Water Quality and Health Issues in the Zayandeh Rud Basin

H. Pourmoghaddas, Ph.D

Professor of Environmental Health

Department of Environmental Health, School of Public Health

University of Medical Sciences, Isfahan, Iran

Comprehensive Assessment of Water Management in Agriculture

International Water Management Institute

Comprehensive Assessment of water management in agriculture

Abstract

The Zayandeh Rud River is the most important watershed in the center of Iran and is a crucial source of water for irrigation, as well as for industries, animal farming, municipal supply and wastewater dilution. Sustainable management of water resources of the Zayandeh Rud River could be examined by continuous monitoring of the river water quality.

To study the evolution of water quality in the Zayandeh Rud River, water samples were collected from 12 stations along the river during the last 10 years. Water quality parameters, pH, EC, BOD, COD, DO, TDS, Ca, Mg, Na, Cl, SO4, NO3, P, Cd, Cr,, Ni, Zn, were determined at each stations. The average of all the parameters were calculated, showed by the curves and compared with the standards.

The results of the study showed that at the station"Pole Chom"the river water was highly polluted. The BOD and DO were 21 and 3.3 mg/L respectively at this station. These changes in river water chemistry have been attributed to alterations of Isfahan wastewater treatment plant, discharged into the river. Water uptake from the river before effluent discharge into the river is the main reason for the high pollution of the water. The EC increases from 0.25 dS/m at the first station to 19.6 dS/m at the last station. Almost all the parameters under this study exceeded the standard level of water quality for drinking purposes after passing Isfahan City. Also, in most of the downstream stations, the water is not suitable for industrial and agricultural uses.

Key Words: **Zayandeh Rud River, Water quality, Water Pollution**

Table of Contents

1 Introduction:

The Zayandeh Rud River is the most important river in Isfahan province, which is located in the center of Iran. It passes 2 provinces in Iran. It extends from west to east, passing a length of about 350 Km and finally it terminates in Gavkhoni Swamp. The river basin is about 41500 Km2 (Salemi et al 2000). The highest level of this river is 4300, and the lowest is 1450 meters above the sea level. The river has provided the basis for centuries of important economic activity. More recently large increases in industrial activity have increased demand water, so the Zayandeh Rud is showing typical signs of a river basin under threat.

The continuous growth of urban population of Iran and the recent rapid increases for industrial and agricultural uses have led to saline soils in lower portions of the basin. In addition to increased salinity in the downstream of the Zayandeh Rud River, domestic, agricultural, and industrial wastewater being returned into the river, result in waste; salinity is increased and its leaching capacity decreased (Pourmoghadas, 2000).

During the recent years, wastewater has emerged as an attractive alternative source to supplement irrigation supplies. Current estimates show that more than 20 million hectares worldwide are irrigated by using wastewater. Although no exact information is available it is believed that the use of wastewater for irrigation in Iran is on the rise, most of it is used without prior treatment (Qureshi, 2003). In some of the cities in Iran, urban and industrial waste is discharged in fresh water bodies. Extensive study is required to evaluate the surface and groundwater quality to control the pollution.

Pesticides have different toxic effects on various forms of life and are considered as poisonous to human beings and animals. If the pesticides introduced into an ecosystem do not have a direct and immediate effect on certain groups of organisms, they may still have indirect toxic effects on them after some time (Ince et al, 1991). The circulation of pesticides in the environment is complex. For example chlorinated hydrocarbon compounds could accumulate in the adipose tissue of the body, give rise to chronic poisoning and other diseases. Among this group of pesticides, Dieldrin is known to pass through the placenta to the foetus and through the mother's milk to babies (Harmancioglu et al, 2001). While in the river basin of the Zayandeh Rud River a huge amount of pesticides is used each year and there is not much information about the chlorinated hydrocarbon compounds, the measurement of total organic halogen in river water and the wells along the river could provide valuable information about the quality of water in relation to this aspect. This evaluation could lead to control of the river and the ground water pollution.

In many parts of the developing world, one of the main threats to food security is the degradation of water for drinking, industrial and agricultural uses. Natural resources preservation has a great value for each country. During old days human beings caused much less adverse effect on the environment. Industrialization is unavoidable, but should not destroy the environment. Surface and ground water contamination, not only makes the water supplies useless for drinking water purposes, but also cause the agricultural products to be contaminated with toxic compounds.

Unplanned, indirect wastewater reuse, through effluent discharge to streams for subsequent downstream use, has been a long accepted practice. Taste and odor in drinking water can be caused by algal growth, by- products of aquatic organisms and disinfectant agents (Montgomery, 1985). The common factors to be analyzed to estimate the pollution level of the stream are biological oxygen demands (BOD), chemical oxygen demands (COD), sodium absorption ratio (SAR), pH, dissolved oxygen (DO), electrical conductivity (EC), cations, anions and trace elements. The purpose of this investigation is to evaluate the water quality of Zayandeh Rud River for pollution control.

Effluent of the wastewater treatment plant discharge into the river at the station"Pole Chom", located on the east side of Isfahan city is about 2 m^3/s. The river flow at this station was as low as 1.3 m^3/s in 1999 (table 2), and zero in 1998 (drought year). There was not enough flow to dilute the effluents and the river usually cannot perform its self-purification process. Downstream water always was used for agricultural irrigation. Soil and agricultural products could be affected by river water pollution. The river water contains biodegradable organic matter and could fertilize the soil. Utilization of treated municipal wastewater has caused an increase in the yield as compared with irrigation with well water (Erfani 2001). The study showed that the concentration of toxic trace elements such as Cd, Pb in agricultural products (such as wheat, and corn) exceeded the suggested levels using effluent of wastewater treatment plants. The concentration of these toxic trace elements in the soil also was much higher compared with the soil irrigated with tap water (Vahid 1996).

Some of the chemical parameters of the ground waters along the Zayandeh Rud basin were studied by analysis of collected water sample from the wells (Mossavi 1995, Pourmoghadas 2002). The wells under the investigation were not deep, the range of the depth of the wells were 1.5 up to 9.5 meters. Although the year of the study of the river and the ground water along the river were not the same, in general, comparing the trend of the chemical parameters such as EC, TDS, COD in the river water and the wells, it seems that the wells were affected by river water. In other words, it could be concluded that pollution could be transferred from the river water to groundwater

2 Material and Methods

Water samples were collected from 12 stations along the Zayandeh Rud River during the period of 1989-1999. Characteristics of the stations are presented in the table 1.

Table 1: Stations characteristic for sampling of the Zayandeh Rud River Water

No.	**Stations**	**Locations**
1	Pole Cham Hydar	Located at 90 km west of Isfahan. Wastewater from rural area (upstream of this station) discharge into the river. Water quality does not change significantly due to high flow of the river in all seasons.
2	Pole Morgan	Located at south west of Isfahan. Rural area wastewater discharge into the wells and river water, due to lack of a rural wastewater treatment system
3	Sade Cham Asman	Located at 11 km west of Baba Shiekh Ali water treatment plant, Isfahan drinking water supply is located at this station.
4	Zarin Shahr	Isfahan Steel Mill industries, wastewater discharge into the river, samples were collected from 200 m downstream from the discharge. Water quality would be affected especially during low flow of the river
5	Polyacril	Effluent of Poly Acril factory from the wastewater treatment plant with 300 m^3/d discharge into the river. Sampling is from 200 m downstream of this station. Water quality is affected especially during low flow of the river.
6	Pole Vahid	This station is located in the city of Isfahan
7	Sade Abshar	Located at east and right before the effluent of Isfahan wastewater treatment plant discharge into the river
8	Pole Chom	Located at 7 km from Sade Abshar. Discharge of the effluent from Isfahan wastewater treatment plant into the river takes place after this station..
9	Pole Ziar	Located at 25 km east of Isfahan city
10	Pole Sharif, Abad	Located at 25 km east of pole Ziar
11	Pole Egie	Located at Egie village
12	Pole Varzaneh	Located at Varzaneh city, 125 km east of Isfahan. At this station water is highly polluted due to the industrial, agricultural and municipal wastewater discharge into the river. Average flow of the river was 430 lit/sec. (year 77-78)

Sampling performed at least once during each season. Grab sampling methods were applied. Replicates of the samples were prepared for quality control check. The samples were carried under ice to the laboratory, kept in the refrigerator and analyzed for the following chemical parameters. In the meantime temperature was determined at the sampling station and the samples stabilized for DO untill analyzed in the laboratory. The parameters and the methods of determination are as follows, which mainly based on standard methods 1985).

PH : pH meter
EC : EC Meter, Model 644
BOD : BOD meter Model Aqfa Lytic
COD : Closed reflex and Titration
DO : Idometric Method
TDS: Gravimetric Method
Ca : EDTA method
Na: Flame Photometry
K : Flame Photometry
Cl : Argentometric method
SO4: Turbidimetric Method
NO3 : Spectrophtometric Method
P : Amonium Phosphomolybdate
Cd , Cr, Ni, Zn, : Atomic Absorbtion Methods

The average of each parameter, over the 10 years period of study, were shown as bar graphs to show the water quality changes along the river.

3 River discharge

One of the most important parameters, which affect the degree of the water pollution is the flow of the river. If the amount of the pollutants, discharged into the river is constant, high flows in the river would increase dilution and would lower pollution. Calculation and estimation of the degree of the river pollution could be performed if the amount of the pollutants and the discharge of the river are known. There are non point sources of pollution along the river basin, which could affect the estimation and the degree of the pollution. Table 2 shows the discharge variation of the river within the years 1994-1999 in the stations Sade Tanzimi, Pole Zamankhan, Pole Kale, Sade Nekoabad , Pole Chom and Mossian. The highest discharge is related to April and the lowest are related to January, February and March. From this table the average discharge in upstream, midstream and downstream could be estimated.

