Examination of Turbidity Problem of Drinking Water Treatment Plant By Using Fault Tree Analysis

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Abstract

Access to a reliable supply of drinking water and acceptable water quality are basic requirements for human health. Efficient risk management is becoming increasingly important within drinking water treatment plants (DWTP) since drinking water systems are vulnerable and subject to a wide range of risks. In this scope, it is crucial to analyze the risk by using risk evaluation methods such as Fault Tree Analysis. Fault Tree Analysis (FTA) is used to deductively breakdown the causes of a problem in a tree structure and commonly employed in root cause analysis. The method starts by identifying an undesired event/fault at the top of the tree. The tree continues downward until all basic events have been described. In this study, turbidity problem, one of the water quality problems of Samsun Drinking Water Treatment Plant, was investigated by using FTA.

Key words: Risk Management, Drinking Water, Turbidity, Fault Tree

1. Introduction

The growth of population and industrial development all around the world cause water resources to diminish rapidly. In order to rectify this problem, intense efforts on protecting available water resources, treatment of low quality waters obtained from resources for using/drinking purposes, and treating polluted waters to make them harmless have been continuously maintained.

Healthy water is colorless, odorless and clear water that contains healthy minerals at adequate levels and that is freed of any pollutants that may be unhealthy. For the provision of clean and reliable water to the public, enforcement of related legal regulations, conservation of water resources, proper treatment/processing of waters and delivery to users through a safe supply network system is required.

It is possible to gather the risks consumer may be exposed to concerning drinking water under two groups as Quality and Quantity Failures. A failure on quality means that the drinking water does not comply with the "*water quality standards*". A quantitative failure on the other hand indicates the failure of providing the demanded quantity of drinking water due to a variety of causes such as insufficient precipitation, unplanned population growth, inadequate flow rates of

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resources, failures and leakages in water supply networks, infrastructure works and any damages due to extraordinary cases like wars or earthquakes.

Quality and Quantity failures occur in consequence of some undesired cases within any of the processes of Raw Water Provision, Treatment and Distribution in a drinking water system [1]. In this context, it is understood that drinking water systems operate in the way of a serially connected system (Figure 1). Accordingly, the success of the system depends on the successfully accomplishment of the tasks of all sub systems.

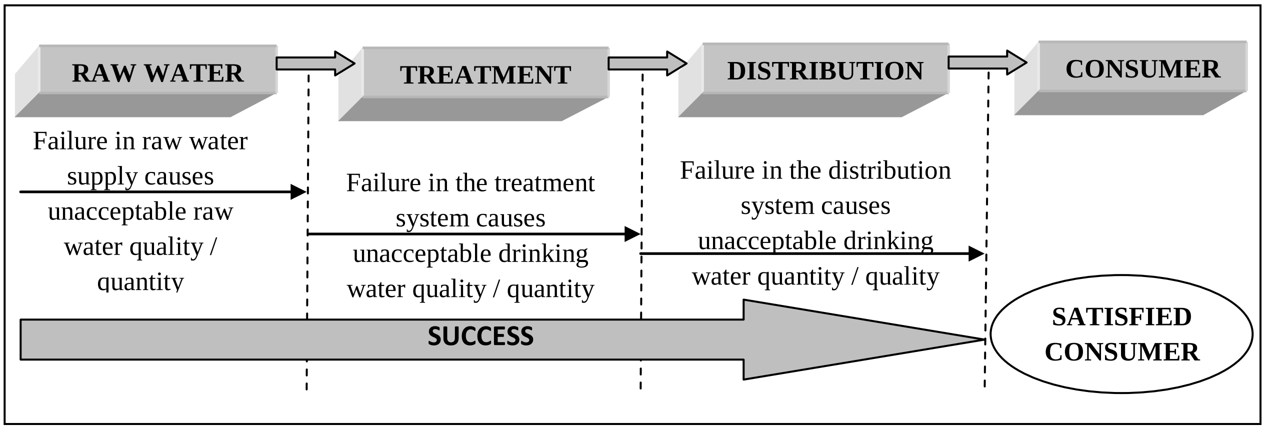

Figure 1. Drinking Water System (Adapted from Lindhe et al. [1])

The principle adopted today is to foresee and prevent environmental problems before they actually occur. With the efforts focusing on the causes of environmental problems, instead of the exposed consequences, environmental risks and their effects on humans can be significantly reduced. Utilization of Fault Tree Analysis (FTA), which is used for risk analysis in many different fields, in this context seems to be possible. The fundamental concept in FTA is the translation of a physical system such as water treatment plant into a structured logic diagram in which certain specified causes lead to one undesired top event. Some studies that utilized FTA in the field of water pollution were carried out by Lindhe et al. [1], Risebro et al. [2], Rosen et al. [3], Tchorzewska-Cieslak and Boryczko [4], Jian et al. [5], XueBin [6], Rodak and Silliman [7] and Tchorzewska-Cieslak and Boryczko[8].

