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Evaluation of a Household Drinking Water Purification System Performance in terms of Organic – Inorganic Water Pollution Indicators and Ecological – Health Risk Assessment Indices

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Abstract

In this study, the performance of one of the most popular household drinking water purification systems (WPS) of Turkey was evaluated. Tap and purified water samples were taken from İpsala District (Thrace Region). A total of 23 significant water quality assessment parameters including essential and toxic metals (pH, TDS, EC, turbidity, Cl, NO_3, SO_4, PO_4, BOD, COD, B, Al, Cr, Mn, Ni, Cu, Zn, As, Sr, Mo, Sb, Ba, Pb) were measured in water samples and how much the WPS improves these parameters were determined. Also Water Quality Index (WQI), Heavy Metal Pollution Index (HPI), Heavy Metal Evaluation Index (HEI), Nutrient Pollution Index (NPI), Cancer Risk (CR), Hazard Quotient (HQ) and Hazard Index (HI) were applied to data in order to assess the qualities of tap and purified water in terms of multiple effects of toxicants and possible risks of human health. As a result of this research, it was determined that the investigated WPS significantly improved the drinking water quality and significantly reduced the scores of applied ecological and health risk assessment indicators.

Keywords: Household drinking water purification systems, Water qulity, İpsala District, Ecological indicators, Health rish indicators

Introduction

Water purification history is quite old and it is known that even in the ancient times, water was purified by passing through some materials such as stones or sands or by boiling. When the history of modern water treatment systems is examined, it is seen that the first water softening device was made in 1903, the first membrane for water purification devices was developed in 1980, the purification devices with UV in its structure were developed in 1995, the first closed water purification system was made in 2001, carbon filters were developed for water purification devices in order to provide the mineral support to water in 2007 and more portable water purification systems were made in 2015 (Maden et al., 2019).

With the developing technology, many different filter types have been added to the household WPSs, whose main purpose is to get the hardness of the water. Recently, the most used technology in household WPSs is the devices equipped with reverse osmosis technology, which helps to filter the ions, heavy metals, all bacteria and all the substances harmful to the human health in the water. Also, the amount of lime, which constitutes a significant problem in drinking water, and the bad odours due to various reasons can be cleaned by the reverse osmosis method (http://www.cebilon.com.tr/).

Heavy metals, which may strongly accumulate and biomagnified in organisms, have numbers of hazardous effects both on the ecological balance of environment and on the

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human health. They can be adsorbed by biota and transported and bio-accumulated to human through the several food chain interactions or directly by consuming drinking water containing heavy metals. Toxic metals may cause various non-carcinogenic and carcinogenic health problems and diseases (Song et al., 2018; Mutlu and Uncumusaoğlu, 2018; Köse et al., 2020; Ustaoğlu and İslam, 2020). Chronic exposure of these toxicants at lower doses for a long time may cause many types of cancer (Park et al., 2004). It has been well documented that significant quantities of toxic metals are being discharged to the environment and threatens the health of environment and human (İslam et al., 2018; Varol and Tokatlı, 2021; Tokatlı and Varol, 2021).

Toxic metal pollution in drinking water has been a significant risk factor for human health in almost all the globe and many new methods have been developed to assess the potential risks and the multiple effects of toxicants in freshwater (Varol and Davraz, 2015; Tokatlı, 2019; Ustaoğlu and Tepe, 2019; Saleem et al., 2019; Tokatlı and Ustaoğlu, 2020; Varol, 2020; Ustaoğlu and Aydın, 2020; Tokatlı et al., 2021). In the present study, the performance of a widely used household water purification system (WPS) in Turkey was evaluated by determining some significant organic and inorganic water pollution indicators and by using some significant health risk and water quality assessment indices.

