Technical Note

Management of Groundwater Quality and Quantity: Gediz River Basin Pilot Study

Yeraltı Suyunun Kalite ve Miktar Bakımından Yönetimi: Gediz Nehir Havzası Örnek Çalışması

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Abstract

This study provided methods and methodologies in compliance with the national legislations that will ensure proper management of groundwater in terms of both quality and quantity. The methodologies developed in this manner were implemented in the Gediz River Basin in Turkey. A total of 76 groundwater bodies delineated in the Basin were subjected to characterization, where the anthropogenic pressures on the quality and quantity of groundwater and their possible impacts were determined. Detailed risk analysis done by the available data revealed to the groundwater bodies which were under risk of achieving good status in terms of quality and/or quantity. In order to disclose the current status of all groundwater bodies, in-depth analyses (establishing threshold values, comparison of the measured values to the threshold values/quality standards, water budget calculations, etc.) were performed and supported by the comprehensive field investigations and monitoring. Ultimate results indicated that 33 groundwater bodies out of 76 were in poor status; and hence, all these bodies should be included in the programme of measures. Moreover, all the monitoring points at which the threshold values and/or quality standards are exceeded were also included in the programme of measures. Finally, the required measures to be taken in the Gediz River Basin at different scales (basin, groundwater body and monitoring point); to improve the poor status or to conserve the good status of groundwater, were pointed out considering both its quality and quantity.

Keywords: *groundwater management, quantitative and chemical status assessment, programme of measures, Gediz River Basin.*

Öz

Bu çalışma, hem nitelik hem de nicelik bakımından yeraltı sularının doğru yönetimini sağlayacak yasal düzenlemelere uygun yöntem ve metodolojiler sunmaktadır. Bu kapsamda geliştirilen yöntemler Gediz Nehir Havzası'nda (Türkiye) uygulanmıştır. Gediz Nehir Havzası için belirlenen 76 yeraltı suyu kütlesi, kalite ve miktar bakımından antropojenik baskılar ile bunların olası etkilerinin belirlendiği karakterizasyona tabi tutulmuştur. Mevcut verilerle yürütülen ve konservatif yaklaşımları benimseyen ayrıntılı risk analizi ile miktar ve kalite bakımından iyi bir duruma gelme riski altındaki yeraltı sıuyu kütleleri belirlenmiştir. Tüm yeraltı sularının mevcut durumunu ortaya çıkarmak için kapsamlı saha araştırmaları ve izleme sonuçları ile de desteklenen derinlemesine analizler (eşik değerlerin belirlenmesi, ölçülen değerlerin eşik değer/kalite standartları ile karşılaştırılması, su bütçesi hesaplamaları, vb.) gerçekleştirilmiştir. Nihai sonuçlar, 33 yeraltı suyu kütlesinin genel durumunun zayıf olduğunu ve dolayısıyla bunların tedbirler programına dahil edilmesi gerektiğini göstermiştir. Ayrıca, eşik değerler ve/veya kalite standartlarının aşıldığı tüm izleme noktaları da tedbirler programına dahil edilmiştir. Son olarak bu çalışma kapsamında, Gediz Nehir Havzası için farklı ölçeklerde (havza, yeraltı suyu kütlesi ve izleme noktası) tedbirler önerilmiş; zayıf durumun iyileştirilmesi veya iyi durumdaki yeraltı sularının statüsünün korunması için miktar ve kalite bakımından alınması gerekli tedbirler belirtilmiştir.

Anahtar kelimeler: *yeraltı suyu yönetimi, miktar ve kimyasal durum değerlendirmesi, tedbirler programı, Gediz Nehir Havzası*

Introduction

Freshwater is an indispensable resource for existence of life. Owing to its significance for the survival of societies; laws and regulations related to water rights date back to the world's oldest justice codes; and evolved ever since. Water Framework Directive (WFD, 2000/60/EC) emphasizes the importance of water by stating in its first recital that "*water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such*" (European Commission, 2000). Moreover, in today's industrialized societies, it is not only the quantity but the quality of freshwater that has to be considered for its sustainable management. This is the rationale behind WFD set by the Ministerial Seminar held at The Hague in 1991, which recognized "*the need for action to avoid long-term deterioration of freshwater quality and quantity"* and called for *"a programme of actions to be implemented aiming at sustainable management and protection of freshwater resources*".

In 2006, another Directive (2006/118/EC, revised as 2014/80/EU), commonly known as Groundwater Directive (GWD), was published by European Commission (2006, 2014) specifically on the protection of groundwater against pollution and deterioration, focusing on the implementation stages to be completed after groundwater bodies are delineated. Besides, a common strategy for supporting the implementation of WFD (known as Common Implementation Strategy, CIS) was

developed aiming to allow a coherent and harmonious implementation of WFD. With this initiative several Guidance Documents and Technical Reports were published. Taking all these Directives and Guidance Documents as reference, Turkish bylaw on protection of groundwater against pollution and deterioration was first issued in 2012 (revised on 2015).

Background Information about Groundwater Management Practices in Turkey

This article focuses on groundwater, which constitutes around 15% of the annual freshwater consumption in Turkey. Although it seems like a minor contribution in total; for rural areas, most of the times, groundwater is the only available freshwater resource to supply domestic and irrigational water demands. Owing to the fact that it is not easily be quantified and characterized like surface water resources, special care and effort should be taken in the management of groundwater resources.

Turkish bylaw on the protection of groundwater against pollution and deterioration was first issued in 2012 (Official Gazette 28257, 07.04.2012) and revised in 2015 (Official Gazette 29363, 22.05.2015), taking the WFD and the GWD as reference. This bylaw obliges the determination of groundwater bodies, as the management units of groundwater resources, which will be the basis of the succeeding implementation stages, from characterization to status assessment. On the other hand, determination of the status of groundwater in terms of quality and quantity; and development of a programme of measures (PoM), is a vital part of River Basin Management Plans (RBMP). Having such significance, General Directorate of Water Management – established under the Ministry of Forestry and Water Affairs (MoFWA) carried out a pilot project for developing and implementation of methodologies for determination and assessment of groundwater quantity and quality, in line with the above-mentioned bylaw (MoFWA, 2017). Within the content of this project ("*Developing and Implementation of Methodologies/Methods for Determination and Assessment of Groundwater Quantity and Quality: Gediz Basin Pilot Study*"), which forms the basis of this paper, all provisions of WFD on groundwater were realized; methodologies were developed for each implementation stage; and tested on a pilot river basin (Gediz River Basin shown in Figure 1).

The GRB is listed among the nine river basins having priority according to the "Action Plan on Groundwater Management" put in force in 2013 (MoFWA, 2013). The GRB is named after its major river (Gediz River) having an approximate length of 400 km, draining a basin of about 17,500 km² and discharging to the Aegean Sea, along the western coast of Turkey. Basin hosts the very fertile agricultural lands,

animal husbandry activities, organized industrial sites, high potential geothermal fields, variety of mineral deposits; in addition to the densely populated settlements. All these factors impose a complex and interacting set of natural and anthropogenic pressures on both quality and quantity of water resources in the basin.