In case that the potential failures and their causes in a drinking water treatment plan are determined, the measures against these can be taken quickly and easily. In this study, the "Turbidity" problem, which is determined to be a serious issue of Drinking Water Treatment Plants, was examined with Fault Tree Analysis for Samsun Drinking Water Treatment Plant. The developed Fault Tree provides an approach that applies to all drinking water treatment plants operating with a similar procedure.

2. Materials and Method

2.1. Fault Tree Analysis

Fault Tree Analysis is a comprehensive technical examination based on the graphical display of parallel and sequentially logical combination of the faults that cause the occurrence of an undesired event [9]. Based on deductive logic, FTA enhances the comprehensibility of the system and enables the detection of the real source (root cause) of the fault.

FTA was originally developed by Bell Laboratories in 1962 for the United States Air Force, to be used in Minuteman system. It was later adapted and widely used by Boeing Company. Today, the analysis is commonly used in all sectors that include reliability and safety concerns.

A Fault Tree is a graphical model of parallel and sequential combinations of faults that cause an event (top event) that is not desired in a system in terms of reliability and safety. Fault trees are formed by using gates and events. The most used gates in a fault tree are the *AND* ( ) and the *OR* ( ) gates. In case that the occurrence of any of the events causes the occurrence of the top event (the undesired event), than these events are connected with the *OR* gate. In case that the occurrences of all of the events included in the tree are required for the occurrence of the top event, then these events are connected with the *AND* gate.

A cut set is any fault tree group that causes the occurrence of the top event in case that all events in the group occur. A minimal cut set on the other hand, is the minimal fault tree group that causes the occurrence of the top event in case that all events in the group occur. In order to determine Minimal Cut Sets, a comprehension on Boolean Mathematics is necessary. The point that particularly needs to be emphasized here is that in the case that the events A and B are connected with the *AND* gate they are displayed as (*A.B*), while in the case that connected with the *OR* gate, they are displayed as (*A+B*). Boolean mathematics' rules are listed herein below**.**

$$\begin{array}{lll} A+B=B+A & A.B=B.A & A+(A.B)=A \\ A+A=A & A+0=A & A+B+C=(A+B)+C=A+(B+C) \\ A+1=1 & A.A=A & A.B.C=(A.B).C=A.(B.C) \\ A.0=0 & A.1=1 & A.(B+C)=(A.B)+(A.C) \end{array} \tag{1}$$

Besides of being a qualitative assessment of the events that cause a top event to occur and their interrelations, a fault tree also enables to make quantitative assessments. In qualitative assessments, minimal cut sets are obtained by utilizing Boolean relation. In this way, the actions that will cause the top event to occur are determined. As for the case in quantitative assessment, the occurrence likelihood of the top event is calculated from the probabilities of basic events (root causes). In this way, the root causes that make the highest contribution to the occurrence of the top event can be determined.

2.2. Samsun Drinking Water Treatment Plant

Samsun Drinking Water Treatment Plant is located on an area of approximately 300 decares in Tekkekoy District Asagicinik vicinity about 25 km away from the center (Figure 2). The water coming via gravitation from the Cakmak Dam to Treatment Plant 13.346 meters away is supplied to the city after being subjected to the processes of ventilation, conditioning, filtering and chlorination as presented in the flowchart provided in Figure 3. The daily capacity of the plant is 200.000 m³ and it serves approximately 500.000 people.

