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The Geographical Information System (GIS) based water quality assessment of a drinking water distribution system in the Denizli City

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ABSTRACT

Nowadays, continuous, healthy water supply and total water quality management have emerged as an important issue in engineering applications. In a wide ranging assessment, the quality of the drinking water is being monitored in the distribution system, until it is supplied to the end user. It includes regular sampling and testing performed for assessing compliance with guideline values. The major purpose of this study was to monitor, evaluate and control the water quality in distribution system by using GIS to assess the drinking water quality in Denizli. The drinking water necessity in Denizli is supplied from various drinking water sources as Gokpinar, Derindere, Kozlupinar and Benlipinar springs and more than 30 deep wells. The storage reservoir volume fed by the water sources varies from 20 m^3 to 5500 m^3. Almost 56% of Denizli drinking water distribution system consists of asbestos cement and cast iron pipes. The non-revenue water in the water supply system is about 50%. In the old distribution systems, epidemic illness risk is at high rate and the free residual chlorine has to be kept at certain amount. Therefore, the free residual chlorine amount has to be measured during the summer months against the epidemic danger. The chlorine reacts with the organic matter and the amount decreases; it forms the carcinogenic trihalomethanes (THMs). In this study, three organic matter precursors; namely total organic carbon (TOC) concentration, UV absorbance at 254 nm and free residual chlorine concentration has been measured in 30 points at various parts of the Denizli city water distribution system and mapped by GIS.

Keywords: Water distribution system; Water quality; TOC; UV_{254}; Free residual chlorine; GIS; Denizli

1. Introduction

The water users, as well as the general public who may affect and be affected by healthy water supply and water quality, should be considered an important part in engineering applications. Water quality problems mostly connected with long-term health risks are considered to be of first priority for the citizens [1]. In urban cities, the environmental services are in the responsibility of the public sector that supplies piped water for all kind of household works [2]. The aim of this public sector is to be capable to maintain high water quality from the water treatment facilities or water resources to the end user. In a wide ranging assessment, the quality of the drinking water is being monitored in the distribution system, until it is supplied to the last consumer. The distribution system itself can contribute to this deterioration. Water quality monitoring includes regular sampling and testing performed for assessing compliance with guideline values.

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Contamination of pipelines due to intermittent supply, low pressure in distribution network, inadequacy of wastewater collection systems, and leaking pipes are common problems in developing countries [2,3]. Numerous factors also influence the quality of the water within a building's distribution pipes system and may result in microbial and/or chemical contamination of drinking water. In most cases, fecal contamination of drinking water within buildings arises from cross connections of sewer pipes [4] and the presence of organic matters would lead to deterioration of water quality in the distribution system [5]. Therefore, chlorine constitutes the most common disinfectant used in the drinking water treatment process throughout the world. When applied at the end of the process, its aim is to eliminate pathogens [6] and to control microbial re-growth in summer when water temperature exceeds 20°C [7]. When leaving the treatment plant, water requires a residual amount of chlorine to ensure its microbiological stability during transportation throughout the distribution system. However, chemical reaction of chlorine with organic compounds in the treated water favors the formation of disinfection by-products (DBPs), some being suspected to be mutagenic [6,8]. The more added chlorine and the greater the organic matter contained in the water, the higher the potential for formation of DBPs. In addition, high chlorine doses are frequently related to consumer complaints about odor. Consequently, operators of drinking water utilities are facing a considerable challenge to balance the benefits and the drawbacks of disinfection by chlorine. They have to ensure adequate chlorine doses to maintain microbiological quality and minimize DBP formation throughout the distribution system. Concentrations of residual chlorine decrease and may become very low far from the chlorination point, at the extremities of the distribution system. Operators periodically have to adjust chlorine doses (by increasing or decreasing) in the distribution system [8].

This investigation conducted a pilot study for the drinking water distribution system in Denizli City, Turkey. Denizli is an important industrial, tourism, and export center in the Aegean region of Turkey which extends from the Aegean Sea coast to the inner parts of western Anatolia. Denizli city has a population of 475,000 which makes it the second largest city in the Aegean region.

In this study, three organic matter precursors; namely total organic carbon (TOC) concentration, UV absorbance at 254 nm and free residual chlorine concentration have been measured in 30 points at various parts of the Denizli city water distribution system and mapped by GIS.

