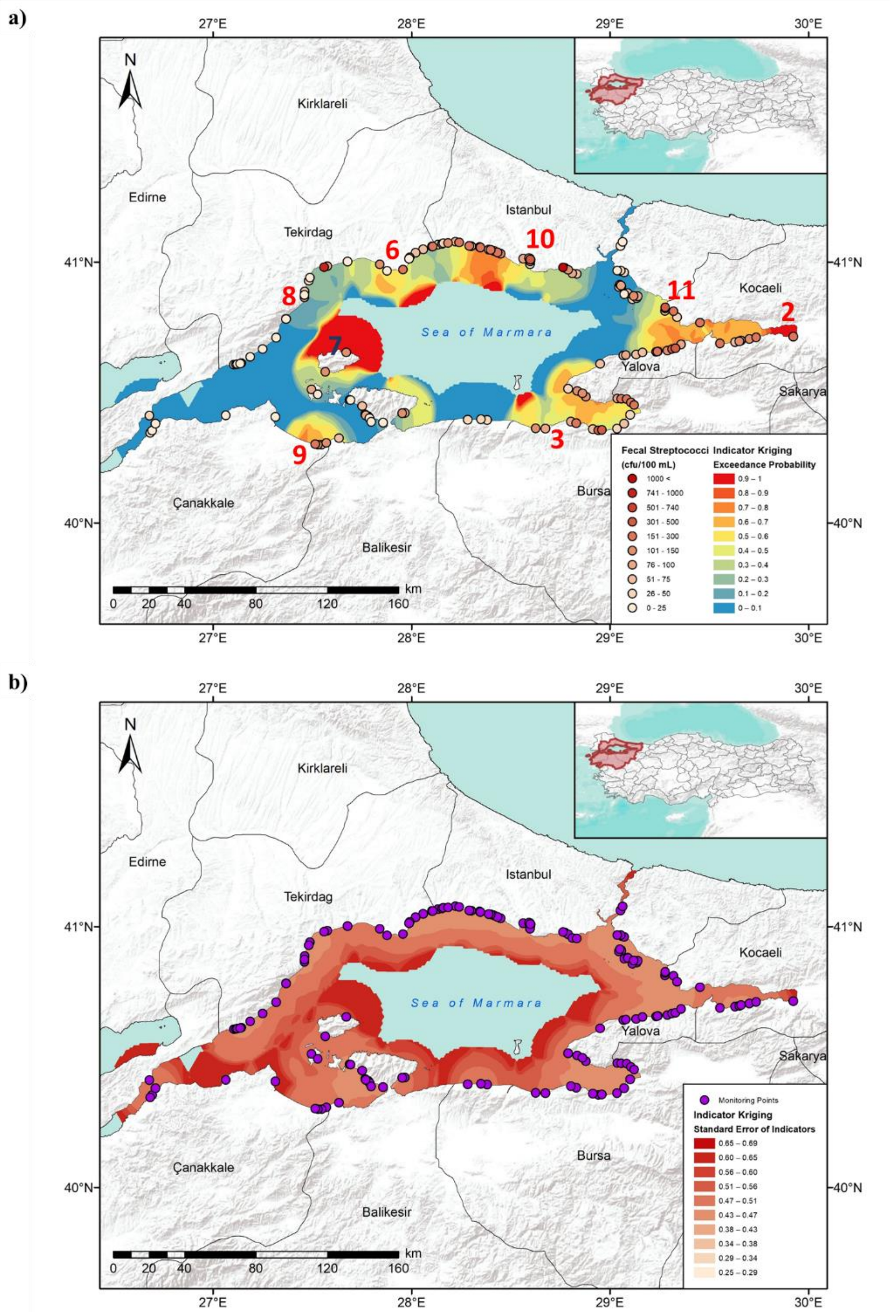


Figure 4.81. a) Exceedance probability and b) standard error maps generated for Marmara Region over years 2010 – 2012 for FS (GA period 2)

After 2010, number of monitoring stations along Marmara Sea coastline has increased significantly, thus, predictions were conducted for all Marmara coastal zone. Although, according to FC and FS parameters in terms a range of BWQ was present, i.e. there exists areas with poor BWQ as well as sufficient BWQ, according to TC measurements insufficient BWQ dominated the region. This may be related to the source of pollution; during that period the main pollution source causing high TC concentrations may be land/soil related. Therefore, hydrological events such as runoffs or anthropogenic activities such as construction or agriculture may be the cause of the observed difference between TC and other BWQ parameters. However, there were also some areas such as Marmara Island/Balıkesir (7) which had a high exceedance probability over 90% in all three BWQ parameters. This clearly indicates the presence of a fecal contamination in that region.

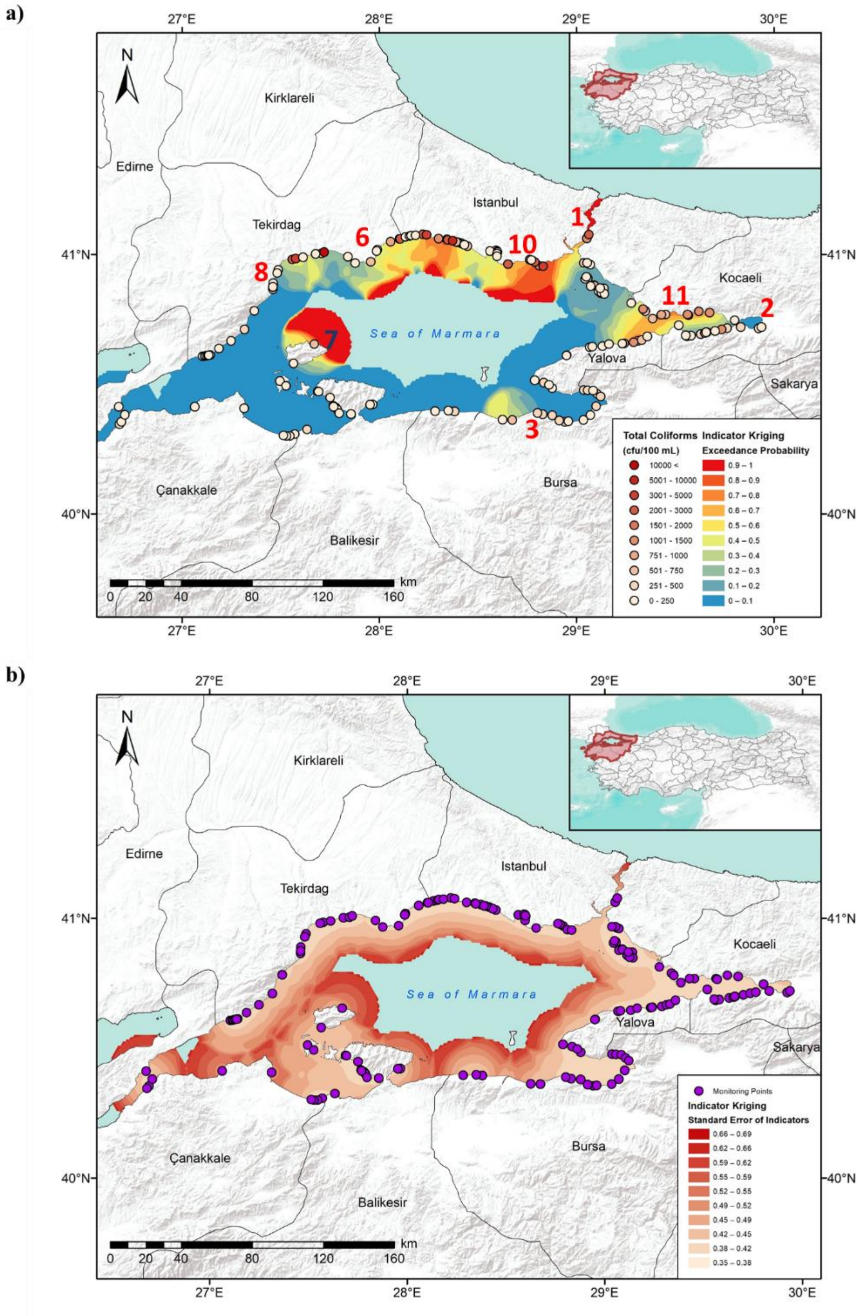


Figure 4.82. a) Exceedance probability and b) standard error maps generated for Marmara Region over years 2013 – 2015 for TC (GA period 3)

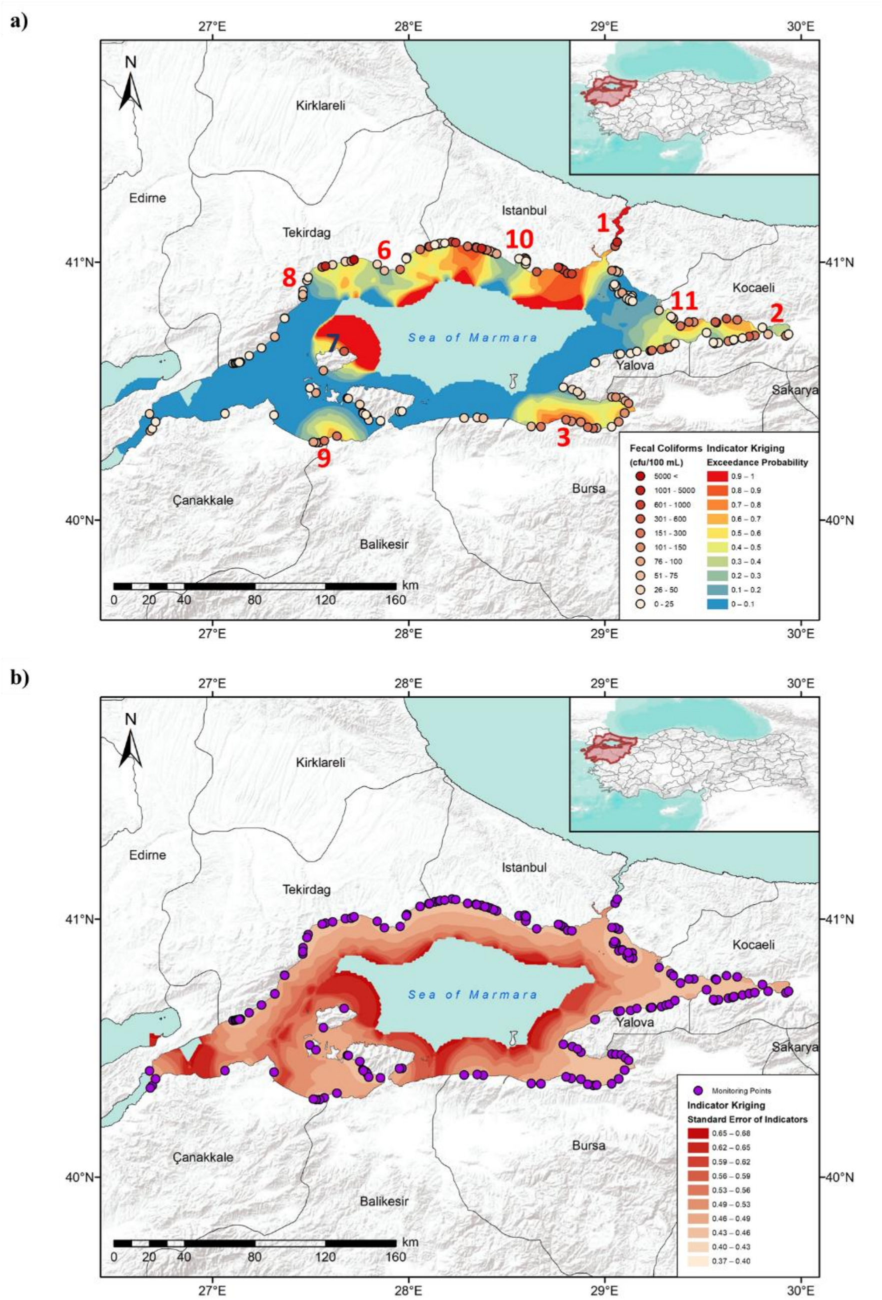


Figure 4.83. a) Exceedance probability and b) standard error maps generated for Marmara Region over years 2013 – 2015 for FC (GA period 3)

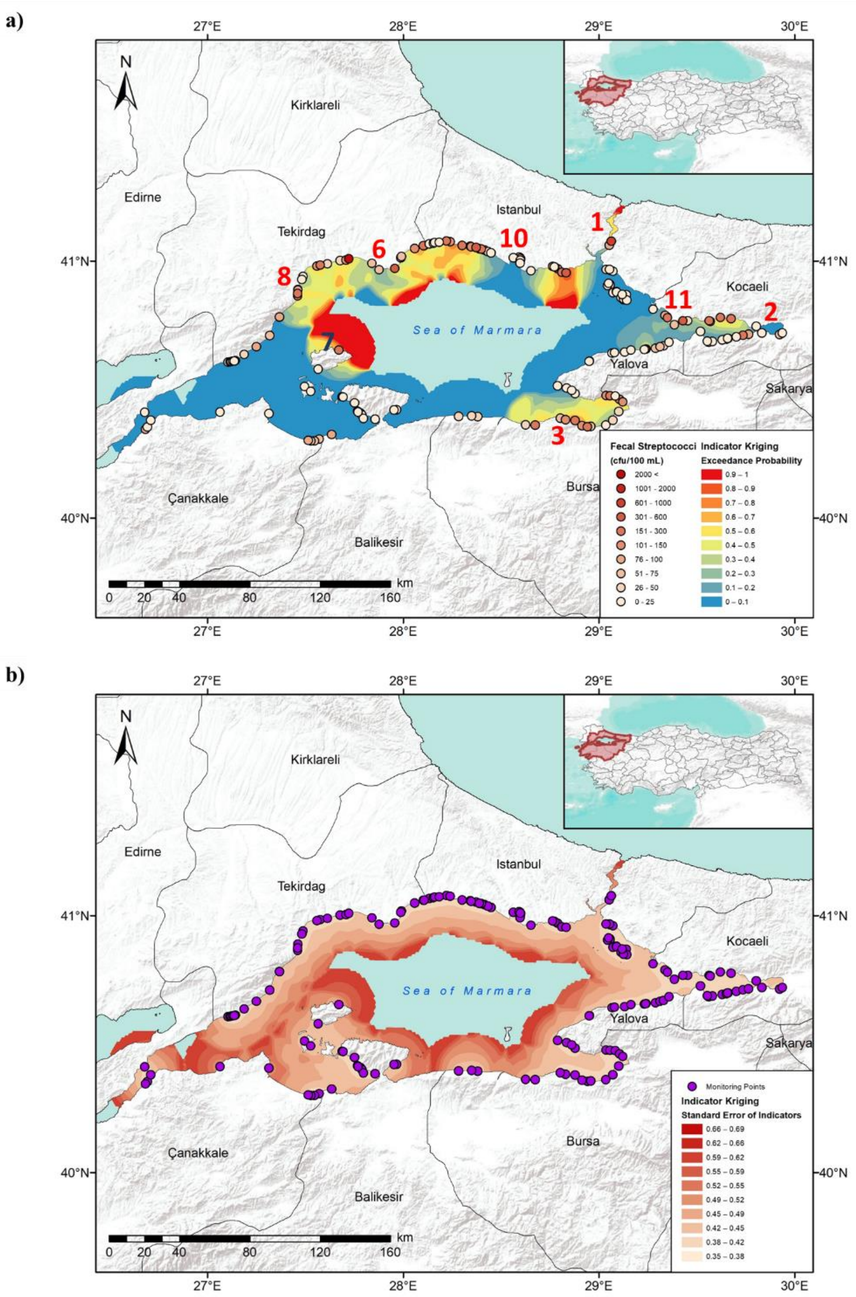


Figure 4.84. a) Exceedance probability and b) standard error maps generated for Marmara Region over years 2013 – 2015 for FS (GA period 3)

Between 2013 – 2015 all three BWQ parameters show higher exceedance probabilities in same regions, namely Bosphorus (1), Büyükçekmece/İstanbul (10), Mudanya/Bursa (3), Marmaraereğlisi/Tekirdağ (6), Şarköy/Tekirdağ (8) and Marmara

Island/Balıkesir (7). The error maps show TC and FS has lower errors, ranged between 35 –49 %, in comparison to FC (error range 43 – 68%).

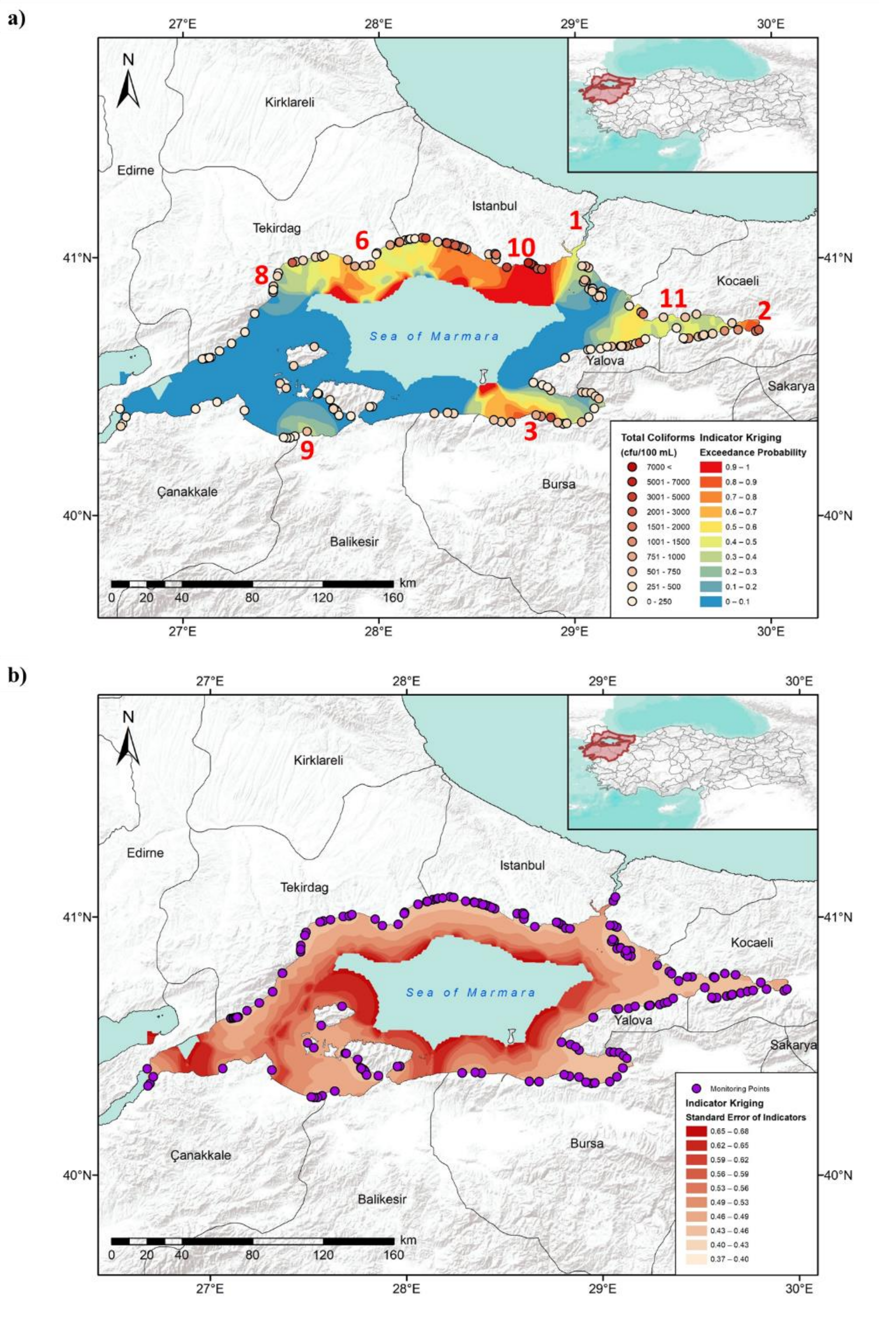


Figure 4.85. a) Exceedance probability and b) standard error maps generated for Marmara Region over years 2016 – 2018 for TC (GA period 4)

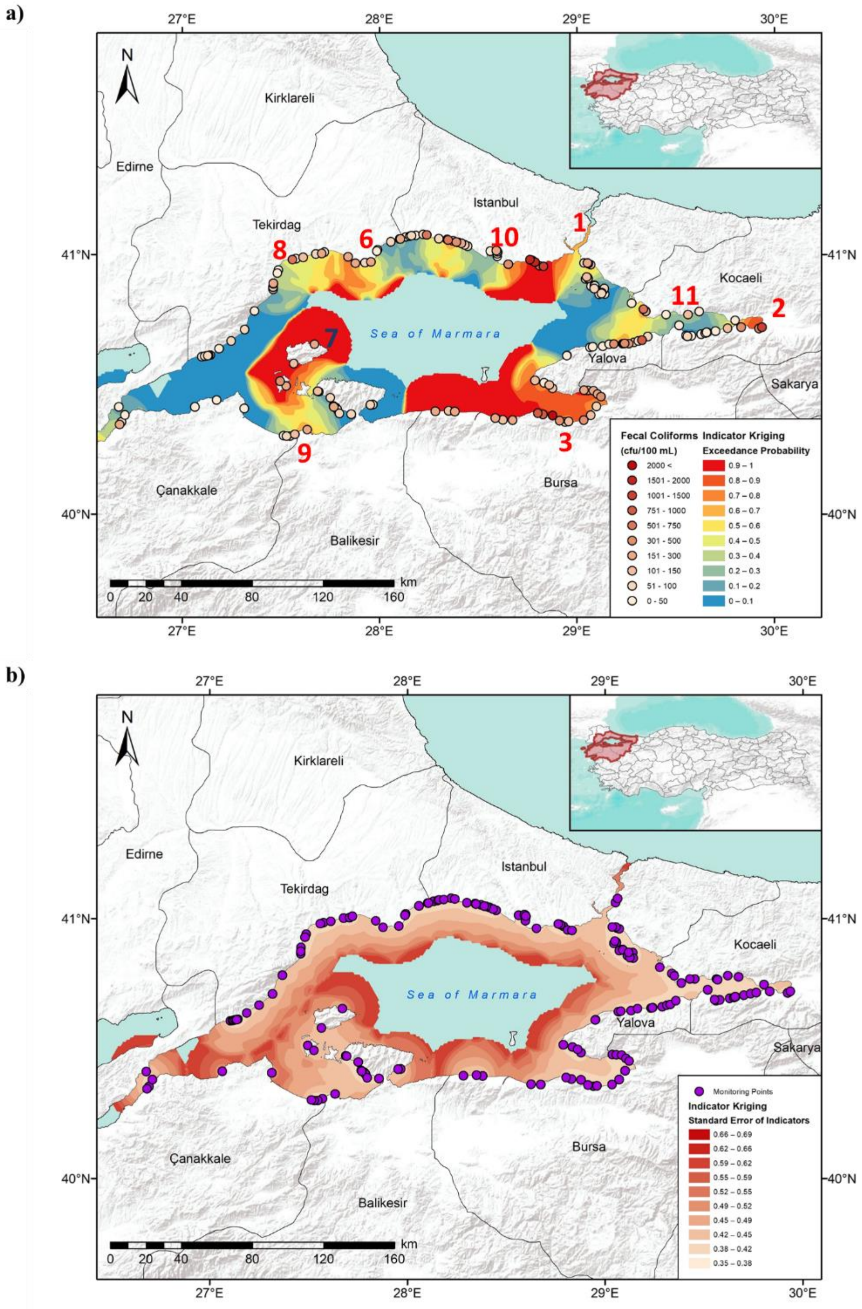


Figure 4.86. a) Exceedance probability and b) standard error maps generated for Marmara Region over years 2016 – 2018 for FC (GA period 4)

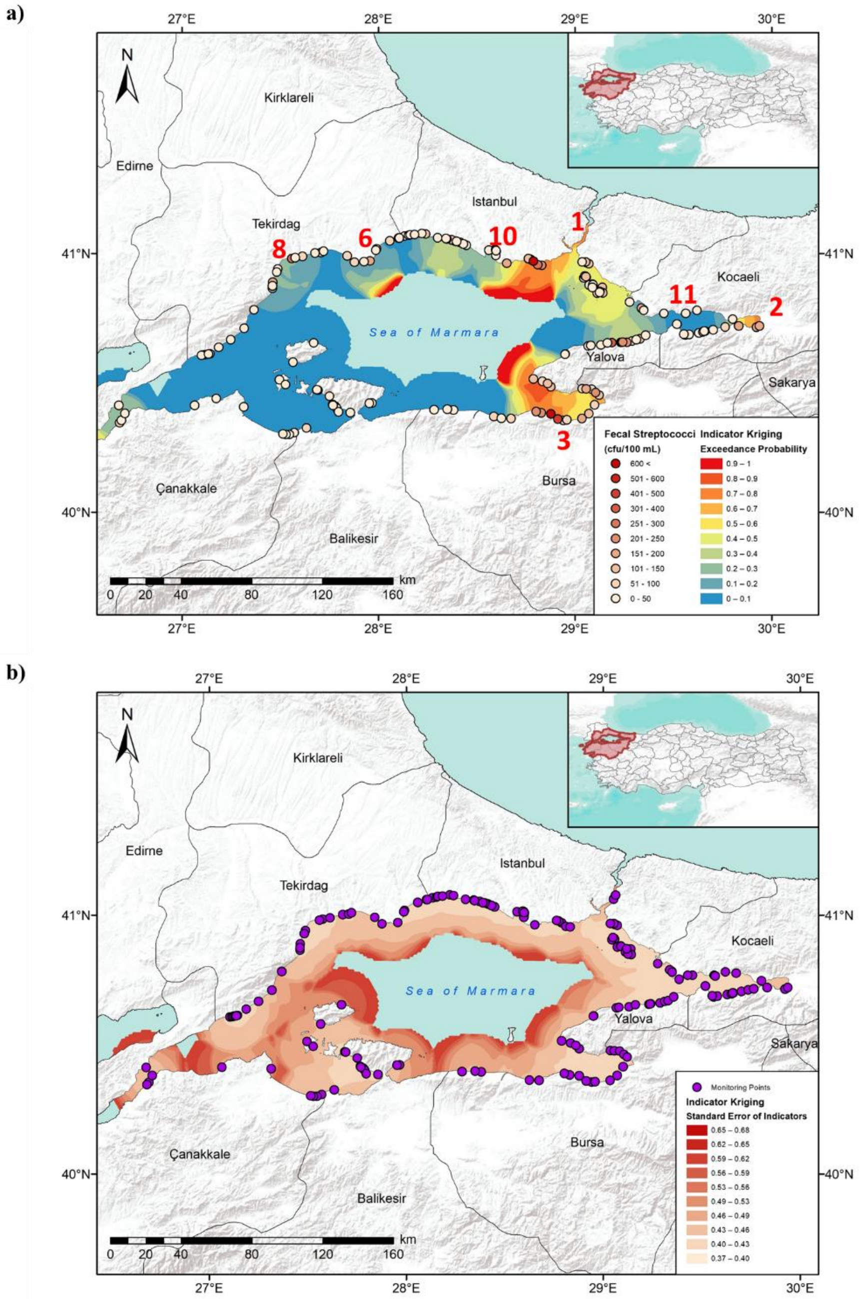


Figure 4.87. a) Exceedance probability and b) standard error maps generated for Marmara Region over years 2016 – 2018 for FS (GA period 4)

In Figure 4.85, Figure 4.86 and Figure 4.87, the results of IK analysis are shown for the most recent period, *i.e.* period 4. The figure also depicts the error maps in addition to showing all three BWQ parameter exceedance probability results. According to

Figure 6, between 2016 – 2018, in terms of TC and FC, Marmara Sea coastlines show poor BWQ. Even though FS illustrates a better scenario than other BWQ parameters, critical areas are still dominating the region. Yet, it should be noted that the error map of TC gives higher standard error in the approximately 50%. This is caused by the variation in the measured valued of TC in nearly located monitoring stations. In the region FS and FC parameters did not show same regions as critical. In addition to pollution sources in these regions, there may be other reasons which are causing this difference between FS and other BWQ parameters. Altuğ et al. (2012) revealed that as a transitional water, contribution of ship ballasts to fecal pollution is at significant levels in the Sea of Marmara, although, it is forbidden by The International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978 (MARPOL 73/78) (International Maritime Organization, 2003). In that study, EC, as fecal indicator bacteria, is reported in Marmara Sea due to ship ballasts rather than IE or FS. The study suggests that fecal contamination is transported through the Sea of Marmara by ships are human originated, which is supported by our available dataset.