Purpose, Scope and Impact of the Study

As mentioned above, this study sets up the very first steps in Turkey on the implementation of the provisions of the WFD, GWD and the Turkish bylaw on the protection of groundwater against pollution and deterioration. In this sense, its scope was setting up structured methodologies, which are applicable for Turkey, for each implementation step of the bylaw minimizing the differences in the execution on country scale and allowing flexibility for minor modifications to adapt into different river basins in Turkey. Moreover, it should be noted that this study aimed to build on the results achieved with the already completed and/or ongoing projects in various scales and scopes, which are executed by the MoFWA. The significance of this study derives from the fact that it constituted the first step in order to close the gap in the implementation of the groundwater management policy in terms of both quality and quantity. Its impacts will be more apparent in time, as the similar scoping studies will start to build on the methodologies developed with this one; and once PoM proposed with this study is started to be executed.

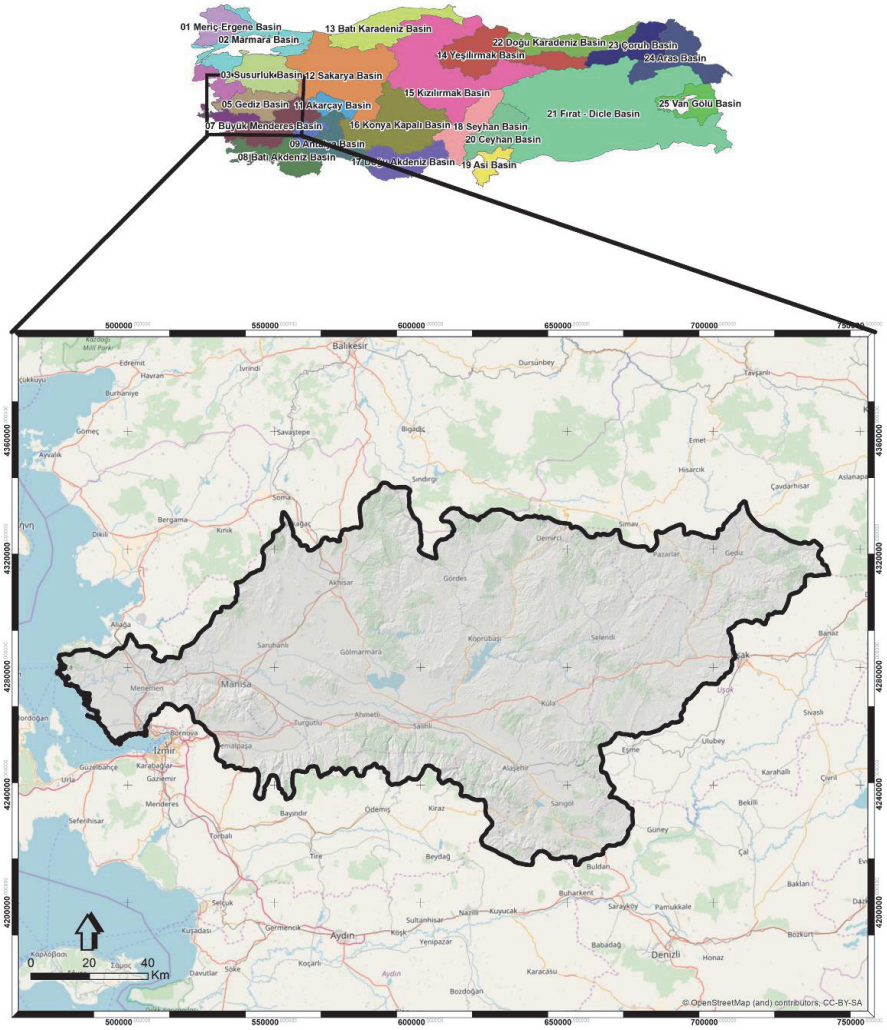

Figure 1. Location map of Gediz River Basin

Method

Implementation Steps and Methodologies

As implied by the legislation, the ultimate scope is to preserve the status of groundwater that is classified to be of good status; and to protect and improve the status of the groundwater against pollution and deterioration. To reach this goal a methodological and stepwise approach was introduced and a PoM was also set up based on the results and findings throughout the study.

Delineation of Groundwater Bodies

Within the scope of the Turkish bylaw on the protection of groundwater against pollution and deterioration, "groundwater body" is defined as the significant amount of groundwater in aquifer(s), and it is introduced as the basis for the other implementation steps. Therefore, in every consequent implementation step from characterization to risk analysis, determination of threshold values, assessment of status and establishing of the PoM; groundwater bodies to be determined at this stage shall be used.

Upon the examination of various guidance documents and applications; it was observed that different methodologies were applied and different criteria were taken into consideration in delineation of groundwater bodies, due to the local characteristics that can be quite different in each country/basin. While some of these criteria (hydraulic properties, hydro/geological boundaries, etc.) were taken into account in almost all applications; use of other criteria (ecosystems, water use, pressures, risk potential, differences in status etc.) seem to depend on local characteristics. Moreover, very specific criteria (temperature, vertical flow, topography, administrative units/boundaries, etc.) were also considered to address unique and rare characteristics of the area. Hence, it is not possible to apply these not often seen distinguishing criteria in all applications.

The methodology for delineation of the groundwater bodies in the GRB was developed with thorough investigations and revised in line with the opinions and remarks of the decision making and implementing institutions. The resulting methodology was set up by combining the geological and hydrogeological criteria used in most applications together with the criteria having great importance for Turkey (such as drinking water use and protection requirements for ecosystems and agricultural pressures). The 7-tier methodology is composed of the following stages:

- **Tier-1:** Division of the basin according to the boundaries of the geological units
- **Tier-2:** Grouping units according to their water bearing potential (as *aquifers* and *non-aquifers*)
- **Tier-3:** Identification of ecosystems (potentially) associated with groundwater
- **Tier-4:** Classification of aquifers according to their hydrogeological properties (as *higher-yield aquifers of significant groundwater potential* and *lower-yield aquifers of limited groundwater potential*)
- **Tier-5:** Assessment of wells/springs used for drinking water above a certain yield (determined to be 10 l/s, for the GRB)

- **Tier-6:** Implementation of scoring system (considering *hydraulic conductivity* and *specific capacity* of the units, which are indicative of productivity of the aquifers; and *population density* and *land use* that can be used as a preliminary indication of pressures on groundwater). In that sense, this stage is a kind of control mechanism to check if there is a critical location which could not be determined in previous stages; and if so include them in process.
- **Tier-7:** Sub-division/aggregation of groundwater bodies (groundwater bodies of small outcrops located at close proximity and of similar characteristics were combined; while larger ones were divided into smaller ones, if there are locally different types of pressures