GIS is widely used in water quality modeling, monitoring, forecasting, planning and management [9]. In this study, GIS is used for mapping of the sampling points, data storing for the measurement results and creating surface grid.

2. Materials and methods

2.1. Water sampling and GIS mapping

Water is supplied to Denizli from five main sources: the Gokpinar spring (580 l/s), Derindere spring (95 l/s), Kozlupinar spring (70 l/s), Benlipinar spring (20 l/s) and numerous wells (550 l/s) [10]. Two springs are located to the south of Denizli while the two higher capacity springs are located to the southeast of the water service area (Fig. 1). The wells are distributed both within and beyond the water service area; the water from these sources is collected in water storage tanks, chlorinated and released to the distribution system. Due to the topography of the area, the water distribution system relies on gravity flow

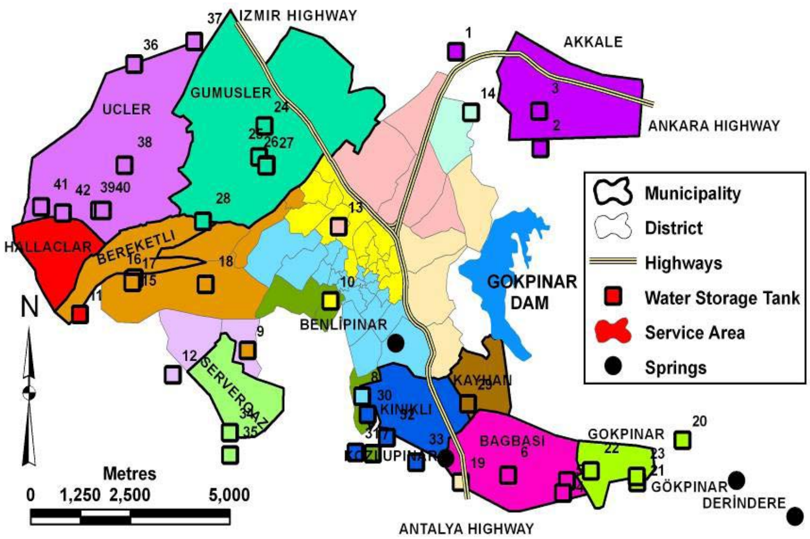

Fig. 1. Denizli City water supply system, location of springs and water tanks/service areas [11].

Table 1
Raw water quality parameters of Derindere and Gokpinar springs

Parameters	Derindere	Gokpinar
pH	7.7	7.9
Conductivity, µs/cm	520	483
Total dissolved solids, mg/L	254	208
Turbidity, NTU	0.17	0.49
Chloride, mg/L	2.54	3.81
Total hardness, mg/L as $CaCO_3$	227	284
Iron (+2), mg/L	0.03	0.09
Nitrate (as N), mg/L	6.5	4.5
Ammonia-N, mg/L	0.060	0.065
UV_{254}, 1/cm	0.001	0.001
TOC, mg/L	0.24	0.32
TTHMs, µg/L	Not measured	5.0

[11]. Raw water quality parameters of the two main water resources of Denizli City are given in Table 1.

Total pipe length of Denizli water distribution system is about 1,745 km with some 95% of the transmission and connection lines made of steel. The main and distribution lines are asbestos cement (AC 54%), polyvinyl chloride (PVC 44%) and cast iron (CI 2%). The diameter of the distribution lines is between 65 and 200 mm, whereas the main lines are between 100 and 600 mm in diameter [11]. The map of the Denizli City water supply system is given in Fig. 2.

For this study 30 sampling points were selected at various parts of the Denizli City. Sampling points were selected mostly as mosques and shopping malls due to the easy sample taking opportunities. The coordinates of sampling points were determined using handheld GPS. Measurements and samplings were performed in May 2009. Sampling points and population density (people/km^2) of the Denizli City are given in Fig. 3.

Chlorination process of the Denizli City water distribution system varies for different water sources. Derindere spring water is directly transmitted to the water tanks without pre-chlorination. Gökpinar spring has a small open surface lake and this lake is chlorinated with gaseous chlorine at the residual dose of 0.2 mg/l. Some water tanks, especially big volume ones, have liquid chlorination systems. Wells are generally used in the summer and some of them are directly connected to the distribution pipes instead of water tanks.