Due to high industrialization in the region, there exists high amounts of heavy metals, antibiotics and other kinds of toxic material accumulations through Sea of Marmara (Yümün, 2017; Yaşar, Aksu, & Uslu, 2001; Otansev, Taşkın, Başsarı, & Varinlioğlu, 2016). It is reported that, there is high bacterial diversity in the Sea of Marmara, for both FS and FC families and some of these species are antibiotic and heavy metal resistant (Türetken, Çardak, & Zeki, 2016). It was recorded as most of the FC species are more resistant to toxic materials found in Sea of Marmara than FS species, therefore, survival of FS species is harder than FC species in this coastal zone (Türetken, Çardak, & Zeki, 2016). This statement explains the difference observed between probability maps of FS and other BWQ parameters in all GA periods, especially between 2016 – 2018.

Marmara region is the most industrialized and urbanized region in Turkey and therefore impacts of anthropogenic sources on marine environment is expected to be more stressful than on other coastal zones. Only from Istanbul a total of 25 municipal WWTPs discharge directly to Marmara Sea, and in total more than 50 marine outfalls discharge municipal and industrial wastewaters directly to Marmara Sea (TÜBİTAK MAM, 2010a; TÜBİTAK MAM, 2010b). The rest of the WWTPs and outfalls (more than 30) discharges wastewaters to streams which also flow through Sea of Marmara.

As stated in Chapter 4.1, wastewater treatment plants are significant sources of fecal pollution. Therefore, wastewater discharges are evaluated in the scope of this study. Figure 4.88 shows the wastewater discharge points and threshold exceedance probabilities for FC in 2016 – 2018.

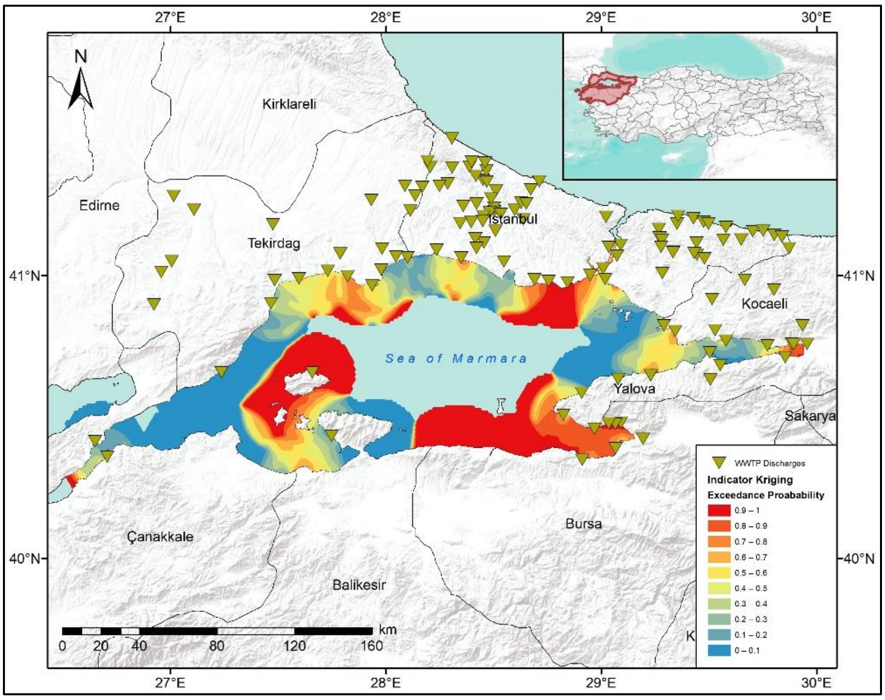


Figure 4.88. WWTP Discharge Locations in Marmara Region embedded in FC Exceedance Probability Map for GA Period 4 (İstanbul Provincial Directorate of Environment and Urbanization, 2018; Kocaeli Provincial Directorate of Environment and Urbanization, 2018; Yalova Provincial Directorate of Environment and Urbanization, 2018; Bursa Provincial Directorate of Environment and Urbanization, 2018; Balıkesir Provincial Directorate of Environment and Urbanization, 2018; Çanakkale Provincial Directorate of Environment and Urbanization, 2018; Tekirdağ Provincial Directorate of Environment and Urbanization, 2018)

In the northern coast of the Marmara Sea, number of WWTPs is quite high (81) and most of them are serving to large populations, i.e. more than 14 millions. Although, most of the WWTPs are discharging to rivers, their pollution loads still accumulates in the Marmara Sea. To validate the distributions of WWTPs, the population density graph around the region was also plotted (Figure 4.89).

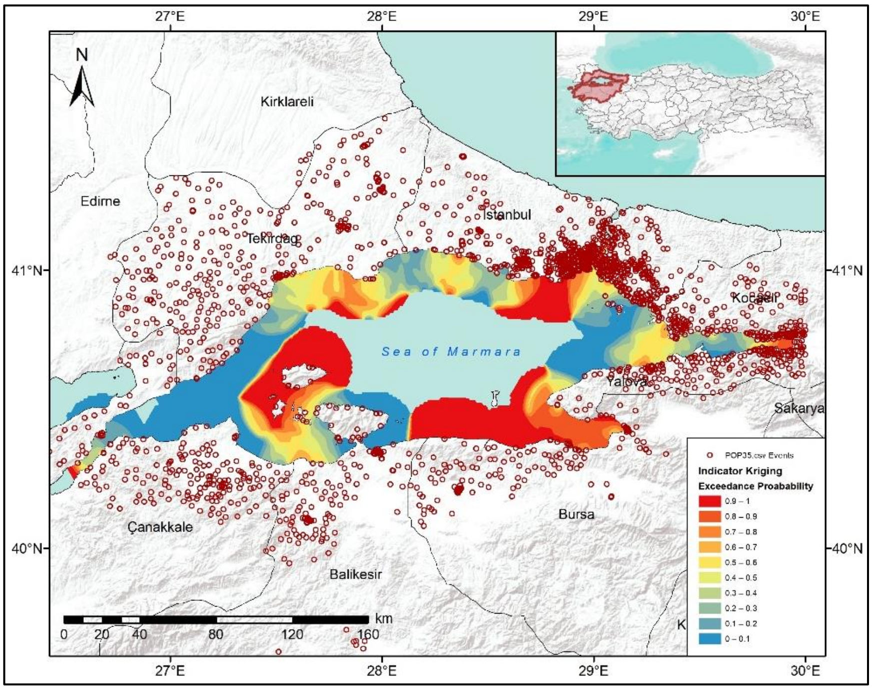


Figure 4.89. Population Density Along Marmara Region embedded in FC Exceedance Probability Map for GA Period 4 (Adapted from: TÜİK, 2018)

Household based population data is obtained from Turkish Statistical Institute (TÜİK) (TÜİK, 2018). The population map is correlated with locations of WWTPs since increase in population density leads increase in wastewater load of WWTPs. Yet, a clear correlation between observed BWQ and WWTP discharge locations were not observed perhaps mainly because of the even distribution of poor BWQ over the coastline. While the results of this study are indicative of fecal pollution, it should be noted that in this study direct comparison of average of individual data points with the threshold values are performed, unlike the 90th percentile calculation required in the Bathing Water Quality Regulation. Therefore, the results of this study may be more conservative than the currently applied regulation.

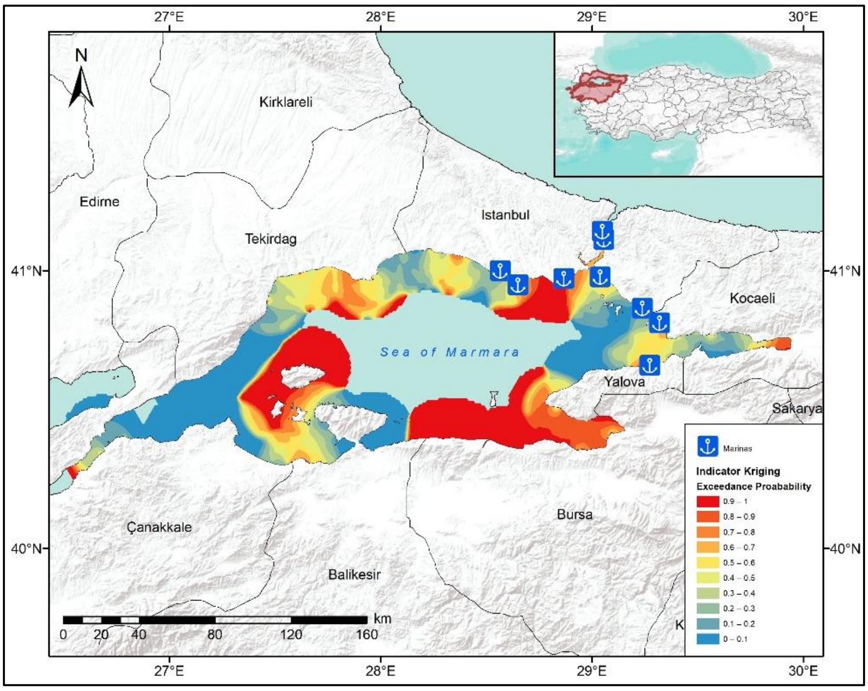


Figure 4.90. Location of Marinas in Marmara Coasts embedded in FC Exceedance Probability Map for GA Period 4 (Chamber of Shipping, 2019)

Marinas are known as an important pollution sources in bathing sites due to sewage discharges (US EPA, 2015). Thus, locations of marinas and critical BWQ areas are also compared in Marmara region. Figure 4.90 shows the locations of marinas in Marmara coastline. Most of the marinas within the Marmara region are located around Bosphorus, although, it is not clear that fecal pollution in that region is caused by marinas, since whole Marmara Sea shows critical patterns in terms of FC, it could be commented as marinas are also significant human originated pollution sources contributing fecal contamination in Marmara Sea. Yet, they are apparently not the only reason of poor water quality especially since none exists in the rest of the coastal line.

4.3.3. Concluding Remarks for Marmara Region

- Sea of Marmara is the least preferred marine water in Turkey for beach tourism, however, bathing sites still exist around the coastline. Also, it represents an inner sea which increases the probability of pollution accumulation.

- This region has the lowest number of monitoring stations with 219 for all GA periods.
- For all GA periods semivariograms show moderate spatial dependency regarding nugget/sill ratios.
- Marmara Island (7) is the most fecally polluted area (Table 4.28).
- It is highly critical for decision-makers to conduct a comprehensive study investigating the reasons of insufficient BWQ around the region and relevant actions should be taken.

Table 4.28. *Coastal areas with >90% threshold exceedance probability in the Marmara Region*

Period	*TC*	*FC*	*FS*
Before 2010	2-4-7-9-10-11	5-9-10-11	3-5-9
2010 – 2012	1-2-4-6-7-8-9-10	1-2-3-7	2-7
2013 – 2015	1-7	1-7	7
2016 – 2018	10	2-7-10	-

- High rate of urbanization show negative impacts on BWQ in the region and fecal contamination is mainly human originated.

Table 4.29. *The frequency of observation of >90% threshold exceedance probability in a given coastal area* in Marmara region*

Regions**	*Designated Areas*	*All Periods*	*Last Two Period*
1	Bosphorus	4	2
2	İzmit Bay	5	1
3	Mudanya/Bursa	2	-
4	Erdek/Balıkesir	2	-
5	Dardanelles	1	-
6	Marmaraereğlisi	1	-
7	Marmara Island	8	4
8	Çorlu/Tekirdağ	1	-
9	Biga/Çanakkale and Gönen/Balıkesir	4	-
10	Büyükçekmece/İstanbul	5	2
11	Tuzla/İstanbul	2	-

**Coastal Areas are designated with a number.*
*** Table 4.25 shows the designated areas..*

Based on the data analysis stated in Section 3.2 using Table 4.29 above Marmara Island is the most critical BWQ site which is determined for Marmara region.

4.4. Bathing Water Quality Assessment around Black Sea Region

Black Sea constitutes the northern part of Turkey coastline with 1,175 km of length (Turkish Marine Environment Protection Association, 2019). Salinity of Black Sea is average of 18 PSU (Altiok, Sur, & Yüce, 2012). Black Sea region has wet climatic conditions (TÜBİTAK MAM, 2010c; TÜBİTAK MAM, 2010a; TÜBİTAK MAM, 2010d), which is the reason why bathing season in Black Sea region starts later than other regions. General Directorate of Public Health stated that for Black Sea bathing season starts on 15th of June and ends on 15th of September (General Directorate of Public Health, 2008).

Black Sea region has 366 monitoring stations (General Directorate of Public Health, 2018). The first monitoring activities started in Ordu and Rize in 1996, regular monitoring applications along all coastline were started after 2010. Before 2010 monitoring stations were denser in the eastern part of the coastal zone, where Ordu, Rize, Giresun and Trabzon are located.

From the perspective of beach tourism, similar to Marmara, Black Sea is not the first place which comes to mind compared with Mediterranean and Aegean regions, however, due to high population living near shoreline, it provides a proper place for recreational demands of locals. In total 16 cities have coasts to Black Sea. In this section, first of all dataset used for GA in the Black Sea region will be explored by some basic statistics and then GA results will be discussed.

4.4.1. Exploratory Data Analysis for Black Sea Coastline

BWQ monitoring has started in Black Sea region in 1996. At first, monitoring activities were limited with Rize and Ordu, but, the number of monitoring stations were increased year by year (Figure 3.9). Figure 4.91 provides the change in the number of measurements in bathing seasons and all other periods including bathing season.

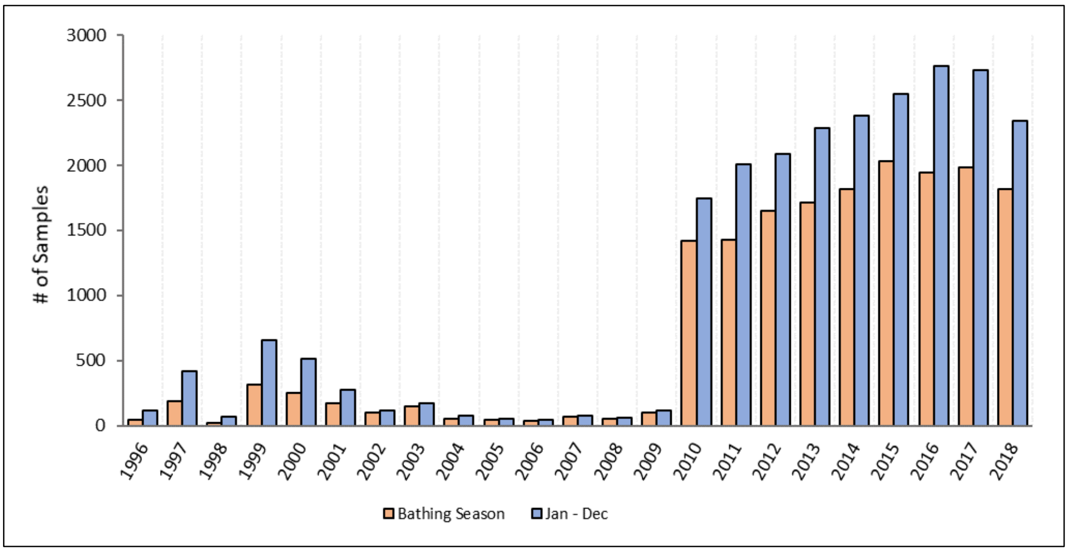
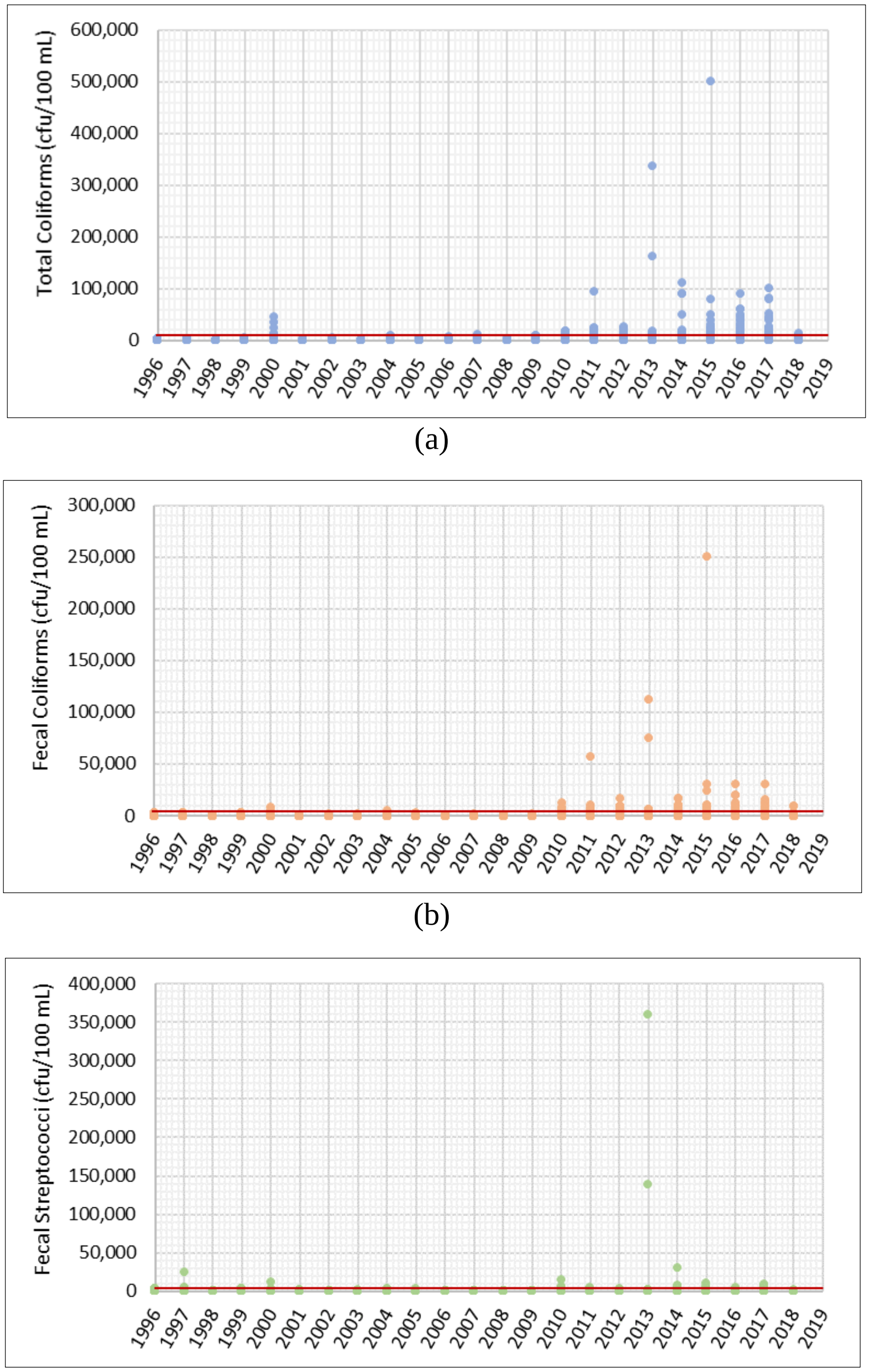


Figure 4.91. The Change in the Number of BWQ Measurements in the Black Sea Region

In Black Sea region, monitoring stations are located sparsely in some zones such as western Kastamonu, however, in some regions such as Giresun and Ordu monitoring stations are located more frequently. Although, Figure 4.91 shows that the number of monitoring stations in Black Sea coastline is increased by each year. Especially after 2010, similar to other coastal zones of Turkey, i.e. Mediterranean, Aegean and Marmara Sea, a drastic increase has been observed in the number of BWQ measurements.

Black Sea region is not competitive with Aegean and Mediterranean regions, in Blue Flag awards but currently tourism facilities in the region provide more investments for Blue Flag awards and thus, number of Blue Flag awarded beaches are increasing, i.e. increased from 3 to 27 from 2010 to 2018 (TÜRÇEV, 2018). Give number here. Black Sea region does not show poor BWQ as Marmara Sea coastline, however, it is also not good as Mediterranean and Aegean seas. Very high concentrations of BWQ parameters were also recorded in this region. Especially after measurements extended to western part of the Black Sea coastline, number of insufficient BWQ measurements started to increase. Figure 4.92 provides the change in the concentrations of BWQ parameters in all bathing sites located in the Black Sea coastline in between years 1996 and 2018. Although, most the samples satisfy the relevant regulatory criteria, the number of locations with poor BWQ is not negligible (Figure 4.92).



(a)

(b)

(c)

Figure 4.92. The Variation in the Concentrations of (a) TC (b) FC (c) FS over the cycle of 1996 – 2018 in the Black Sea Coastline[9]

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[9] Circles represents the measured data, and red line shows the regulatory limit for good quality, which refers to 500 cfu/100 mL for TC, 100 cfu/100 mL for both FC and FS.

The highest concentrations for each BWQ parameter were observed after 2010, and consequently, the number of exceedances for all BWQ parameters were also increased (Figure 4.92). Yet, one should keep in mind that both the number of monitoring stations (Figure 3.9) and the number of collected samples for BWQ monitoring (Figure 4.91) were increased after 2010. In order to account for this, the percentage of samples that are exceeding the regulatory limits are reported in Figure 4.93 for each parameter.

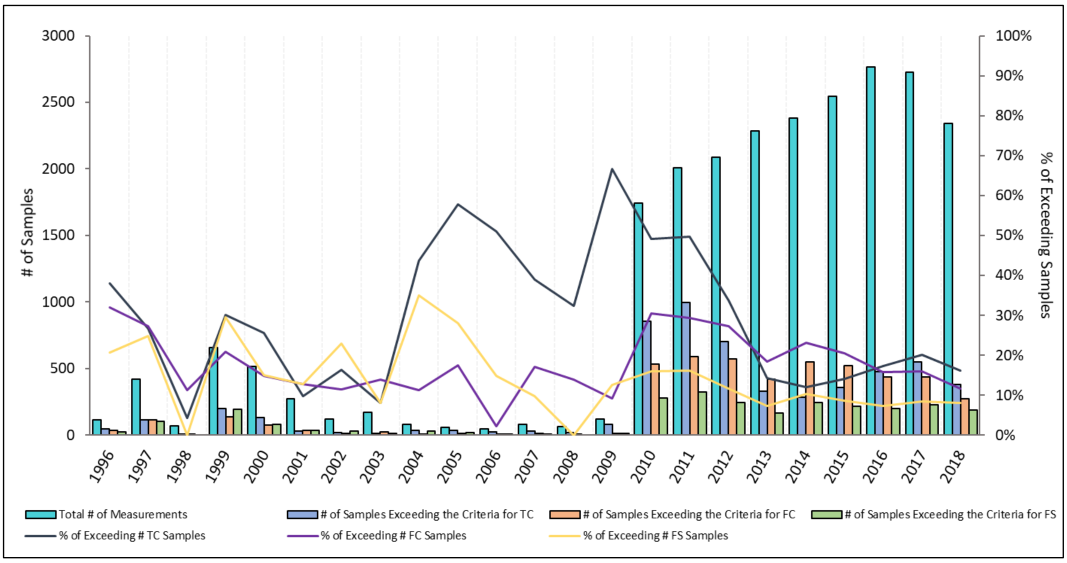


Figure 4.93. Number of Threshold Exceeding Measurements in Black Sea Coastline

Over the past 23 years of measurements along the Black Sea coastline, especially between 2004 - 2009, the number of samples which exceeded the regulatory limits were quite high (Figure 4.93), yet, sampling numbers in these years were very low. After 2010 the percentage of exceeding observations has decreased year by year for all BWQ parameters. The single sample maximum concentrations of each BWQ parameter in between years 1996 and 2018 is presented in Figure 4.94. The single sample maximum concentrations of TC ranged between 1,554 and 500,000 cfu/100 mL with 12 single sample maximum concentrations that are exceeding 10,000 cfu/100 mL. The highest concentrations for all BWQ parameters were observed in 2013 and 2015.

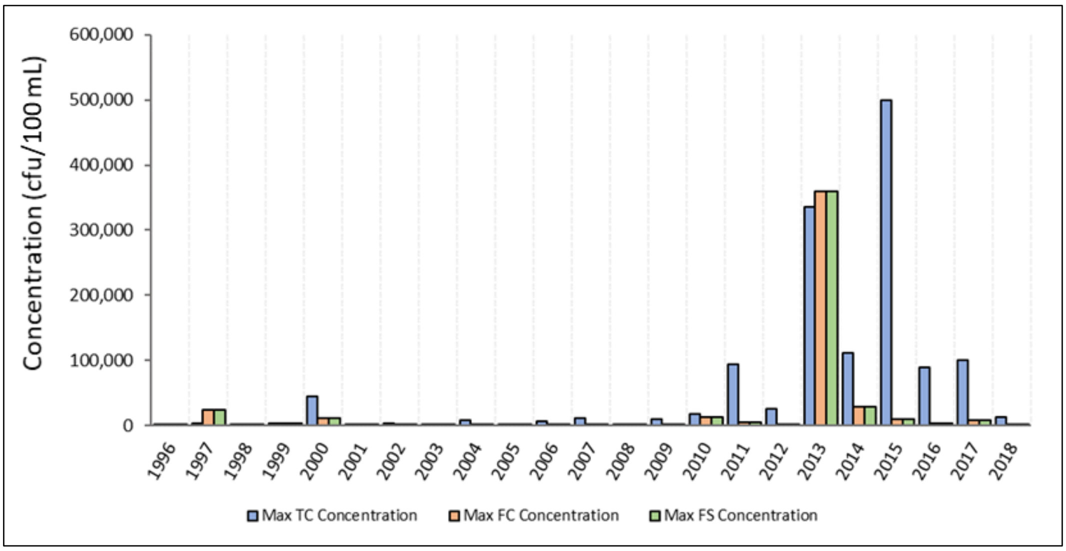


Figure 4.94. The Change in the Single Sample Maximum Concentrations of BWQ Parameters in the Black Sea Coastline over the years 1996 - 2018

Figure 4.95 provides number of monitoring stations with respect to their purpose of monitoring, most of the stations are in operation for the purpose of BWQ monitoring only less than 10% is being monitored because of complaints.