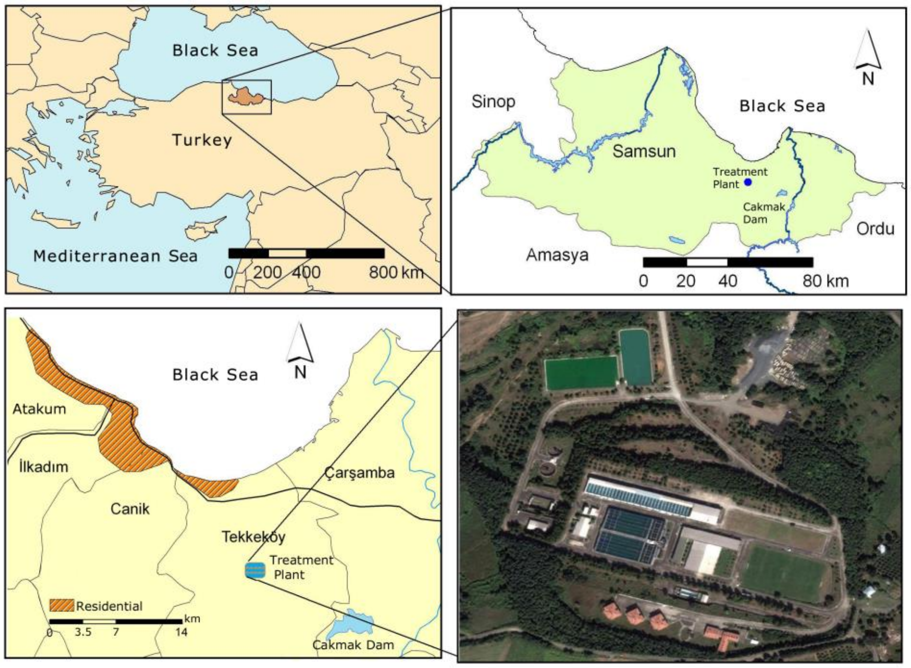

Figure 2. Location of Samsun Drinking Water Treatment Plant

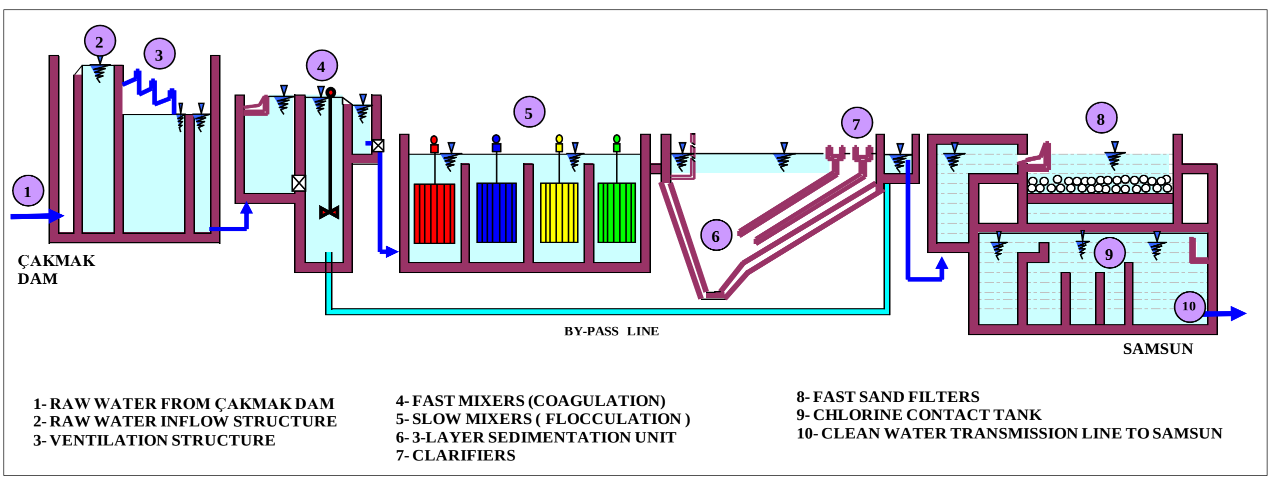

Figure 3. Flowchart of Samsun Drinking Water Treatment Plant

Daily routine analyses (for turbidity, pH, temperature, organic substance) and weekly, biweekly and monthly chemical and bacteriological analyses are carried out in the Clean Water and Wastewater Laboratories of the General Directorate of Water Treatment. With these regular tests, it is ensured that the water complies with the standards of TS-266 (Turkish Standards) and World Health Organization-WHO.

Being one of the drinking water quality parameters, turbidity is the measure of light permeability of waters that contain suspended solids. It is also a state that is caused by clay, silt, organic substances, algae, diatoms, iron bacteria and other microorganisms in water. Turbidity indicates the presence of undesired substances. Generally, it is caused by dissolved, suspended and colloidal particles [10]. Turbidity originating from the soil carried with rain or from the domestic-industrial wastewaters mixing up with the stream is found in high rates particularly in river waters. During this pollution, inorganic substances mix with the water as well as organic substances. Unhealthy germs and bacteria may be present within such suspended substances. Also bacterial growth increases water turbidity. Water turbidity is an undesired event since it can be associated with organic activities or mixture of polluted water. Turbid waters are deemed to be suspicious and it is particularly required for drinking waters that the turbidity value must not exceed the limit value stipulated in TSE [11].