The GIS program ARCGIS, ESRI [12] was used primarily during the data input and analysis phases. Sampling

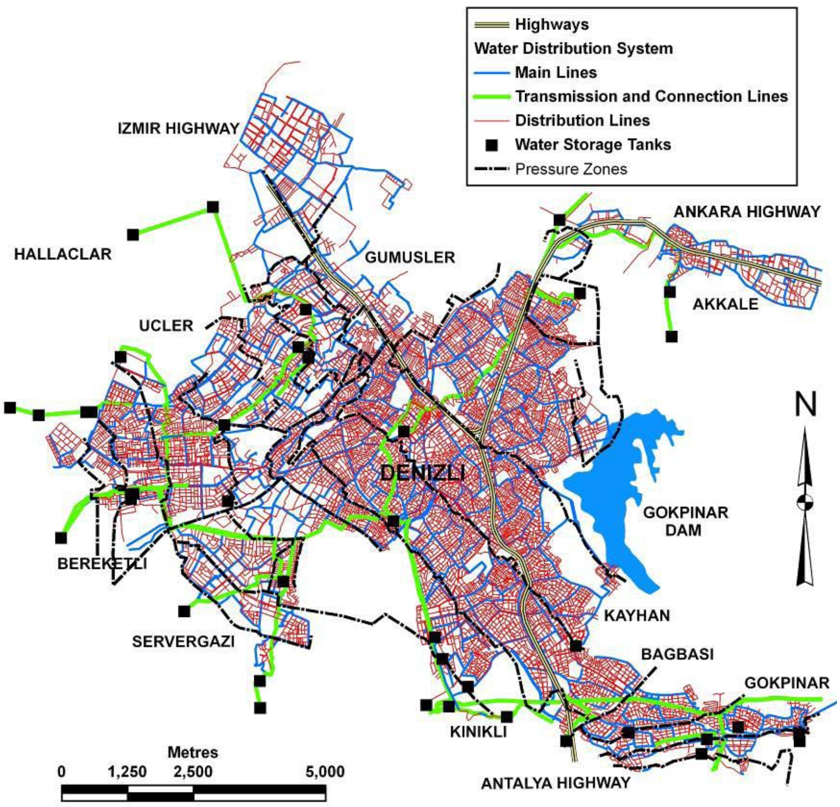

Fig. 2. Map of the Denizli City water supply system [11].

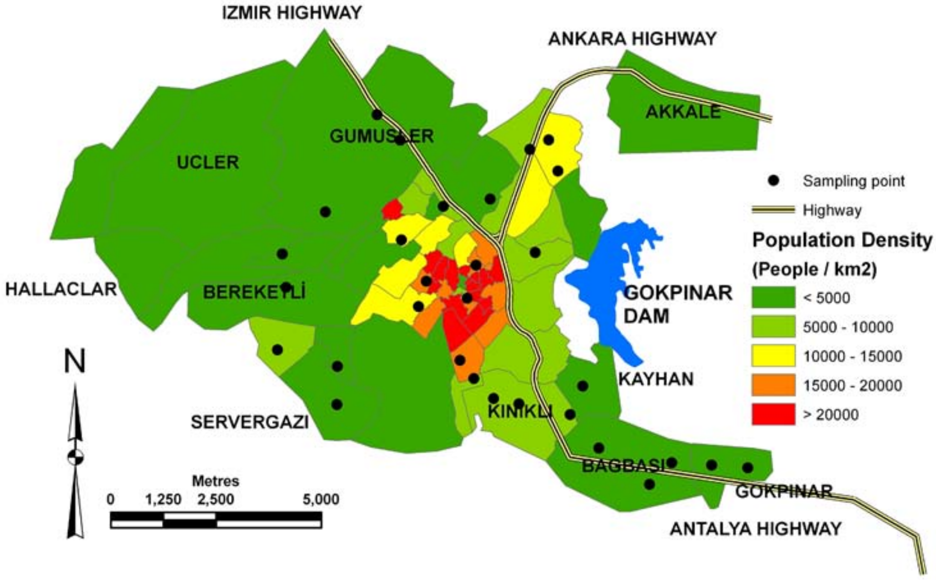

Fig. 3. Sampling points and population density map of the Denizli City.

points and the results of the measurements are located in the GIS.