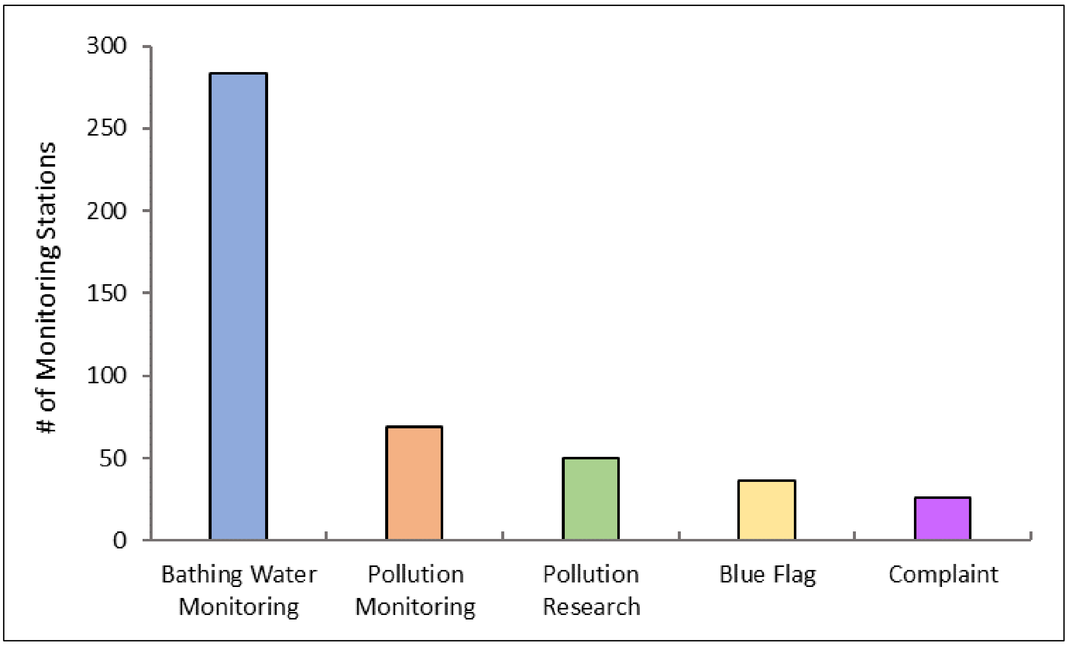
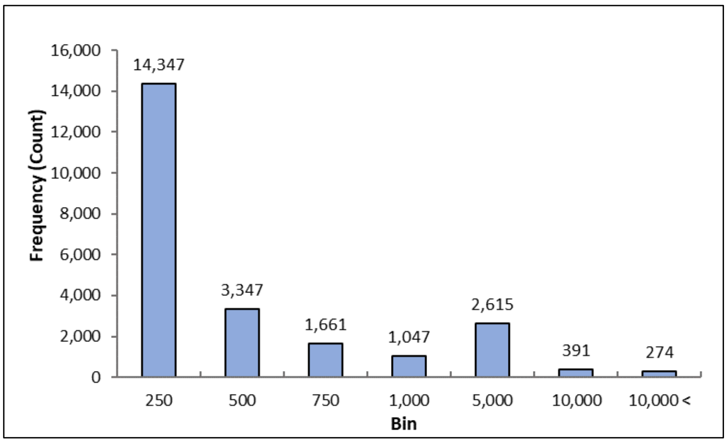
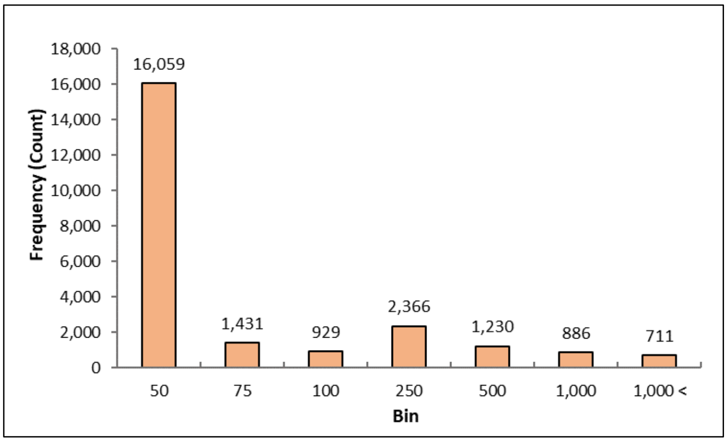


Figure 4.95. Number of Monitoring Stations for Different Purposes in Black Sea Region

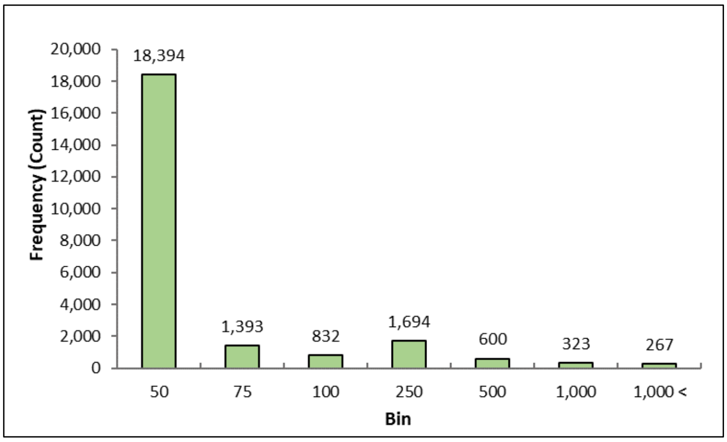
Please note that one beach can be monitored regarding more than one purpose which may have led to counting a beach more than once in Figure 4.95. Although, single sample maximum concentrations for each parameter increased after 2010, when the whole dataset is evaluated, it is observed that the number of samples satisfying the BWQ criteria represents the majority of the entire dataset for each BWQ parameter (Figure 4.96). Data set histograms illustrate that 74.7%, 77.8% and 87.1% of samples satisfy BWQ regulatory criteria for TC, FC and FS, respectively.



(a)



(b)



(c)

Figure 4.96. Histograms of (a) TC (b) FC and (c) FS concentrations in Black Sea Region

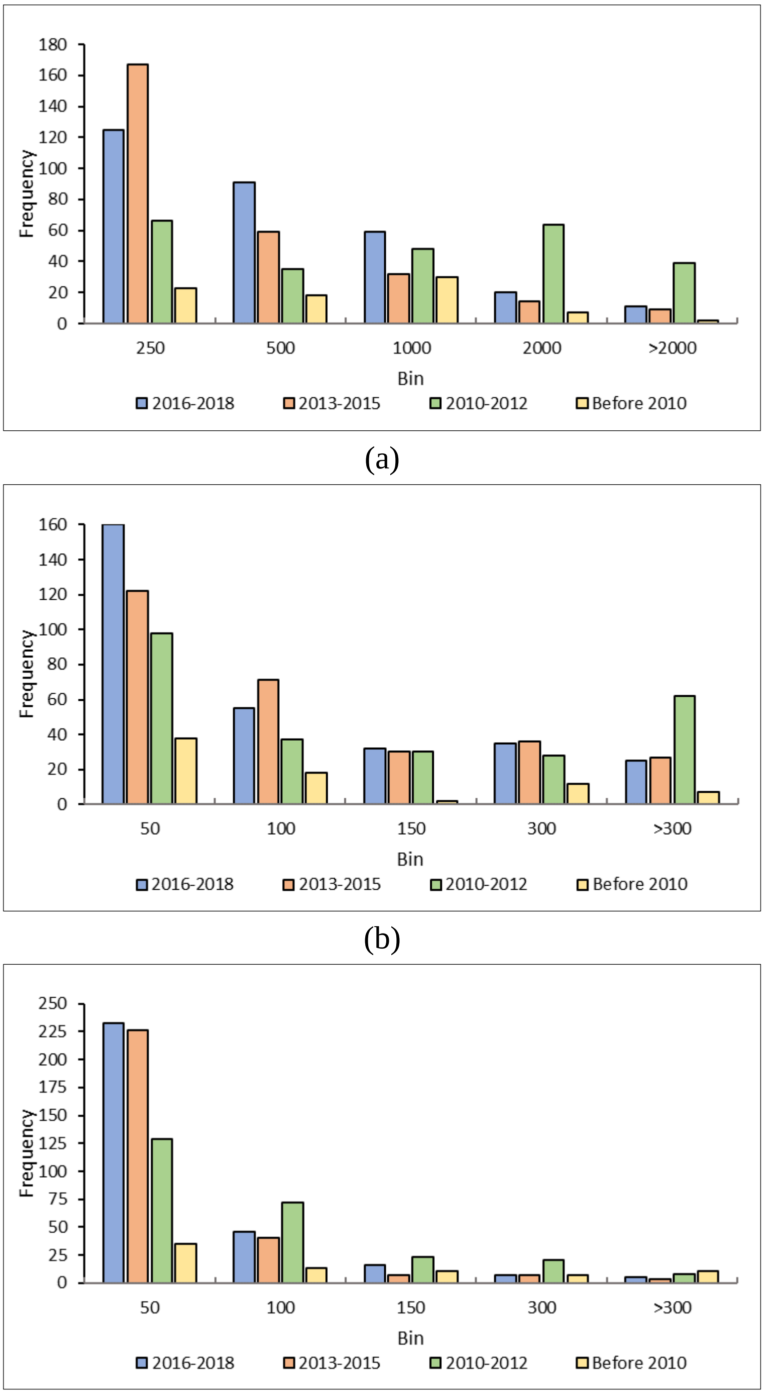
Table 4.30 provide general statistics of the dataset used in GA for the Black Sea region. The total number of measurements is around 23,000 all of which is used in further GA analysis.

Table 4.30. *General Statistics of the GA Dataset of Black Sea Region*

Parameter	*TC*	*FC*	*FS*
Total number of measurements	23,682	23,612	23,503
Maximum value (cfu/100 mL)	500,000	250,000	360,000
Minimum value (cfu/100 mL)	0	0	0
Mean (cfu/100 mL)	774.3	184.3	90.6
Standard Deviation (cfu/100 mL)	4,939.3	2,031.8	2,546.5

4.4.2. Geostatistical Analysis of BWQ Data of the Black Sea Coastline

In this study, for Black Sea region, total of 366 monitoring stations are used for GA, but this number is different for each study period. During GA all monitoring stations were taken into consideration and data analysis was conducted over 4 periods, i.e. 2016 – 2018, 2013 – 2015, 2010 – 2012 and before 2010. The average of all samples collected in these 4 GA periods, i.e. before 2010, 2010 – 2012, 2013 – 2015 and 2016 – 2018 were calculated. GA is conducted using the average values calculated for each period. Figure 4.97 shows the histograms of GA dataset for each period.



(a)

(b)

(c)

Figure 4.97. Histogram of GA Dataset for a) TC (b) FC and (c) FS concentrations over different GA periods in the Black Sea Region

As can be seen from Figure 4.97, data distribution shows variety among each GA periods. Most of the data used for GA for each period is below the threshold values considered in analyses except TC in period 1 (before 2010). Especially in more recent periods, observations show better BWQ. Therefore, it is expected to observe mostly lower exceedance probabilities in Black Sea coastline. Table 4.31 shows the model parameters estimated by GA.

Table 4.31. *Values of Model Parameters for IK in Black Sea Region between 1993 - 2018*

Parameter	*Model*	*Range (m)*	*Nugget*	*Lag Size (m)*	*Partial Sill*	*Nugget/Sill* Ratio*
TC	Rational Quadratic	103,140	0.140	9,600	0.101	0.581
FC	Exponential	89,549	0.154	9,600	0.079	0.661
FS	Exponential	34,767	0.063	9,600	0.047	0.573

Exponential model was chosen for FC and FS, and rational quadratic model was chosen for TC parameter due to low nugget values compared to other models. Nugget/sill ratios are ranged between 25 – 75% for each BWQ parameter which indicates that in Black Sea region, data used in analyses show moderate spatial dependency (Essington, 2004). Lag sizes are selected as the same for each BWQ parameter since same monitoring stations were used for each BWQ parameter. Range values, on the other hand, show that spatial correlations become meaningless at distances longer than 103,140, 89,549 and 34,767 meters for TC, FC and FS, respectively. Therefore, it is expected to observe higher variety for FS values in longer distances. Figure 4.68 shows the semivariograms of BWQ parameters for 1997 – 2018 BWQ sampling results and visualizes Table 4.31.

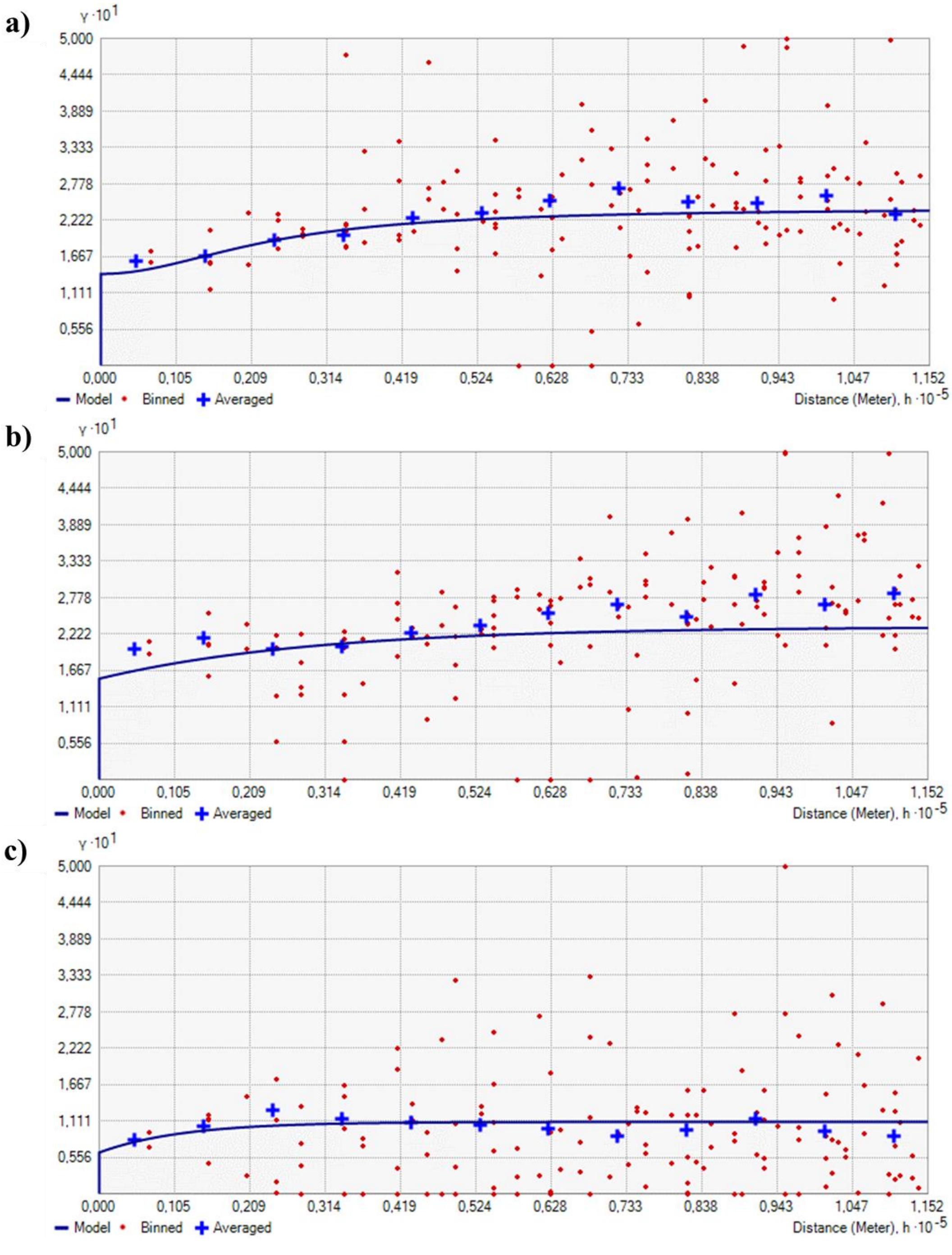


Figure 4.98. Semivariograms of a) TC, b) FC and c) FS in Black Sea Region between 1996 – 2018

Similar to Mediterranean, Aegean and Marmara regions which were discussed in previous sections in Black Sea region first, “Indicator Prediction” results were also assessed to compare the exceedance probability values with measurement values.

According to this assessment, if a point with the high concentration has lower exceedance probability, this indicates that most of the neighbors used to predict that point's exceedance probability has lower concentrations and lower exceedance probabilities. Figure 4.99 shows the indicator predictions for all three BWQ parameters.

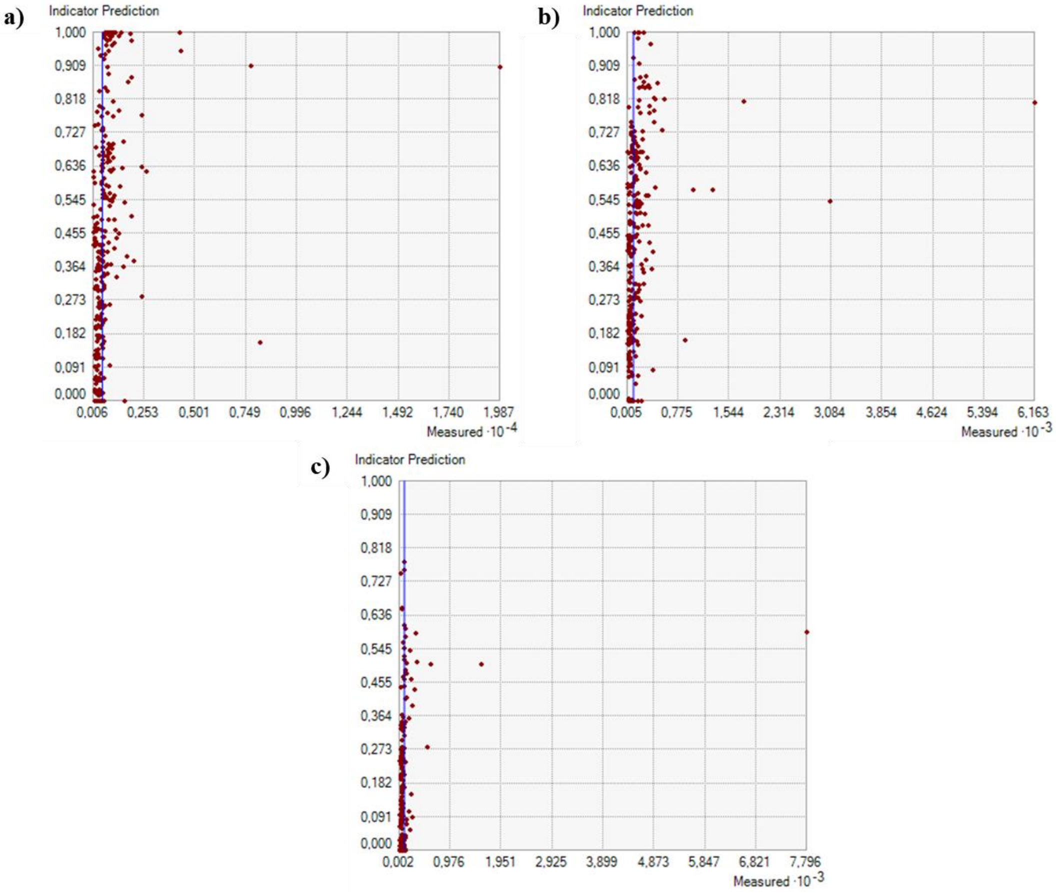


Figure 4.99. Indicator Predictions for a) TC, b) FC and c) FS for Black Sea Region between 1996 – 2018

According to Figure 4.99, although there are some outliers in each parameters' dataset, yet for most measurement points exceedance probabilities are correlated with measurement results. Therefore, first step of cross validation shows that the prediction results are acceptable. The second step of cross validation involves estimation and comparison of prediction errors, i.e. comparison of measured values with predicted values. For this purpose, 5 types of error estimations (RMSE, ASE, ME, MSE and

RMSSE) were calculated. Table 4.32 shows the cross-validation results of GA between 1996 – 2018.

Table 4.32. *Cross Validation Results for Black Sea Region*

Parameter	*RMSE*	*ASE*	*ME*	*MSE*	*RMSSE*
TC	0.407	0.408	-0.005	-0.010	1.007
FC	0.428	0.435	-0.006	-0.012	1.001
FS	0.292	0.298	0.001	0.002	1.003

Table 4.32 represents that for each parameter, ME values are almost zero and therefore it could be commented that predictions are unbiased. For all BWQ parameters, RMSE and ASE values are closer to each other, which eliminates the possibility of under/overestimation (Arétouyap, et al., 2016). Since for each parameter RMSSE values are closer to 1, ME and MSE values are closer to 0 and RMSE values are almost equal to ASE values, predictions are seemed to be acceptable. Depending on these results, exceedance probability maps are obtained and 3rd step of cross validation takes place, namely, standard error of indicators maps. Figure 4.100, Figure 4.101 and Figure 4.102 provide the exceedance probability and standard error of indicators maps for Black Sea region considering the complete GA dataset (between 1996 – 2018). Critical zones are identified by numbers and the designated areas by the numbers are given in Table 4.33.

Table 4.33. *Designated Areas in Exceedance Probability Maps of Black Sea Region*

Bathing Site Number	*Designated Area*
1	Kırklareli Coast
2	Bosphorus
3	Şile/İstanbul and Kandıra/Kocaeli
4	Sakarya River Mouth
5	Zonguldak Coast
6	Kastamonu Coast
7	Sinop Coast
8	Kızılırmak River Mouth

Bathing Site Number	*Designated Area*
9	Yeşilırmak River Mouth
10	Giresun Coast
11	Trabzon Coast
12	Artvin Coast
13	Ordu Coast
14	Rize Coast
15	Bartın Coast

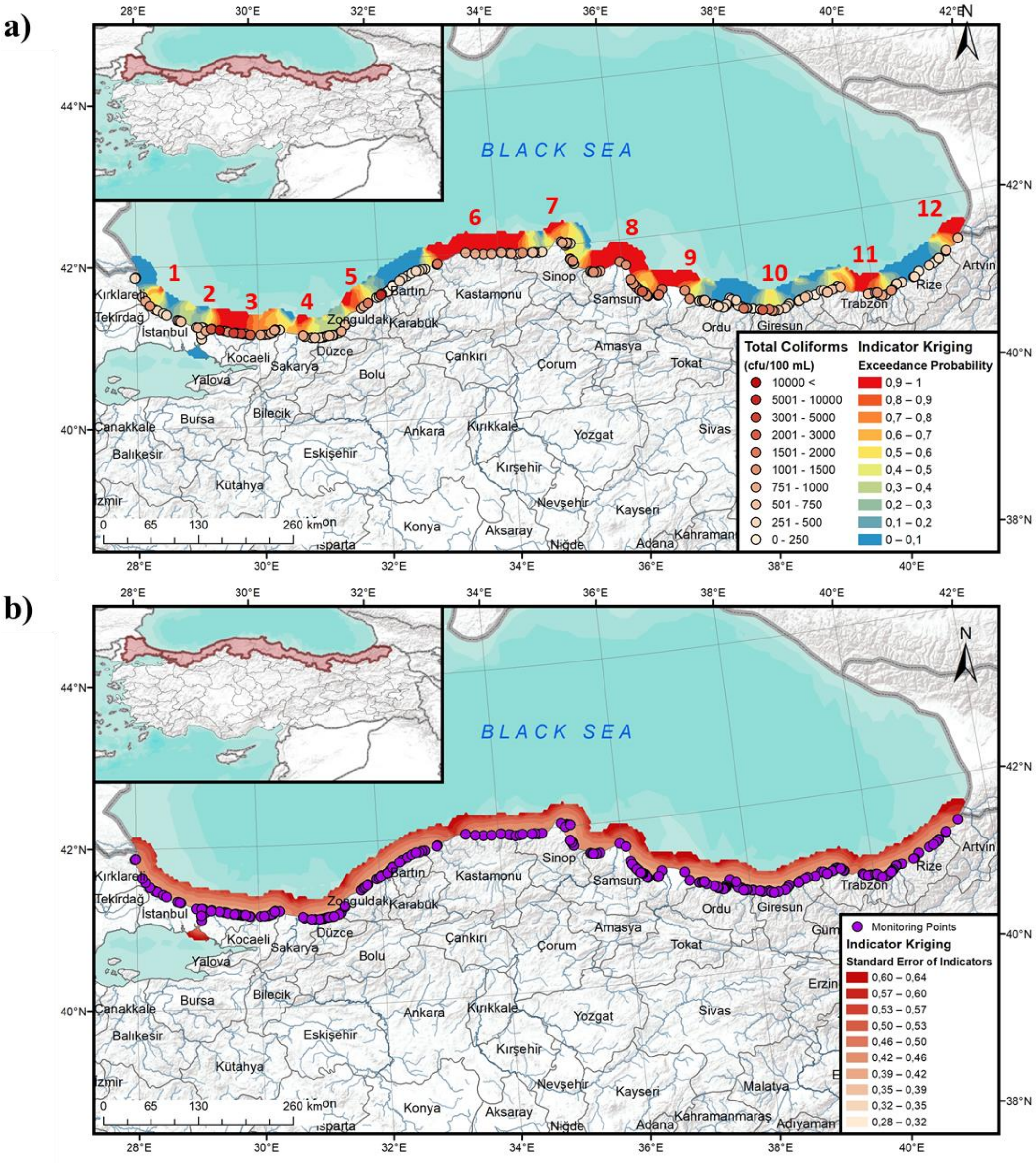


Figure 4.100. a) Exceedance Probability and b) Standard Error of Indicators Maps of Black Sea Region over years 1996 – 2018 for TC

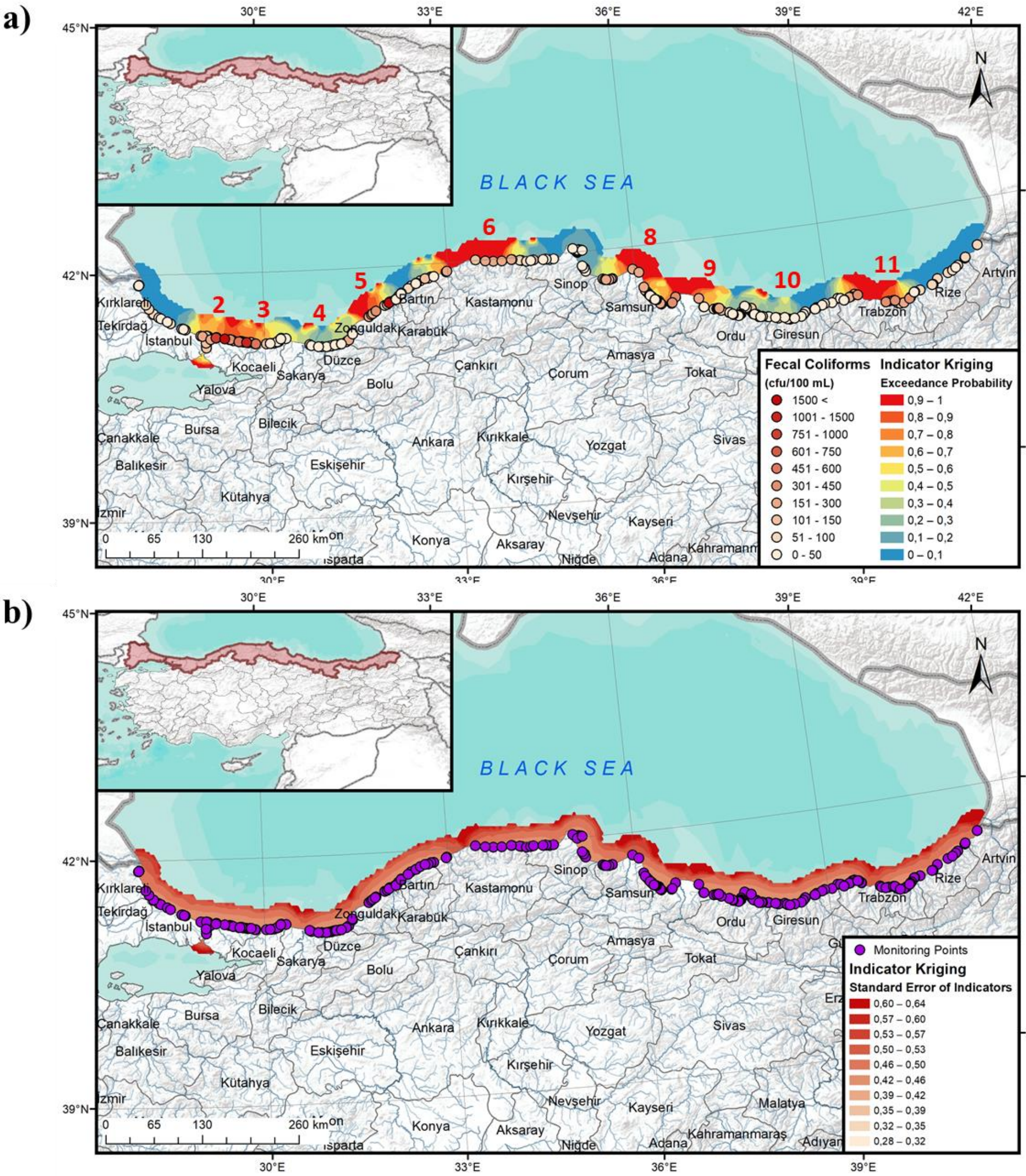


Figure 4.101. a) Exceedance Probability and b) Standard Error of Indicators Maps of Black Sea Region over years 1996 – 2018 for FC