The histogram prepared from the monthly drinking water analysis reports of the period January - August 2012 published by Samsun Metropolitan Municipality General Directorate of Water and Sewage Administration, is presented in Figure 4. The existence of the values above upper limit indicates consumption water with quality that is contrary to the current standard of drinking water. According to Eq. (2), 16.85% of the turbidity related observation values for the period in question were above the allowed limit value (1 NTU) with the assumption of normal distribution. In other words, in every 100 days of water consumption, consumers experienced turbidity problem approximately for 17 days. Similar cases apply to many water treatment plants.

$$P(X > \text{Upper Limit=1}) = P(Z > \frac{\text{Upper Limit} - \text{Mean}}{\text{Std. Deviation}}) = P(Z > \frac{1-0.75}{0.26}) = P(Z > 0.96) = 0.1685 \qquad (2)$$

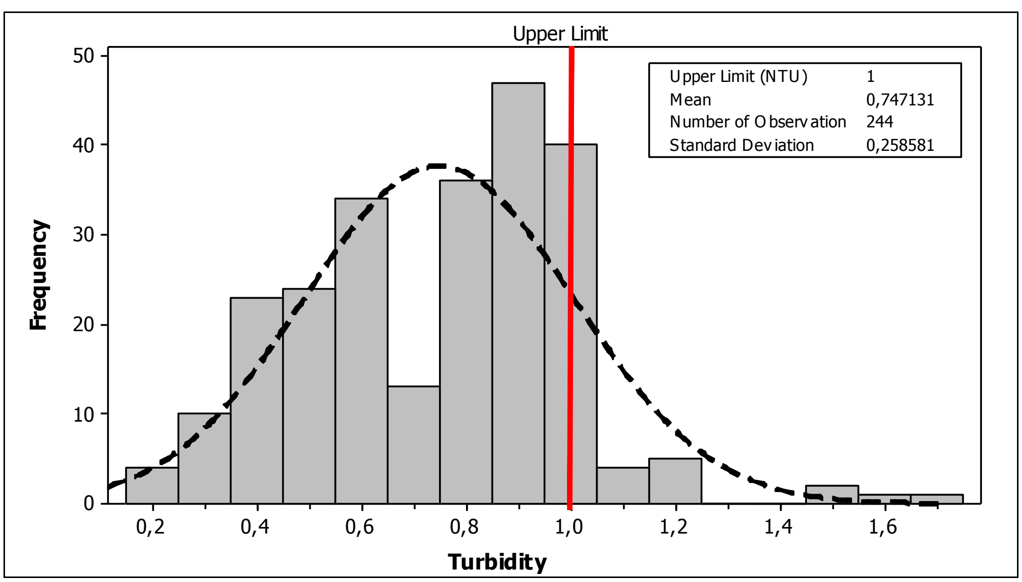

Figure 4. Histogram of Turbidity Data

Box-and-Whisker Plot (also called box-plot) in Figure 5 summarizes monthly turbidity data through five statistics (minimum, lower quartile, median, upper quartile and maximum) and outliers. It was used to assess and compare the data on monthly basis. The difference between box widths indicates that there is a great deal of variability between months in terms of turbidity. July (7) demonstrates the greatest variability. In spite of exhibiting least variability, March (3) and June (6) have outside points. April (4) has the highest outliers which are also above the maximum allowed limit for turbidity. Based on the findings of Figure 4 and 5, it can be concluded that turbidity is a problem for treatment plant.