Materials and Methods

Collection of water samples

İpsala District is located in the downstream of Meriç – Ergene River Basin and known as an agricultural city. Intensive agricultural activities are conducted around it and nearly 25% of Turkey›s total rice production is produced from this region. Therefore, it is known that the drinking waters of the region are quite polluted especially in terms of organically (Tokatlı, 2015; 2017; Bülbül and Elipek, 2017; Öterler, 2017). Drinking water samples were taken from the tap water of İpsala District, where is known as an agricultural city and intensive agricultural activities are conducted around it, and from the purified tap water of the district treated by a widely used household water purification system with reverse osmosis in the winter season (2019), when the precipitation was at the highest level. Water samples were taken to the 1 L pre-cleaned and acid washed polyethylene bottles. pH of water samples to be used in the elemental analyses were reduced with nitric acid in order to make them below 2 (APHA, 2005).

Water purification stages of investigated household drinking water purification system

5 different filtering systems are used in the investigated WPS. Sediment Pre-Filter (SPF) (1) collects coarse dirt. Granular Activated Carbon Filter (GACF) (2) retains chlorine and other gases and gives clarity to water. Block Carbon Filter (BCF) (3) is a second carbon filter in addition to the GACF filter. It makes the incoming water to enter the membrane. It holds even the finest particles. Membrane (M) (4) is the heart of the reverse osmosis system. It separates all negative elements in water except water molecules. The Final Carbon Filter (FCF) (5) gives flavour to the water and removes the odour that may occur in the tank (http://www.cebilon.com.tr/).

Physicochemical and macro – micro element analysis

pH, TDS and EC parameters were measured by using a multiparameter device (Hach Lange, HQ40D), turbidity parameter was measured by using a turbidimeter device (Hach Lange, 2100Q), Cl, NO_3, SO_4, PO_4 and COD parameters were measured by using a spectrophotometer device (Hach Lange, DR3900) and BOD parameter was measured by using a BOD device (Hach Lange, BOD Trak 2).

Water samples were filtered and their volumes have been set to 50 ml with ultra – pure water. Then the macro – micro element contents were measured by an Agilent branded (7700 XX) ICP-MS in the central laboratory of Thrace University (accreditation certificated laboratory). All the macro – micro element analyses were listed as the average of triple reads (TS EN / ISO IEC 17025) (EPA, 2001).

Water Quality Index

WQI is a widely used method to assess the groundwater and sufacewater quality (Wang et al., 2017; Varol, 2020; Ustaoğlu et al., 2020). The formula of WQI is given in the Equation (1) and (2).

$$WQI = \sum \left[W_I \times \left(\frac{C_i}{S_i} \right) \times 100 \right] \quad (1)$$

$$W\iota = \frac{w_i}{\Sigma w_i} \quad (2)$$

W_I is relative weight. W_i coefficients are assigned as 5 (maximum) – 1 (minimum), according to the effects of toxicants on health (Meng et al., 2016). C_i is the parameter level determined in water. S_i is the standard value for drinking water specified by WHO (2011), EC (2007) and TS266 (2005). The scale of WQI is given in Table 1 (Xiao et al., 2019).

Heavy Metal Pollution Index

HPI is an assessment method the combined effects of each heavy metal on the overall water quality (Herojeet et al., 2015; Wagh et al., 2018; Tokatlı and Ustaoğlu, 2020). The formula of HPI is given in the Equation (3) and (4) (Mohan et al., 1996).

$$HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \quad (3)$$

$$Q_i = \sum_{i=1}^{n} \frac{M_i}{S_i} \times 100 \quad (4)$$

Q_i is the subindex of the toxicant. W_i is the unit weight. M_i is the determined levels of toxicant. S_i is the standard of the toxicant. n is the total number of toxicants considered. The scale of HPI is given in Table 1 (Saleh et al., 2018).

Heavy Metal Evaluation Index

HEI helps to determine the overall assessment of water quality in terms of toxic metals (Edet and Offiong, 2002). The formula of HEI is given in the Equation (5).

$$HEI = \sum_{i=1}^{n} \frac{H_C}{H_{MAC}} \quad (5)$$

H_c is the level of toxicant determined in water sample. H_{mac} is the maximum admissible concentration (MAC) (WHO, 2011). The scale of HPI is given in Table 1 (Bodrud-Doza et al., 2016; Saleh et al., 2018).