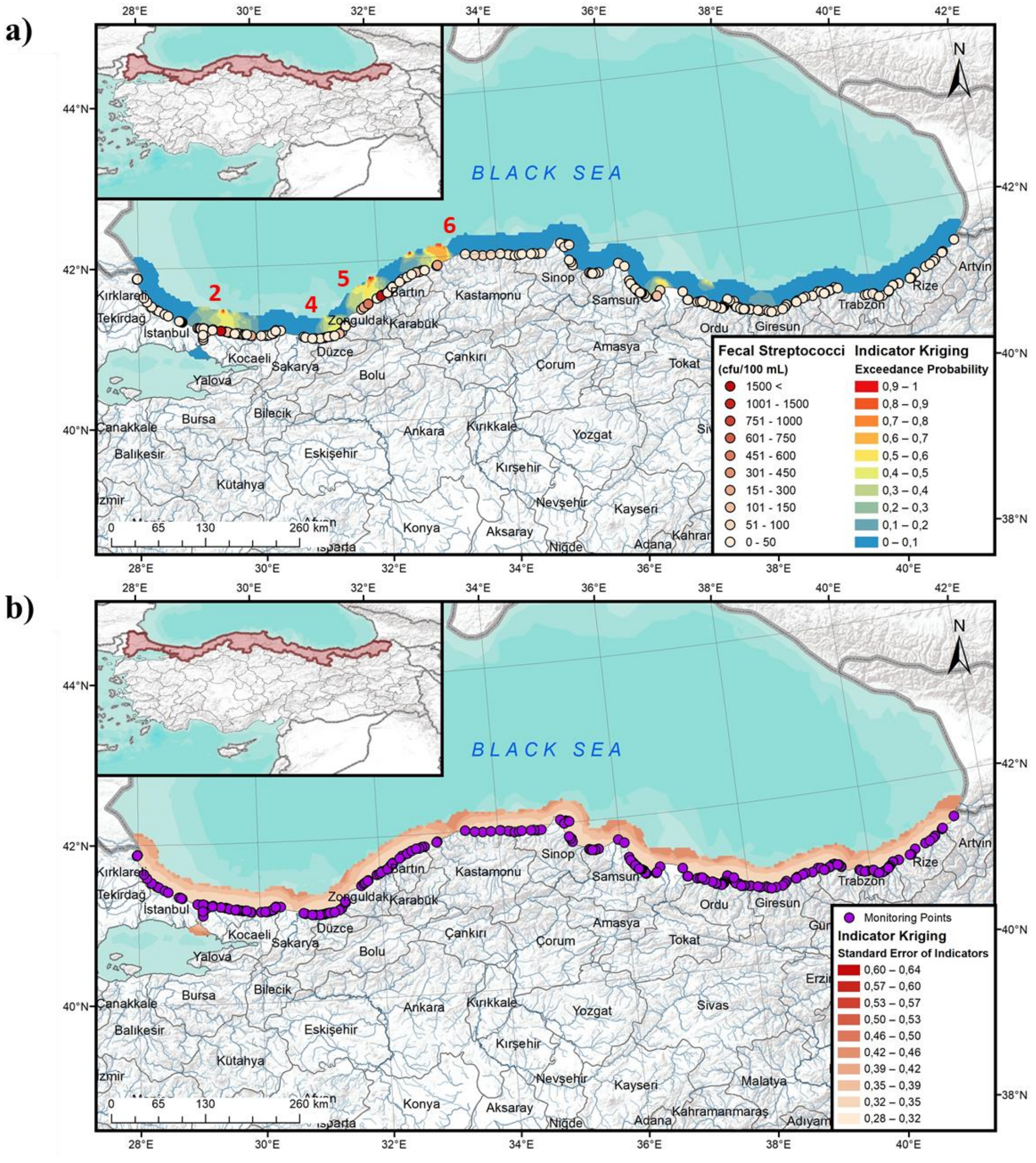


Figure 4.102. a) Exceedance Probability and b) Standard Error of Indicators Maps of Black Sea Region over years 1996 – 2018 for FS

Figure 4.100, Figure 4.101 and Figure 4.102 gives a general overview of BWQ over years 1996 – 2018. To examine the critical areas in Black Sea coastline, analyses considering smaller time intervals were also conducted. . Figures generated using all available data show that most of the time poor BWQ is present around bathing areas, namely Bosphorus (2), Şile/İstanbul and Kandıra/Kocaeli (3), Sakarya river mouth (4), Zonguldak coastline (5), Kastamonu coastline (6), Kızılırmak (8) and Yeşilırmak

(9) river mouths and Trabzon coastline (11). Locations of river mouths are provided in Appendix C. Since the number of stations with high exceedance probability is lower in parameter FS, it shows a significantly different and clearly more optimistic scenario, in comparison with TC and FC. There are at least 4 regions at which all three parameters regulatory limits were exceeded. These are Bosphorus (2), Şile/İstanbul and Kandıra/Kocaeli (3), Sakarya river mouth (4) and Zonguldak coastline (5), which is in the Black Sea coastline located and are closer to Marmara region. To identify the causes of poor BWQ and have a closer look at the situation, GA was also conducted separately for four periods. Table 4.34 provides the model parameters for each BWQ parameter and GA period.

Table 4.34. *Values of Model Parameters for IK Analysis in Black Sea Region*

Parameter_Period*	*Model*	*Range (m)*	*Nugget*	*Lag Size (m)*	*Partial Sill*	*Nugget/Sill** Ratio*
TC_1	Exponential	115,200	0.052	9,600	0.138	0.274
FC_1	Exponential	102,145	0.097	9,600	0.082	0.542
FS_1	Gaussian	102,145	0.087	9,600	0.102	0.460
TC_2	Circular	68,337	0.063	9,600	0.161	0.281
FC_2	Gaussian	74,171	0.104	9,600	0.170	0.380
FS_2	Spherical	99,815	0.074	9,600	0.088	0.457
TC_3	Exponential	115,200	0.092	9,600	0.061	0.601
FC_3	Exponential	115,200	0.088	9,600	0.147	0.374
FS_3	Exponential	115,200	0.044	9,600	0.021	0.677
TC_4	Exponential	65,718	0.107	9,600	0.071	0.601
FC_4	Exponential	35,004	0.086	9,600	0.113	0.432
FS_4	Hole Effect	35,665	0.050	9,600	0.039	0.562

*Period Number 1: Before 2010, 2: 2010 – 2012, 3: 2013 – 2015, 4: 2016 – 2018
**Sill = Partial Sill + Nugget

There is no specific pattern observed in nugget or sill values given in Table 4.34 in terms of BWQ parameters, however, when nugget to sill ratios are examined, it is observed that for all BWQ parameters, nugget/sill ratios are between 25 – 75%, indicating that there is a moderate spatial dependency (Essington, 2004). Depending on these model parameters, semivariogram models are obtained separately for each parameter and for each period. Cross-validation results for each BWQ parameter in each period is provided in Table 4.35. Cross-validation results shown in Table 4.35 validates the possibility of presence of higher measurement errors for FC in each period since RMSE values are higher for FC in most periods.

Table 4.35. *Cross Validation Results for Black Sea Region*

Parameter_Period*	*RMSE*	*ASE*	*ME*	*MSE*	*RMSSE*
TC_1	0.332	0.334	-0.001	-0.004	1.002
FC_1	0.394	0.397	-0.003	-0.003	1.004
FS_1	0.330	0.349	-0.007	-0.012	1.001
TC_2	0.298	0.302	0.001	0.002	1.001
FC_2	0.349	0.352	0.003	0.008	1.004
FS_2	0.302	0.307	-0.004	-0.010	0.997
TC_3	0.332	0.338	-0.003	-0.009	1.002
FC_3	0.346	0.349	0.002	0.002	1.000
FS_3	0.229	0.231	0.002	0.008	0.998
TC_4	0.368	0.371	-0.001	-0.003	0.998
FC_4	0.363	0.368	0.002	0.005	0.998
FS_4	0.247	0.254	-0.001	-0.005	1.002

* Period Number 1: Before 2010, 2: 2010 – 2012, 3: 2013 – 2015, 4: 2016 – 2018

When ASE and RMSE values are compared, it is observed as prediction of errors are correct because difference between them is at most 2%. Another kind of cross validation that is conducted in this study is to compare indicator predictions with measured data, i.e. average BWQ concentrations at each sampling point. Figure 4.103, Figure 4.104 and Figure 4.105 provides the indicator predictions at each data point, for TC, FC and FS, respectively.

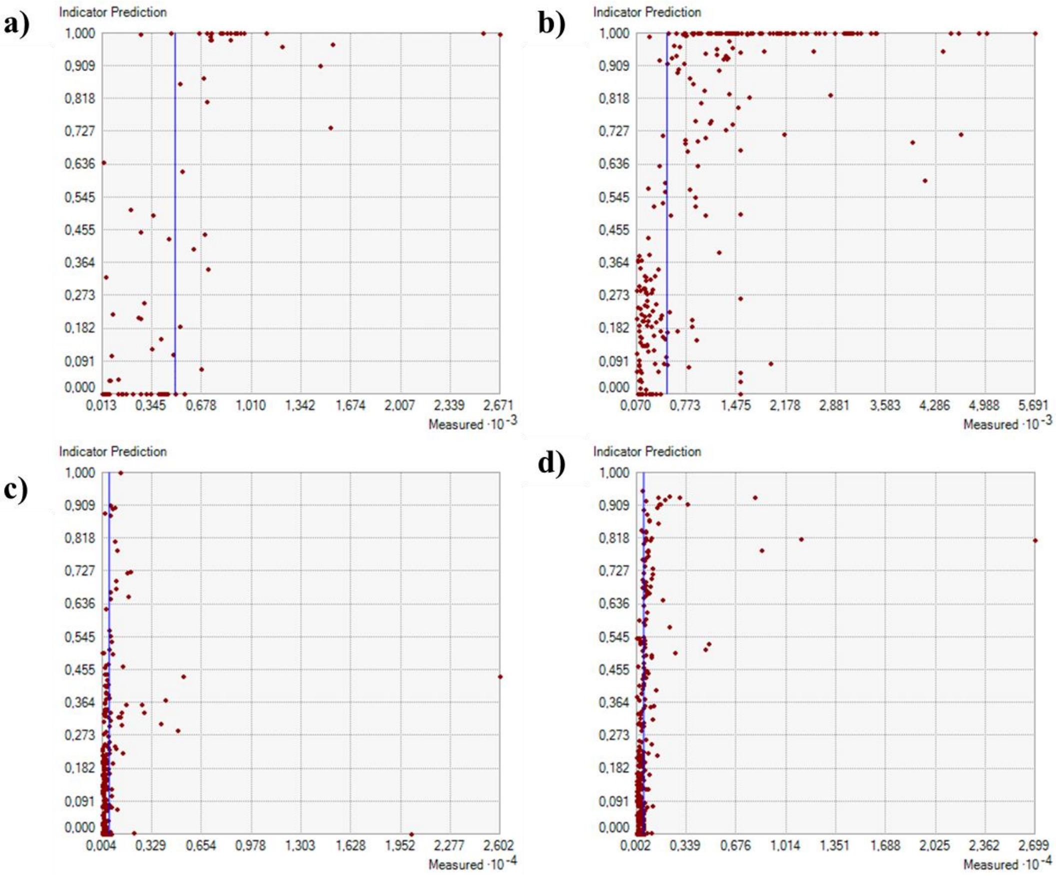


Figure 4.103. Indicator Predictions of TC for Black Sea Region between a) 1996 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

Figure 4.103 shows that, recently, i.e. between 2016 - 2018, TC indicator predictions, therefore, exceedance probabilities are mostly lower than 50%. However, there are also some bathing areas with exceedance probabilities over 70% This indicates that, in those areas there is high levels of fecal pollution which poses risk on marine environment and health of bathers using Black Sea for recreational purposes.

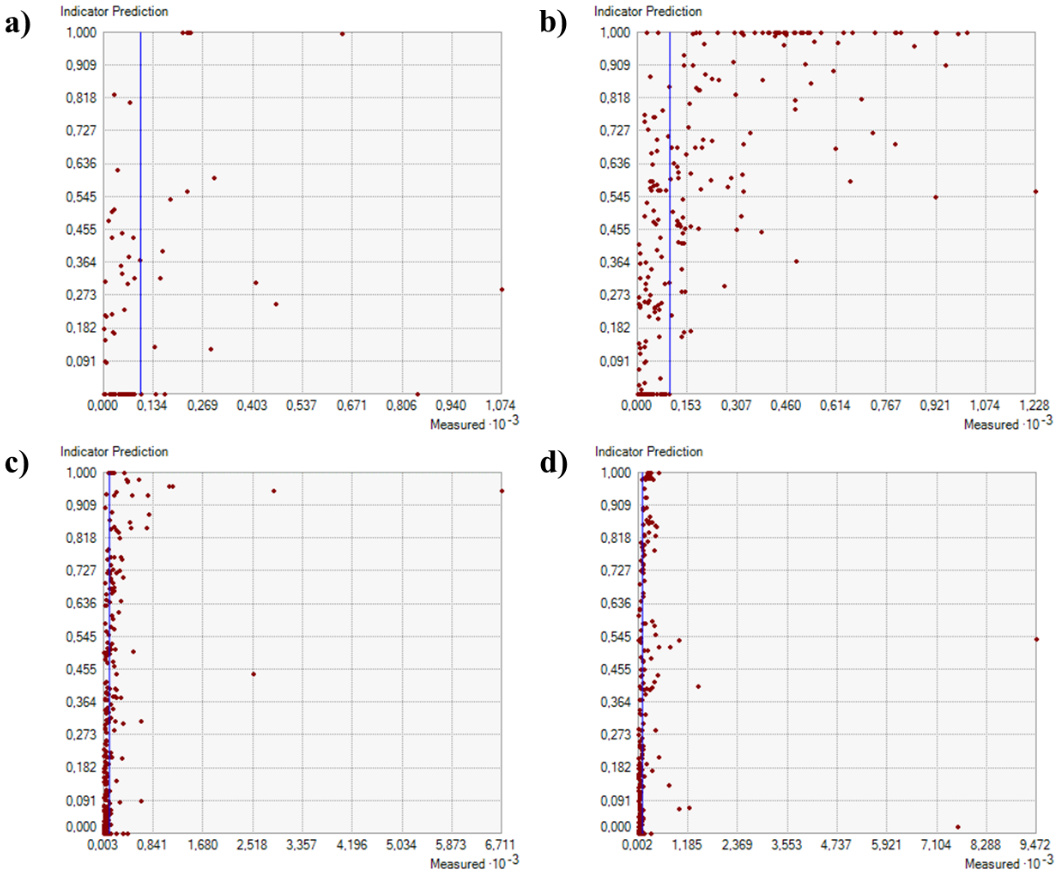


Figure 4.104. Indicator Predictions of FC for Black Sea Region between a) 1996 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

When indicator predictions of FC is analyzed especially between 2010 – 2012, i.e. GA Period 2, exceedance probabilities are mostly higher than 90%, which indicates that there is high levels of fecal pollution creates risk on Black Sea environment and health of bathers using Black Sea for recreational purposes (Figure 4.104b).

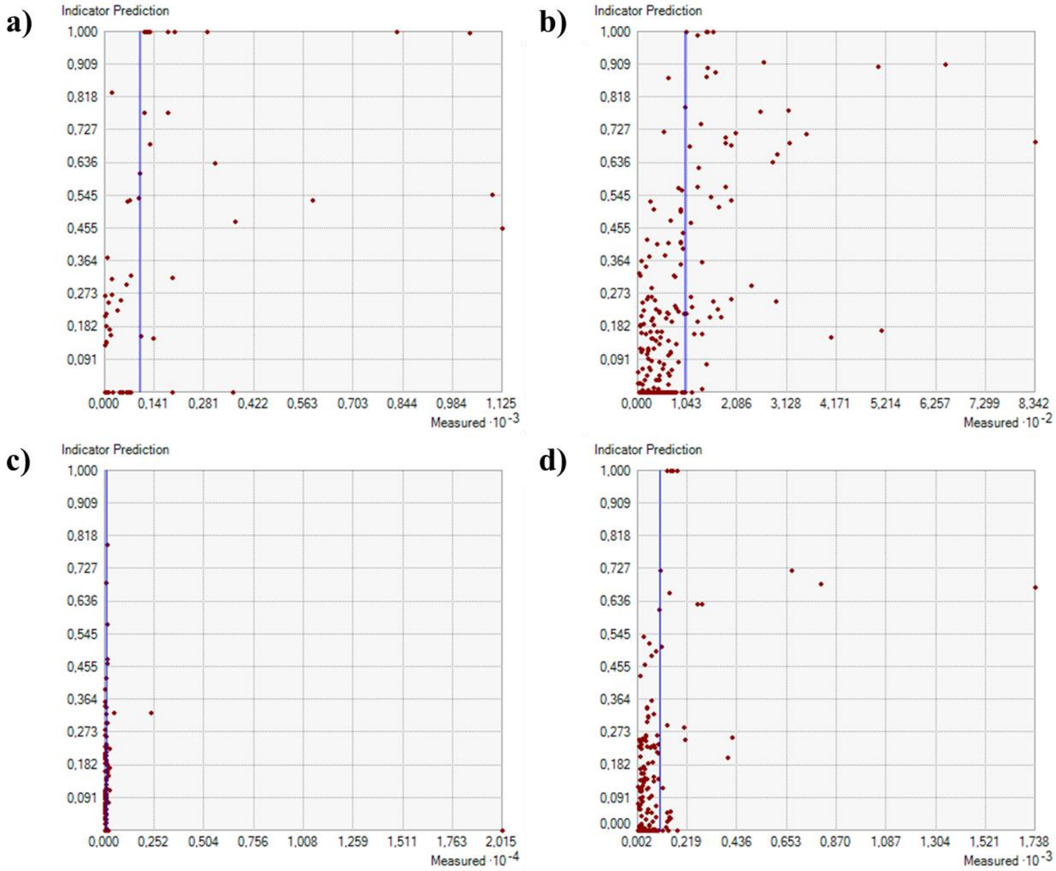


Figure 4.105. Indicator Predictions of FS for Black Sea Region between a) 1996 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

Unlike TC and FC, FS shows more optimistic results in terms of exceedance probabilities (Figure 4.105). Between 2016 – 2018, most of the exceedance probabilities are below 55%. Same situation is also valid for other GA periods. Exceedance probability maps were also obtained for each period for all three BWQ parameters. From Figure 4.106 to Figure 4.117 threshold exceedance probabilities for 1996 – 2010, 2010 – 2012, 2013 – 2015 and 2016 – 2018 periods are shown, respectively.

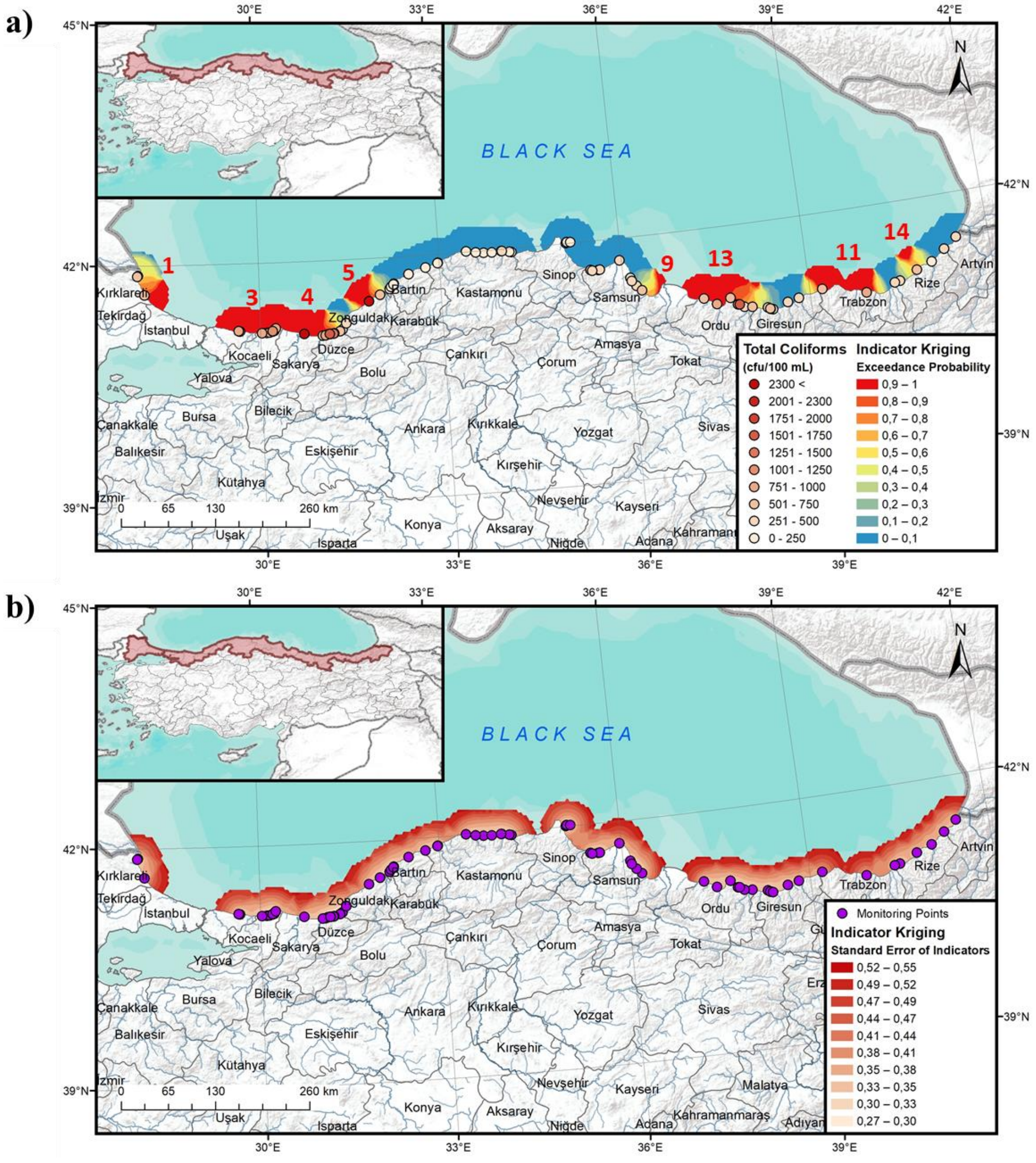


Figure 4.106. a) Exceedance probability and b) standard error maps generated for Black Sea Region before 2010 for TC (GA period 1)

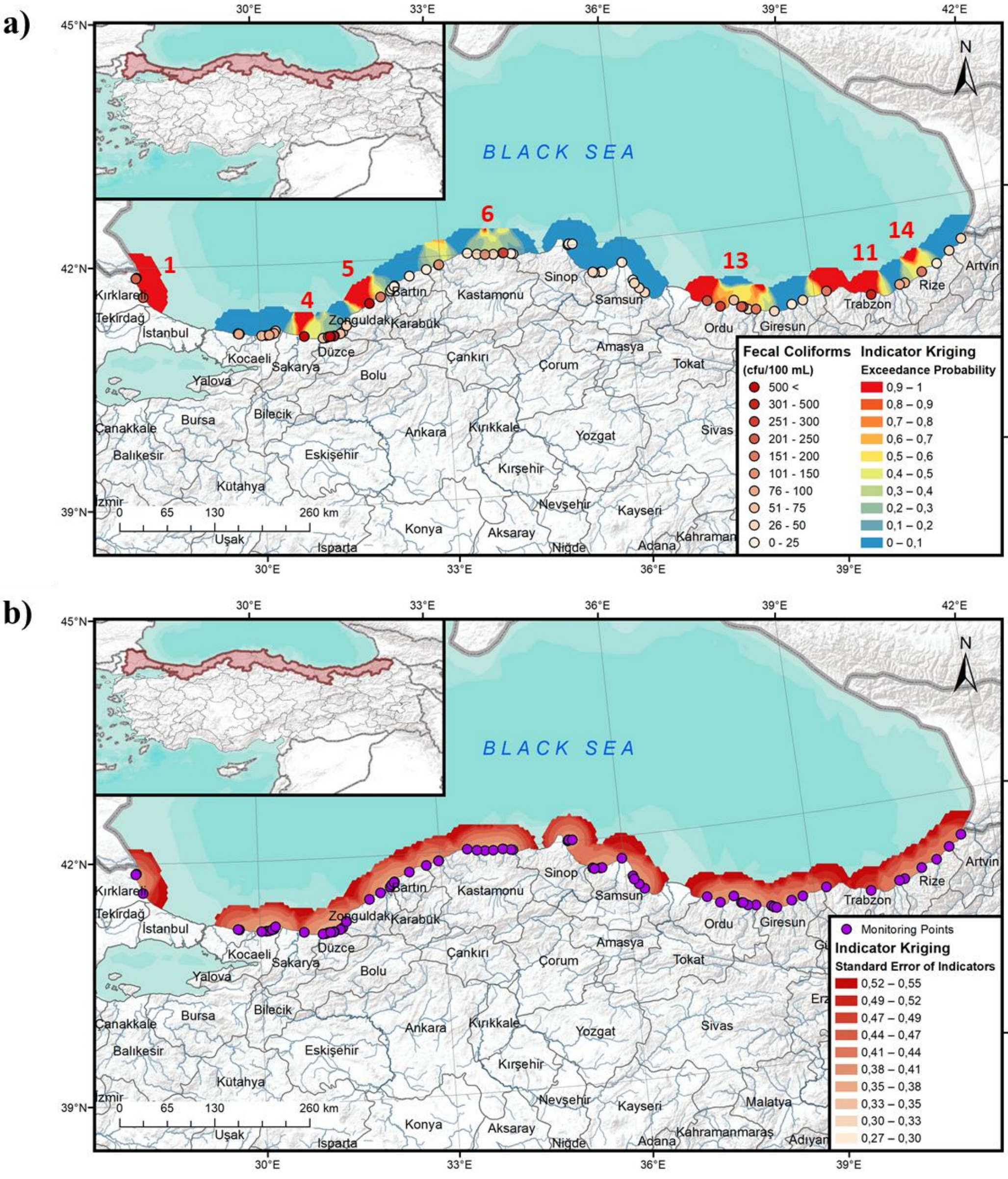


Figure 4.107. a) Exceedance probability and b) standard error maps generated for Black Sea Region before 2010 for FC (GA period 1)

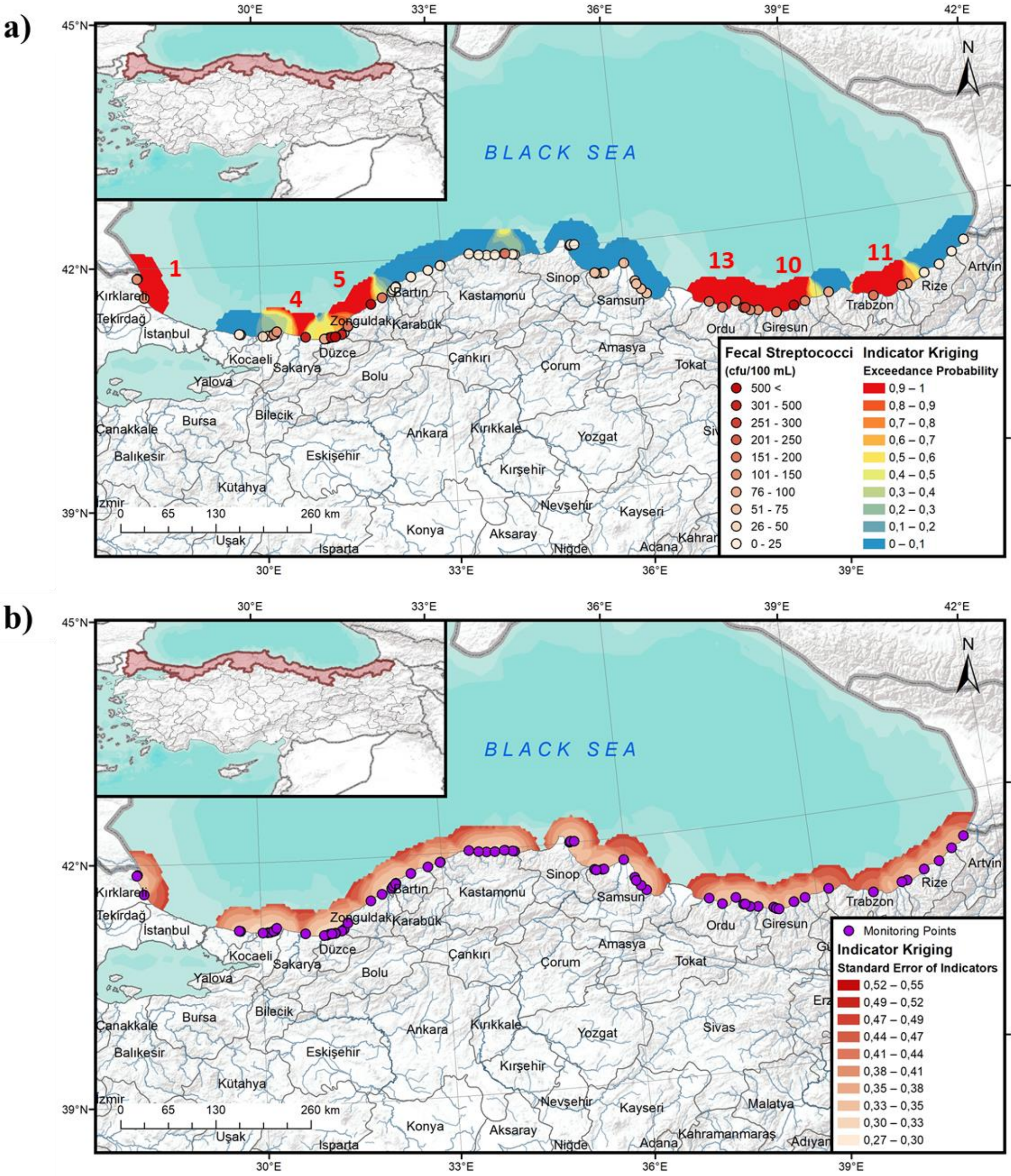


Figure 4.108. a) Exceedance probability and b) standard error maps generated for Black Sea Region before 2010 for FS (GA period 1)

As can be seen from Figure 4.106, Figure 4.107 and Figure 4.108 before 2010, Kırklareli coast (1), Sakarya river mouth (4), Zonguldak (5), Ordu (13) and Trabzon (11) shows critical BWQ in terms of all three parameters in GA period 1. TC also show poor BWQ near Şile/İstanbul and Kandıra/Kocaeli (3) and FS show poor BWQ around Giresun coast (10). In addition to these, TC and FC show critical appearance around Rize (14) shoreline. The error maps show FS has lower errors, ranged between

27 – 44 %, in comparison to TC (30 – 49%) and FC (35 – 55%). However, for all BWQ parameters errors are lower when predicted points become closer to coastal zone, as expected. Therefore, lowest errors are considered for each BWQ parameters' standard error of indicators maps.