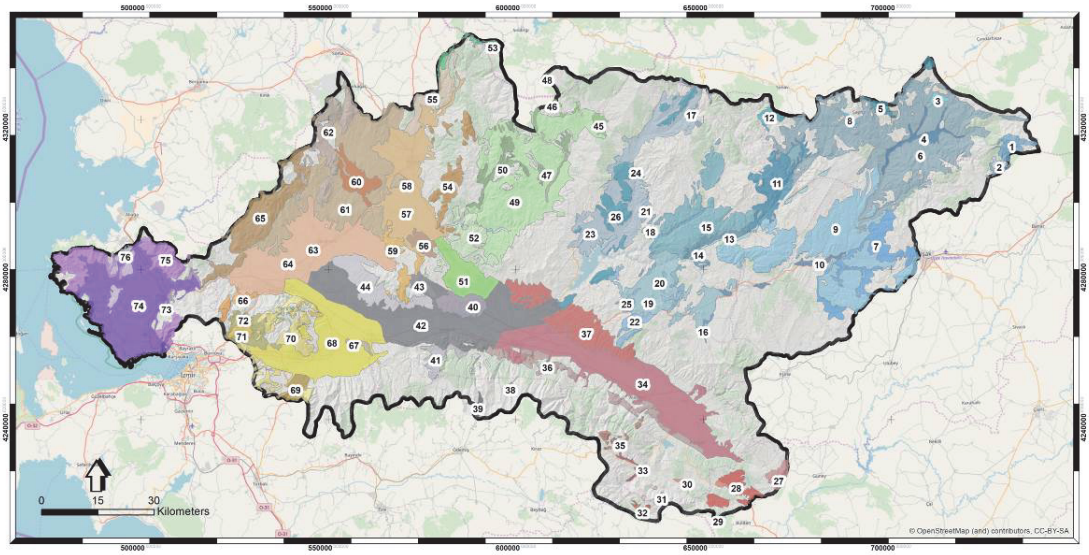

Figure 2. Groundwater bodies delineated in the Gediz River Basin.

Finally, following the guidance of the 7-tier methodology, 76 groundwater bodies, total area of which corresponds to 54% of the basin, were identified (Figure 2).

Initial characterization.

Following delineation of groundwater bodies, it is necessary to carry out characterization studies. As stated in WFD, initial characterization to be implemented for all identified groundwater bodies, should be based on existing information and be supported with the conceptual models, where appropriate.

According to WFD, following information must be specified for each groundwater body: location and boundaries of groundwater bodies; pressures on groundwater bodies; general characteristics of the formations located in drainage area recharging groundwater bodies; and groundwater bodies on which surface water or terrestrial ecosystems directly depend. On the other hand, determination of the pressures on quantity and quality of groundwater and possible impacts of these pressures require very detailed studies. Therefore, within the scope of current implementation step (initial characterization), pressures on the quantity and quality of groundwater and probable impacts were discussed briefly; while the detailed work carried out regarding these stages were elaborated in next steps of implementation ("Determination of Pressures and Impacts" and "Risk Assessment"). The general aspects were elaborated in order to clarify characteristics of both groundwater bodies and the basin more clearly and have been enriched by including additional parameters. As a result, all parameters selected for the initial characterization of groundwater bodies are listed below in Table 1. By using these criteria; characterization tables were generated for each groundwater body together with a generalized section and a map showing geographical location of the body in the basin.

Table 1
Contents of Initial Characterization Tables

Main Context	**Required information/data**
General Information	1. Groundwater body number and code
	2. Central point coordinate
	3. Area
	4. Surrounding groundwater bodies
Geology	5. Geological unit
	6. Lithological structure
Hydrogeology	7. Groundwater level
	8. Annual groundwater level fluctuation
	9. Aquifer type
	10. Aquifer thickness
	11. Hydraulic conductivity
	12. Surface water bodies and wetlands within groundwater body boundaries
Hydrogeochemistry	13.Physicochemical parameters
Pressures	14.Type of pressure
	15.Land use
	16.Possible hazardous substances
	17.Purpose of abstractions
	18.Artificial recharge

Determination of pressures and impacts.

For each groundwater body, pressures on quantity and quality of groundwater, and their possible impacts, were examined in detail. All related works were carried out in compliance with the legislation.

Determination of Pressures and Impacts on Groundwater Quantity

The main pressure resulting from human activities on the quantity of groundwater is groundwater abstractions in the basin. Its possible impacts can be determined directly by the evaluation of the long-term groundwater level changes. The impacts can also be determined indirectly by the ratio of quantity of abstraction to recharge. Within the scope of this study, due to the absence of historical groundwater monitoring data representing each groundwater body; indirect method, based on the comparison of quantities of groundwater recharge and abstraction, was used. Amount of recharge was calculated by "hydrological model" approach. The amount of groundwater abstractions were calculated on basis of studies presented in the GRB Hydrogeological Investigation Report (MoFWA, 2015). In this approach, the amount of abstraction and recharge, together with their proportion as a percentage, were calculated in Geographical Information System environment. Consequently, the classification of pressure (such as high, medium, low, and no pressure) was determined according to the ratio for each groundwater body.

On the other hand, impacts of these pressures could be determined directly by assessing of the long-term groundwater level changes, which were not available for all groundwater bodies. For this reason, classification of pressure at this stage was done based on all quantitative assessments throughout the consecutive implementation steps.

Determination of Pressures and Impacts on Groundwater Quality

In the basin, the main pressures on quality of groundwater were determined as agriculture, livestock, solid waste storage, urban and industrial activities, as well as mining and geothermal activities. Each groundwater body was classified in four classes (high, medium, low, no pressure) in terms of each pressure element, by calculating pressure class intervals obtained from the statistical analysis. Information on criteria by which each pressure element is classified is summarized below.

- ***Pressures from agricultural activities*** were related to the size of agricultural areas within the boundaries of groundwater bodies, using CORINE (EEA, 2012) data.
- ***Pressures from livestock activities*** were expressed in terms of total pollutant loads within the boundaries of each groundwater body. For this purpose, pollutant load constants determined in Basin Protection Action Plan (BPAP) for the GRB (MoFWA, 2013) and number of livestock were used.
- ***Pressures from solid waste disposal activities*** were evaluated by relating these pressures to the capacities of waste disposal areas located within the boundaries of each groundwater body.
- ***Pressures from domestic activities*** were represented by wastewater discharge. The amount of wastewater discharge was determined using population dependent wastewater generation coefficients given in BPAP per capita and the census information for all settlements within boundaries groundwater bodies.
- ***Pressures from industrial activities*** can vary widely depending on type of active industry, produced product and quantity of the waste generated. For this reason, it is not possible to clearly identify, grade and compare pressures arising from industrial activities. It shall be a safe approach to represent pressures of industrial activities with quality of the resulting receiving environment (surface waters); all of which were classified either as contaminated or very contaminated water within the scope of "Application of Total Maximum Daily Load Approach Project in the GRB (TMDLAP)" (MoFWA, 2017). Therefore, with a conservative approach, groundwater bodies where industrial activities are present were classified to be under high pressure.
- ***Pressures from geothermal activities*** were expressed by the number of geothermal wells per groundwater body; as they may put a pressure on the quality of groundwater due to the problems with their installation and due to improper re-injection of the abstracted hot water.
- ***Pressures from mining activities*** were related to the presence of mining operations, which may be associated with uncontrolled discharges and wastes; as the main purpose of this implementation step is to examine pressures of anthropogenic activities rather than natural enrichment of certain elements.