Nutrient Pollution Index

NPI is an important technique to evaluate the drinking water quality in terms of nutrient contamination (Isiuku and Enyoh, 2020). The formula of NPI is given in the Equation (6).

$$NPI = (CN/MAC_N) + (CP/MAC_P) \quad (6)$$

$C_{N/P}$ are the levels of NO_3 and PO_4 detected in the water samples. $MAC_{N/P}$ are the maximum permissible levels of NO_3 and PO_4 specified by WHO (2011). The scale of NPI is given in Table 1.

Health Risk Assessment

In the present investigation, one of the most effective human health risk evaluation technique developed by EPA (2004) was applied to data. Chronic daily intake (CDI), exposed from digestion ($CDI_{ingestion}$) and absorption by dermally (CDI_{dermal}) were calculated. The formulas of $CDI_{ingestion}$ and CDI_{dermal} are given in the Equations (7) and (8):

$$CDI_{ingestion} = Cwater \; x \; \frac{(IR \; x \; EF \; x \; ED)}{(BW \; x \; AT)} \quad (7)$$

$$CDI_{dermal} = Cwater \; x \; \frac{(SA \; x \; Kp \; x \; ET \; x \; EF \; x \; ED \; x \; CF)}{(BW \; x \; AT)} \quad (8)$$

$CDI_{ingestion}$ is the chronic daily intake by ingestion. CDI_{dermal} is the chronic daily intake by dermal adsorption (ppb/day). C_{water} is the concentration of the toxicant in water. IR is the ingestion rate. EF is the exposure frequency. ED is the exposure duration. BW is the average body weight. AT is the average time. SA is the exposed skin area. $ABS_{gastrointestinal}$ is the gastrointestinal absorption factor. Kp is the dermal permeability coefficient in water. ET is the exposure time during bathing. CF is the unit conversion factor (Saleem et al., 2019; Xiao et al., 2019; Varol et al., 2020; Ustaoğlu, 2020).

The probable non – carcinogenic risks of toxicants were determined by means of risk hazard quotient formula (HQ) both for adults and children. The formulas of $HQ_{ingestion}$ and HQ_{dermal} are given in the Equations (9), (10) and (11) (Chen et al., 2018).

$$HQ_{ingestion} = \frac{CDI_{ingestion}}{RfD_{ingestion}} \quad (9)$$

$$HQ_{dermal} = \frac{CDI_{dermal}}{RfD_{dermal}} \quad (10)$$

Hazard index (HI) is being calculated by summing the total amount of $HQ_{ingestion}$ and HQ_{dermal} (Equation (11)) and shows the total of potential non – carcinogenic effects formed by all the investigated toxicants (EPA, 2004; Wang et al., 2017).

$$HI = HQ_{ingestion} + HQ_{dermal} \quad (11)$$

If HQ and HI were bigger than 1 that means probable negative effects on human health. If HQ and HI were lower than 1 that means no negative effects on human health sourced from toxicants (Yang et al., 2017).

Carcinogenic Risk (CR) is being used to determine the potential risks for human by being exposed to several carcinogens for a life and it may be found by multiplying the Chronic Daily Intake (CDI) values with the Cancer Slope Factor (CSF) coefficients (Equation (12)) (Saha et al., 2017; Gao et al., 2019) The range of acceptable carcinogenic risk suggested by the EPA (2004) is $10^{-6} – 10^{-4}$.

$$CR = CDI \; x \; CSF \quad (12)$$

Table 1. Water quality classes in terms of applied ecologic indices

Value	Water Quality Classes	Usage Possibilities
	WQI	
< 50	Excellent quality	Drinking, irrigation, industrial
50 – 100	Good quality	Drinking, irrigation, industrial
100 – 200	Poor quality	Irrigation, industrial
200 – 300	Very Poor quality	Irrigation
> 300	Unsuitable for drinking purpose	Treatment is required
	HPI	
< 100	Low heavy metal pollution	Suitable
> 100	High heavy metal pollution	Not suitable
	HEI	
< 10	Low pollution	Suitable
10 – 20	Medium pollution	Not suitable
> 20	High pollution	Not suitable
	NPI	
< 1	No pollution	-
1 – 3	Moderate polluted	-
3 – 6	Considerable polluted	-
> 6	Very high polluted	-