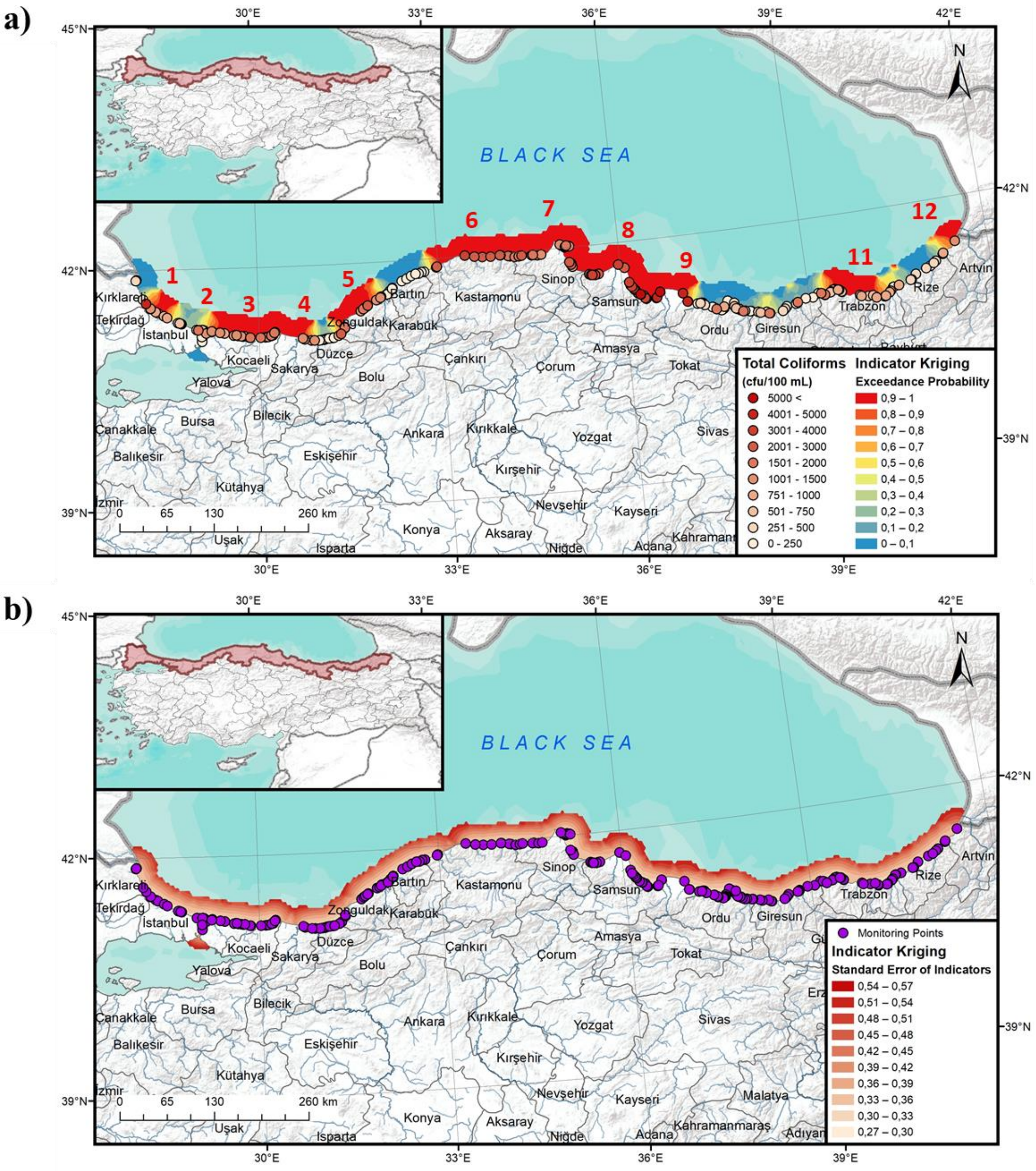


Figure 4.109. a) Exceedance probability and b) standard error maps generated for Black Sea Region over years 2010 – 2012 for TC (GA period 2)

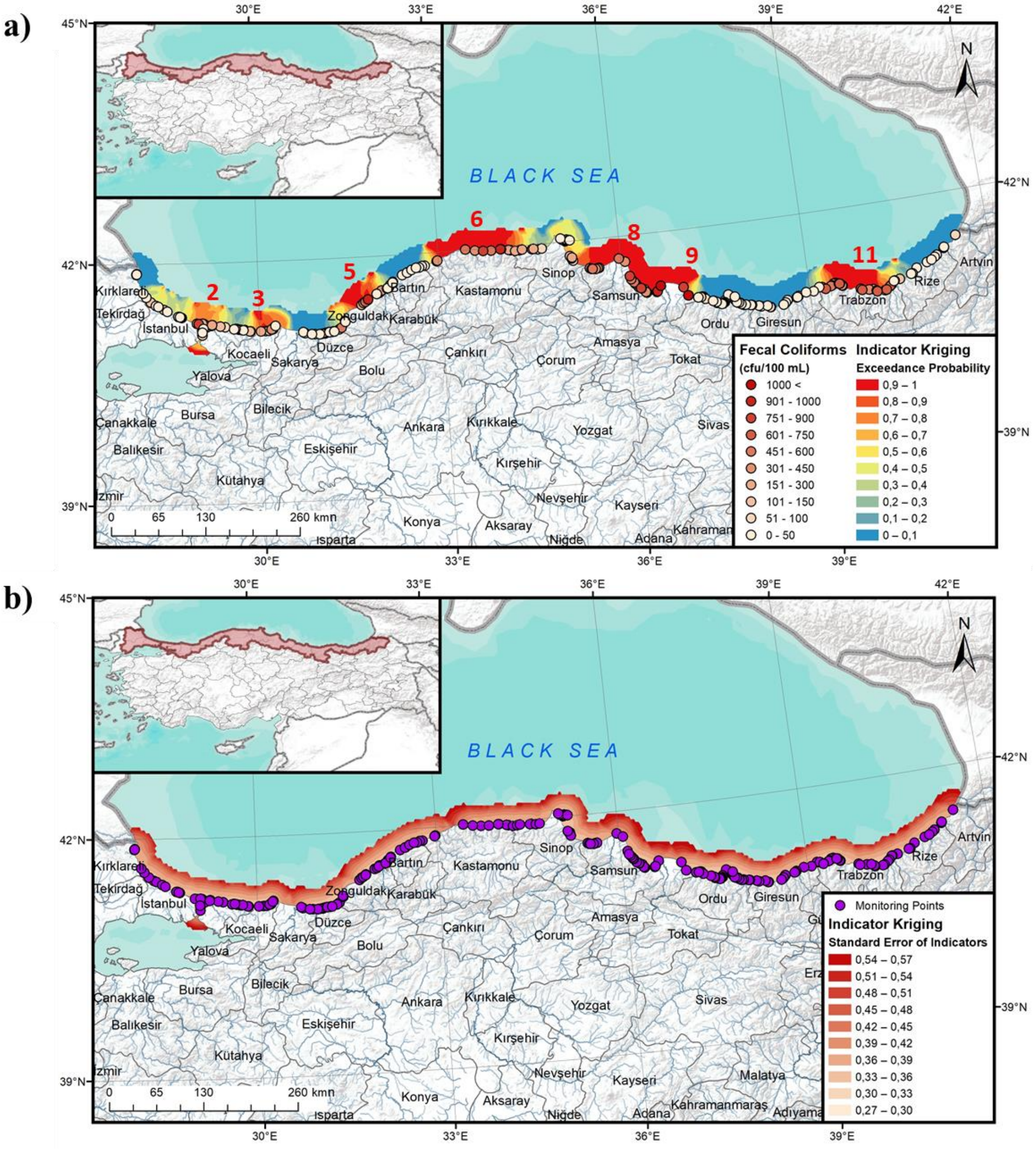


Figure 4.110. a) Exceedance probability and b) standard error maps generated for Black Sea Region over years 2010 – 2012 for FC (GA period 2)

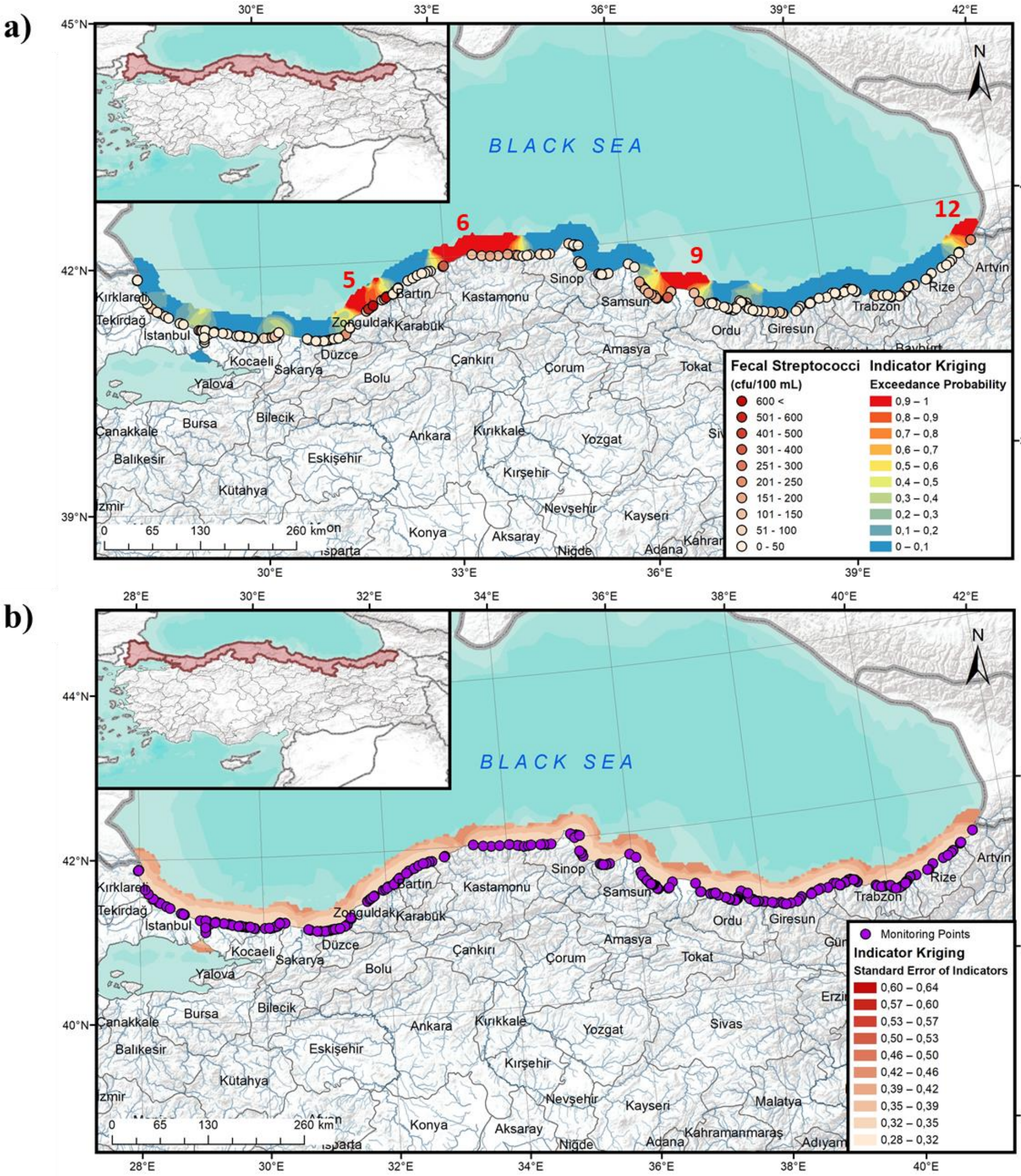


Figure 4.111. a) Exceedance probability and b) standard error maps generated for Black Sea Region over years 2010 – 2012 for FS (GA period 2)

After 2010, number of monitoring stations along Black Sea coastline has increased significantly. Although, according to FC and FS parameters in terms a range of BWQ was present, i.e. there exists areas with poor BWQ as well as sufficient BWQ, according to TC measurements insufficient BWQ dominated the region, yet there is both good and poor BWQ according to FC and FS measurements. This may be related to the source of pollution; during that period the main pollution source causing high

TC concentrations may be land/soil related. Therefore, hydrological events such as runoffs or anthropogenic activities such as construction or agriculture may be the cause of the observed difference between TC and other BWQ parameters. However, there were also some areas such as Yeşilırmak river mouth (9), Zonguldak (5) and Kastamonu (6) coasts which had high exceedance probabilities over 90% in terms of all three BWQ parameters. This clearly indicates the presence of a fecal contamination in these regions.

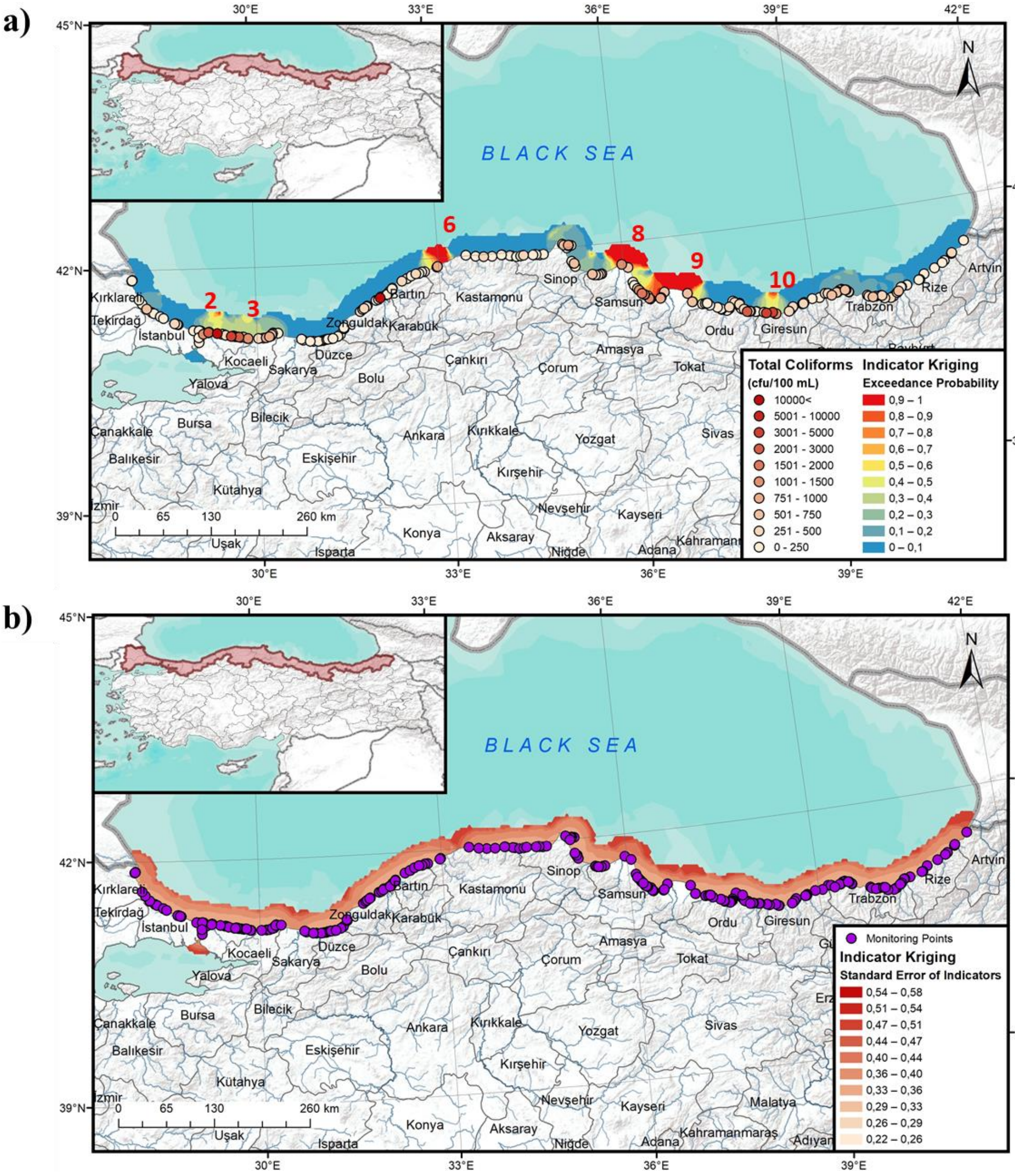


Figure 4.112. a) Exceedance probability and b) standard error maps generated for Black Sea Region over years 2013 – 2015 for TC (GA period 3)

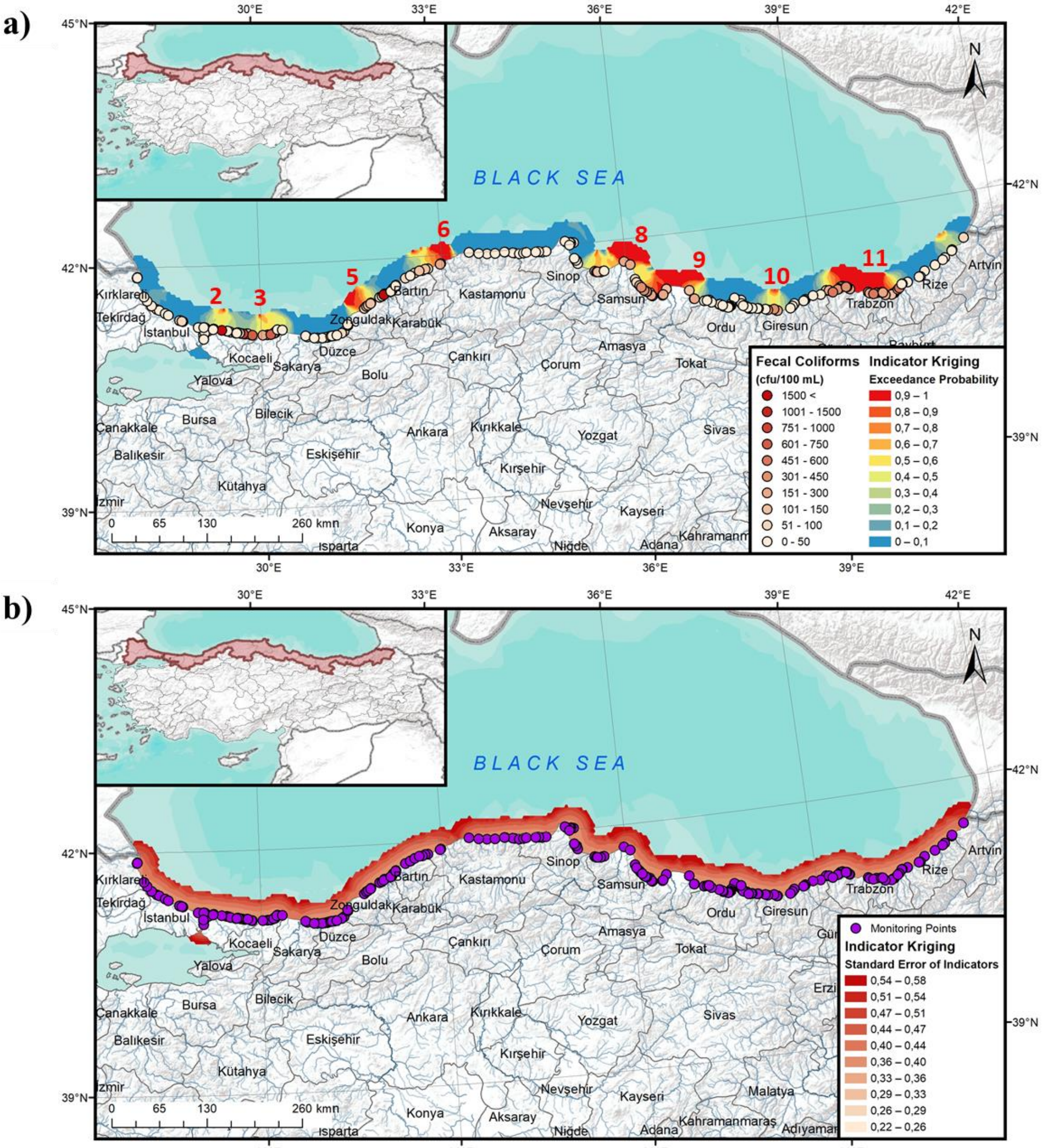


Figure 4.113. a) Exceedance probability and b) standard error maps generated for Black Sea Region over years 2013 – 2015 for FC (GA period 3)

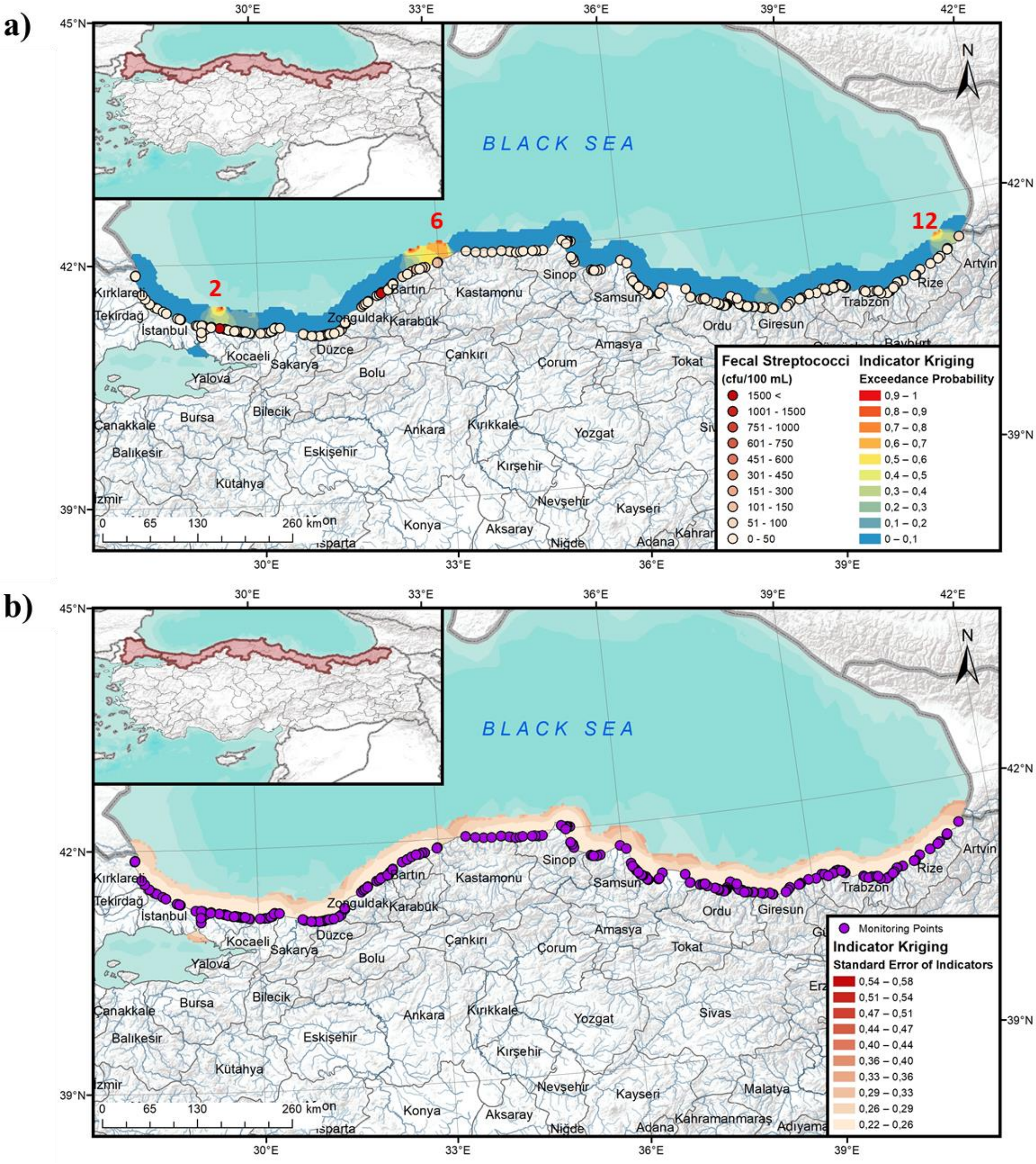


Figure 4.114. a) Exceedance probability and b) standard error maps generated for Black Sea Region over years 2013 – 2015 for FS (GA period 3)

An improved BWQ was observed in GA period 3 in comparison to GA period 2, especially when the graphs generated for TC were analyzed. However, there were still some critical regions present. Between 2013 – 2015 all three BWQ parameters show critical patterns in same regions, namely Bosphorus (2) and Kastamonu coast (6). However, TC and FC also shows critical behavior in additional locations such as Zonguldak (5), Kızılırmak (8) and Yeşilırmak (9) river mouths, and Trabzon coastline

(11). When the FC/FS ratios in those regions are compared it is observed that human originated fecal contamination is dominating in these areas (Table 4.36). The error maps show TC and FS has lower errors, ranged between 22 –40 %, in comparison to FC (error range 40 – 58%).