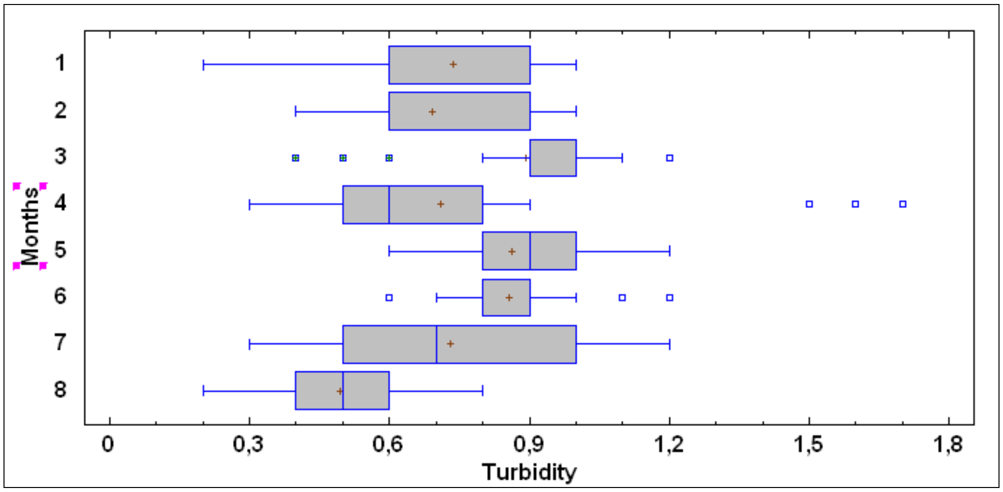

Figure 5. Boxplot for Turbidity Data

3. Results

The fault tree developed for turbidity problem is presented in Figure 6. In this stage, ReliaSoft BlockSim 8 Academic Demo software was utilized. The *UE-Undeveloped Event* abbreviation in the fault tree indicates an event that does not require any further analysis at the current stage. On the other hand, *BE-Basic Event* indicates a basic event or root cause that does not require any further development.

Since the probabilities of the basic events obtained in relation with the problem in question are unknown, only a qualitative analysis was made at this point. Functional solution of the fault tree in Figure 6 according to Boolean mathematics is as follows.

$$A = UE1 + UE2.(BE1 + BE2 + BE3 + BE4 + BE5 + BE6 + BE7 + BE8 + BE9) \quad (3)$$

The final equation obtained is equal on the basis of basic events. The top event was denoted as a function of various combinations of the basic events. According to this equation there are 10 minimal cut sets and the reduced fault tree is presented in Figure 7 in symbolic display.