Results and Discussion

The detected physicochemical data and macro – micro element concentration levels in tap and purified water samples and the results of applied health risk and ecological risk indices are given in Table 2. Also the percent and fractional exchanges between the tap and purified water in terms of physicochemical results and the data of risk assessment indices are given in Table 1. Monomial scores of toxic metals used in HPI and HEI and also HI and CR scores are given in Figure 1.

Table 2. Standard values, detected data and the scores of applied indices

	Standard Values	Tap Water	Purified Water	Percent Exchange[1]	Fractional Exchange[2]
pH	6.5 – 9.5	7.26	8.21	13.09	1.13
TDS (ppm)	500	319.00	21.70	**-93.20**	**-14.70**
EC (µS/cm)	300	616.00	44.10	**-92.84**	**-13.97**
Turbidity (NTU)	5	0.59	0.47	-20.34	**-1.26**
Cl (ppm)	250	76.60	10.20	**-86.68**	**-7.51**
NO3 (ppm)	50	7.89	1.39	**-82.38**	**-5.68**
SO4 (ppm)	250	30.00	12.00	**-60.00**	**-2.50**
PO4 (ppm)	5	1.49	0.21	**-85.91**	**-7.10**
BOD (ppm)	3	5.40	2.10	**-61.11**	**-2.57**
COD (ppm)	5.5	16.30	4.47	**-72.58**	**-3.65**
B (ppb)	500	52.94	28.66	-45.87	-1.85
Al (ppb)	200	3.52	1.00	**-71.42**	**-3.50**
Cr (ppb)	50	6.14	0.23	**-96.18**	**-26.16**
Mn (ppb)	50	1.41	0.27	**-81.05**	**-5.28**
Ni (ppb)	70	1.89	1.04	-44.81	-1.81
Cu (ppb)	2000	2.80	0.26	**-90.85**	**-10.92**
Zn (ppb)	3000	96.16	15.05	**-84.35**	**-6.39**
As (ppb)	10	5.59	0.69	**-87.62**	**-8.08**
Sr (ppb)	1500	753.56	21.31	**-97.17**	**-35.36**
Mo (ppb)	70	1.07	0.39	**-63.57**	**-2.75**
Sb (ppb)	20	0.09	0.06	-30.89	-1.45
Ba (ppb)	700	106.95	3.96	**-96.30**	**-27.03**
Pb (ppb)	10	0.32	0.03	**-90.08**	**-10.08**
Ecological Risk Assessment	**WQI**	42.58	11.79	**-72.31**	**-3.61**
	HPI	19.41	2.44	**-87.41**	**-7.94**
	HEI	1.60	0.19	**-87.93**	**-8.29**
	NPI	0.46	0.07	**-84.69**	**-6.53**
Non - Carcinogenic Risk Assessment	**HI – Cr** (Adult)	5.88E-02	2.25E-03	**-96.18**	**-26.16**
	HI – As (Adult)	5.35E-01	6.63E-02	**-87.62**	**-8.08**
	HI – Pb (Adult)	6.57E-03	6.52E-04	**-90.08**	**-10.08**
	HI – Cr (Child)	6.62E-02	2.53E-03	**-96.18**	**-26.16**
	HI – As (Child)	6.03E-01	7.46E-02	**-87.62**	**-8.08**
	HI – Pb (Child)	7.37E-03	7.31E-04	**-90.08**	**-10.08**
Carcinogenic Risk Assessment[3-4]	**CR – Cr** (Adult)	**8.77E-05**	3.35E-06	**-96.18**	**-26.16**
	CR – As (Adult)	**2.40E-04**	2.97E-05	**-87.62**	**-8.08**
	CR – Pb (Adult)	7.82E-08	7.76E-09	**-90.08**	**-10.08**
	CR – Cr (Child)	**9.82E-05**	3.76E-06	**-96.18**	**-26.16**
	CR – As (Child)	**2.68E-04**	3.32E-05	**-87.62**	**-8.08**
	CR – Pb (Child)	8.76E-08	8.69E-09	**-90.08**	**-10.08**