Table 4.36. *FC/FS Ratios in Critical Bathing Regions of Black Sea*

Monitoring Point	FC_{ave} *(cfu/100 mL)*	FS_{ave} *(cfu/100 mL)*	*FC/FS*
Alaçam_1	99.3	16.7	5.9
Alaçam_2	37.1	11.6	3.2
Alaçam_3	144.5	15.7	9.2
Arnavutköy_1	53.4	5.9	9.1
Arnavutköy_2	51.9	8.5	6.1
Arnavutköy_3	63.9	5.6	11.3
Arnavutköy_4	58.6	7.5	7.8
Arnavutköy_5	56.7	8.9	6.4
Atakum_1	399.1	50.0	8.0
Atakum_2	416.5	54.6	7.6
Atakum_3	321.3	153.0	2.1
Atakum_4	374.3	70.9	5.3
Atakum_5	114.6	14.4	7.9
Atakum_6	105.2	13.8	7.6
Atakum_7	66.5	12.2	5.5
Atakum_8	247.5	73.3	3.4
Atakum_9	122.4	42.3	2.9
Atakum_10	297.2	80.6	3.7
Bafra_1	156.1	14.2	11.0
Bafra_2	219.9	18.9	11.7
Canik_1	241.9	35.8	6.8
Çarşamba_1	111.5	50.6	2.2
Çarşamba_2	187.5	49.8	3.8
Çarşamba_3	202.0	35.9	5.6
Çatalca_1	3.1	7.8	0.4
Çatalca_2	8.9	23.1	0.4
Çatalca_3	7.5	13.6	0.6
Çatalca_4	114.1	12.1	9.4
Çatalca_5	3.8	21.5	0.2
Çatalca_6	8.6	26.5	0.3
Çatalca_7	32.7	15.5	2.1
İlkadım_1	94.6	10.7	8.8
İlkadım_2	213.2	17.4	12.2

Monitoring Point	*FC_{ave} (cfu/100 mL)*	*FS_{ave} (cfu/100 mL)*	*FC/FS*
Kandıra_1	62.5	29.9	2.1
Kandıra_2	322.8	23.0	14.0
Kandıra_3	749.7	14.4	52.0
Kandıra_4	369.2	50.0	7.4
Kandıra_5	409.3	17.0	24.1
Kandıra_6	172.1	34.1	5.1
Kandıra_7	99.1	21.4	4.6
Kandıra_8	291.2	21.1	13.8
Kandıra_9	1.6	2.0	0.8
Ondokuzmayıs_1	59.7	13.0	4.6
Ondokuzmayıs_2	68.3	22.5	3.0
Şile_1	83.3	27.0	3.1
Şile_2	718.4	177.4	4.1
Şile_3	85.4	26.8	3.2
Şile_4	82.8	48.2	1.7
Şile_5	955.4	251.6	3.8
Şile_6	47.0	35.3	1.3
Şile_7	56.4	32.8	1.7
Şile_8	36.5	29.7	1.2
Şile_9	71.4	31.9	2.2
Şile_10	74.9	17.3	4.3
Şile_11	75.3	24.9	3.0
Şile_12	50.0	39.5	1.3
Şile_13	324.4	143.2	2.3
Şile_14	71.9	33.7	2.1
Şile_15	51.0	8.8	5.8
Şile_16	480.7	247.5	1.9
Şile_17	35.0	38.6	0.9
Şile_18	64.2	38.7	1.7
Şile_19	109.4	29.4	3.7
Şile_20	95.3	46.7	2.0
Şile_21	98.0	77.3	1.3
Şile_22	22.8	28.3	0.8
Şile_23	9472.0	2352.7	4.0
Şile_24	967.5	436.3	2.2
Terme_1	189.9	13.6	14.0
Terme_2	99.9	17.6	5.7
Terme_3	142.2	24.1	5.9
Yakakent_1	118.6	16.7	7.1
Yakakent_2	114.6	18.8	6.1
Yakakent_3	116.5	29.1	4.0

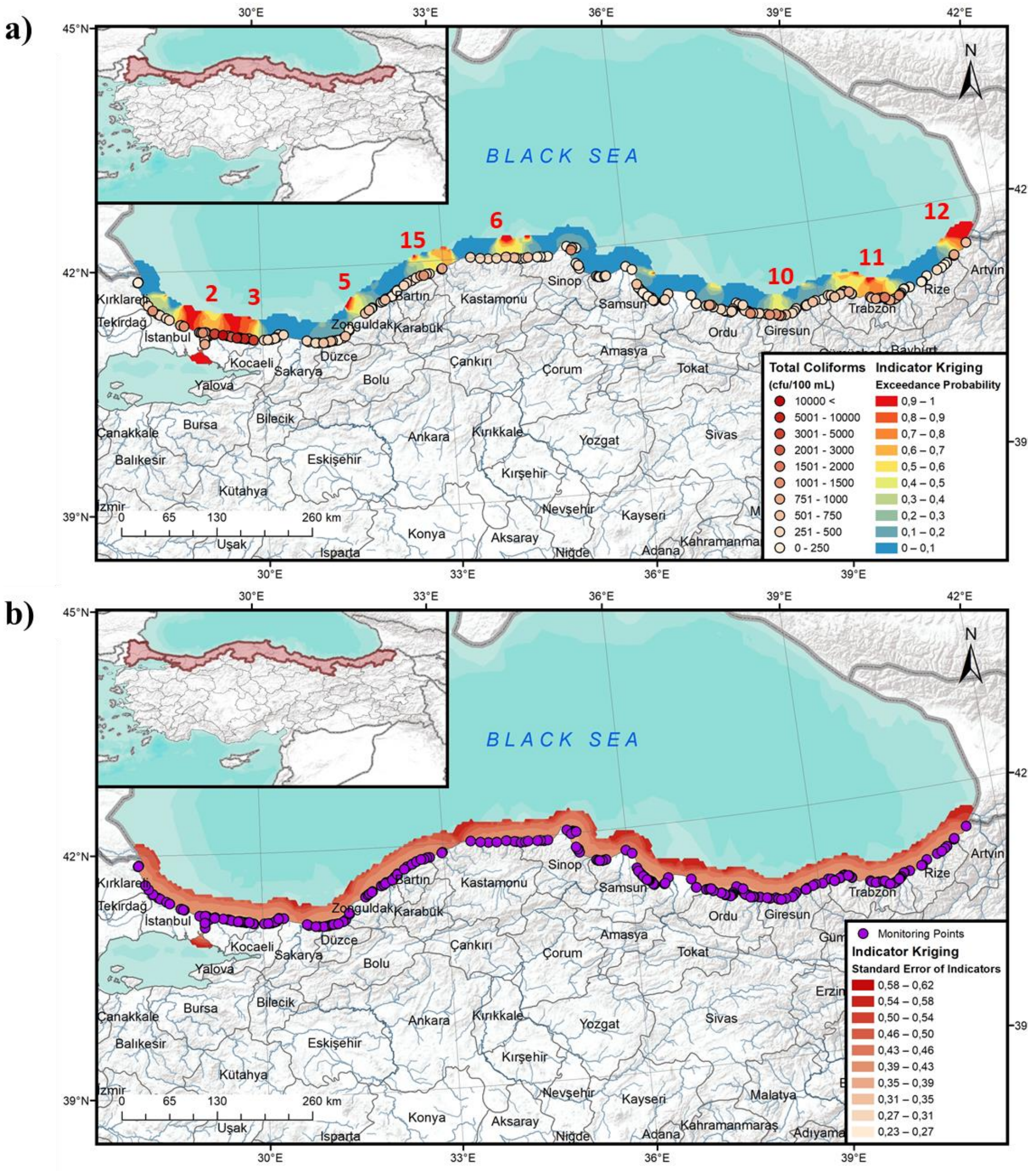


Figure 4.115. a) Exceedance probability and b) standard error maps generated for Black Sea Region over years 2016 – 2018 for TC (GA period 4)

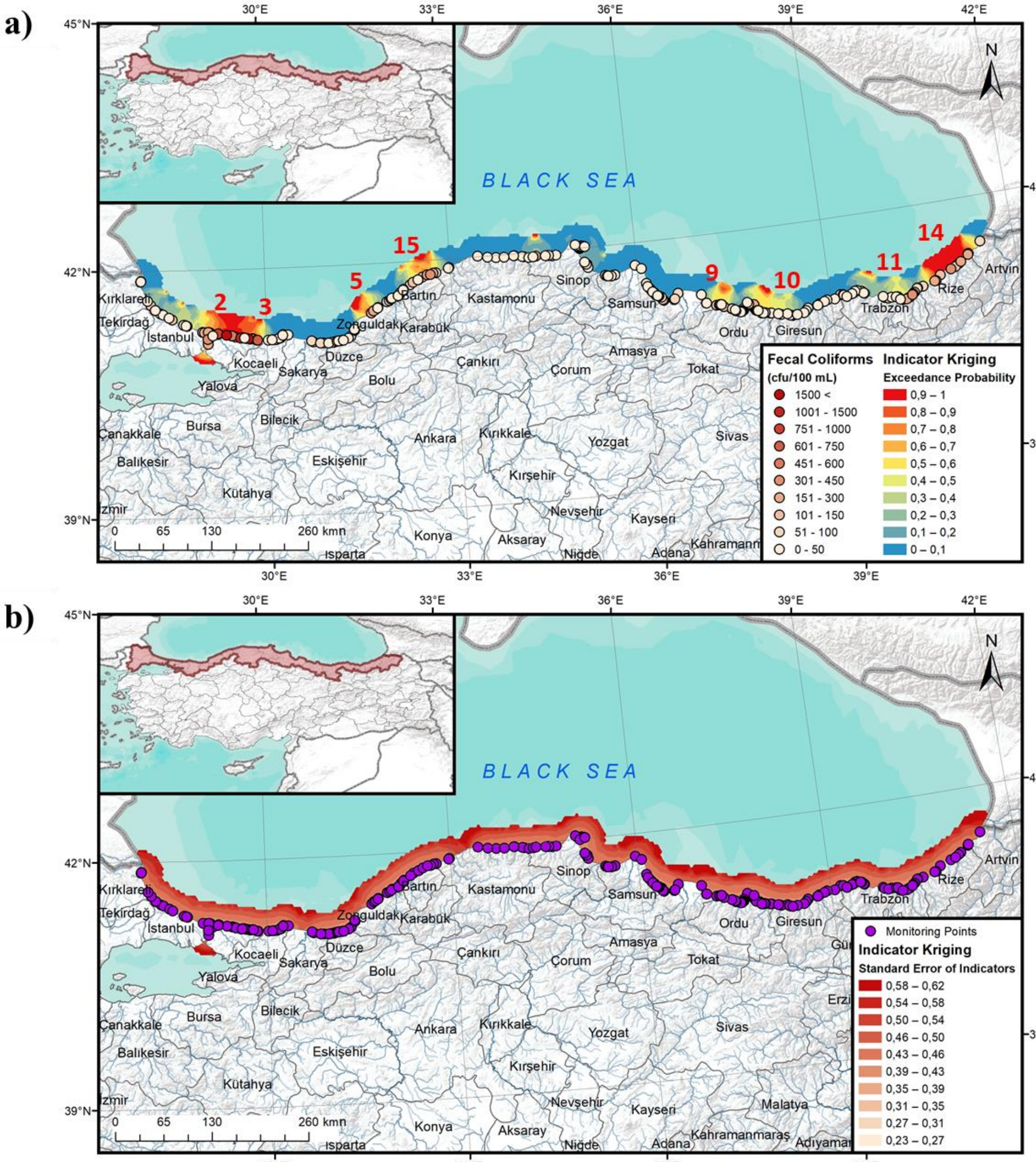


Figure 4.116. a) Exceedance probability and b) standard error maps generated for Black Sea Region over years 2016 – 2018 for FC (GA period 4)

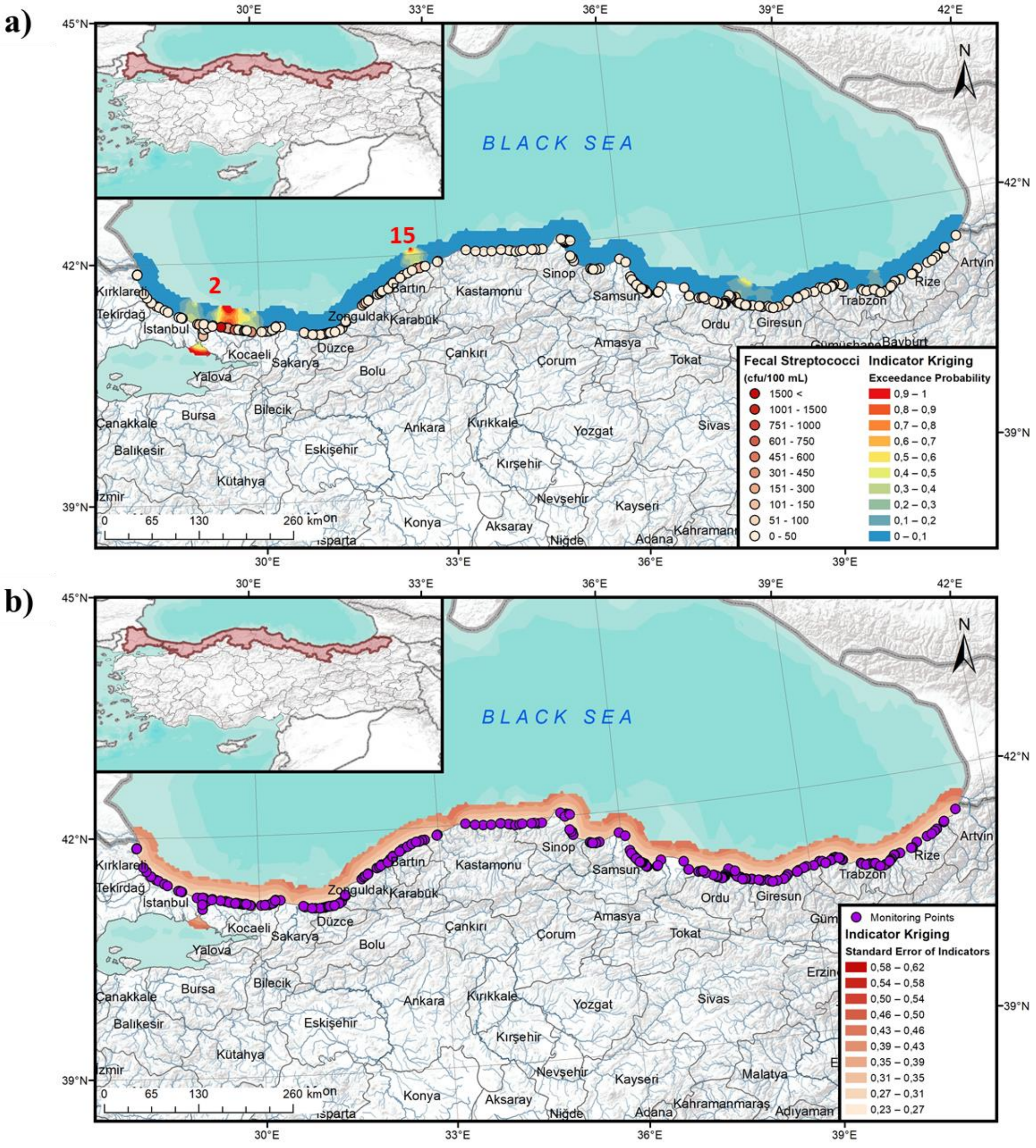


Figure 4.117. a) Exceedance probability and b) standard error maps generated for Black Sea Region over years 2016 – 2018 for FS (GA period 4)

It is observed that moving from GA period 3 to 4 the improvement continued, except the coastal zone near Marmara Sea. For example, Kızılırmak (8) and Yeşilırmak (9) river mouths shows a significant improvement. Between 2016 – 2018, in terms of TC and FC, Black Sea coastlines show poor BWQ around Bosphorus (2), Şile/İstanbul and Kandıra/Kocaeli (3), Zonguldak coast (5), Bartın coast (15) and Rize coast (14). Even though FS illustrates a relatively better scenario than other BWQ parameters, only for Bosphorus (2) FS also show critical BWQ. In this period, errors are also higher for FC than other BWQ parameters which makes FC results less reliable in comparison to others. Figures 4.129b and 4.131b depicts that the error in TC ranged between 35 and 50%, and for FS it was between 23 and 35%. For FC, measured values show high variety, i.e. closer measurement locations do not show similar behavior in all areas, which leads an increase in standard errors (ranged between 49 – 62%).

Since FC/FS ratios underline that fecal contamination is mostly related with human sources, impacts of WWTPs, which are considered as one of the main human originated fecal pollution sources, on Black Sea coastline was investigated. Figure 4.118 provides the locations of WWTPs which are discharging to Black Sea or rivers those flow through Black Sea.

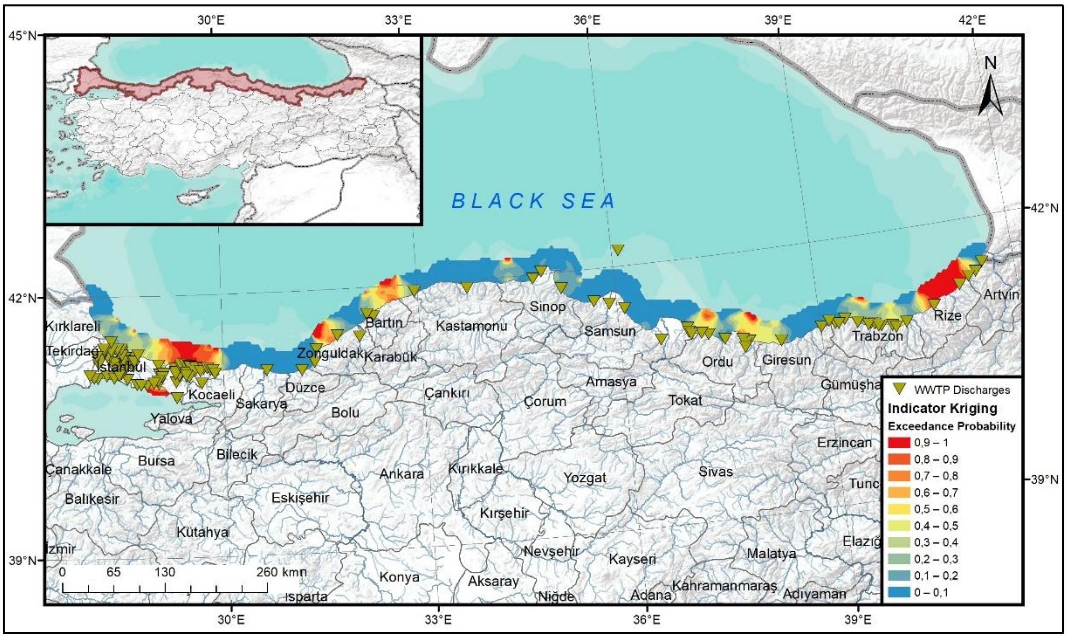


Figure 4.118. WWTP Discharge Locations in Black Sea Region embedded in FC Exceedance Probability Map for GA Period 4 (İstanbul Provincial Directorate of Environment and Urbanization, 2018; Kocaeli Provincial Directorate of Environment and Urbanization, 2018; Rize Provincial Directorate of Environment and Urbanization, 2018; Samsun Provincial Directorate of Environment and Urbanization, 2018; Kırklareli Provincial Directorate of Environment and Urbanization, 2018; Düzce Provincial Directorate of Environment and Urbanization, 2018; Zonguldak Provincial Directorate of Environment and Urbanization, 2018; Bartın Provincial Directorate of Environment and Urbanization, 2018; Kastamonu Provincial Directorate of Environment and Urbanization, 2018; Sinop Provincial Directorate of Environment and Urbanization, 2018)

According to Figure 4.118, areas with high number of WWTP outfalls also show correlation with poor BWQ. This case is especially observed around Bosphorus. Although, number of WWTP discharge points are not as much as Bosphorus, along Rize shoreline, it is reported that, untreated wastewater discharges through Black Sea is present and one of the main environmental problems in the region is the inadequacy of WWTP, especially in the city center there is no WWTP (Rize Provincial Directorate of Environment and Urbanization, 2018). In addition to these, Samsun, where an improvement in BWQ has observed as time passes, after 2014 a deep sea discharge system has started to operate for wastewater treatment (Samsun Provincial Directorate of Environment and Urbanization, 2018). To validate the impacts of WWTPs, distribution of population density around the region was also evaluated. Figure 4.119 illustrates the population densities in the Black Sea region.

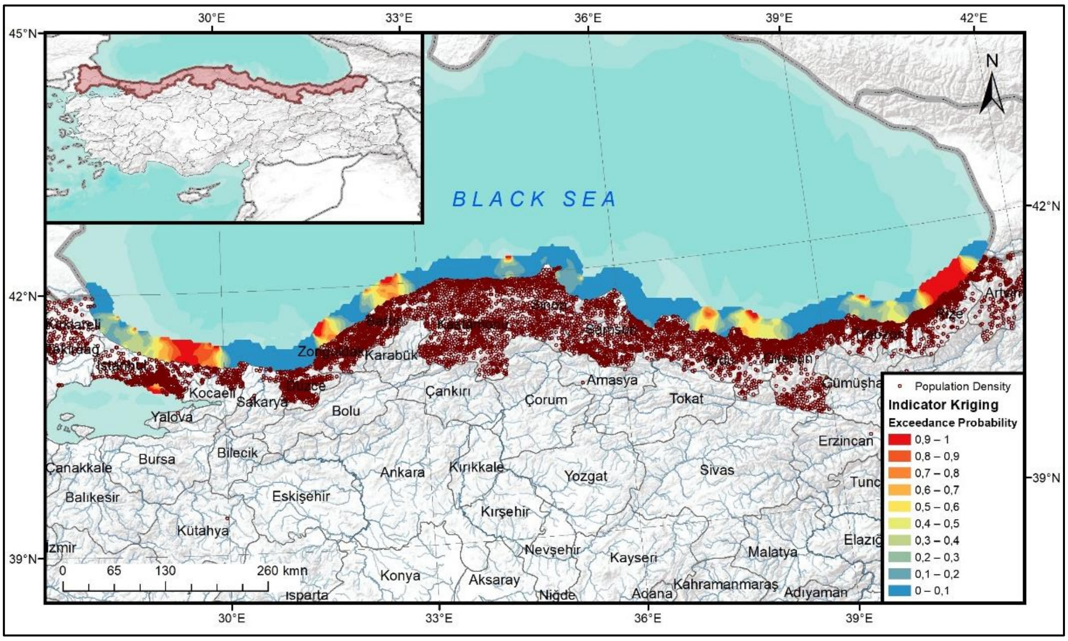


Figure 4.119. Population Density Along Black Sea Region embedded in FC Exceedance Probability Map for GA Period 4 (Adapted from: TÜİK, 2018)

Figure 4.119 shows that the population in the Black Sea region is mostly settled in the coastal regions which also validates that the main source of fecal pollution in the region is human activities. Also, one of the most populated and industrialized city in the region, namely Zonguldak, also shows critical BWQ. This figure is also correlated with locations of WWTPs since increase in population density leads to an increase in wastewater load of WWTPs. Therefore, population densities validate the relationship between critical bathing sites and WWTPs.

4.4.3. Concluding Remarks for Black Sea Region

- Black Sea is the region where the highest amount of annual precipitation occurs in Turkey. Although, climatic conditions are not available for bathing activities for most of the time, region has a long coastline.
- There is total of 366 monitoring stations in Black Sea region for all GA periods.
- For all GA periods semivariograms show moderate spatial dependency regarding nugget/sill ratios.
- Bathing sites around Bosphorus (2) shows critical appearance in terms of all BWQ parameters in each GA period (Table 4.37).

Table 4.37. *Coastal areas with >90% threshold exceedance probability in the Black Sea Region*

Period	*TC*	*FC*	*FS*
Before 2010	1-3-4-5-9-11-13	1-4-5-11-13	1-4-5-10-11-13
2010 – 2012	1-3-4-5-6-7-8-9-11-12	3-5-6-8-9-11	5-6-9-12
2013 – 2015	6-8-9	5-6-8-9-11	-
2016 – 2018	2-3-12	2-3-14	2

- TC and FC show similar patterns in Black Sea coastline; however, FS differs in illustrating BWQ in the region for all GA periods.
- For more recent periods, an improvement in BWQ along Black Sea coastline was observed.
- Discharge locations of WWTPs show correlation with exceedance probabilities of FC between 2016 – 2018.

Table 4.38. *The frequency of observation of >90% threshold exceedance probability a critical BWQ in a given coastal area* in Black Sea region*

Regions**	*Designated Areas*	*All Periods*	*Last Two Period*
1	Kırklareli Coast	4	-
2	Bosphorus	3	3
3	Şile/İstanbul and Kandıra/Kocaeli	5	2
4	Sakarya River Mouth	4	-
5	Zonguldak Coast	7	1
6	Kastamonu Coast	5	2
7	Sinop Coast	1	-
8	Kızılırmak River Mouth	4	2
9	Yeşilırmak River Mouth	6	2
10	Giresun Coast	1	-
11	Trabzon Coast	6	1
12	Artvin Coast	3	1
13	Ordu Coast	3	-
14	Rize Coast	1	1
15	Bartın Coast	-	-

**Coastal Areas are designated with a number.*
*** Table 4.33 shows the designated areas.*

Based on the data analysis stated in Section 3.2 using Table 4.38 above Bosphorus is determined as the only critical BWQ site for Black Sea region.

CHAPTER 5

CONCLUSION

Fecal pollution was reported as one of the main causes of bathing water related diseases, such as gastrointestinal illnesses, eye-skin-throat infections, acute febrile respiratory illnesses and so on. Therefore, monitoring of BWQ is imperative and conducted by the Ministry of Health in Turkey. The data collected by the Ministry almost over 25 years of time, and yet there was no spatio-temporal BWQ analysis conducted so far. The BWQ related samples were analyzed for three microbiological parameters namely TC, FC and FS. In order to determine the critical bathing sites of Turkey in the coastlines of Turkey coastline we have adopted a geostatistical method called kriging. Kriging is a spatial estimation method and there are several kriging methods that have been developed so far. Among other kriging methods, in this thesis IK has been selected for the ability to predict the BWQ of the non-monitored regions and the possibility of comparing BWQ with a threshold value rather than predicting the concentration of the parameter. Threshold values were selected as 500 cfu/ 100 mL for TC and, 100 cfu/100 mL for both FC and FS, which are regulatory criteria stated in Bathing Water Quality Control Regulation (Official Gazette Notice 26048, 2006).

As a result, IK, a geostatistical method, was selected to predict threshold exceedance probabilities of each BWQ parameter around each coastal zone of Turkey, namely Mediterranean, Aegean, Marmara and Black Sea. In the Marmara coastal zone, the most critical region was identified as Marmara Island. In Black Sea region, although, BWQ shows high variation along all coastline and for the current situation, critical regions was identified as Bosphorus. Mediterranean region also showed critical appearance in one bathing site which is identified as the river mouth of Orontes. The possible cause of insufficient BWQ observed in this area may be stated as the contribution of the fecal pollution into bathing sites. Unlike, other three coastal zones, according to analysis results Aegean region had no critical bathing region which eliminates the potential risks. For regions showing critical BWQ, should be evaluated by decision-makers and the reasons lying behind them should be further investigated.

CHAPTER 6

RECOMMENDATIONS FOR FUTURE STUDIES

This study adopted a geostatistical tool for historical data analysis of BWQ and determined the critical regions of Turkey coastline without providing recommendations for managerial actions. However, the results of this study will be a guide to decision-makers to develop management options. Therefore, the most significant recommendation for future studies is on the identification of possible reasons of critical BWQ observance. A number of actions may be considered and move this work one step further. Recommendations for future studies are as follows:

- Several studies indicate that there is a significant relationship between meteorological events with BWQ, especially temporary deteriorations of BWQ is usually caused by high amounts of precipitation (Federigi, Verani, & Carducci, 2017; Noble, Moore, Leecaster, McGee, & Weisberg, 2003; Karydis & Kitsiou, 2013). Considering the results of this study, impact of meteorological events on Turkey coastline will be a good practice to develop management options for such situations.
- Whether a municipality has combined sewer overflow (CSO) system or not and impact of this on BWQ may be evaluated in a future study. This would also be helpful in identification of the insufficient BWQ due to meteorological events and thus diffused pollution since one cause of diffused pollution in water resources is urban runoff and contribution of this runoff to receiving bodies such as marine environment.
- Several studies indicated that aquaculture and coastal fish farms may contribute to fecal pollution (Cao, et al., 2007; Niemi & Taipalinen, 1982). There is no such study conducted in Turkey which examines whether fish farms have an impact on BWQ or not. Assessment of fish farms along coastline

regarding the BWQ would be a beneficial approach to determine the pollution causes and decide the management options.

- In this thesis, the impacts of marinas were evaluated only regarding the locations of the marinas. For more accurate assessment, other properties such as size, details of sewage discharge systems of marinas should be further investigated.

- Although the discharge locations of WWTPs were identified in this thesis, the treatment processes in urban and municipal WWTPs were not taken into consideration. Yet, the impact of WWTPs with and without a disinfection unit on BWQ may be different. Hence, a distinction between WWTPs according to the presence/absence of a disinfection unit and even the type of disinfection unit could be more informative. The main deficiency in regulatory criteria used for WWTP operations is that there are no regulatory criteria for fecal indicators in neither Regulation on Treatment of Urban Wastewaters nor the Water Pollution Control Regulation. Therefore, the evaluation of the contribution of WWTP discharges to the rivers (eventually to bathing sites) and the discussion on their impact on fecal pollution in bathing areas stays limited.