Inverse Distance Weighted (IDW) is used as a method of creating a surface grid in ArcGIS. IDW is a method of interpolation that estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. The closer is a point to the center of the cell being estimated, the more influence, or weight; it has in the averaging process. This method assumes that the variable being mapped decreases in influence with distance from its sampled location.

The interpolated values have been calculated from the values recorded at the neighboring stations according to Eq. (1) [13]:

$$Z(S_0)=\frac{\sum_{i=1}^{n}\frac{Z(S_i)}{h_i^{\beta}}}{\sum_{i=1}^{n}\frac{1}{h_i^{\beta}}} \qquad (1)$$

where $Z(S_0)$ is the interpolated grid value, $Z(S_i)$ is the neighboring data point, h_i is the distance between the grid node and data point and power β is taken as 3 in this study, n is the number of measuring points. By defining a higher weighting power (β), more emphasis is placed on the nearest points, and the resulting surface will have more detail. Specifying a lower weighting power will give more influence to the points that are farther away, resulting in a smoother surface. The characteristics of the interpolated surface can be controlled by applying a fixed or variable search radius, which limits the number of input points that can be used for calculating each interpolated cell. In this study 5 nearest input points are taken into consideration.

2.2. *Analytical methods*

Three parameters were selected as the precursor of organic matter and trustworthy of the distribution system: free residual chlorine, TOC and UV_{254}. All measurements were carried in accordance with Standard Methods [14].

- Free residual chlorine analysis: Free residual chlorine measurements were performed using DPD free chlorine reagent by portable instruments (Lovibond portable colorimeter). Before sample collection, the water was allowed to flow for at least 5 min, until free residual chlorine reach a constant value.
- TOC analysis: TOC measurements were performed with a Shimadzu TOC-5000 analyzer equipped with an auto sampler, according to the combustion-infrared method as described in the Standard Methods 5310 B [14]. This analytical method relies on oxidation of organic carbon to inorganic carbon (CO_2 gas), which is further quantified with infrared spectroscopy.
- UV_{254} analysis: UV_{254} absorbance was measured in accordance with Standard Methods 5910 B [14], using a Shimadzu 1601 UV/Vis spectrophotometer at wavelength of 254 nm with a 1 cm quartz cell. The samples were first filtered through a prewashed 0.45 μm filter to remove turbidity, which can interfere with this measurement, and a blank with distilled ultra filtered water was run prior to sample analysis.

3. Results

Free residual chlorine concentration is a very important water quality parameter because the occurrence of high coliform group and total bacterial count often correlate with low free available chlorine [15]. Therefore, free residual chlorine contour maps are also very helpful in locating the re-chlorination (booster chlorination) stations. Determination of the locations of re-chlorination stations remains difficult because of the lack of information about the variations of free chlorine residuals along distribution systems. With free residual chlorine contour maps, administrators can easily decide on the necessity of building re-chlorination stations and identify the accurate locations.

Lou and Han found that the variations of free available chlorine concentrations correlated very weakly with the retention time of drinking water in a distribution system, and both distribution system and water storage facilities were responsible for free chlorine decrease in their study performed in South Taiwan [15]. According to the results of their research, free available chlorine of 103 samples (61.3% of total samples) fell outside the regulatory standards (0.2–1.0 mg/l), with only one sample exceeding 1.0 mg/l and the rest lower than 0.2 mg/l.

Free residual chlorine concentration map of the Denizli City is given in Fig. 4. In this study, the free residual chlorine concentration value of 0.2 mg/l is determined as the lower limit. Below this value free residual chlorine concentration in the water distribution system is accepted as inadequate and chlorine addition should be performed. If the free residual chlorine concentration is between 0.2 and 0.5 mg/l, which means the ideal concentration, there is no need for additional action. If the free residual chlorine concentration is higher than 0.5 mg/l, which is above the regulatory orders [16], then free residual chlorine amount should be reduced.

TOC is an index of organic matters which is performs a role of item connected with microorganism and chlorine consumption material [7]. TOC distribution map of the Denizli City is given in Fig. 5. TOC concentrations of the two main water sources of the Denizli City are 0.24 and 0.32 mg/l (Table 1). Then critical TOC concentration is taken as 0.5 mg/l, and below this value the water distribution system is accepted as trustworthy and above this value additional measurement are needed.