[1]Reduces after purification more than 50% are marked in bold, [2]Reduces after purification more than 2x are marked in bold, [3]CR scores very close to the limit value are given in bold, [4]CR scores over the limit value are given in bold – underlined

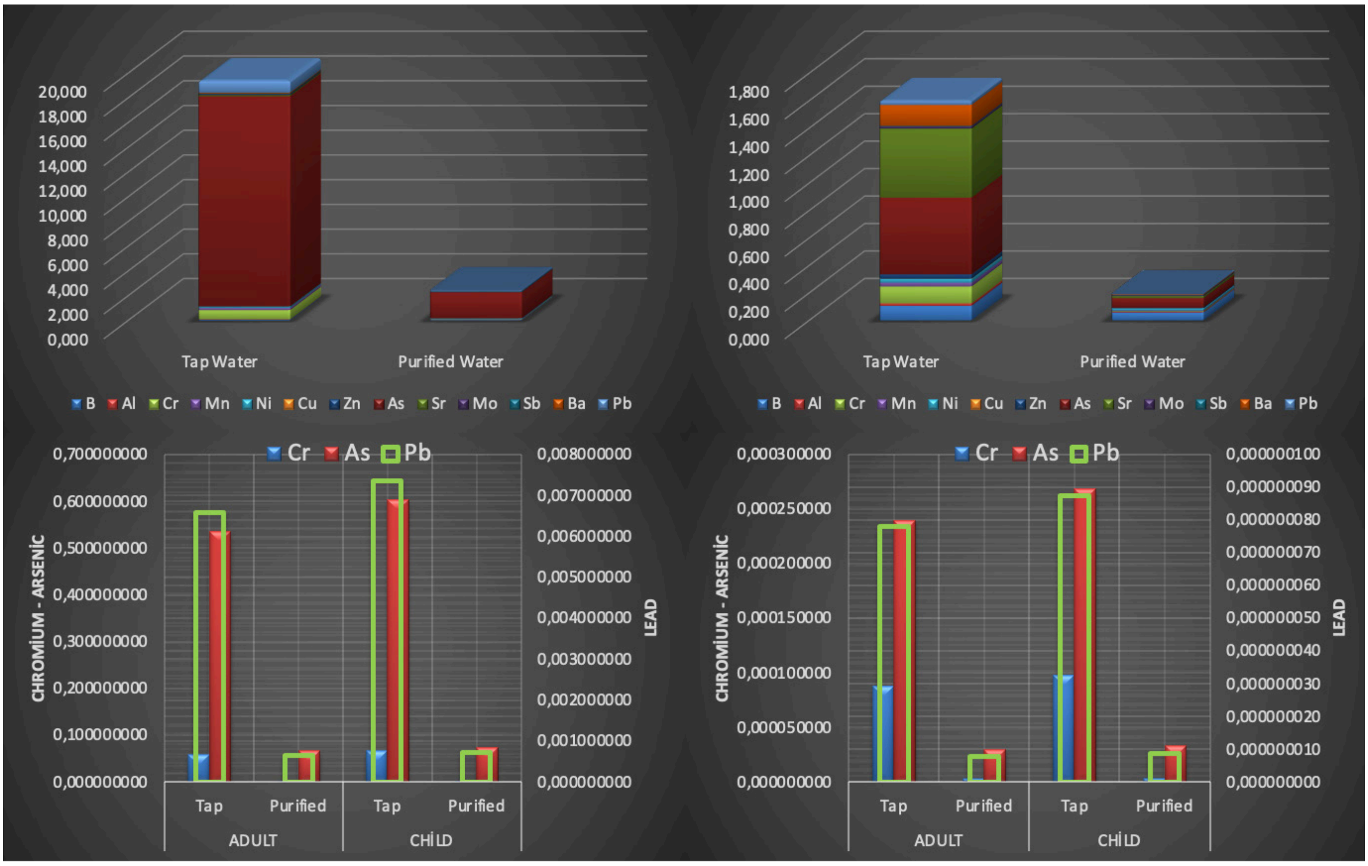

Figure 1. Monomial toxic metal scores (up) of HPI (left) and HEI (right) and results of HI (left) and CR (right)