After pressure classes were obtained for each activity; pressure class of the highest order was defined as the general quality pressure class of the groundwater body. On the other hand, in most cases, it is not possible to determine the individual impacts of all these anthropogenic pressures. As mentioned in Guidance Document

No. 3 (Analysis of Pressures and Impacts), due to the fact that many of the impacts are not easily measurable, quality information of groundwater is often used as an indicator of, or surrogate for, impact (EC, 2003).

Within the scope of this study, impacts of anthropogenic pressures on quality of groundwater were determined using the results of the previous chemical analysis. The results of these analyses were compared to the limit values determined by the Regulation on Waters for Human Consumption in all groundwater bodies from which drinking water is supplied; and compared to the limit values determined by the Draft Regulation on Quality of Irrigation Waters and Reuse of Wastewater (MoFWA) for the groundwater bodies used only for irrigation. Impact assessment was performed on the parameters, for which limit values are set in both regulations. As a result of the detailed analyses, the level of impact on each groundwater body was classified under three classes as "impact", "potential impact", and "no impact" (Figure 3).

Risk assessment.

Risk Assessment Methodology of groundwater bodies is shown in flow chart below (Figure 3). As seen from this flow chart, the first step of the risk assessment is "Determination of Pressures and Impacts". According to the methodology specified in Figure 3, after pressures derived from the human activities and their impacts on quantity and quality of groundwater are revealed, determination of groundwater bodies at risk was carried out in 4 stages. These four steps and applied methodologies are presented below in detail.

Determination of groundwater bodies at risk in terms of quantity (Step 1): The main pressures on quantity of groundwater are abstractions and artificial recharges. In the present case, there is no artificial recharge in the GRB. In order to determine the risk quantitative risk status of groundwater bodies, groundwater level changes must be revealed by long-term monitoring activities. However, as previously mentioned, information on long-term changes in groundwater levels is not adequate. In such cases, Guidance Documents suggest that classification systems can be used at preliminary assessments. Therefore, in this study, pressure classes set up based on the ratio of abstraction to the recharge; were converted to risk classes. This is a fairly conservative approach as no adequate data for groundwater levels is available. As a result, of the 76 groundwater bodies, 12 were defined to be at risk, 8 were defined to be at potential risk and 56 of them were defined to be at no risk.

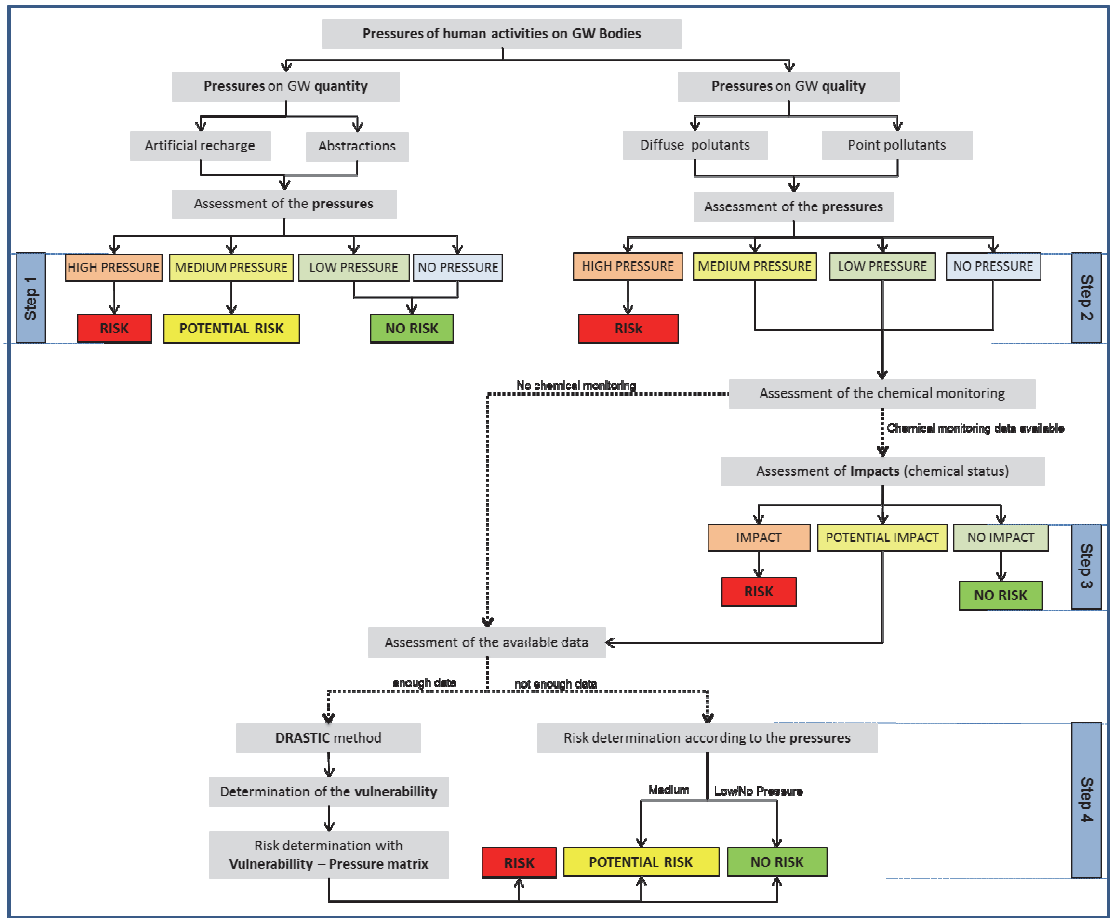

Figure 3. The flow chart of the Risk Assessment Methodology

Risk assessment in accordance with pressures (Step 2): As described above, each groundwater body was assigned an overall quality pressure class (high/medium/low/no pressure) considering each pressure element. At this step, all the groundwater bodies previously determined to be under high pressure, were directly determined to be at risk, without any further analysis.

Risk assessment in accordance with impacts (Step 3): In the GRB, for 55 groundwater bodies, there are previous chemical analyses results revealing their quality. For those groundwater bodies where previous chemical monitoring data is available, a Classification Approach was applied, and impact classes were associated to the risk classes. At this step of the methodology; the groundwater bodies

determined as impacted and no impact, were identified to be at risk and no risk, respectively.