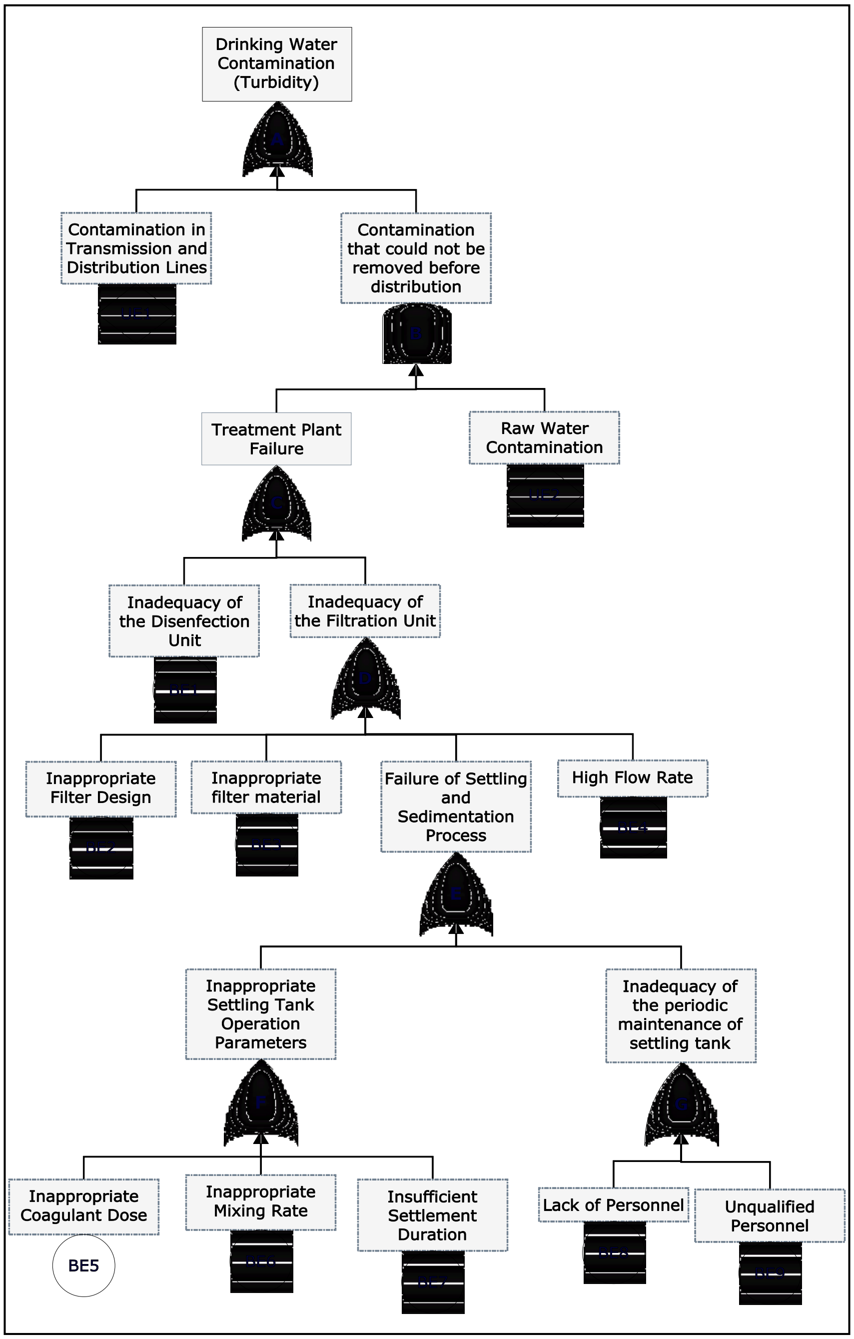

Figure 6. Fault Tree for Turbidity Problem

Conclusions

Turbid waters are not only inconvenient as drinking waters but also for industrial use. Due to this reason, removal of turbidity is among the prioritized tasks for drinking water treatment plants.

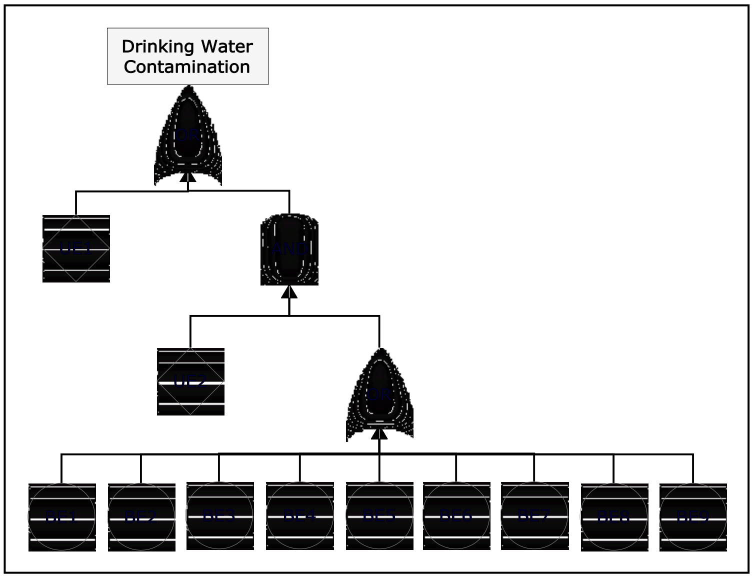

Figure 7. Reduced Fault Tree

In light of the data obtained from the monthly drinking water analysis reports of Samsun Drinking Water Treatment Plant, it is understood that turbidity is an important issue for this plant, as it is in most other water treatment plants. It is essential to remove turbidity, which is a significant drinking water quality indicator, due to the fact that it can cause various negative consequences for the consumers. In the present study, a fault tree analysis for "turbidity" problem was carried out in order to determine preventive measures. The developed fault tree offers a model that applies to all drinking water treatment plants that operate in a similar way.

By means of the FTA, 2 undeveloped and 9 basic events were determined to cause turbidity problem. Since it was considered convenient to particularly focus on the faults in treatment plant, no further analysis was made concerning Contamination in Transmission and Distribution Lines (*UE1*) and Raw Water Pollution (*UE2*). These problems are extensive and significant enough to be the topics of another study.

According to the fault tree, it is understood that turbidity in drinking water can be caused by contamination in transmission and distribution lines or raw material pollution and unsuccessful water treatment made by the plant. Prevention of raw water pollution particularly due to natural circumstances such as precipitation, wind etc. and the structuring and industrialization close to reservoirs is usually not possible or is only partially possible. In this case, treatment plant plays a key role in the short term and effective solution of the turbidity problem. In this context, with the proper determination of operating conditions, performance of the needed periodic maintenance and renewals by allocating the required resources for these operations will significantly reduce the occurrence of the problem in question.

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