According to the Water Pollution Control Regulation criteria in Turkey (WPCR, 2015), tap and purified water have 1st Class water quality in terms of pH, TDS, SO_4, COD and all the investigated macro – micro element levels. Tap water has 2nd Class water quality in terms of EC Cl, NO_3 and BOD and has 4th Class water quality in terms of PO_4 parameters, while the purified water has 1st Class water quality in terms of almost all these parameters.

The high or low pH value affects the drinkability of the water and according to TS266 (2005) and EC (2007) standards, the pH value of drinking water is required to be between 6.5 – 9.5. Slightly acidic pH value in drinking water indicates that the mineral content of the water is partially low and the carbon dioxide level is high, while the pH value is slightly alkaline means that the mineral content is quite higher. Also alkaline waters are known to be considered as more efficient and beneficial for human health (Li and Wu, 2019). In this study, it was determined that the investigated water purification system (WPS) increased the pH value of drinking water considerably and reaches a slightly alkaline level, which is considered to be optimum for human health.

Total dissolved solids and electrical conductivity and chlorine parameters are important for drinking water quality and also for water taste (Li and Wu, 2019). It was found that the investigated WPS reduced the levels of these parameters in drinking water of İpsala District approximately 10 times and significantly improved the taste of water.

Organic fertilizers and chemical fertilizers of inorganic origin are the most important factors that increase the amount of nitrogenous and phosphorous compounds in water. It is also known that phosphate fertilizers used in agricultural activities and phosphorus compounds in detergents are among the most important factors that increase the phosphate content of water. Nitrate in water can be caused by nitrate fertilizers used in agricultural areas, as well as the oxidation of ammonia, which occurs as a result of the decomposition of proteins contained in animal and vegetable wastes and sewage wastes (Wetzel, 2001; Manahan, 2011). It is thought that the main reasons for the quite high nitrate and phosphate detected from the drinking water of the İpsala District are agricultural activities and domestic wastes.

One of the most significant effects of nitrate on human health is methemoglobinemia, which is more common in new-borns and infants younger than six months. The stomach acid of new-born babies is not as strong as in older children and adults, and the condition causes a significant increase in the number of bacteria in the stomach that convert nitrate to nitrite. Pregnant women are susceptible to methemoglobinemia in adults with low stomach acidity and low methemoglobin-reducing enzyme activity. Nitrite is absorbed in blood cells and hemoglobin is converted into methemoglobin, which has a much lower oxygen carrying capacity (Self and Waskom, 2013; Tokatlı, 2014). The Maximum Contaminant Level (MCL) limit for nitrate reported by the EPA is 10 ppm, and the risk of methemoglobinemia in neonates and methemoglobin – sensitive adults above this limit is extremely high (EPA, 2009). Nitrate content detected in the drinking water of the İpsala District was very close to the declared limit value.

It is known that phosphate has a carcinogenic effect and cause cancer risk, when taken in high amounts into the human body. Phosphate can be taken into the body directly by drinking water and may cause some stomach and digestive problems (Coşkunses, 2008). According to the data obtained, it has been determined that the drinking water of the İpsala District have 4th class water quality in terms of phosphate content and this parameter was found as an important risk factor for the health of the people living in this region.

In this research, it was determined that the investigated WPS decreased the nitrate and phosphate concentrations and Nutrient Pollution Index (NPI) values (being calculated by using nitrate and phosphate concentrations) in drinking water of İpsala District considerably (more than 80%) and significantly reduced the probably negative effects of these pollutants on the human health.