The level of UV_{254} absorbance is directly correlated with the existence of humic acids in the water, reflecting their higher aromatic content and greater molecular size [17]. UV_{254} absorbance map of the Denizli City is given in Fig. 6. UV_{254} absorbance values of the two main water sources are 0.001 cm^{-1} whereas due to the old ductile iron pipes existing in the distribution system higher values are measured. For the UV_{254} absorbance 0.1 cm^{-1} value is taken as the critical value. Below this value water the distribution system is accepted as trustworthy and above this value there is a need for additional measurements. The results show that except for two small areas UV_{254} absorbance values are below the critical value.

4. Conclusions

According to the results of this pilot study, free residual chlorine concentration in the water supply system of Denizli is generally within the ideal limits. However, some low or high free residual chlorine concentration areas are observed. Low values are located especially in Kayhan, Bagbasi and Gumusler regions and high values

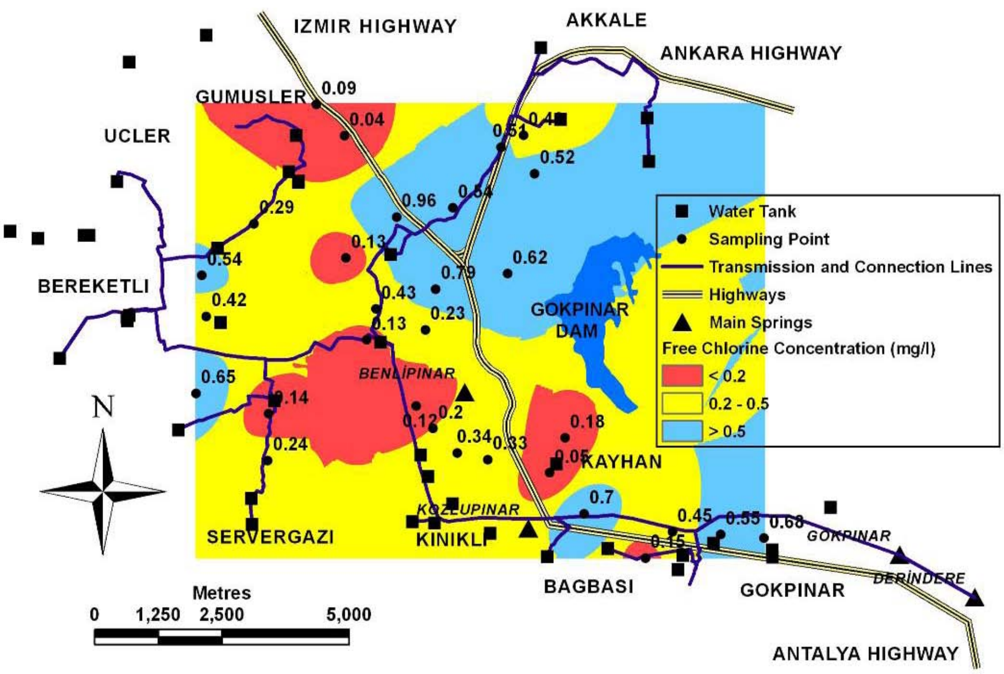

Fig. 4. Free residual chlorine concentration distribution in the water supply system of the Denizli city.