Table 2: Discharge variation of the river within the years 1994-1999, m3/s

Stations and different years	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May.**	**Jun.**	**Jul.**	**Aug.**	**Sep.**
Sade Tanzimi 94-95	39	32/4	30/9	17/1	8/24	13/8	55/7	65/5	68/6	74/9	76/2	62/5
Sade Tanzimi 95-96	41/2	36/4	25/6	11/8	8/05	12/3	44	89/1	88	85/5	83/4	75/4
Sade Tanzimi 96-97	54/8	42/5	37/8	9/52	8/25	26/7	44	66/3	73/5	73/2	77	67/3
Sade Tanzimi 97-98	48	36	35/3	16/2	7/5	13/8	45	75/2	80/7	80/2	79/6	73/5
Sade Tanzimi 98-99	43/7	38/4	33/7	14/2	7/2	7/4	47/6	70/9	67/1	58/9	58/1	47
Sade Tanzimi 99-00	42/8	37/1	31/9	10/9	5/8	5/7	46/1	70/3	68/5	58/9	57/7	47/7
Pole Zamankhan 94-95	35	34/2	29/5	19/6	11/7	12/9	54/3	63	67/5	68	71/6	59/8
Pole Zamankhan 95-96	38/2	32/1	23/6	12/2	7/79	12/6	44/4	87/1	83/8	83/6	81/9	72/6
Pole Zamankhan 96-97	53/2	42/4	37/5	11/4	9/1	27/7	45/9	64/4	72/7	71/5	74/6	66/4
Pole Zamankhan * 97-98	-	-	-	-	-	-	-	-	-	-	-	-
Pole Zamankhan 98-99	42/2	38/4	33/9	11/4	4/6	4/8	45/2	74	68/9	57/6	55/8	-
Pole Zamankhan 99-00	42/4	38/7	33/6	14/2	6/42	6/45	45/8	70	68/4	58/5	56/9	47/9
Polle Kalleh 94-95	30/4	28/5	31/6	16	7/9	9/9	47/7	63/5	66/6	64/2	71/7	60/1
Polle Kalleh 95-96	35/3	34/8	24/1	11	6/78	11/3	39/8	89/2	80/9	78/4	75	68/4
Polle Kalleh 96-97	47/1	36/2	32/1	7/1	6/4	21/8	39/8	61/3	67/9	64/2	65/7	57/3
Polle Kalleh 97-98	48/3	35/5	26/2	18/2	9/5	23/5	34/3	75/2	75/8	70/5	68/5	58/5
Polle Kalleh 98-99	41/5	36/7	29/2	8	3/9	4/2	-	59/8	61/2	54/2	-	-
Polle Kalleh 99-00	35/5	33/3	28/8	7/14	3/17	¾	38/1	63/5	62/9	52/8	52/3	42/6
Sade Nekoabad 94-95	13/9	15/2	21/4	16/8	6/8	6/9	33/7	37/5	38/8	29/6	32/6	29/2
Sade Nekoabad 95-96	18/9	17/4	13	11/8	6/9	12/3	32/3	57/8	45/4	37	34/2	34/2
Sade Nekoabad 96-97	28/7	19/2	20	10/4	7/4	20/8	28/5	34/7	33/6	25/7	29/1	25/7
Sade Nekoabad 97-98	22/9	16/5	18/6	19/8	8/3	15/6	31/6	44/8	38/5	37/8	31/5	36/6
Sade Nekoabad 98-99	16/1	14/3	15/0	10/7	3/78	3/28	26/2	35/3	33/8	23/3	23/1	-
Sade Nekoabad 99-00	15/4	13/8	14/1	9/7	4/1	3/8	25/6	36/3	34/9	24	24	21/2
Pole Chom 94-95	9/1	10/9	18/7	19/6	10/1	9/0	16/2	19/8	20/2	9/0	10/3	8/7
Pole Chom 95-98	6/2	8/0	8/3	12/8	8/0	11/6	23/6	37/7	24/4	19/6	17/5	19/5
Pole Chom 96-97	24/2	11/2	19/5	14/9	7/1	11	16	16/0	21/5	7/1	7/4	7/9
Pole Chom 97-98	-	-	-	-	-	-	-	-	-	-	-	-
Pole Chom 98-99	6/8	3	8/1	15/7	16/4	5/5	11/0	18/0	18/6	1/61	0/9	-
Pole Chom 99-00	6/1	¾	7/9	13/4	12/9	6/5	12/6	17/7	16/8	1/7	¼	1/3
Mossian 94-95	16	17/7	15/9	13/6	3/1	12/4	11/1	12/6	25/1	41/0	26/6	25/5
Mossian 95-96	17	16/6	14/5	11	6/69	10/5	28/4	54/1	46/1	35/1	29/6	32/3
Mossian 96-97	33/2	18/6	16/8	9/9	6/0	18/9	26/8	33/5	35/3	22	26/9	23/4
Mossian 97-98	25	19/6	18/6	12/3	7/5	17/3	23/6	41/3	35/2	28/6	32/1	31/8
Mossian 98-99	18/0	15/4	14/2	9/7	4/1	2/9	23/9	34/7	31/1	19/0	18/1	-
Mossian 99-00	18/9	14/7	13/6	9/3	4/8	4/1	22/6	32/8	29/9	17/6	17/3	15/1

Lowest discharge in winter season is due to decreasing flows and storage of water behind the Zayandeh Rud Dam for the spring season. So the highest pollution should be observed in winter season. Table 3-shows the definition of water flow. Based on this classification, Zayandeh Rud River could be considered in some areas as a river and in some of the seasons and locations as a small stream , while the effluent of the industries and municipalities discharges into the river are established on the effluent standards by Iranian Environmental Protection Agency. Conventional wastewater treatment, including biological secondary, is the lowest level of approved wastewater processing. Considerable dilution in a natural watercourse is necessary to permit indirect reuse for waste supplies (Hammer 2003). It is one of the main reasons for highly pollution of the river. In countries with the fluctuation of the river similar to Zayandehrud, the effluent standards of the industries should be based on river flow. Table 4 shows the estimated Zayandehrud Average Discharge Variations.

Table 3: Classification of rivers based on discharge characteristics, the drainage area and river width (Chapman 1996)

River size	**Average discharge (m3/s)**	**Drainage area (km2)**	**River width (m)**	**Stream order**
Very large river	>10000	>10^6	>1500	>10
large river	1000-10000	100000-10^6	800-1500	7 to 11
River	100-1000	10000-100000	200-800	6 to 9
Small river	10-100	1000-10000	40-200	4 to 7
Streams	1-10	100-1000	8-40	3 to 6
Small streams	0.1-1.0	10-100	1-8	2 to 5
Brooks	<.01	<10	<1	1 to 3

Table 4 : Zayandehrud River Average Discharge Variation

Average up-stream discharge	50 m3/s
Average mid-stream discharge	8 m3/s
Average down-stream discharge	1 m3/s

4 Point source pollution

The main point sources of the Zayandeh Rud pollution are municipal, industrial and agricultural. Table 5 shows the name of the cities and rural area along the river with their populations. Table 6 shows the main point source pollution by large industries along the Zayandeh Rud River.

Table 5: Point Source Pollutants of Zayandehrud River (Cities)

Name of the city or the area	**Type of the Treatment**	**Location of waste water discharge**	**Comments**
Residential Area around the Zayandehrud River	Septic tank	Transferring to remote area by Tanker	Probable seepage into the lake
Employees Residential area of Baghbahaduran	In Process of building	Zayandehrud Wells	Pollution of Zayandehrud
Sedeh Lengan	-	Well	
Chamgardan	-	Well	
Varnamkhast	-	Well	
Zarin Shahr	In process	Well	
Folad Shahr	Lagoons	Agricultural land	
Flavarjan	-	Well	
Kelishad	-	Well	
Dorchepiaz	-	Well	
Isfahan	+	Zayandehrud	
Varzaneh	Lagoon	Agricultural land	

Table 6 : Point Source Pollutants of Zayandehrud by industries

River (name of the industry)	Wastewater Treatment System	Location of Wastewater discharge	Consideration
Steel Mill Industries	Evaporation Lagoons	5 km from ZYR	14400 m3/d
Polyacril factory	Activated sludge	ZDR	3000 m^3/d
Power Generator	-	ZDR	5000 m^3/d
Ghasemi Birds Slaughter house	-	ZDR	90 m^3/d
Abasi Birds Slaughter House	-	ZDR	90 m^3/d
Bafnas Textile Mill	Municipal Wastewater Collection System	ZDR	-
Risbaft Textile Mill	Municipal Wastewater Collection System	ZDR	-
Starch factory	-	ZDR	10 m^3/d
Letter factory	-	ZDR	30 m^3/d

5 River Water Quality Changes

5.1 Acidity (pH) and Alkalinity (HCO3)

Figure 1 shows the average of pH along the river. At the station Pole Chom, decrease of pH was observed (from 7.9 to 7.5) The main reason for this decrease could be because of municipal effluent from wastewater treatment plant discharged into the river, which contains high concentration of CO2 due to biological wastewater treatment. After this station, because of high concentration of HCO3 and CO3 from the agricultural drainage, it reaches the maximum pH of 8.3 (Fig 2). A particular problem associated with acidification is the solubilisation of some metals, particularly of Al +3, when the pH falls below 4.5. The resultant increased metal concentrations can be toxic to fish and render the water unsuitable for other uses.