According to the results of applied ecological risk assessment indices, although both the investigated tap and purified water samples were found as “Excellent quality”, “Low heavy metal pollution”, “Low pollution” and “No pollution” in terms of WQI, HPI, HEI and NPI respectively, it was found that the Water Purification System (WPS) increased the water quality significantly and reduced the detected index data about 4 (%70), 8 (%90), 8 (%90) and 7 (%80) times for WQI, HPI, HEI and NPI respectively.

Arsenic is a carcinogenic and toxic element. Exposure of As may cause many significant health problems. Use of overly pesticides with high arsenic contents especially in the regions, where mono – cultural agricultural practices are intensive as in İpsala District, converts these toxic metals to a significant health risk factor for the local people. (ATSDR, 2012; Liu et al., 2013; Çiçek et al., 2013; Köse et al., 2015; Bhowmick et al., 2018; Tokatlı and Ustaoğlu, 2020).

Thrace Region constitutes among the most productive agricultural lands of Turkey. About 95% of the region, which means over one million hectares, is suitable for agriculture (TZOB, 2003; Anonymous, 2005). However, especially the paddy cultivation is being conducted as a mono-cultural approach in the region without any crop rotation for many years. Therefore, the soil of the reigon has weakened over the years in terms of minerals and the agricultural pests gain resistance. As a result of this mono-cultural approach, use of intensive agricultural fertilizers and pesticides have become a necessity in years for the region (Tokatlı and Ustaoğlu; Tokatlı, 2021; Varol and Tokatlı, 2021). In addition, the social studies conducted in the region show that the local people are not sensitive enough about the environmental pollution and sustainability of their soil (Tokatlı and Gürbüz, 2014; Helvacıoğlu et al., 2016).

Chromium occurs naturally in the Earth’s crust and may penetrate to the water and soil a result of mainly anthropogenic applications. The main anthropogenic origin chromium in the groundwater and surfacewater are wastewater from textile manufacturing and electroplating operations (ATSDR, 2000). Besides the Thrace Region has a great agricultural potential, it has also a significant industrial capacity and there are many industrial enterprises around the region (Tokatlı and Baştatlı, 2016; Tokatlı and Ustaoğlu, 2020; Tokatlı et al., 2020).

According to the results of applied health risk assessment indices in terms of non – carcinogenic effects, calculated HI scores of Cr, As and Pb for tap and purified water samples were found as below the limit score of 1 both for adults and children. According to the results of applied health risk assessment indices in terms of carcinogenic effects, while the calculated CR scores of Pb for tap and purified water were found as below the limit score, CR scores of Cr were found at an alarming rate and CR scores of As were found as over the limit score of 1 both for adults and children for tap water. The WPS reduced the non – carcinogenic and carcinogenic risks of toxicants significantly and reduced the risky CR scores of Cr and As far below the limit value. It was also determined that HI – CR scores were decreased about 26 (%96), 8 (%88) and 10 (%90) times for Cr, As and Pb respectively after the purification process.

Conclusions

In this study, the performance of a widely used water purification system (WPS) in Turkey was evaluated in İpsala District, where is known as under effect of an intensive agricultural pressure, in terms of organic – inorganic water pollution indicators and ecological – health risk assessment indices. In conclusion, organic contents of tap water were found to be at critical levels, while the arsenic and chromium were found as the most dangerous toxicants for the drinking water of İpsala District in terms of human health. CR values of chromium in tap water of İpsala District was found to be at a very risky level and CR values of arsenic in tap water recorded as significantly higher than the limit coefficients of 0.0001. It was determined that the investigated WPS improved the drinking water quality significantly by decreasing the organic - inorganic pollutants and by increasing the pH because of increasing the mineral contents. It was also determined that WPS reduced the scores of applied ecological and health risk assessment indicators significantly and reduced the recorded coefficients of non – carcinogenic and carcinogenic effects of toxicants far below the limit values.

Compliance with Ethical Standards

Conflict of interest

The authors declared that for this research article, they have no actual, potential or perceived conflict of interest.

Author contribution

The contribution of the authors to the present study is equal. All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

Ethical approval

Ethics committee approval is not required.

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Data availability

Not applicable.

Consent for publication

Not applicable.

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