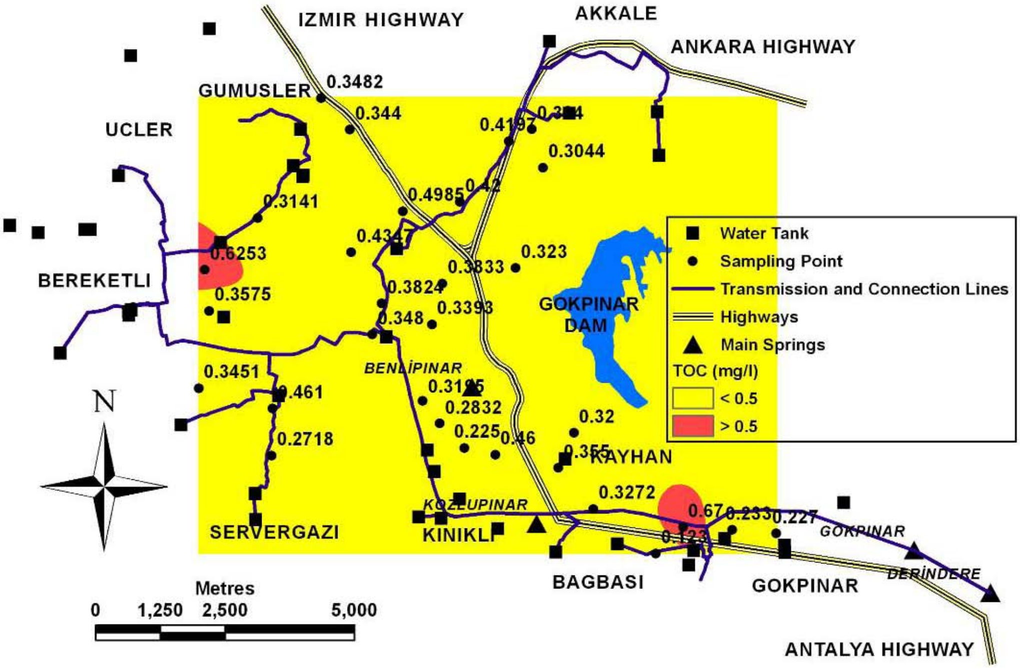

Fig. 5. TOC distribution in the water supply system of the Denizli city.

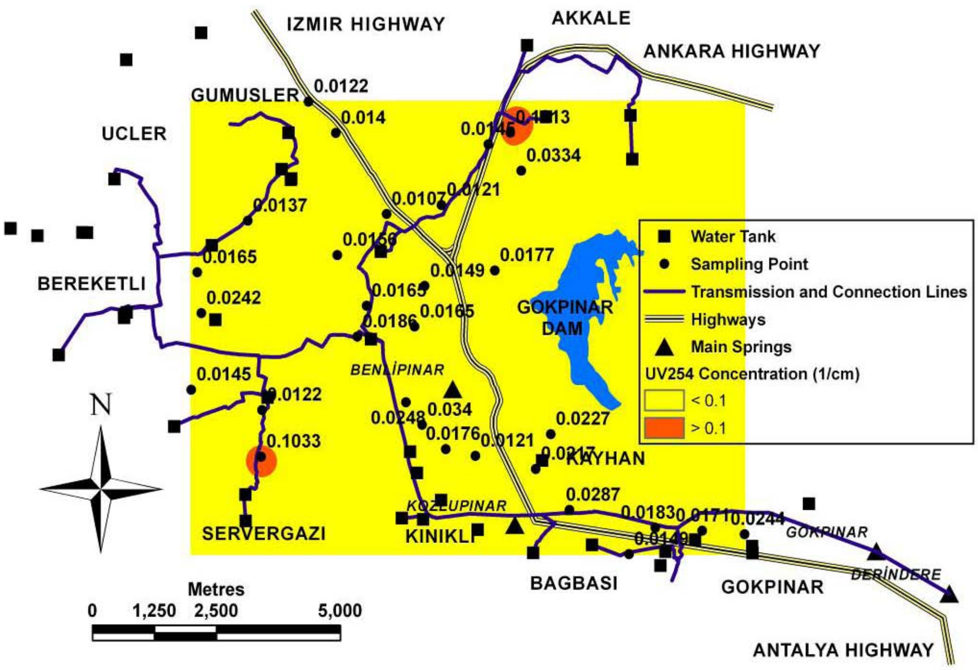

Fig. 6. UV_{254} absorbance distribution in the water distribution system of the Denizli City.

are located around the intersection of Izmir, Ankara and Antalya highways. The reasons of free available chlorine degradation might be attributed to biofilm, pipeline material, hydraulic conditions, etc. [15]. More study should be performed to determine the particular reasons of these variations in the Denizli water distribution system and some countermeasures should be taken accordingly. The Denizli City water distribution system seems to be in good conditions according to the TOC and UV_{254} absorbance because their values are in acceptable limits except for very few points.

As the results of this pilot study are promising, this study will be expanded in several ways. Measurements will be taken at water tanks and the number of measurements at Denizli water distribution system will be increased to get more precise distribution of free residual chlorine, TOC, and UV_{254} in the system. Furthermore, the number of parameters will be increased in the future studies and their seasonal variation may be examined. The results of this study will form the basis for water quality management system in Denizli.

Symbols

h_i — Distance between the grid node and data point
n — Number of measuring points
$Z(S_0)$ — Interpolated grid value
$Z(S_i)$ — Neighboring data point
β — Power

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