Typically observed concentrations of bicarbonate are less than 10 mg/l in rainwater and less than 200 mg/l in surface streams (Montgomery, 1985). From Pole Chom up to Pole Varzeneh the concentration of bicarbonate exceeded this limit.

5.2 Dissolved Oxygen (DO)

One of the important parameter, which shows the river water quality, is the concentration of dissolved oxygen. Figure 3 shows the average of DO in 12 stations. Significant changes of DO were observed along the river. These changes are due to aeration, organic matter elimination or addition from sediments, algal activities and so on. Sharp decrease of DO was observed at the Pole Chom station, where effluent of wastewater treatment plant discharged into the river. The main reason for which the river didn't recover after this station are high pollution of the river due to organic matter discharged from waste water treatment plants, low flow, high TDS, and also higher temperature in downstream. High aquatic plants and algae affects DO along the river in daytime.

5.3 Biochemical Oxygen demand (BOD)

Figure 4 shows the average of BOD in 12 stations along the river within the 10 years study. At the station Pole Cham Hydar the BOD is 3 mg/l, which is the indication of fairly clean water. At the station Pole Chom the BOD reaches 21 mg/l. This sharp increase is because of effluent discharge into the river from municipal wastewater treatment plant. Self-purification of the river causes decrease in BOD, but increase again because of the point and nonpoint source of pollution. This increase continues as far as station Pole Varzaneh. The average of BOD at this station reaches 24.3 mg/l which indication of highly pollution of the river. From the figures it can be concluded that after the effluent discharged into the river at the station of Pole Chom, the river is not able to self purify. Table 7 shows the classification of the river based on BOD5

Table 7: Royal commission classifications of rivers (Klein 1971)

Approximate BOD5 PPM	Classification
1	Very clean
2	Clean
3	Fairly clean
5	Doubtful
10	Bad

5.4 Chemical Oxygen Demand (COD)

Figure 5 shows variation of COD along the river. The average of COD at the station Pole Cam Hydar is 10 mg/l, but it reaches to 105 mg/l at the station Pole varzeneh. Low flow of the river, effluent discharge from small industries and agricultural drainage are the main reasons for high COD after station Pole Chom. The COD at the downstreams stations shows much higher than twice the BOD5, non biodegradable compounds might cause this imbalance with BOD5, which might have a high potential of adverse health effects on human. These non-biodegradable compounds might accumulate and biomagnified in living organism tissue.

5.5 Electrical Conductivity (EC)

The EC at the station Pole Cham hydar is 0.25 ds/m, which shows no problem for agricultural irrigation (Fig 6). From station Pole Vahid as far as station Pole Ziar the EC is in the range of 0.75-3 ds/m, and shows increasing problem for irrigation (Montgomery, 1985). After station Sharif Abad the EC increase gradually and reach up to 19.6 ds/m at the station Pole Varzane, irrigation water could be a severe problem. Although no absolute standard could be stated for irrigation water due to a number of parameters such as soil structure, plant type and chemical component of the water, high EC observed in downstream of the river causes salt accumulation in soil, results in loss of fertility of the soil and finally immigration of the farmers from downstream area to the industrial cities.

5.6 Sodium absorption ratio (SAR)

Evaluation of water quality for agricultural consumption could be performed using SAR. With proper amount of Ca and Mg in irrigation water, the irrigated soil would be granular in texture, easily worked, and permeable. With increasing proportions of sodium, the soil will tend to become less permeable and water-logging may occur. This parameter can be calculated from the following formula:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

The permeability of water in soil decreases with increasing SAR. Reduction of soil permeability causes higher water usage and lack of enough moisture around the roots of the plants. Soil with higher clay structure decreases the penetration of water into the soil. Water quality classification based on EC and SAR is presented in table 8

Table 8 : Guidelines for irrigation water quality (Montgomery, 1985)

	Water Quality Guidelines		
	No Problem	Increasing Problem	Severe
Salinity EC of Irrigation Water, Umhos/Cm	<750	750-3000	> 3000
Permeability EC of Irrigation water , Umhos/Cm SAR	< 500	500-2000 6-9	>2000 >9

From the Figures 6 (EC) and 7 (SAR) and the VillCoks diagram it can be concluded that water quality for agricultural use up to Station Pole Cham Aseman with EC < 250 Umhos /Cm and SAR < 2.22 is in class of C1S1 and considered as high quality of water for irrigation and industrial usage. From station Zarinshahr to Pole Ziar increase for EC and SAR observed, which classified as C3S1. At this station Pole Chom EC is 1300 umhos/Cm is and SAR is 12.68, which classified as C3S2 (Montgomery, 1985). The SAR increases up to 26.69 at the station Pole Varzeneh that makes the water not suitable for drinking water supply, agricultural or industrial uses.

It could be concluded that From Station Shrif Abad the river water in the downstream was not suitable for agricultural purposes, causing salt accumulation in soil and losing fertility of agricultural soil.

5.7 Sulfate

The concentration of sulfate did not show significant changes up to station Sade Abshar, but increasing at the station Pole Chom is almost three times of the previous station (fig. 8) This high changes of sulfate concentration is related to the effluent of wastewater treatment plant. From station Shariff Abad to the last station (Pole Varzeneh) sharp increase of sulfate concentration was observed. Low flow of the river water and discharge of agricultural wastewater are the main reasons for these changes. While the permissible standards for this anion is 250 mg/l (desirable < 50 mg/l) (Hammer, 2003), from the station Sharif Abad, this water source is not suitable for drinking purposes. Discharge of the effluent of wastewater treatment plant, which may contains wastewater from small industries, could be the main cause of these high anions.

5.8 Nitrate

Nitrates represent the final product of the biochemical oxidation of ammonia. Monitoring of nitrates in drinking water supply is very important because of health effects on humans and animals. At the station Pole Chom a sharp increase is observed (Fig. 9). Concentrations greater than 3 mg/l indicate significant man –made contribution (Salvato, 2003). Although high amount of organic matter containing nitrogen is discharged into the river, in nitrification process it finally changes to nitrate ion, which is consumed by algae or the mychrophytes. It is why this anion decreased after Pole Chom. Maximum concentration of NO3 in drinking water is 45 mg/l for human and 100 mg/l for livestock. It seems no limitation exist from this aspect for drinking water consumption. Nitrate is corrosive to tin and should be kept less than 2 mg/l in water used for food canning. Although nitrate at this level could cause algal blooms if other nutrients such as phosphorous and CO2 present.

5.9 Phosphorus

High phosphorus concentration, as phosphates, together with nitrate and carbon dioxide are often associated with heavy aquatic plant growth, although other substances in water also have an effect. Uncontaminated waters contain 0.01 to 0.03 mg/l total phosphorus. Most waterways naturally contain sufficient nitrogen and phosphorus to support massive algal blooms. The concentration of phosphorus along the river is very small up to Pole Chom. A sharp increase observed (0.4 mg/l) at this station. Effluents of wastewater treatment plant discharged into the river cause this changes (Fig. 10). The effluents contain high concentration of detergents, which contain phosphorus. This concentration is 20 time of previous station (Sade Abshar). The concentration of phosphorus gradually decreases, and at the last station, Pole varzeneh, the concentration is 0.05 mg/l. The reason for this decrease along the river is algae macrophyte uptake, adsorption on the sediments and conversion to insoluble inorganic compounds.

5.10 Chloride

Fig 11. shows the 10 years average of chloride ion at the 12 stations along the river. The WHO guideline for chloride ion is 250 mg/l. A goal of less than 100 mg/l is recommended. Irrigation waters should contain less than 200 mg/l. When the chloride is in the form of sodium chloride, use of water for drinking purposes may be inadvisable for persons who under medical care for certain forms of heart disease. The concentration of chloride ion is 50 mg/l at the station Pole Cham Hydar, and increases up to 100 mg/l at the station Sade Abshar. It has a sharp increase at the station Pole Chom, where the effluent of wastewater treatment plant discharged into the river. The concentration of chlorides in urine is about 5000 mg/l and in sewage from a residential community 50 mg/l. It is why such increase is observed after Pole Chom. A sharp increase observed at the station Sharif Abad brings the chloride ion to 933 mg/l. At the last station, the chloride ion reaches 5433 mg/ l, which shows a high pollution of the Zayandeh Rud river. Low flow of the river, discharge of agricultural drainage and higher temperature of the downstream cause such condition. Chloride at the concentration over than 355 mg/l causes limitation in agricultural uses, so from station Sharif Abad we might have toxicity to most plants, decrease fertility of the soil and growth of the plants. While chloride in high concentration causes corrosion in pipes, this quality of water is not suitable for industrial usage.

5.11 Sodium

Water containing more than 200 mg/l sodium should not be used for drinking by those on moderately restricted sodium diet. It can be tasted at this concentration when combined with other anions. A maximum drinking water standard of 100 mg/l has been proposed for the general public. Fig. 12 shows that at the station Poly acril the concentration of Sodium is twice that of Zarin Shahr station, because the industrial wastewater from Polyacril is discharged into the river and causes a sharp increase. At the station Pole Chom, a sharp increase of sodium concentration brings it up to 496 mg/l, which is related to the effluent of wastewater treatment plant. The reason for the decrease of this element in some of the stations could be the dilution with incoming waters into the Zayandeh Rud. From Pole Ziar to the last station (Pole Varzeneh) the concentration increased up to 2273 mg/l. The concentration of chloride ion is too high at the downstream stations, at the station (Pole Varzeneh) the concentration increased up to 2273 mg/l. While the concentration of chloride ion is too high at that station (5433mg/l) it could be concluded that the main salts could be sodium chloride.