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APPENDIX A

SEMIVARIOGRAMS OF GEOSTATISTICAL ANALYSES

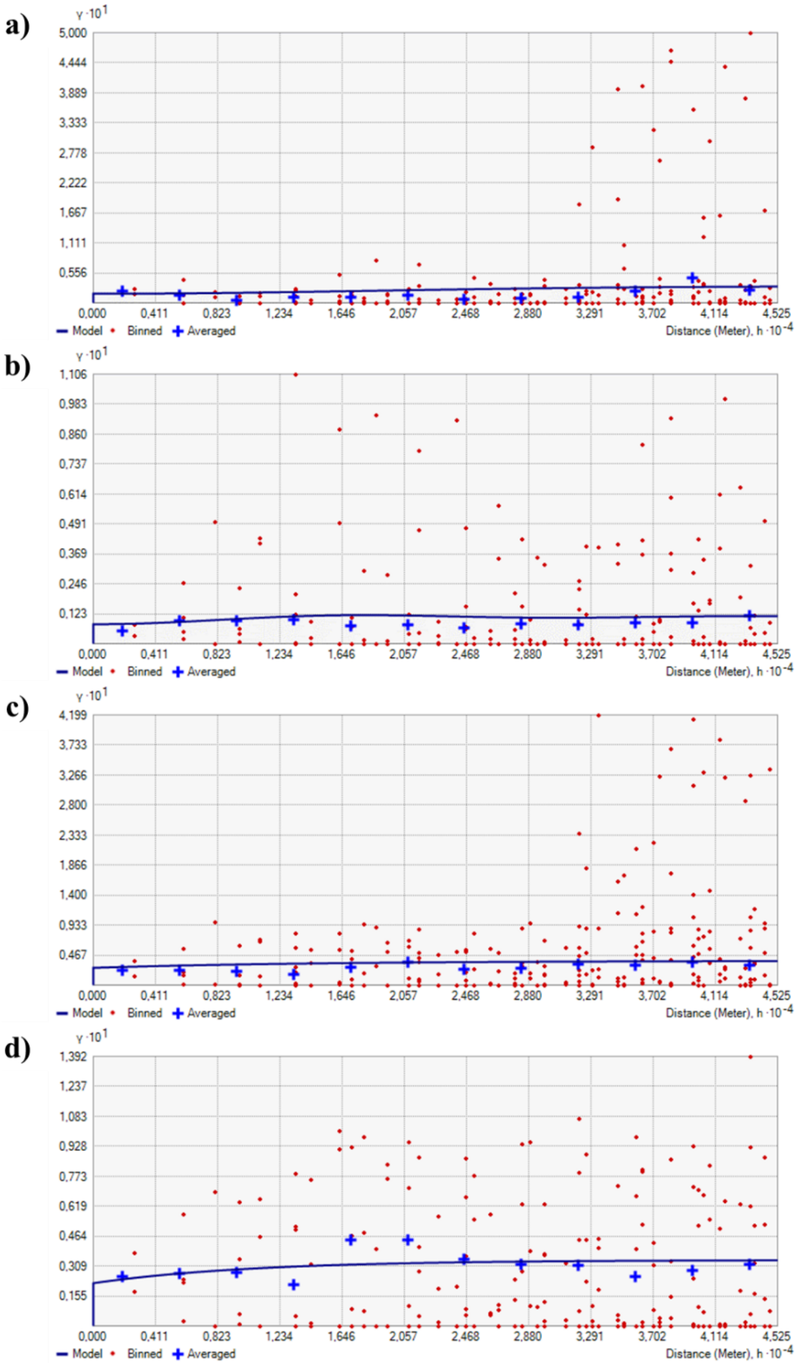

Figure A-1: Semivariograms for TC in Mediterranean Region between a) 1993 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

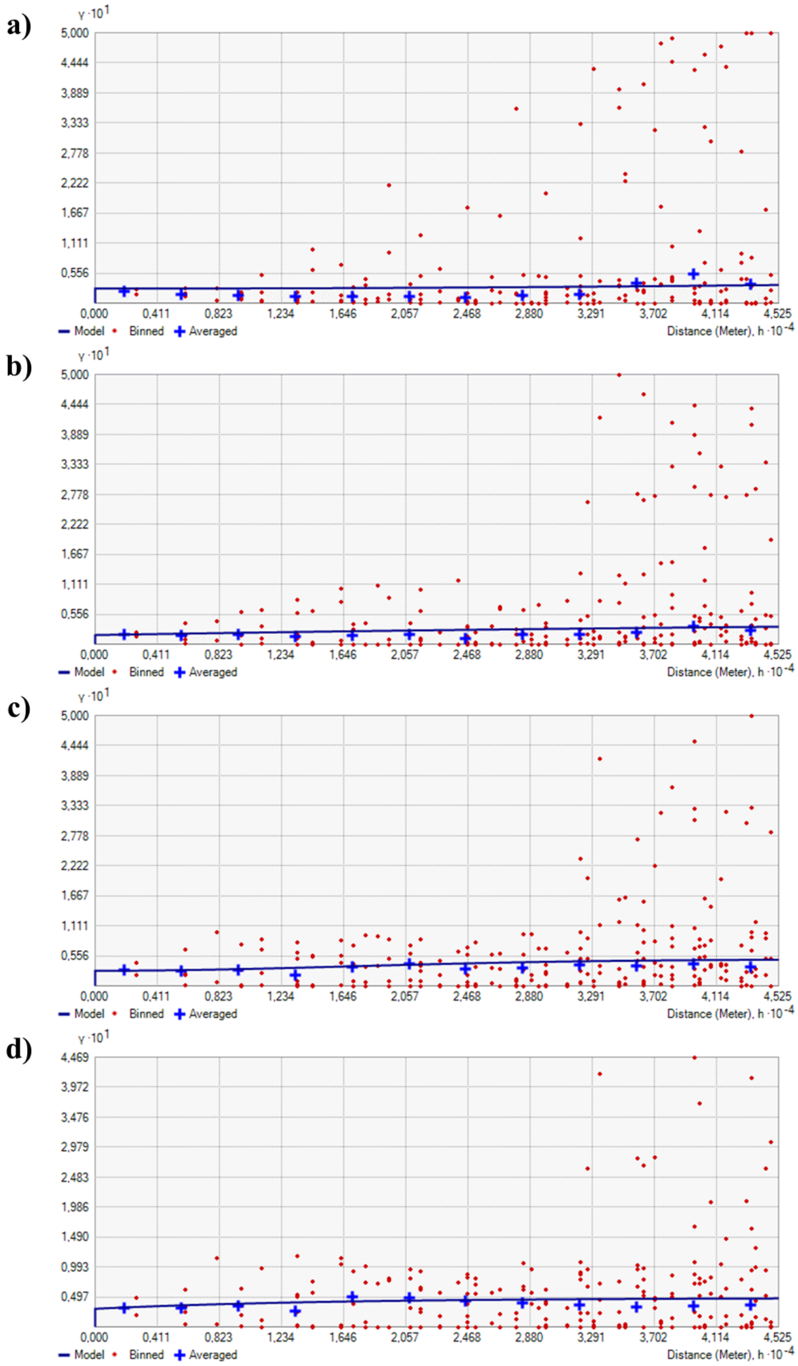

Figure A-2: Semivariograms for FC in Mediterranean Region between a) 1993 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

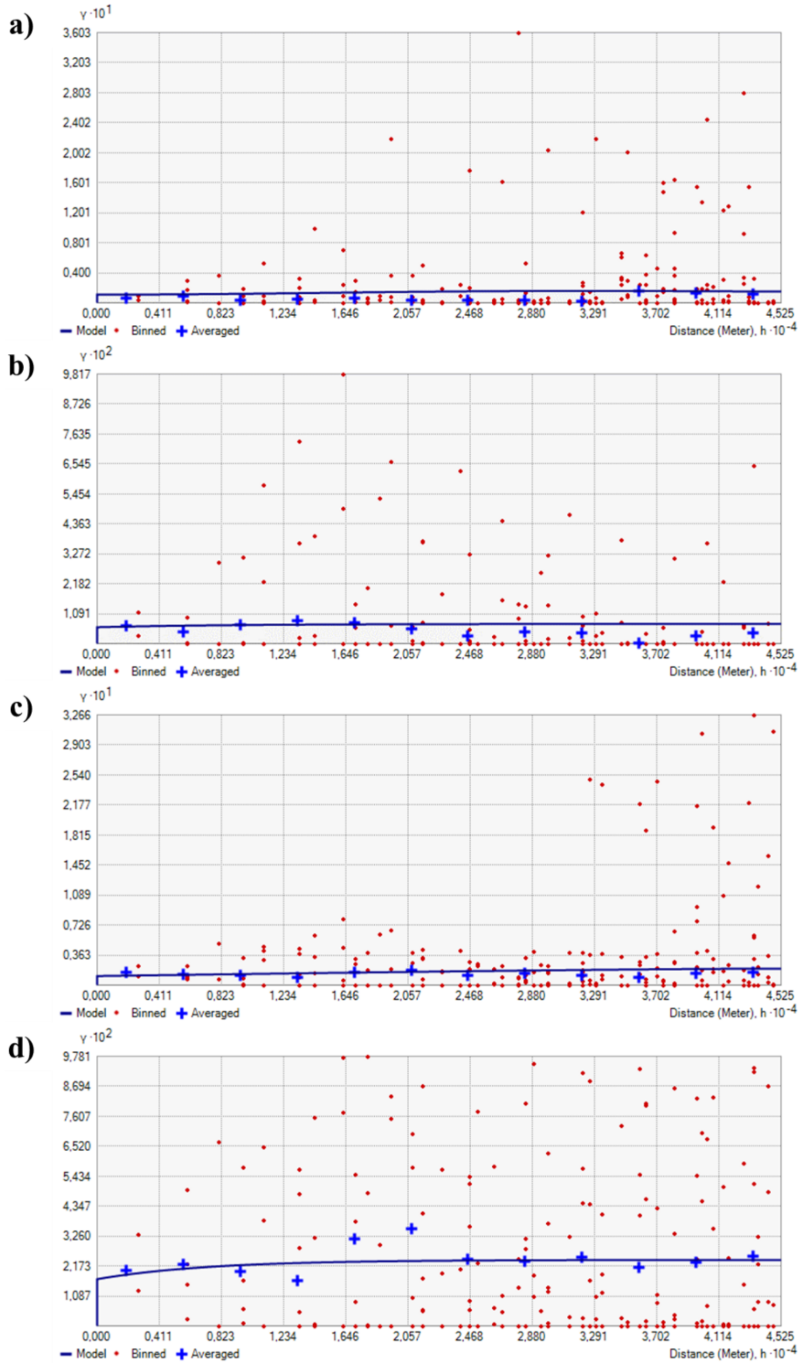

Figure A-3: Semivariograms for FS in Mediterranean Region between a) 1993 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

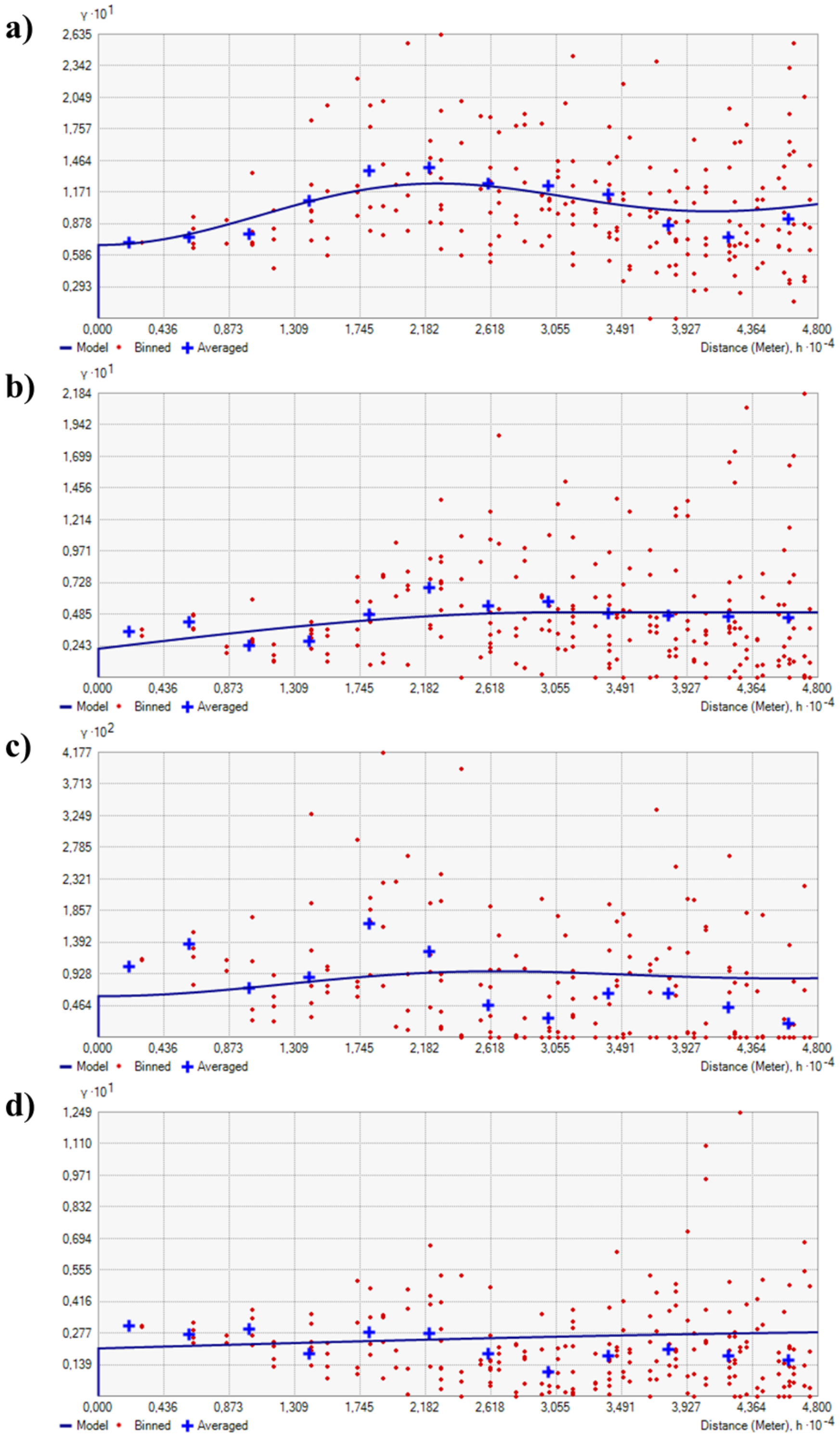

Figure A-4: Semivariograms for TC in Aegean Region between a) 1993 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

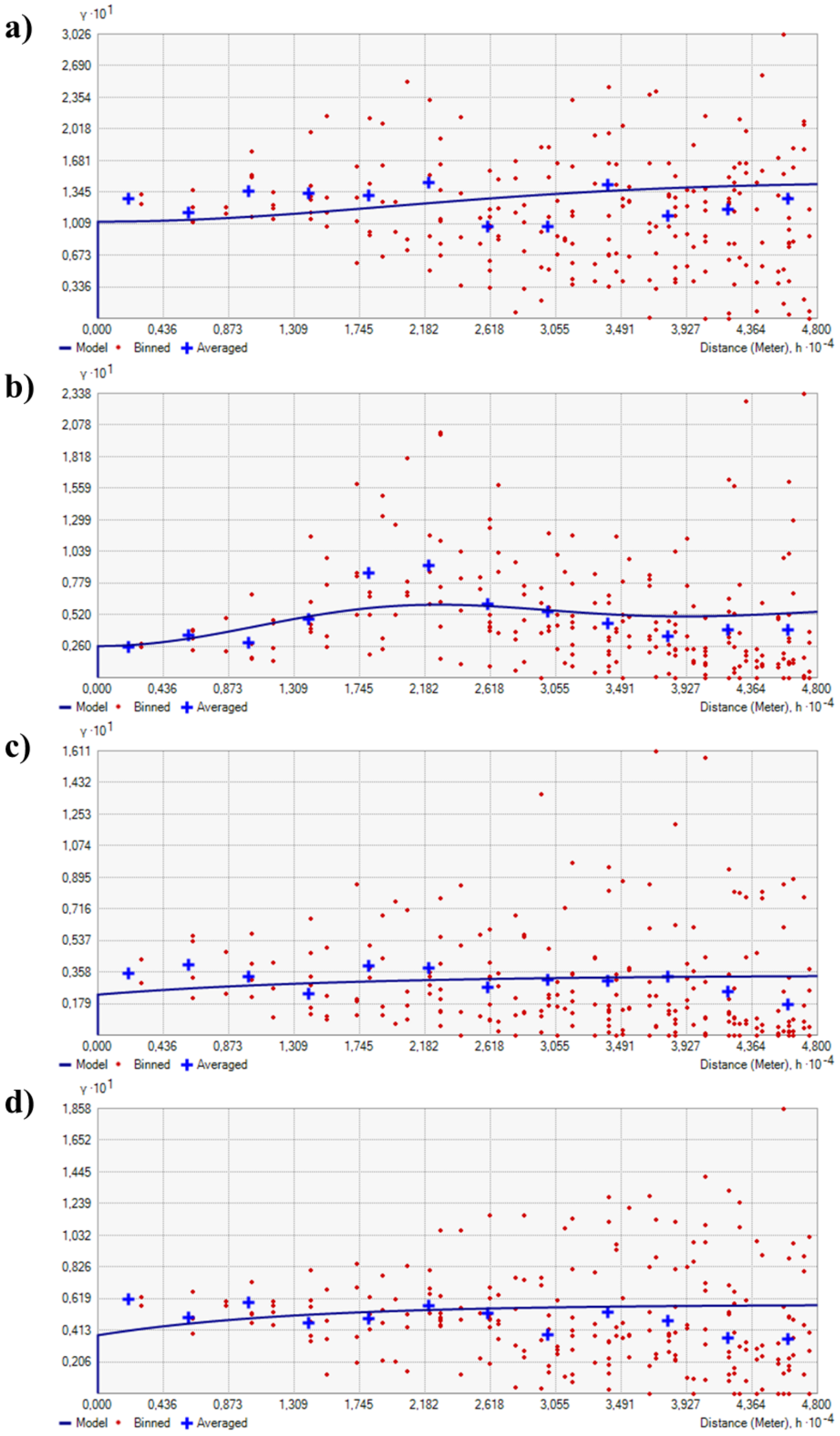

Figure A-5: Semivariograms for FC in Aegean Region between a) 1993 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

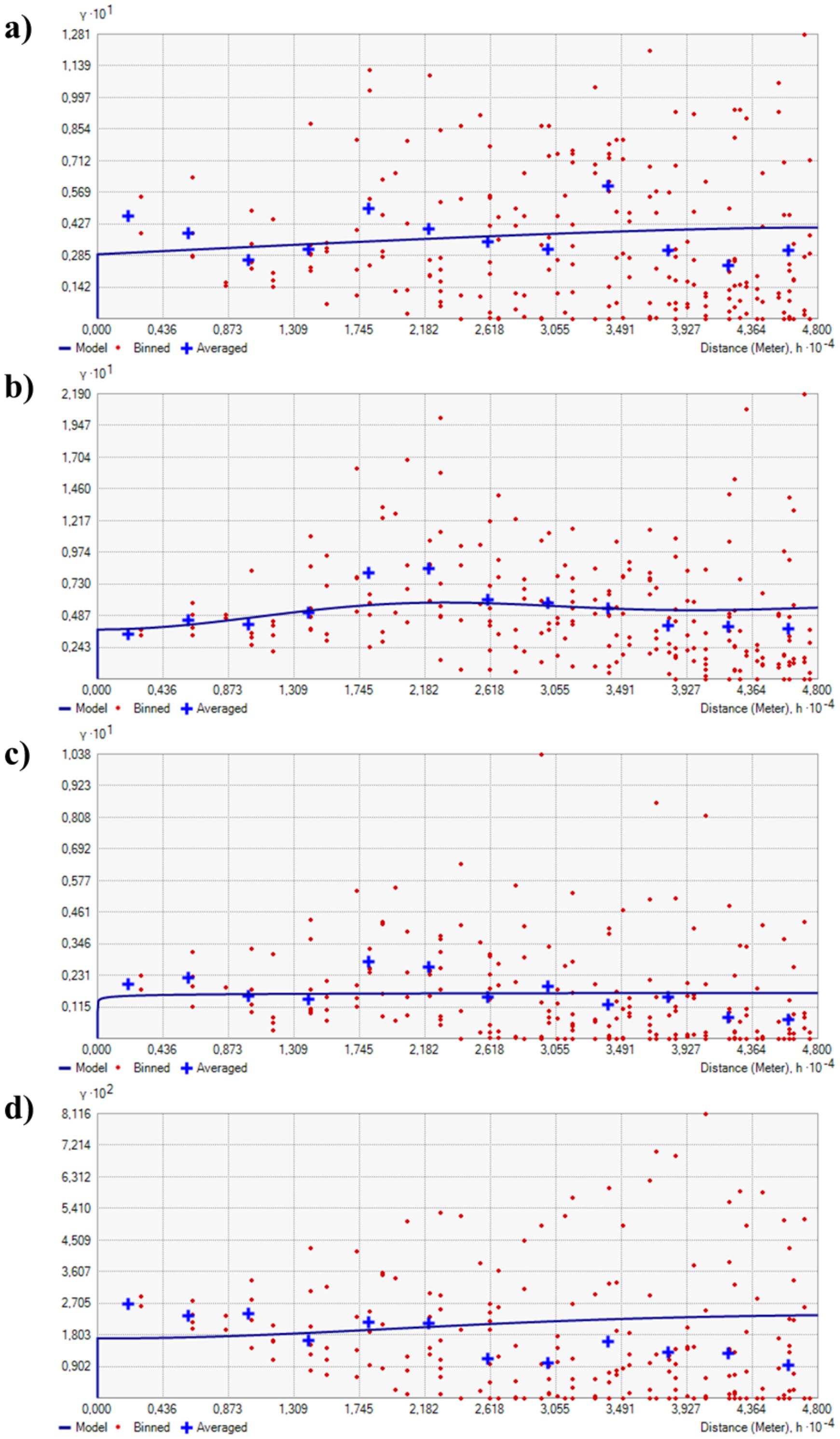

Figure A-6: Semivariograms for FS in Aegean Region between a) 1993 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

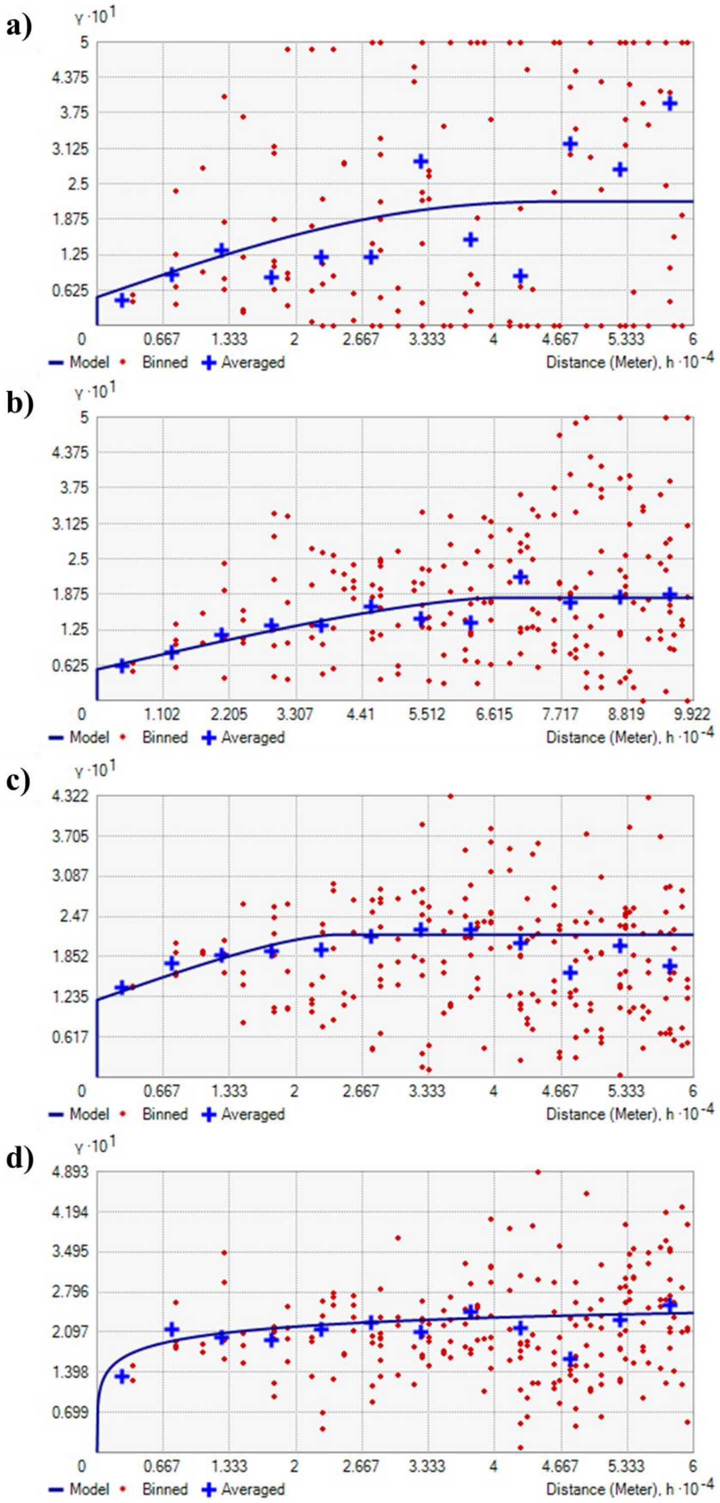

Figure A-7: Semivariograms for TC in Marmara Region between a) 1997 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

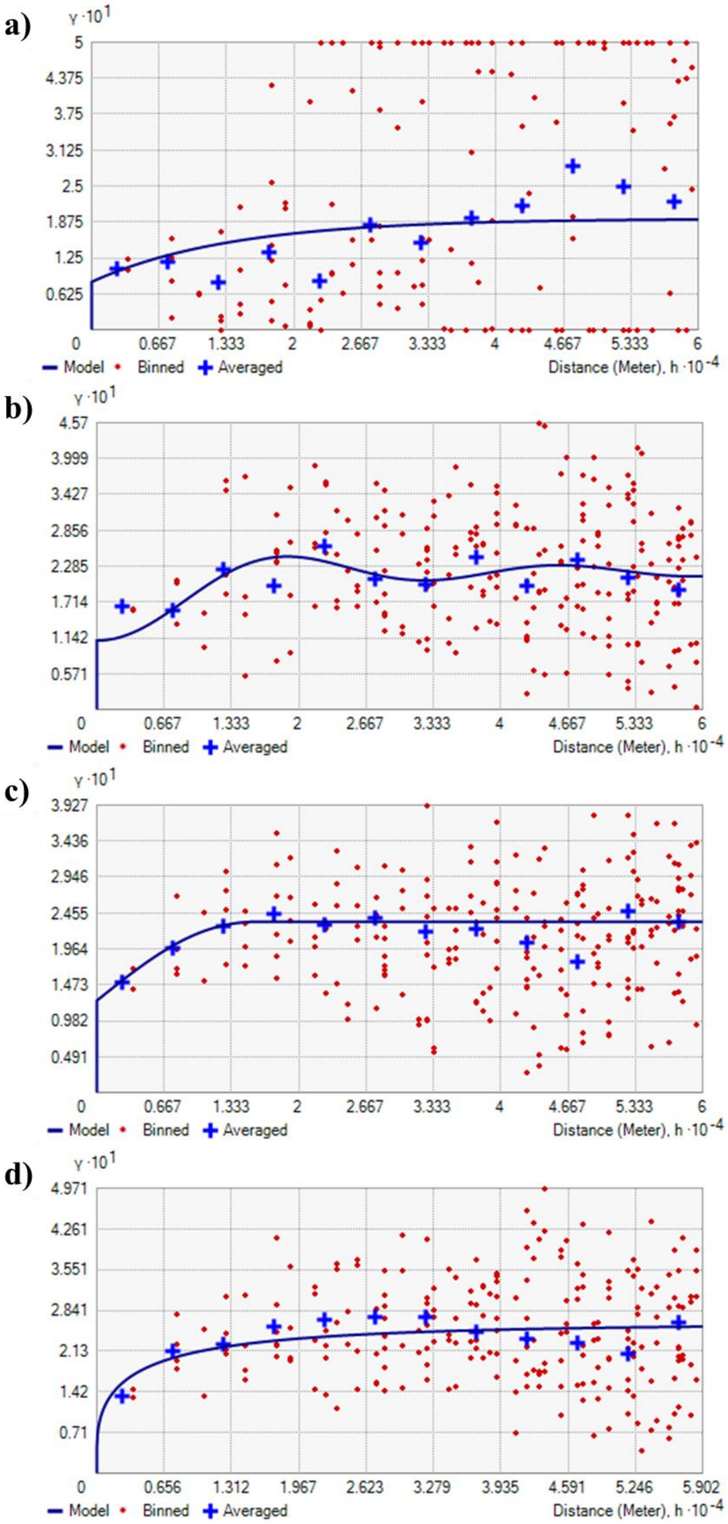

Figure A-8: Semivariograms for FC in Marmara Region between a) 1997 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