Risk assessment with sensitivity - pressure analysis (Step 4): Risk status of the groundwater bodies, for which there are no previous chemical analyses that can be used as a direct indicator of impacts; together with those, which were identified as potentially affected in Step 3; was determined by the indirect methods based on the correlation of pressures of pollutants and the vulnerability of aquifers to pollution. As noted in Guidance Documents; indirect methods have been used while assessing risk of groundwater contamination during initial implementation of WFD. At this step DRASTIC method was applied to determine the vulnerability of groundwater bodies to pollution in case sufficient data and information are available. Pollution vulnerability determined by DRASTIC method was then associated with pressures of pollutants on the groundwater body in order to assign to the risk status of groundwater bodies, indirectly. In the cases where data and information were insufficient or limited for the application of DRASTIC method; then, risk classification was based on the pressures regardless of the vulnerability; which was a highly conservative approach. This approach, referred to as "weight of evidence", is defined in Guidance Document No. 26 (Guidance on Risk Assessment and the use of Conceptual Models for Groundwater) as the use of whatever data are available to make an assessment of the most likely outcome or the 'direction of travel' in the assessment (EC, 2010). Hence, low pressure class was classified as "no risk"; while medium pressure class was associated with "potential risk".

As a result of risk assessment process for the quality aspects, 34 of 76 groundwater bodies in the GRB were determined to be at risk, 7 at potential risk, and 35 at no risk.

Further characterization.

In line with WFD requirements, "Further Characterization" studies have to be executed for groundwater bodies identified as "at risk". Moreover, the groundwater bodies determined to be potentially at risk; were also included in this implementation step. As a result, "Further Characterization" studies were carried out for a total of 44 groundwater bodies according to the risk classes considering both quantity and quality. In this stage, studies carried out in "Initial Characterization" were elaborated with the additional data/information. Moreover, during "Further Characterization" studies, new data/information was compiled to overcome deficiencies. In cases, where there is no information available based on the performed office and field studies, this missing information was completed by methods such as literature survey,

stimulating groundwater bodies, etc. At this implementation step, two main groups (Classification and Land Use) were added to the existing five main context presented in the initial characterization table (Table 1). The complementary items added to the initial characterization table (Table 1) are:

- Hydrogeology: porosity; neighbouring groundwater bodies in the lateral plane; neighbouring groundwater bodies in the vertical plane
- Pressures: quantity of abstractions; recharge
- Hydrogeochemistry: chemical class; parameters that cause the groundwater body to be defined as impacted
- Land use: large surface water storage structures
- Classification: pressures; impacts; risks

Finally, further characterization table included a total of 29 parameters under 8 main contexts with the inclusion of the context "Other", which includes the following information:

- Site location maps showing geographical location of each groundwater body in the basin;
- Properties and spatial distribution of soil hydrotypes within the boundaries of the bodies;
- Generalized stratigraphic sections for the groundwater bodies, representative well logs and geological cross sections;
- Piper Diagrams used to demonstrate chemical class of groundwater;
- Inventory tables that summarize the pressures on each groundwater body;
- Maps showing land use of each groundwater body according to CORINE (2012) data and
- Maps showing distribution of total nitrogen and phosphorus loads calculated for micro-basins for surface water bodies as an indicator of the pressures from human activities;
- Maps showing distribution of quantity and quality monitoring points within the groundwater body.

Groundwater monitoring.

The aim of this implementation was to establish a groundwater monitoring programme so that data/information on the quantity and quality of groundwater can be obtained. Considering the duration and the scope of the study conducted in the GRB, it was taken three rounds for monitoring of groundwater. One of the important

factors in the design of the monitoring network was the location of pressure elements with respect to the locations of current wells and springs. In addition, groundwater flow directions were also taken into consideration in order to infer the possible impacts. Similarly, to reveal pressures on quantity, the areas where abstractions are concentrated were taken into account. Consequently, a preliminary field study was conducted to determine the current conditions of the monitoring points; and to replace the selected monitoring points with appropriate alternatives, if required.

Quality Monitoring Programme: 107 groundwater samples were collected from wells/springs; and besides 3 samples were also collected from surface waters. In process of determining the parameters to be analysed, outputs of the Determination of the Pollutants having Potential to Seep into Groundwater Project (DPPSGP), MoFWA (2015), were utilized. Within the scope of that project, possible contaminants that may emerge from industrial activities; together with the widely used pesticides were determined for the GRB, which were all included into the monitoring programme. In addition to this list, results of surface water chemical analyses carried out in TMDLAP were evaluated and seven parameters having potential to seep into groundwater were also added to the list. As a result, 151 parameters were analysed in each sample.

Quantity Monitoring Programme: Groundwater level measurements were performed at the selected 145 points to be able to assess groundwater quantity for three periods.

Distribution of the monitoring points within the GRB is presented in Figure 4. The results obtained from this monitoring programme guided the consecutive implementation steps (determination of thresholds, assessment of status, setting up of the PoM, etc.). It should be noted that the quality and quantity of groundwater at the scale of groundwater bodies in the basin was firstly done by this study. Therefore, the continuation of this monitoring programme is of utmost importance in terms of ensuring the persistence of all implementation stages.

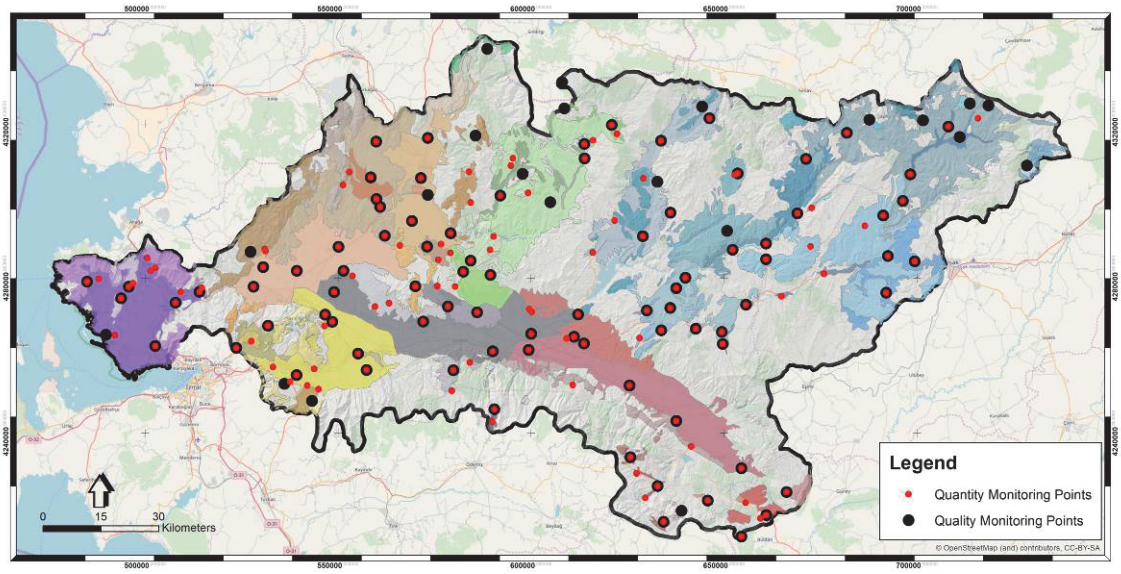

Figure 4. Monitoring network for the Gediz River Basin

Determination of threshold values.