5.12 Potassium

It is reported that world average of river potassium concentration is 2.3 mg/l. In highly cultivated areas, such as the Zayandeh Rud basin, runoff may contribute to high water concentrations since plants take up potassium in fairly significant proportions and their decay releases it. Fig. 13 shows potassium concentration at 12 stations along the river. Gradual increase of this element from 1.8 mg/L at station Pole Cham Hydar to 2.9 at the station Sade Abshar was observed. This concentration increased up to 9.6 mg/l at the station Pole Chom (230 % increase). This sharp increase is because of the discharge of the effluent of the wastewater treatment plant into the river. At the station Pole Varzeneh the highest concentration (52.3 mg/l) observed. Runoff from agricultural land could be the main reason for such an increase. Maximum admissible concentration for drinking water is 12 mg/l. So the quality of water for drinking from station of Pole Sharif Abad is not suitable from this aspect.

5.13 Calcium (Ca)

Fig.14 shows the 10-year average of calcium concentration at 12 stations along the Zayandeh Rud River. Minor changes were observed from station Pole Cham Hydar up to Sade Abshar Station. At the station Pole Chom about 50 percent increase compared with the previous station was observed because of the discharge of the effluent of the wastewater treatment plant. The concentration increased up to 220 mg/ L at the station Pole Varzaneh.

Calcium and magnesium are the major elements, which make hardness of water. These elements contribute to hardness of water at the station Pole Cham Hydar to 141 mg/L, which increase up to 1355 mg/L as $CaCO_3$ at Varzaneh station. Sharp increases in the concentration of calcium from station Sharif Abad, make the river water unsuitable for drinking and most of the industrial uses.

The high level of hardness can result in a cake deposition, particularly when heating the water, and can lead to an increased incidence of urolithiasis (kidney stones) (WHO 1984 and 1993). Water is not suitable for drinking when it has TDS of more than 1000 mg/L (WHO 1993). A TDS below 600 mg/L is considered to be good drinking water.

5.14 Magnesium (Mg)

Concentration above 10-20 mg/l in surface waters and above 30-40 mg/l in groundwater are unusual. At high concentrations (400 mg/l for sensitive people, and 1000 mg/l for normal population) magnesium salts may have a laxative effect (Salvato 2003).

Calcium and magnesium together comprise most natural water hardness. WHO suggests that the highest permissible level in water supplies should be 50 mg/l. As it could be observed from Figure 15, fluctuation of Mg concentration up to the Sade Abshar is negligible, but it increases sharply at the station of Pole Chom, at this station effluent of wastewater treatment plant discharge into the river, low flow of the downstream, higher temperature, discharge of agricultural drainage into the river increase the Mg concentration up to 197 mg/L at Varzaneh station. Regarding the water hardness at Pole Cham Hydar which is 141 mg/L as CO_3Ca, this element contributes to water hardness up to 1355 mg/L as $CaCO_3$ at Varzaneh station, which limits the beneficial use of river water.

5.15 Cadmium (Cd)

Cadmium could enter the food chain through sewage sludge and synthetic fertilizer, which are used in agricultural land. In non-smoker people the main source of contamination is the food, as in US the body uptake of this toxic element is 5 to 19 ug daily. Cadmium is a good protector from metal roasting, so it is widely used in containers, especially acidic foods. Common sources of cadmium could be industrial wastes, as a yellow pigment and in ceramic, photography, as an alloy with copper, lead, silver aluminium and nickel (HDR Engineering, 2001).

WHO and FAO established 400-500 ug as maximum amount of Cd for human with 60-70 Kg weight, weekly (WHO 1992, FAO/WHO 1973). The direct relationship between cardiovascular death rates in the United State, Great Britain, Sweden, Canada, and Japan and the degree of softness or acidity of water point to cadmium as suspect. EPA has classified Cd as a probable human cancer (Group B) based positive carcinogenicity testing, however Cd is being regulated based on its renal toxic effects because carcinogenicity occurs via inhalation (HDR Engineering, 2001).

The average concentration of cadmium in the stations under study changed from 0.00 at the station Pole Cham Hydar up to.0.02 mg/l at the station Sade Chamasman (Fig16). EPA set Maximum Contaminant Level (MCL) of 0.01 mg/l and WHO guideline is 0.005 mg/l for drinking water. The concentration of this element exceeded the standard of drinking water at most of the stations. While chemical fertilizers and pesticides might have Cd (HDR Engineering, 2001, Salvato 2003), and significant amounts are used on the Zayandeh Rud river basin, this element could get into the river easily.

5.16 Copper (Cu)

The changes in copper concentration along the river were not significant. The concentration varied from 0.03 to 0.08 mg/l and did not exceed drinking water standards. Although Cu is an essential nutrient for all living organisms, the concentration from 0.25 to 1 mg/l is toxic to fish; copper salts are used to control the algal growth. So the concentration of this element does not limit the consumption for different purposes (Fig. 17).

5.17 Manganese (Mn)

The average of the Manganese concentration along the river was in the range of 0.005 to 0.07 (Fig. 18) which didn't exceed drinking water standards. The Maximum contaminant level (MCL) of Mn in drinking water is 0.5 mg/l, but it is preferred to have less the 0.01 mg/L in drinking water.

5.18 Zinc (Zn)

The average of zinc concentration at the stations along the river were 0.008 to 0.04 mg/L (Fig. 19) The MCL of zinc concentration in drinking water is 5 mg/L, so there is no limitation of water consumption from this aspect. The adult requirement for zinc is 15 mg/day. Drinking water contributes about 3 percent of this requirement. In excess, zinc has been reported to cause muscular weakness and pain, irritability, and nausea. The level of zinc associated with these effects was 40 mg/l over a long period.

5.19 Nicle (Ni) and Iron (Fe)

The minimum concentration of Ni along the river was 0.04 mg/L at Cham Asman Station and the maximum was 0.1 mg/L at Varzaneh Station, which is twice the standard concentration for drinking water (Fig. 20).

The range of concentration of iron in the river water at the stations was 0.11 to 0.34 (Fig 21), which didn't exceed the standard level (0.3 mg/L) (WHO, 1993) of drinking water. Iron is considered as an essential nutrient, but in the concentration of about 1mg/L could change the taste of tea and coffee.

6 Summary and Conclusion

The study assessed the evolution of water quality in the Zayandehrud River during ten years. The results of the study showed that downstream of the river is highly polluted: after passing Isfahan city, the water quality is unsuitable as drinking water supply, agricultural and industrial uses. The results of the study showed that at the station No. 10, the river water was highly polluted. At this station the effluent of main wastewater treatment plant is discharged into the river. Water uptake for agricultural use before effluent discharge through a canal, caused a low flow in the river with a very high concentration of BOD and low DO. Other chemical parameters also showed a sharp increase.

For controlling water quality of Zayandeh Rud River, following steps are suggested:

1. Stop extending industrial and agricultural development along the river.
2. Changing the law, basing the flow of the river for receiving the effluent from municipal, agricultural and industrial wastewater, rather than the effluent standards
3. Monitoring the river water quality using standard procedures, including the toxic trace elements, refractory organic compounds and….
4. Monitoring the chemical fertilizer to check the impurities to toxic trace elements
5. Monitoring the type of pesticides being used in the river basin
6. Monitoring the ground water quality along the river
7. Increase the river flow mainly for down-stream

7 References

Chapman D. (1996) Water Quality Assessments 2nd Ed., UK, University Press, Cambridge

Erfani A., G.H. Haghania and A. Alizadeh (2001) Effect of irrigation by treated wastewater on yield and quality of Tomato J. Agr. Scie. And Tecnol 15(1): 65-70

FAO/WHO (1973), Expert Committee of Food Additives: "Evaluation of Mercury, Lead, Cadmium and the Food Additives" Amaranth, Diethl Pyrocarbonate, and Octyl Gallate", 53-54.

Hammer M. J. (2003) "Water and Wastewater Technology, 4th Ed**.**

Ince and Bekbolet (1991) In Turkeiya de Cevre Kirlenmesi, Turkey

Klein (1971) "River Pollution" London Butterworths Publisher

HDR Engineering Inc. (2001) "Handbook of Public Water Systems", Second Ed.

Harmancioglu et al (2001) "Irrigation, Health and environment" IWMI

Montgomery j M. (1985) "Water Treatment, Principles and Design", A Wiley, Interscience Publications Printed in USA.

Mossavi. "Water Resources Management Project (1995)" Final Report, Isfahan Environmental Protection Agency, Isfahan, Iran

Pourmoghadas H. "Water Resources Management Project (2002))" Final Report, Isfahan Environmental Protection Agency, Isfahan, Iran

Qureshi, A.S. Development of IWMI-AREO Collaborative Research Program to Improve land and Water Management in Iran (2003) IWMI Karaj, Iran

Pourmoghadas H. "Water Resources Management Project (2000))" Final Report, Isfahan Environmental Protection Agency, Isfahan, Iran

Standard Methods for the Examination of Water and Wastewater. (1995) 16th Ed. American Public Health Association/ American Water Works Association/ Water Environment Federation, Washington DC, USA

Salvato A.J. (2003) Environmental Engineering and Sanitation , Third Ed.