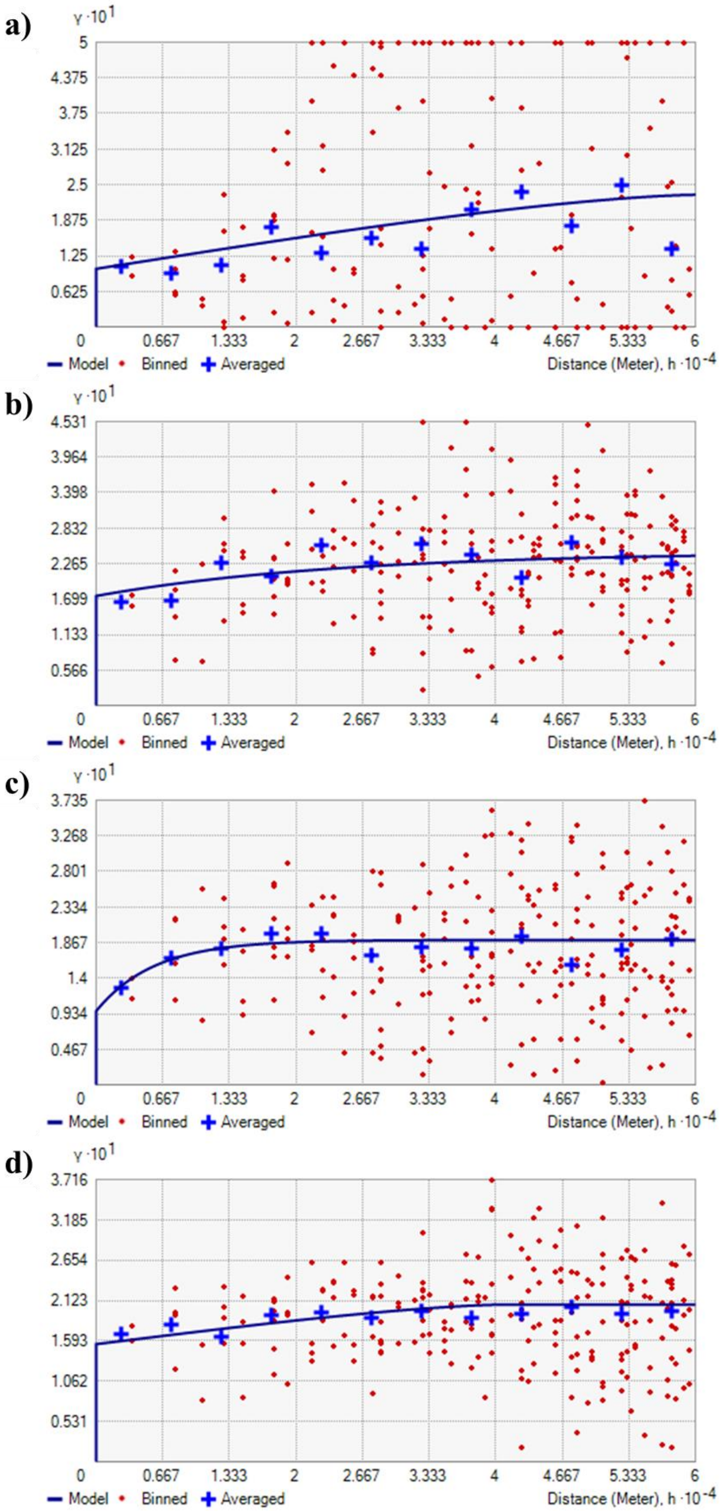

Figure A-9: Semivariograms for FS in Marmara Region between a) 1997 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

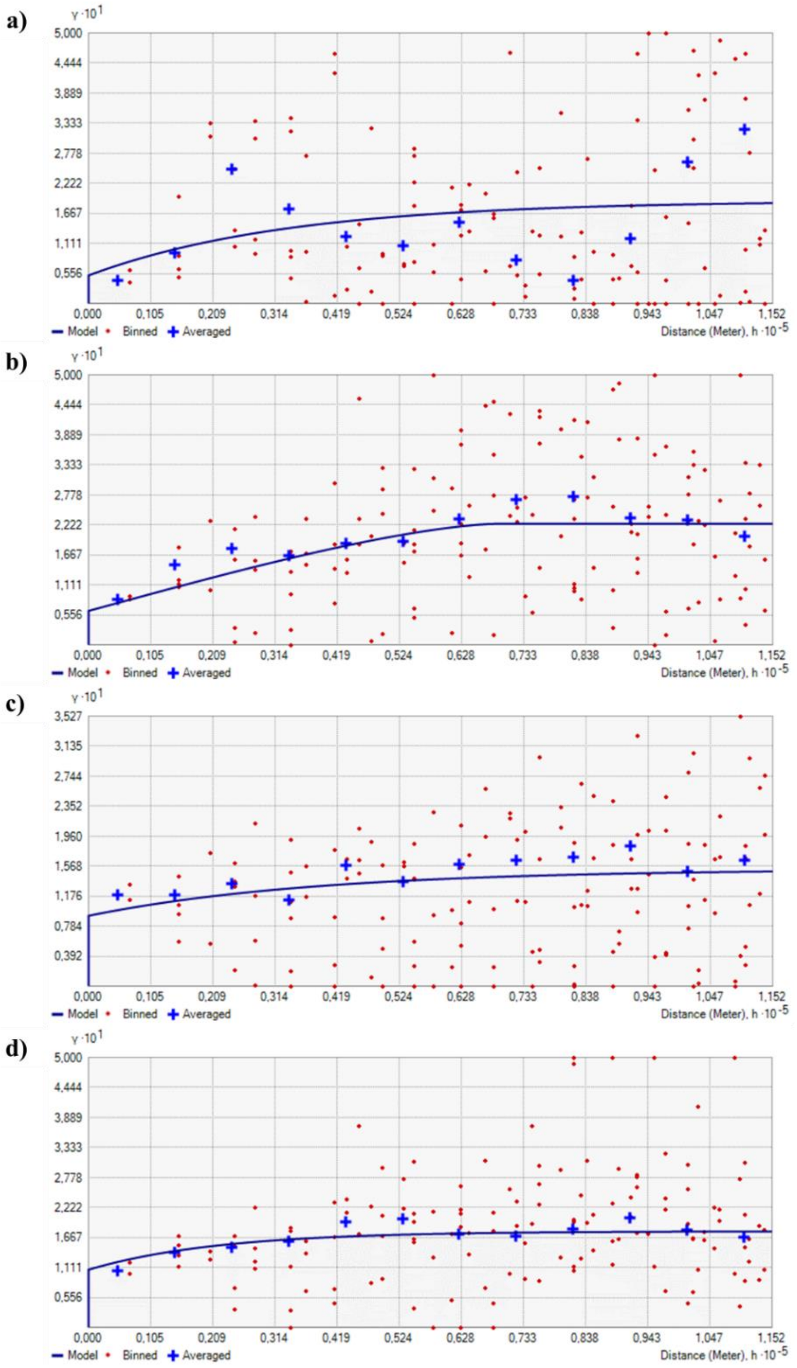

Figure A-10: Semivariograms for TC in Black Sea Region between a) 1996 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

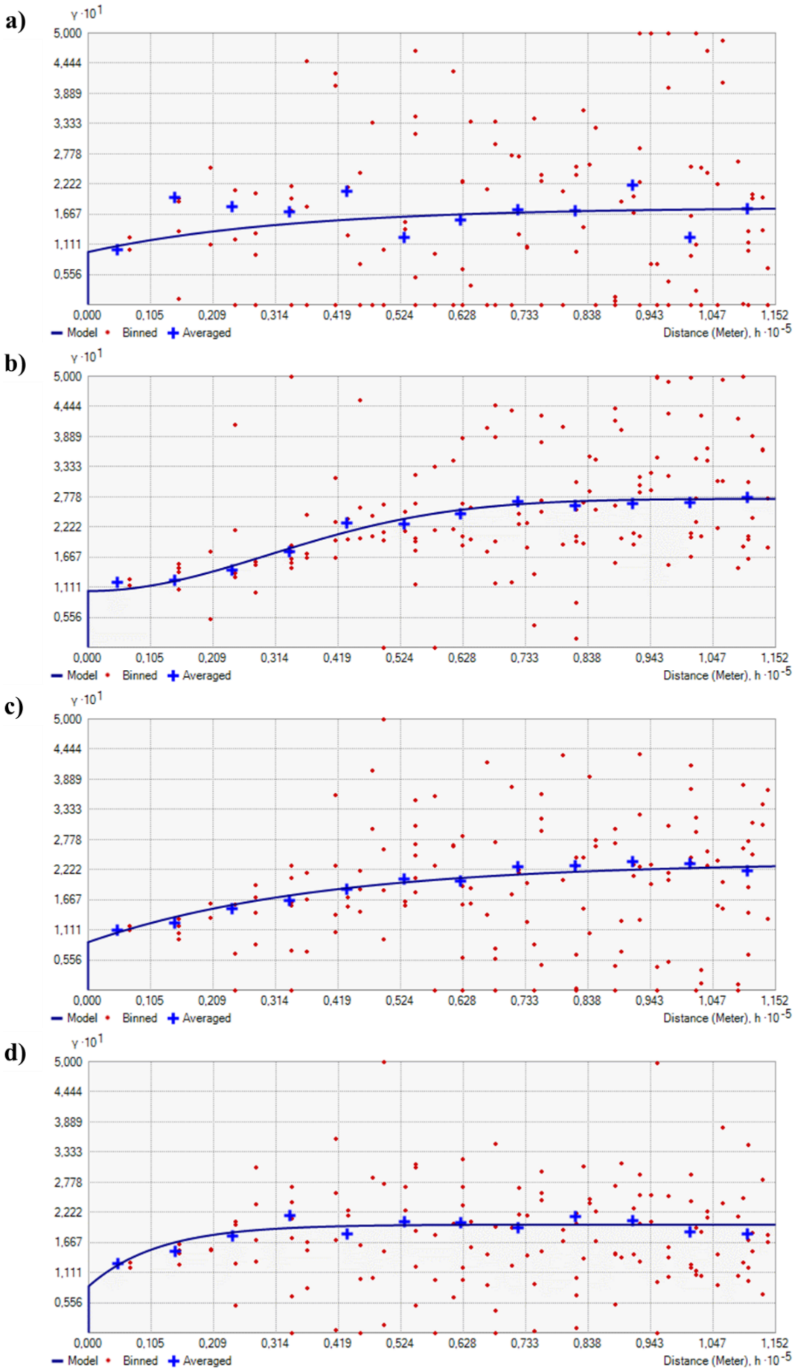

Figure A-11: Semivariograms for FC in Black Sea Region between a) 1996 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

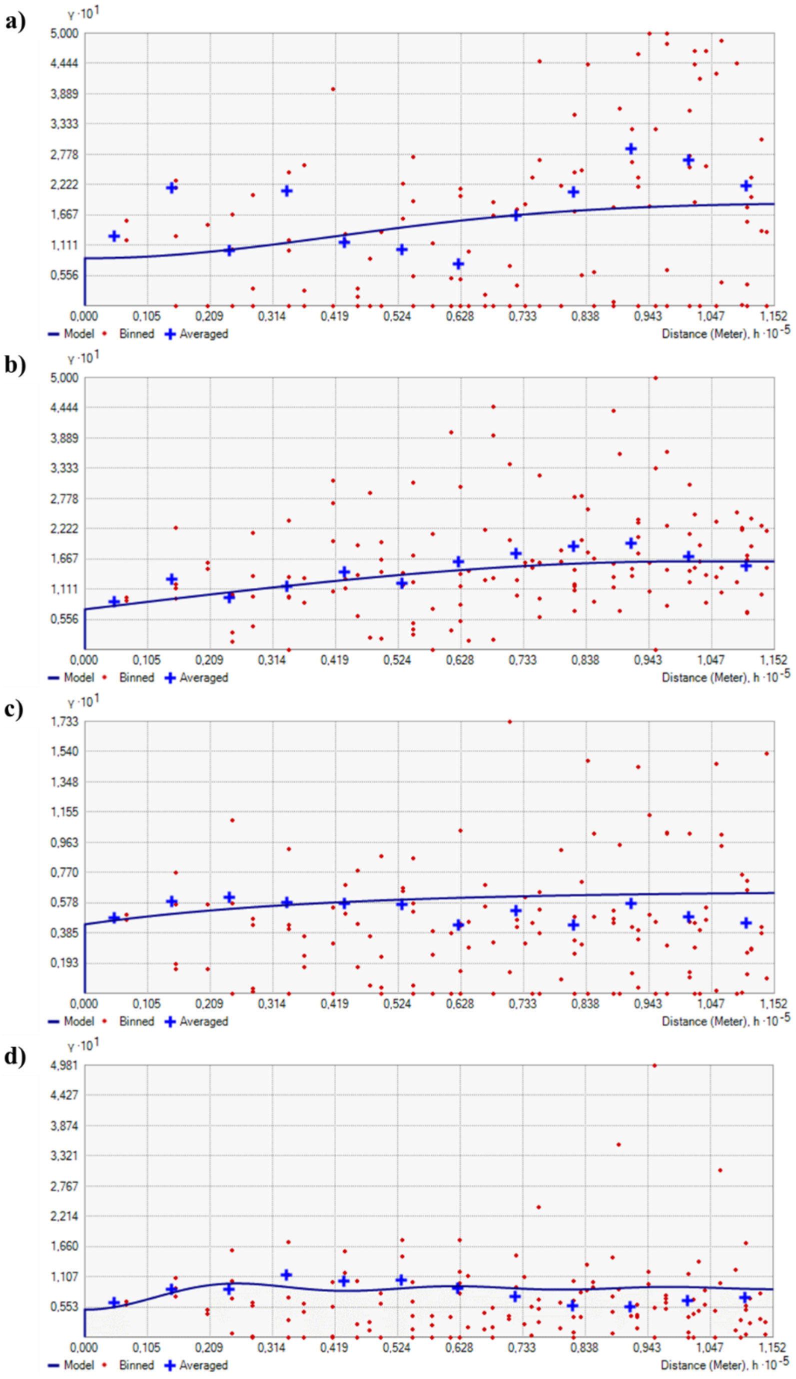

Figure A-12: Semivariograms for FS in Black Sea Region between a) 1996 - 2010, b) 2010 – 2012, c) 2013 – 2015 and d) 2016 – 2018

APPENDIX B

TURKISH REGULATIONS RELATED TO BATHING WATER QUALITY ASSESSMENT

Table B-1: Bathing Water Quality Control Regulation Criteria (Official Gazette Notice 26048, 2006)

	Parameters	**G**	**M**	**Minimum sampling frequency**	**Method of analysis and inspection**
A	**Microbiological**				
1	Total Coliforms/100 ml	500	10000	Fortnightly (1)	Membrane Filter
2	Fecal Coliforms/100 ml	100	2000	Fortnightly (1)	Membrane Filter
3	Fecal Streptococci/100 ml	100	1000	Fortnightly (1)	Membrane Filter
4	Salmonella/1 liter	-	0	(2)	Membrane Filter
5	Enteroviruses PFU/10 liters	-	0	(2)	Membrane Filter for viruses
B	**Physico-chemical**				
6	Ph	-	6 to 9 (0)	(2)	Electrometry with calibration at pH 7 and 9.
7	Color	- -	No abnormal change in colour (0)	Fortnightly (1) (2)	Visual inspection or photometry with standards on the Pt.Co scale.
8	Mineral oils mg/l	-	No film visible on the surface of the water and no odour	Fortnightly (1) (2)	Visual and olfactory inspection or extraction using an adequate volume and weighing the dry residue.
9	Surface-active substances reacting with methylene blue mg/litre (lauryl sulfate)	- □0.3	No lasting foam -	Fortnightly (1) (2)	Visual inspection or absorption spectrophotometry with methylene blue.
10	Phenols mg/l C_6H_5OH	- 0.005	No specific odour 0.005	Fortnightly (1) (2)	Verification of the absence of specific odour due to phenol or absorption spectrophotometry 4-aminoantipyrine (4 AAP) method.
11	Transparency (m)	2	1(0)	Fortnightly (1)	Secchi's disc.
12	Dissolved oxygen % saturation O_2	80–120	-	(2)	Winkler's method or electrometric method (oxygen meter).
13	Tarry residues and floating materials such as wood, plastic articles, bottles, containers of glass, plastic, rubber or any other substance. Waste or splinters	Absence		Fortnightly (1)	Visual inspection.
14	Ammonia mg/L NH_4			(3)	Absorption spectrophotometry, Nessler's method, or indophenol blue method.

	Parameters	**G**	**M**	**Minimum sampling frequency**	**Method of analysis and inspection**
15	Nitrogen Kjeldahl mg/L N			(3)	Kjeldahl method
C	**Other substances regarded as indications of pollution**				
16	Pesticides mg/l (parathion, HCH, dieldrin)			(2)	Extraction with appropriate solvents and chromatographic determination
17	Heavy metals such as: — arsenic mg/liter As — cadmium Cd — chrome VI Cr VI — lead Pb — mercury Hg			(2)	Atomic absorption possibly preceded by extraction
18	Cyanides mg/l CN			(2)	Absorption spectrophotometry using a specific reagent
19	Nitrates -mg/l NO_3 Phosphates mg/l PO_4			(2)	Absorption spectrophotometry using a specific reagent

G: Guide
M: Mandatory

(0) Provision exists for exceeding the limits in the event of exceptional geographical or meteorological conditions.

(1) When a sampling taken in previous years produced results which are appreciably better than those in this Annex and when no new factor likely to lower the quality of the water has appeared, the competent authorities may reduce the sampling frequency by a factor of 2.

(2) Concentration to be checked by the competent authorities when an inspection in the bathing area shows that the substance may be present or that the quality of the water has deteriorated.

(3) These parameters must be checked by the competent authorities when there is a tendency towards the eutrophication of the water.

Table B-2: Discharge Criteria for Urban Wastewater Treatment Plants (Official Gazette Notice 26047, 2006)

Discharge Criteria for Urban Wastewater Treatment Plants with Secondary Treatment		
Parameters	**Concentration (mg/L)**	**Minimum Removal Efficiency (%)**
BOD	25	70 – 90
COD	125	75
TSS	35	90*
Discharge Criteria for Urban Wastewater Treatment Plants with Advanced Treatment		
Parameters	**Concentration (mg/L)**	**Minimum Removal Efficiency (%)**
Total Phosphorus	1 - 2	80
Total Nitrogen	10 - 15	70 - 80

**This standard depends on the population of the region.*

Table B-3: Discharge Criteria for Municipal Wastewater Treatment Plants (Official Gazette Notice 25687, 2004)

Parameters	**2 Hours Composite Sampling**				**24 Hours Composite Sampling**			
	Class				*Class*			
	I	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**
BOD (mg/L)	50	50	50	40	45	45	45	35
COD (mg/L)	180	160	140	120	120	110	100	90
TSS (mg/L)	70	60	45	40	45	30	30	25
pH	6-9	6-9	6-9	6-9	6-9	6-9	6-9	6-9

Table B-4: Discharge Criteria for Deep Sea Discharge Systems (Official Gazette Notice 25687, 2004)

Parameters	**Criteria**
Temperature	< 35 °C Between June and September discharges should not increase the temperature more than 1 °C, in other months temperature should not be increased more than 2 °C.
Total Coliforms and Fecal Coliforms (MPN)	In 90 % of the time, concentration should not exceed 1000 TC/100 mL for total coliforms and 200 FC/100 mL for fecal coliforms.
TSS	There should be no suspended solids on diffuser and at the same sea level.
Other Parameters	Criteria given in Table 4 for Water Pollution Control Regulation should be satisfied.

APPENDIX C

RIVER MOUTHS IN COASTAL ZONES

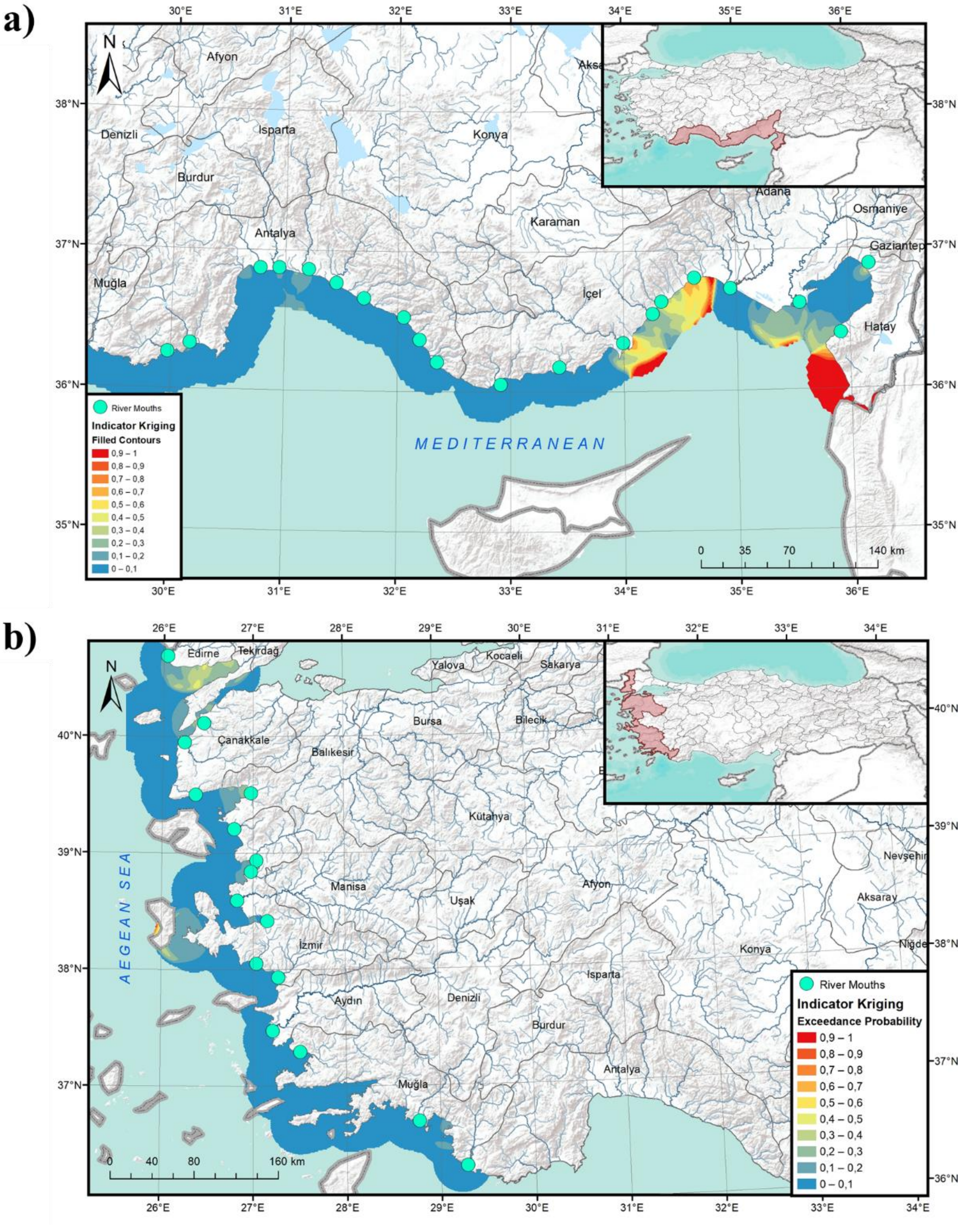

Figure C-1: River mouths along a) Mediterranean Coastline and b) Aegean Coastline embedded in Exceedance Probability Maps of FC for 2016-2018 (GA Period 4)

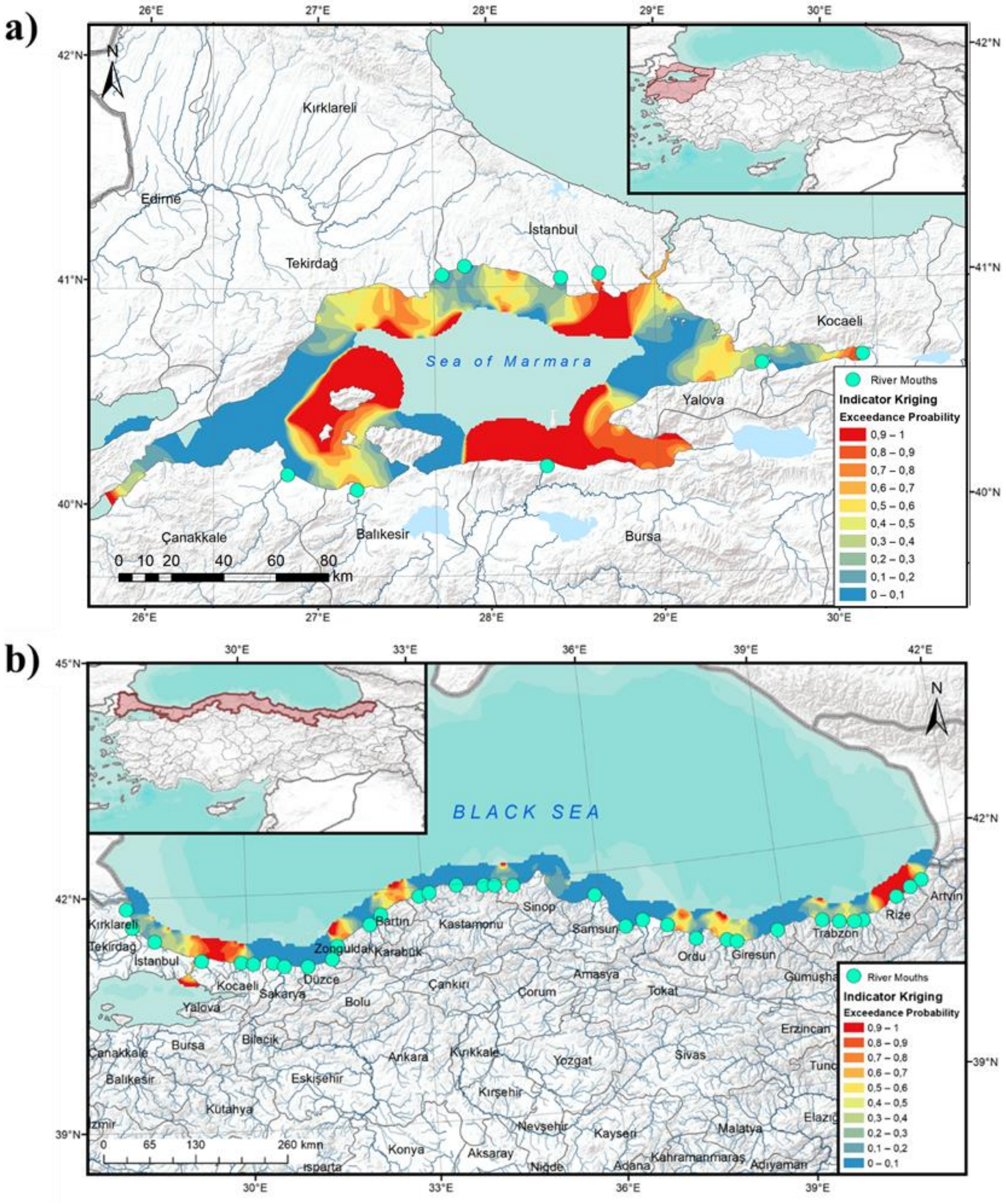

Figure C-2: River mouths along a) Marmara Coastline and b) Black Sea Coastline embedded in Exceedance Probability Maps of FC for 2016-2018 (GA Period 4)