One of the main objectives in management of water resources, as emphasized both in national and European Union (EU) legislation, is to ensure that water bodies are in good qualitative status. For the assessment of chemical status of groundwater bodies; measured and observed chemical properties of groundwater are compared with specific criteria; which are the groundwater quality standards and the threshold values.

- ***Groundwater quality standards*** for nitrates and pesticides were established at community scale with WFD in EU; and were set by the bylaw in our country.
- On the other hand, for all the other parameters, ***threshold values*** have to be determined specifically, on the required scale considering the availability and extend of the monitoring data. Therefore, determination of the threshold values is a very critical step in qualitative status assessment.

According to the legislation, for the groundwater bodies defined to be at risk; it is necessary to set threshold values for each parameter causing that groundwater body to be classified as at risk; namely constituting risk on the quality of groundwater. Throughout the studies for determination of the threshold values, 151 parameters analysed within the scope of this project at 110 sampling points for the three periods

were taken as the basis. Accordingly, threshold values for those parameters having enough data and deemed to pose risk according the results of the analysis were determined.

When directives, regulations and applications based on them are examined, it is seen that process of determining threshold values basically is based on the principle of comparing criterion value of relevant parameter with its natural background levels. Thus, one of the two most important issues in establishing the threshold values stands for the natural background levels (NBGLs), the other is the selection of appropriate reference values (REF). Upon determination of these two values separately for each parameter; threshold value of relevant parameter is determined based on the method in which NBGL and REF values are compared. It should be noted that this method provides an approximate range of values, within which threshold values can be set; rather than imposing a single precise value, thus providing flexibility to the decision makers. In this manner, administrative decisions are included in a process of setting up of the threshold values. Within the scope of this project, methodologies implemented by EU countries and suggested by BRIDGE (Background cRiteria for the IDentification of Groundwater thrEsholds) project (EU FP6, 2006), were adopted in the process of determining thresholds and natural background levels.

As a result of the analysis and evaluations made in accordance with the methodology for the establishment of the threshold values, among the 151 parameters analysed, threshold values for 37 parameters and two groups of parameters (trihalomethanes and sum of trichloroethylene and tetrachloroethylene) were specified. Moreover, it should be noted that nitrate and pesticides already have quality standards determined by regulations.

Assessment of the status.

One of the fundamental objectives for the management of water resources is to reach the good status in quantity and quality for all water bodies, as emphasized both in the legislation of Turkey and the EU. Criteria to be used in determination of the status of groundwater bodies are determined in such directives and legislations. However, even though general definitions are outlined; no precise information is available regarding the method to be implemented or the methodologies to be followed for the assessment of the status of groundwater. For this purpose, some classification tests are introduced with CIS Guidance Documents. These classification tests would be implemented as per the status of information about existing data and system. To determine the status of groundwater bodies in the GRB, all the information and data gathered in the previous stages were considered and suitable

tests were performed. Assessments were carried out in the three phases as summarized below:

Quantitative Status Assessment: Considering the existing data/information for the GRB; Water Budget Test was implemented to assess the quantitative status. Basic parameters considered in this test are groundwater recharges and abstractions; which were already calculated in the previous steps. For the Water Budget Test, ratio of abstraction to recharge in each groundwater body was used. Considering safe yield of the aquifers, groundwater bodies for which the ratio is over %75 were defined as in the poor status; while groundwater bodies in which this ratio is equal to or less than %75 were classified as in the good status.

Qualitative Status Assessment: Assessment of the qualitative status is basically based on a comparison of the threshold values (TV) and the quality standards (QS) to the measured concentrations. However, exceedance at one or more points within the boundaries of the groundwater body is not sufficient to classify it as in the poor status; but further analysis and additional assessments (classification tests) are required. Hence, a methodology based on comparison of TV and QS with the measured concentrations; and enriched with the tests to be conducted with the available data/information and point based investigation of pollutant sources was set up as follows:

- ***Comparison of Measured Concentrations with TV and QS***: Groundwater bodies, where TV and QS are not exceeded, were classified to be at good status.
- ***Implementation of Relevant Tests***: In cases of exceedance, classification tests should be executed. In this study, considering the available data/information and those required for the tests; General Quality Assessment Test was implemented. It involves the comparison of the TV and QS to the spatial average for the relevant parameter calculated for all monitoring points within the boundaries of a groundwater body. If the spatial average does not exceed TV and QS; the groundwater body is classified to be at good status.
- ***Distinguishing between Anthropogenic and Natural Sources of Pollution***: In cases where spatial average exceeds TV and QS; its reasons should be investigated. For this purpose, a detailed field survey was conducted to distinguish between anthropogenic and natural sources behind the exceedance. If it is associated with human activities, the groundwater body is classified to be at poor status. On the contrary, if it is derived from natural reasons, the groundwater body is classified to be at good status.

Integrated Status Assessment of Groundwater Bodies in terms of Quantity and Quality: At this stage, ultimate status of the groundwater was determined as per the relatively worse one of the qualitative and quantitative status.

Results

A number of strategies should be developed in order to reach good status for all water bodies and to prevent the groundwater from pollution as well as to keep them under control. Firstly, the groundwater bodies and monitoring points, where the measures should be taken, need to be determined. As a result of the comprehensive works and analysis, it was determined that overall status of 33 groundwater bodies in the basin, has to be improved. Hence, they were included in the PoM. Monitoring points located in groundwater bodies having good status, while the TV and QS were exceeded were also included in the PoM. Figure 5 presents the map showing the overall status of groundwater bodies and the monitoring points included in the PoM.

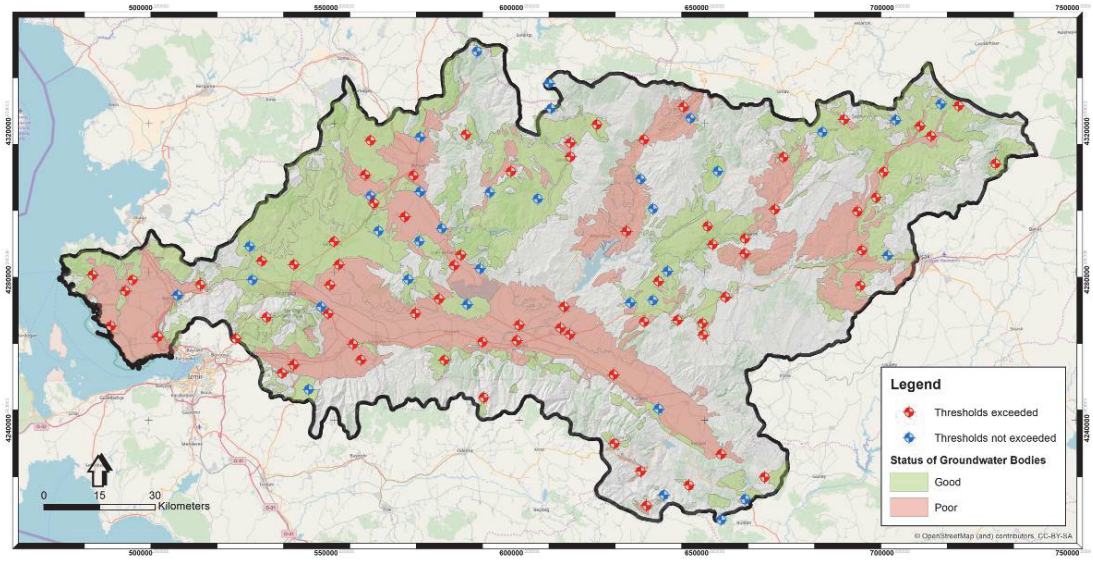

Figure 5. Overall status of groundwater bodies and monitoring points included in PoM.