Salemi H. R. et al (2000) Water Management for Sustainable Irrigated Agriculture in the Zayandeh Rud basin, Isfahan Province , Iran, Research Report No. 1, IWMI

Tomar M. (1999) "Quality Assessment of Water and Wastewater" Lewis publishers, CRC Press.

Vahid Dastjerdi M. (1996) A study of Toxic Trace elements Cd, Pb, Ni in Agricultural Products Using effluent of Wastewater Treatment Plant, Masters Thesis, School of Public Health, Isfahan University of Medical Sciences, Isfahan, Iran

WHO (1992) Environmental Health Criteria, Cadmium. Geneva, IPCS, 131, 36-45.

WHO (1984) Guidelines for drinking water quality, Vol. 2 Health Criteria and other supporting information,. Geneva Switzerland,

WHO (1993) Guidelines for drinking water quality, Vol.1: Recommendations, 2ed edition, Geneva Switzerland, WHO

Youngsug K. et al (1997)"Treatment of Taste and Odor Causing Substances in Drinking Water" Water Sci. Tech. Vol. 35 No. 8 pp 29-36.

Figure 1: The Average pH In Zayanderud River At Different Stations

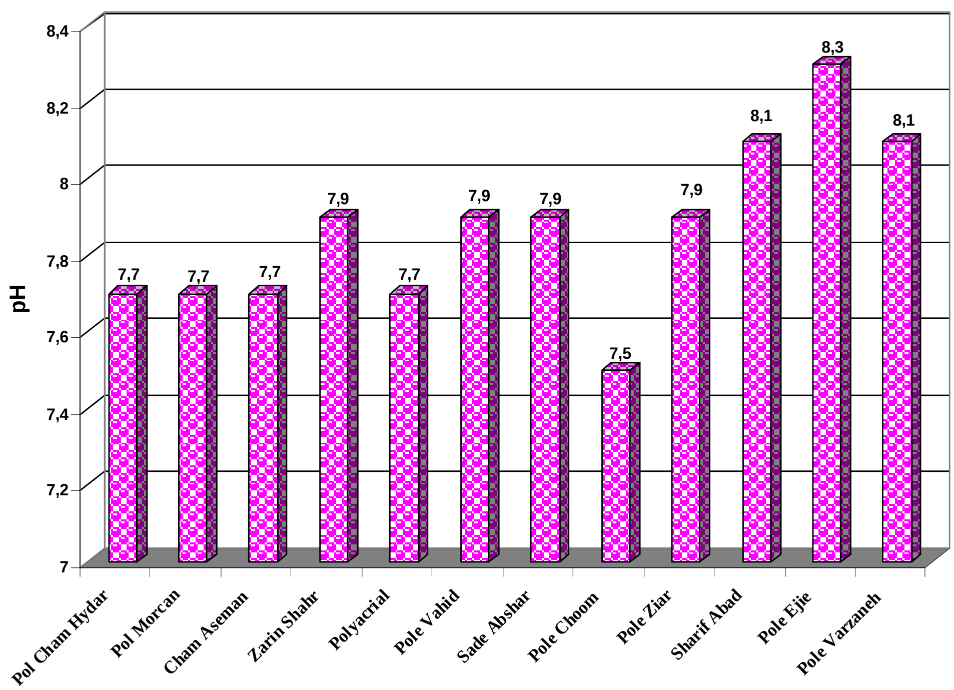

Figure 2: The Average HCO3 In Zayanderud River At Different Stations

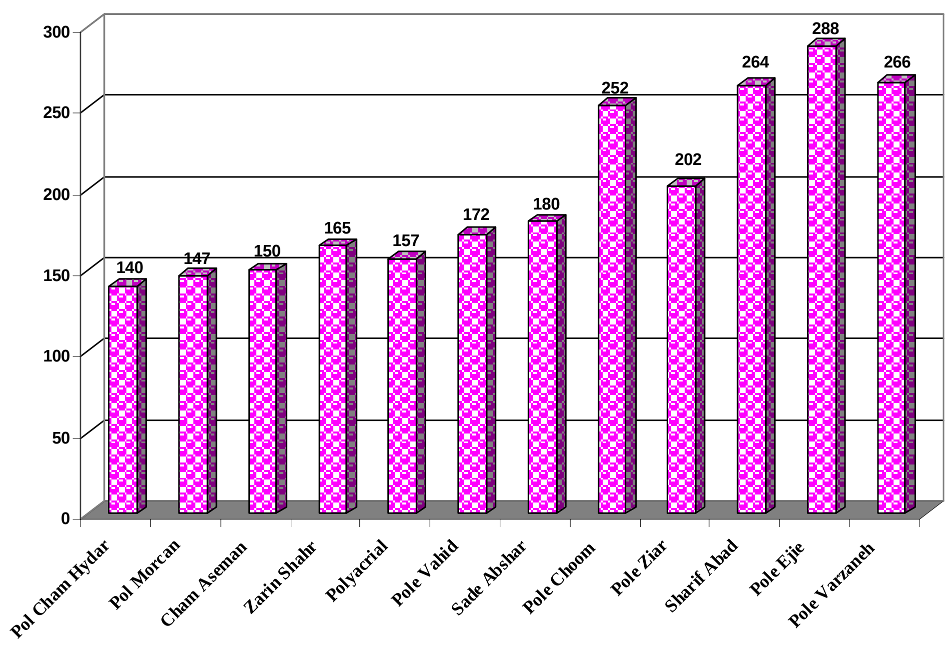

Figure 3: The Average DO In Zayanderud River At Different Stations

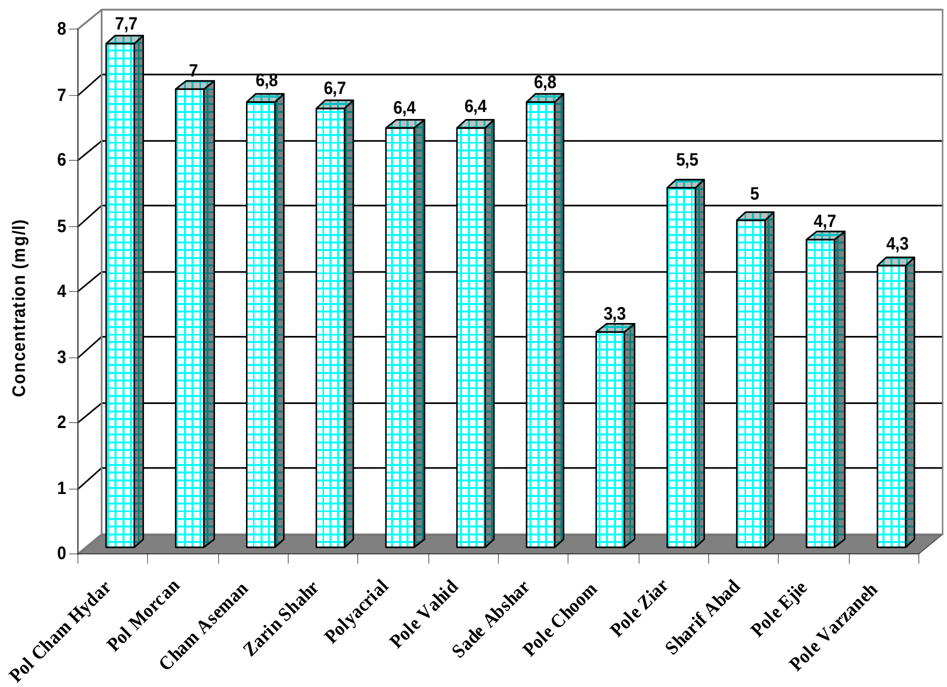

Figure 4: The Average BOD In Zayanderud River At Different Stations

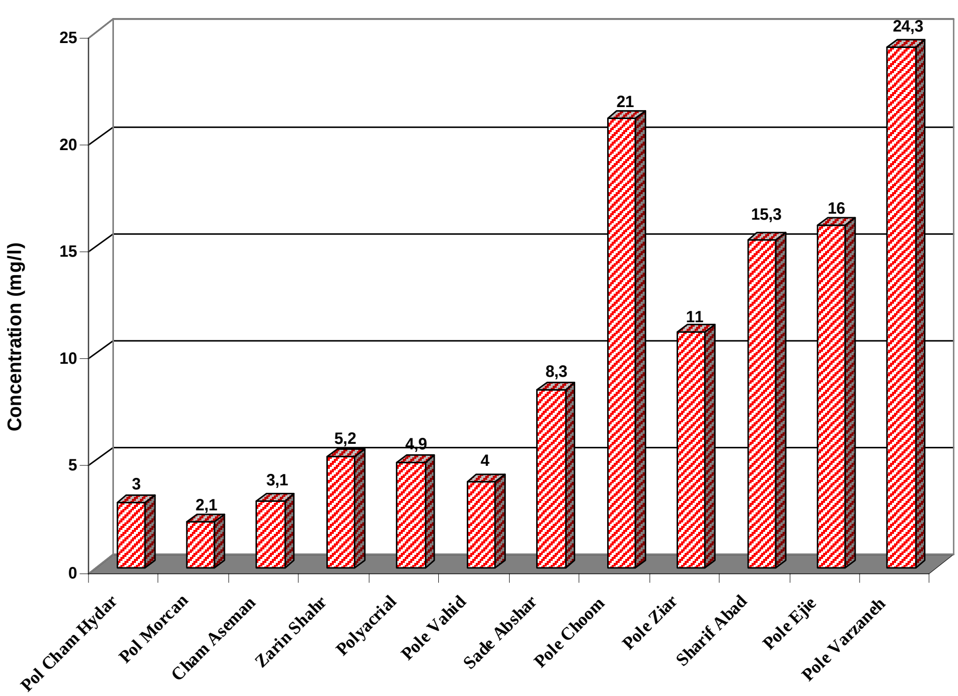

Figure 5: The Average COD In Zayanderud River At Different Stations

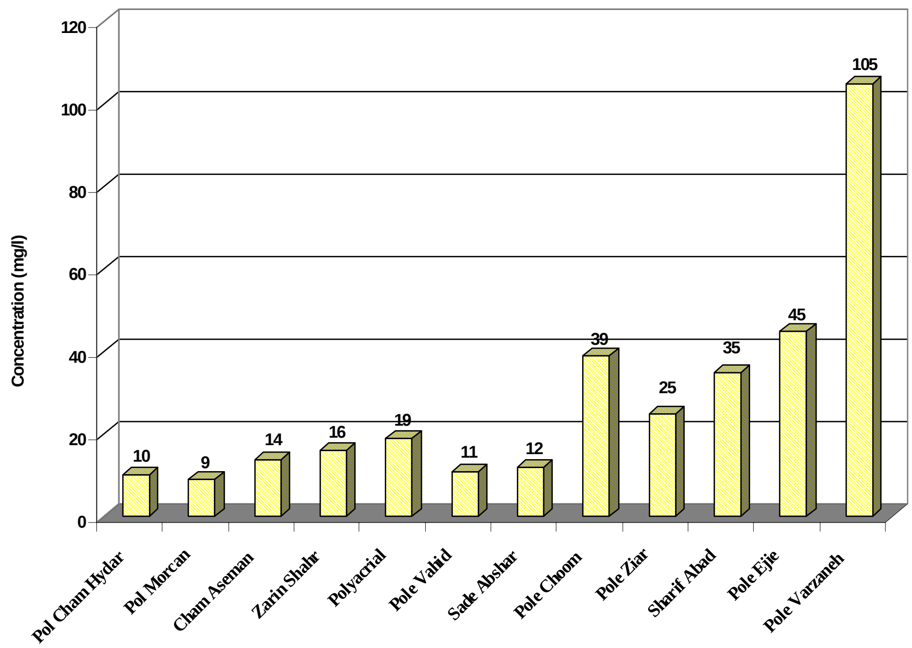

Figure 6: The Average Electrical Condactivity In Zayanderud River At Different Stations

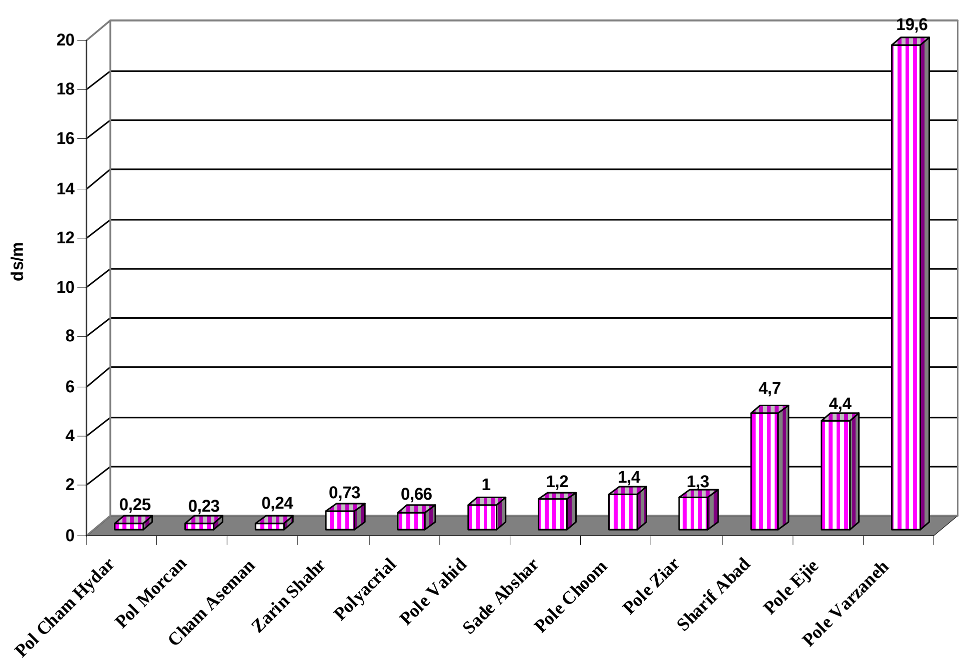

Figure7: The Average SAR In Zayanderud River At Different Stations

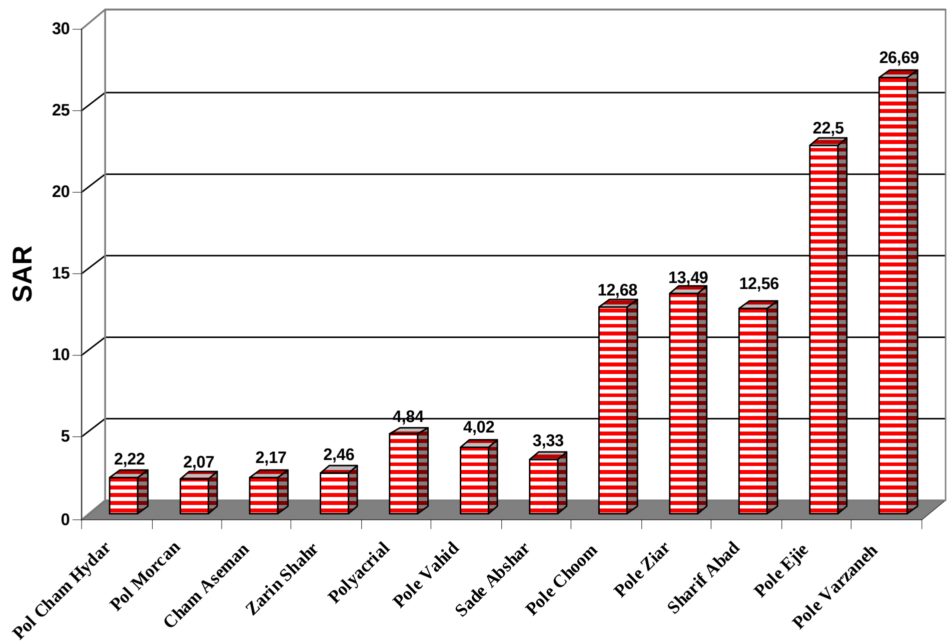

Figure 8: The Average Sulfate concentration In Zayanderud River At Different Stations

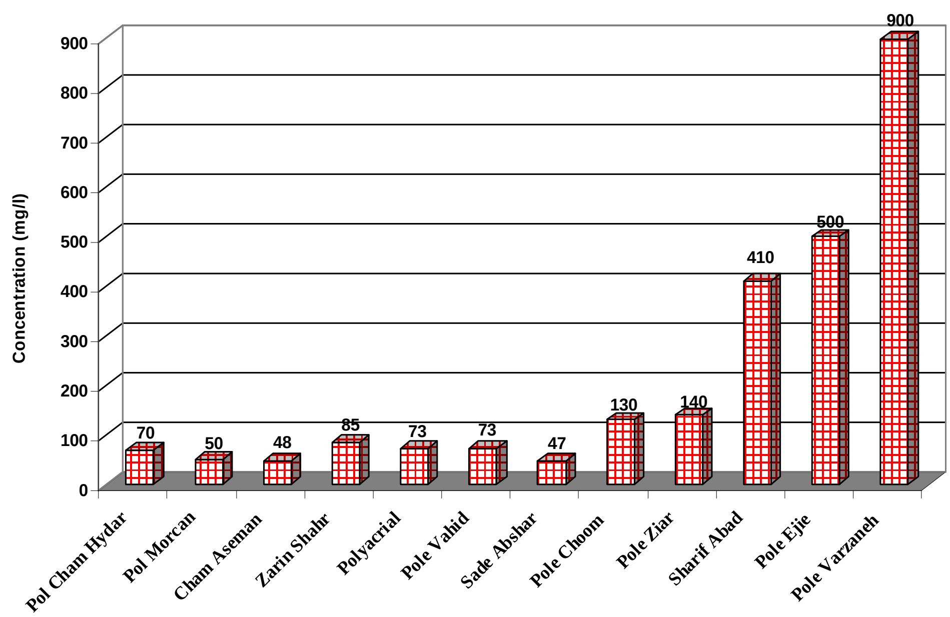

Figure 9: The Average Nitrate concentration In Zayanderud River At Different Stations