After determination of the groundwater bodies and monitoring points to be counted in the PoM, detailed studies were conducted both in the office and at the field. As previously mentioned, an extensive field investigation was performed and

every anthropogenic pressure element was investigated and associated to the high concentration of the measured parameters, if possible. On the basis of the monitoring points, at the 35 groundwater sampling locations (among 106); reasons of exceedance were associated with the anthropogenic pressures. It is notable that among these 35 points, where threshold values or quality standards were exceeded due to the human activities; 30 of them were associated to agriculture, followed by animal husbandry (6), domestic discharges (4), solid waste disposal (2), geothermal activities (2) and mining activities (1). All of these were included in the PoM and measures were provided at several scales.

In the end, a PoM was set up in the compliance with the regulations including basic measures, specific measures and measures that should also be taken with the purpose of protections of coastal aquifers and groundwater bodies supplying drinking water. It should be noted that while some measures (like prohibition of direct discharges, monitoring and auditing) are valid for all groundwater bodies, some measures might pertain to a specific groundwater body (prevention of salt water intrusion along coastal aquifers) or even to a specific monitoring location (closing the geothermal wells executing improper re-injection). Moreover, some aspects recommended in the PoM (such as commissioning waste water treatment plants, conversion to regular waste storage, etc.) were also debated, prioritized and scheduled in BPAP (dated back to 2013). However, it was observed that implementation of the proposed actions in BPAP, is currently far behind the proposed schedule, in many aspects.

Discussion and Conclusion

In this study, the framework determined with national regulation on protection of groundwater against pollution and degradation was taken as basis. In that sense, this is the first study, in which the requirements of the national regulation were implemented in line with the guidance of the EU directives. Considering the fact that this was the first study executed in our country; the outcomes of project were aimed to be a guide for the projects following it. Therefore, while methodologies were being set up for each implementation step, it was aimed that the proposed methods would be applicable with already existing and/or obtainable data/information. In such studies to be conducted either in the Gediz River Basin or in the other basins from then on, continuity and improvement of the proposed methods and methodologies would be possible by filling out the gaps in the data/information outlined with the outcomes of this study.

Continuation of the monitoring studies that were started in the basin with this study would be very crucial. However, it should be emphasized that monitoring studies conducted within the scope of this study included only existing wells and springs. Although, the most representative points were selected; it should be noted that the distance of existing wells to the pollution sources would complicate the determination of a possible pollution due to the dilution and attenuation processes along the transport pathway. Hence, a supplementary monitoring network was designed proposing new wells closer to the possible pollution sources; which is one of the most significant outcomes of this study for the future implementations.

Moreover, this being a part of the proposed PoM; BPAP, which was observed to fall behind the schedule foreseen, should be kept on track. Concurrently, implementation of the measures proposed as the outputs of this study should be ensured. Close and regular follow-up of the execution of the PoM is strongly recommended, to observe the effects of the decisions made and detect the trends in the status of groundwater bodies, which supposed to improve, if all the measures are taken on time.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Yeraltı Suyunun Kalite ve Miktar Bakımından Yönetimi: Gediz Nehir Havzası Örnek Çalışması

Bu çalışma, ülkemizin en önemli doğal kaynaklarından biri olan yeraltı sularının miktar ve kalite özelliklerinin belirlenmesi süreçlerini kapsamaktadır. Ayrıca AB mevzuatlarını uyumlaştırma çalışmaları sonucunda yayımlanan "Yeraltı Sularının Kirlenmeye ve Bozulmaya Karşı Korunması Hakkında Yönetmelik"inde yer alan tüm uygulama adımlarının Türkiye'de uygulanabilmesi için yöntem ve metodolojilerin geliştirilmesi ve bunların Gediz Nehir Havzası örneğinde uygulanması hedeflenmiştir.

Söz konusu yönetmeliğin ilk uygulama adımı olan "***Yeraltı Suyu Kütlelerinin Belirlenmesi***" aşaması, yeraltı suyu yönetimine ilişkin uygulamalarda, kendisinden sonra gelecek çalışmaların temelini oluşturması bakımından büyük önem arz etmektedir. Bu konu ile ilgili daha önceki çalışmalar incelendiğinde farklı metodolojilerin uygulandığı ve farklı kriterlerin dikkate alındığı görülmüştür. Bu çalışmada; pek çok örnek uygulamada kullanılan jeoloji ve hidrojeoloji kriterlerine ek olarak Türkiye için önem arz eden diğer kriterlerin de dahil edilmesiyle 7 aşamalı bir metodoloji oluşturulmuş ve Gediz Nehir Havzası için, 76 adet yeraltı suyu kütlesi belirlenmiştir.

Belirlenen tüm kütleler için "***Başlangıç Karakterizasyonu***" uygulama adımının gerçekleştirilmesi gerekmektedir. Bu adım temel uygulama adımlarından olan "Baskı ve Etkilerin Belirlenmesi" ve "Risk Değerlendirmesi" aşamalarını da kapsamaktadır. Ancak, her birine ilişkin mevzuatın ayrıntıları ile ortaya koyulabilmesi ve metodolojilerin ayrı ayrı incelenebilmesi amacıyla, her bir süreç ayrı başlıklar altında değerlendirilmiştir. Bu aşamada, tüm yeraltı suyu kütlelerini başlangıç düzeyinde karakterize edebilmek amacıyla seçilen parametreler yanı sıra; genelleştirilmiş kesitlerin ve yer bulduru haritalarının da yer aldığı karakterizasyon tabloları oluşturulmuştur.

"***Baskı ve Etkilerin Belirlenmesi***" çalışmalarında, insani faaliyetlerin oluşturduğu baskılar; ve baskıların muhtemel etkilerinin belirlenmesi için gerçekleştirilen tüm çalışmalar miktar ve kalite olarak iki ana başlık altında incelenmiştir. Havzada ***yeraltı suyunun miktarı üzerindeki baskılar***, çekimlerden kaynaklandığından tüm kütleler için Çekim-Beslenim Analizi yapılarak miktar üzerindeki baskılar belirlenmiştir. Buna ek olarak uzun dönem yeraltı suyu seviyelerinin ölçüldüğü lokasyonlarda da Yağış-Rasat Analizleri gerçekleştirilmiştir. Havzada ***yeraltı suyunun kalitesi üzerindeki baskılar*** noktasal (kentsel, endüstriyel, madencilik ve jeotermal) ve yayılı kirleticiler (tarım, hayvancılık ve katı atık depolama) olarak iki temel grupta incelenmiş ve her bir yeraltı suyu kütlesi için tüm bu baskılar derecelendirilmiştir. İnsani faaliyetlerden kaynaklanan bu baskıların, yeraltı sularının kalitesi üzerinde oluşturduğu etkiler ise; mevcut kimyasal analiz sonuçları kullanılarak belirlenmiştir.

"***Risk Değerlendirmesi***" uygulama adımının temelini bir önceki uygulama adımında belirlenen baskı ve etki sınıfları oluşturmaktadır. Risk altındaki yeraltı suyu kütlelerinin belirlenmesi için söz konusu iki uygulamanın birbirleri ile ilişkilerini de içeren 4 aşamalı bir metodoloji oluşturulmuştur. Buna göre; hem miktar hem de kalite bakımından risk altındaki yeraltı suyu kütleleri belirlenmiştir.

İlgili mevzuat gereği, "risk altında" olarak tanımlanan yeraltı suyu kütleleri için "***Ayrıntılı Karakterizasyon***" çalışmalarının tamamlanması gerekmektedir. Bu doğrultuda, başlangıç karakterizasyonunda gerçekleştirilen çalışmalar risk altındaki yeraltı suyu kütleleri için ayrıntılandırılmış ve karakterizasyon adımı tamamlanmıştır. Sonuçlar kütle bazında hazırlanan tablolar, haritalar, grafikler şeklinde sunulmuştur.

"***Yeraltı Sularının İzlenmesi***" uygulama adımı kapsamında, iki yağışlı, biri kurak olmak üzere üç dönem izleme çalışmaları yapılmıştır. İzleme noktaları mevcut kuyu ve kaynakların konumları dikkate alınarak, miktar ve kalite durumunu en iyi şekilde temsil edebilecek noktalardan seçilmiştir. Bu program kapsamında, 110 numunede 151 parametrenin analiziyle yeraltı sularının kalitesi ve 145 noktada yapılan yeraltı suyu seviye ölçümleriyle de yeraltı sularının miktarı izlenmiştir.

Yeraltı suyu kütlelerinin iyi durumda olup olmadıkları kimyasal açıdan değerlendirilirken; ölçülen ve gözlemlenen kimyasal özellikler belirli kriterler ile karşılaştırılır. Bu kriterler yeraltı suyu kalite standartları ve eşik değerlerdir. Bu nedenle, "***Eşik Değerlerin Belirlenmesi***" uygulaması; takip eden aşamalarda kullanılacak temel kriterleri oluşturmaları bakımından; sürecin en önemli adımlarından birini teşkil etmektedir. AB'de ve Türkiye'de nitratlar ve pestisitler için kalite standartları belirlenmiştir. İlgili mevzuat gereği, su kütlesinin risk altında olarak sınıflandırılmasına sebep olan her parametre için eşik değerlerin belirlenmesi süreci, kriter değer ile doğal arka plan seviyelerinin karşılaştırılmasına dayanmaktadır. Bu çalışma kapsamında, Yeraltı Suyu Eşik Değerlerinin Belirlenmesi için Arka plan Kriterleri (BRIDGE: Background Criteria for the Identification of Groundwater Thresholds) projesi incelenmiş ve bu projenin çıktıları olan metodolojiler takip edilmiştir. Sonuç olarak, yönetmelikteki kalite standardı bulunan parametrelere ek olarak, havzada yeraltı sularının kalitesi üzerinde risk teşkil ettiği belirlenen 37 parametre ve iki parametre grubu (trihalometanlar ile trikloretilen ve tetrakloretilenin toplamı) için de eşik değerler belirlenmiştir.

Yeraltı suyu kütlelerinin iyi duruma ulaştırılması amacıyla takip edilecek olan metodolojinin büyük bir bölümü Türkiye'de yürürlükte olan Yeraltı Sularının Kirlenmeye ve Bozulmaya Karşı Korunması Hakkında Yönetmelik ile belirlenmiştir. Buna ek olarak, sınıflandırma testleri ise; mevcut verilerin ve sistem ile ilgili bilgilerin durumuna göre yapılabilmektedir. Miktar ve kalite bakımından ayrı ayrı "***Durum Değerlendirmesi"*** yapılmış ve bu iki değerlendirmenin sonucu birlikte ele alınmıştır. Her bir yeraltı suyu kütlesi, görece daha zayıf olana göre belirlenen tek bir durum ile ifade edilmiştir. Gediz Nehir Havzası için belirlenen 76 kütleden 33'ü zayıf durumda; diğer 43 tanesi ise iyi durumda olarak sınıflandırılmıştır.

Sonuç olarak; yeraltı sularının kirlenmesini önlemek ve kirliliği kontrol altında tutmak için bir takım stratejiler geliştirilmesi gerekmektedir. Ayrıca, kütlelerin durumları ve izleme programı neticesinde elde edilen sonuçlar dikkate alınarak, bir tedbirler programı hazırlanmalıdır. İlgili yönetmelikteki "***Tedbirler Programı"*** kapsamında, temel tedbirler, özel tedbirler ve ilave tedbirlerin yanı sıra kıyı akiferlerinin ve içme suyu amaçlı olarak kullanılan yeraltı suyu kütlelerinin korunması için gereken tedbirler yer almalıdır. Gediz Nehir Havzası için zayıf durumda olduğu belirlenen yeraltı suyu kütleleri tedbirler programına dahil edilmiştir. Bunlara ek olarak; iyi durumda olan ancak, herhangi bir noktasında eşik değer ve/veya kalite standartlarının aşıldığı izleme noktaları da tedbirler programına alınmış ve bu lokasyonlar için ofis ve sahada detaylı çalışmalar gerçekleştirilmiştir. Bir sonraki aşamada ise havzadaki tüm baskı unsurları için havzanın mevcut durumu dikkate alınarak ayrı ayrı tedbirler sunulmuş; bunlara ek olarak içme suyu amaçlı kullanımlara; koruma alanlarına ve kıyı akiferlerine yönelik tedbirlerin de eklenmesi ile tedbirler programı zenginleştirilmiştir.

Türkiye'de yürürlükte olan Yeraltı Sularının Kirlenmeye ve Bozulmaya Karşı Korunması Hakkında Yönetmeliğin gerekliliklerinin baştan sona uygulandığı ilk çalışma bu proje olmuştur. Bu nedenle proje süresince gerçekleştirilen çalışmaların yeni çalışmalar için de yol gösterici olması hedeflenmiştir. Bu proje kapsamında başlatılan izleme çalışmalarının sürdürülmesi en önemli kazanımlardan biri olacaktır.