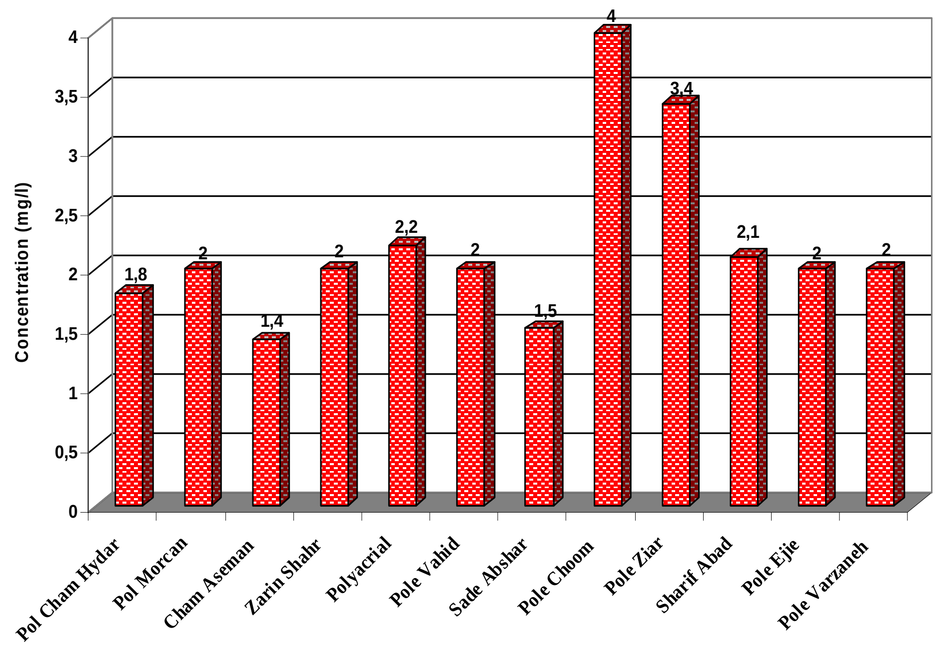

Figure 10:The Average Cancentration of phosphorus In Zayanderud River At Different Stations

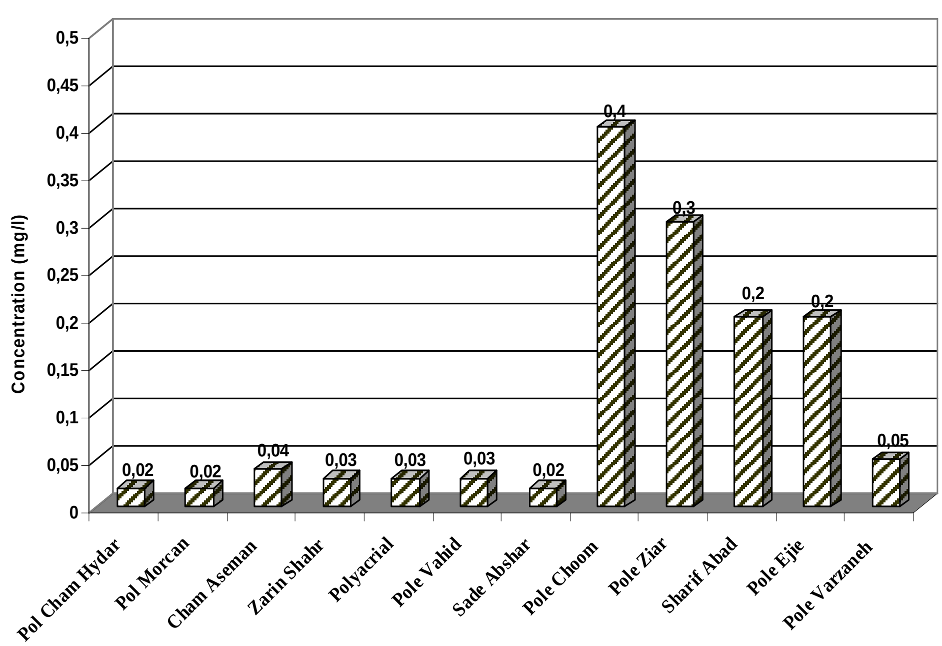

Figure 11: The Average Cancentration Chloride In Zayanderud River At Different Stations

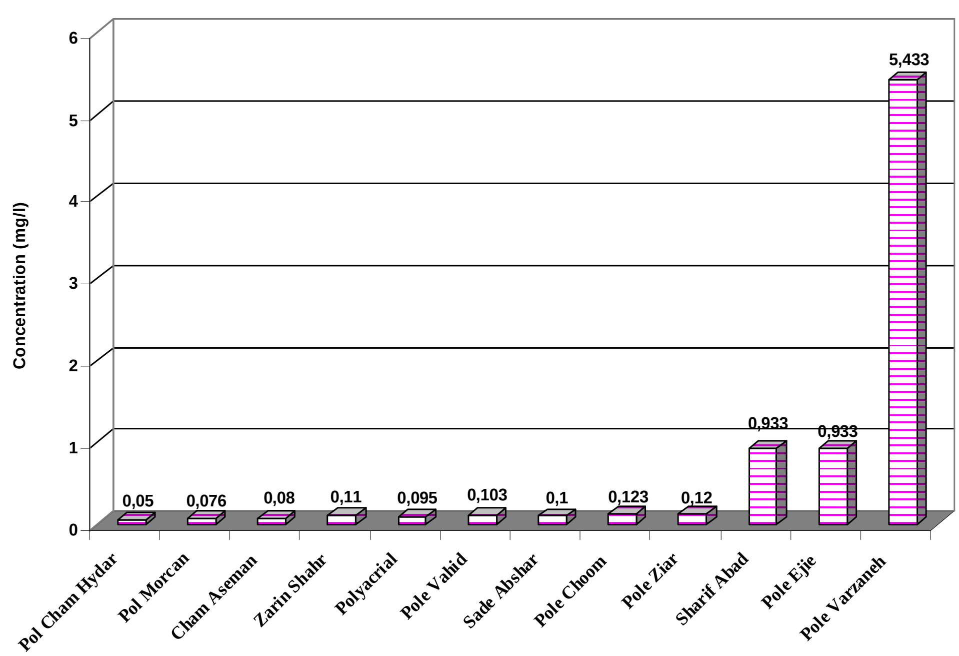

Figure 12: The Average Concentration Of Na In Zayanderud River At Different Stations

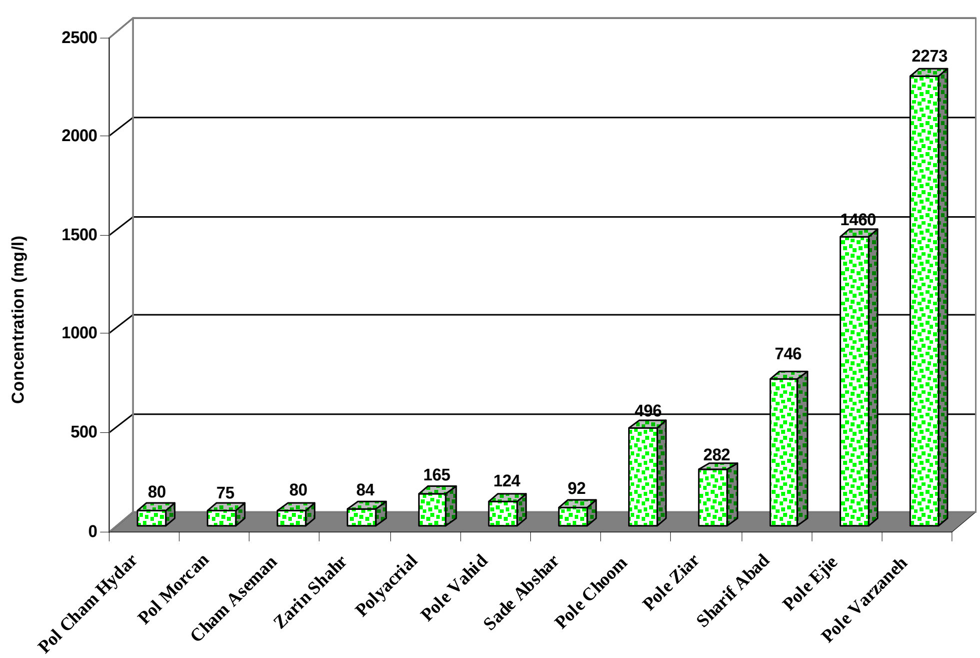

Figure 13: The Average Concentration Of K In Zayanderud River At Different Stations

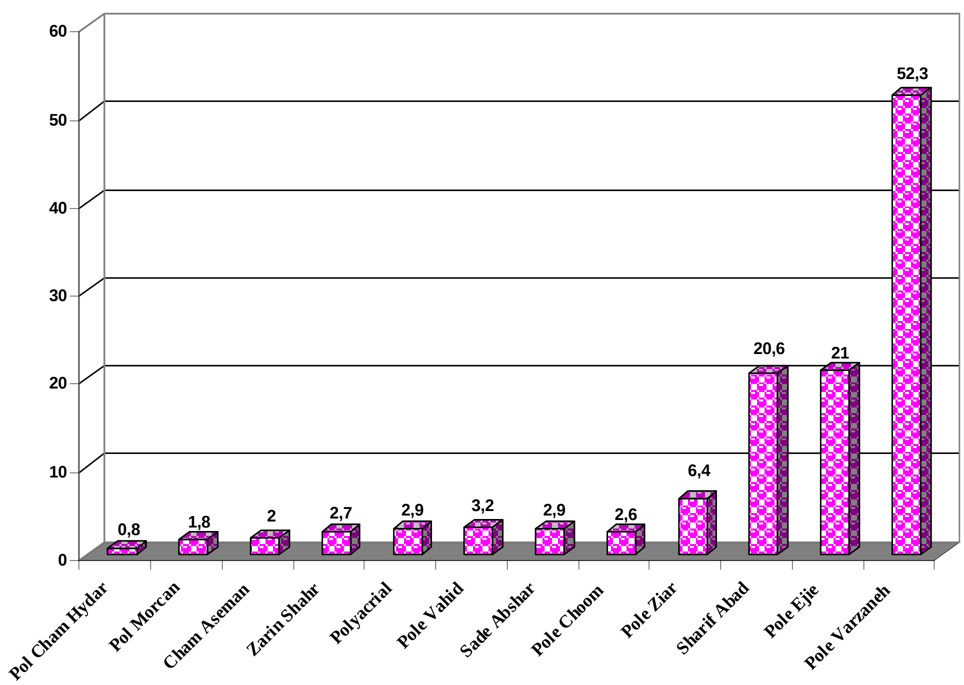

Figure 14: The Average Concentration Of Ca In Zayanderud River At Different Stations

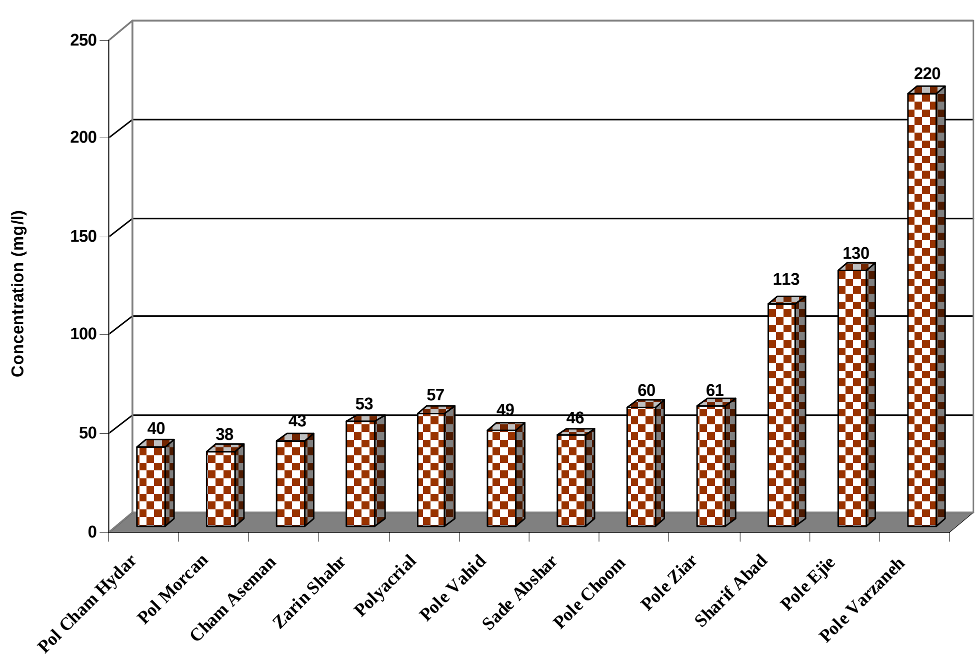

Figure 15: The Average Concentration Of Mg In Zayanderud River At Different Stations

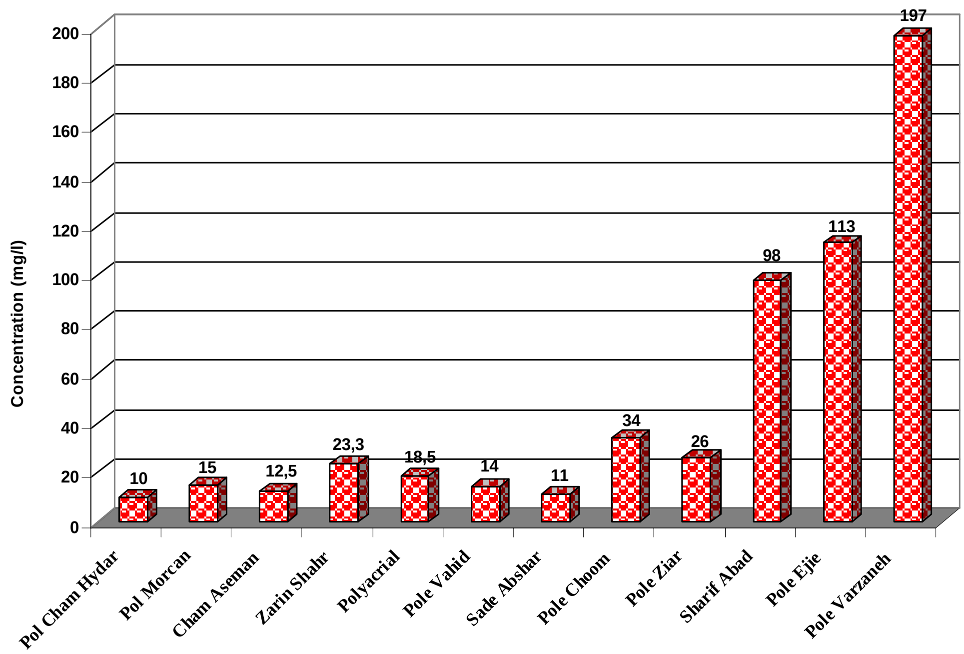

Figure 16: The Average Concentration Of Cd In Zayanderud River At Different Stations

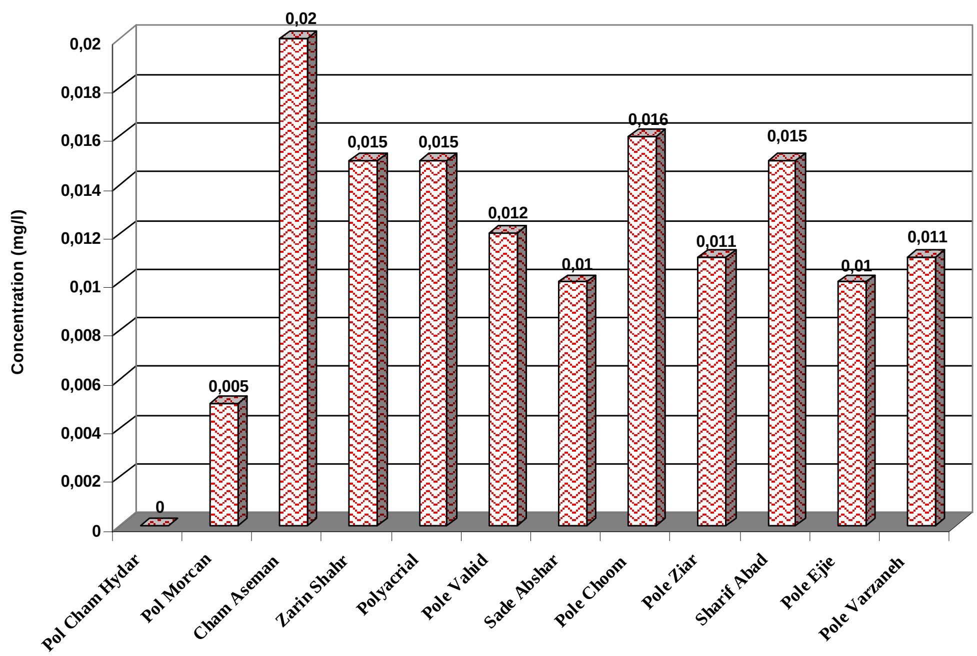

Figure 17: The Average Concentration Of Cu In Zayanderud River At Different Stations

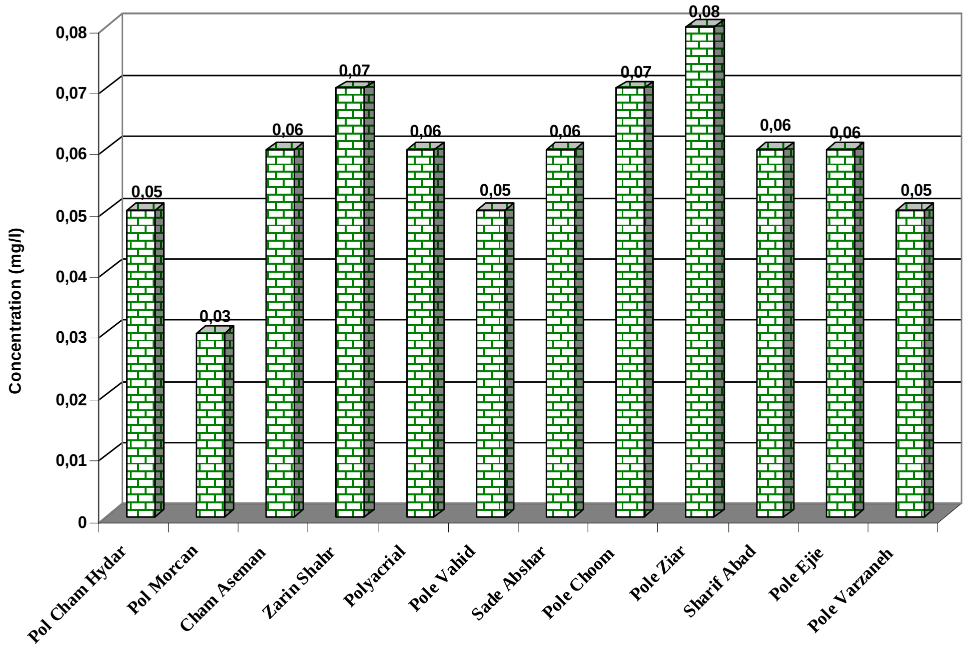

Figure 18: The Average Concentration Of Mn In Zayanderud River At Different Stations

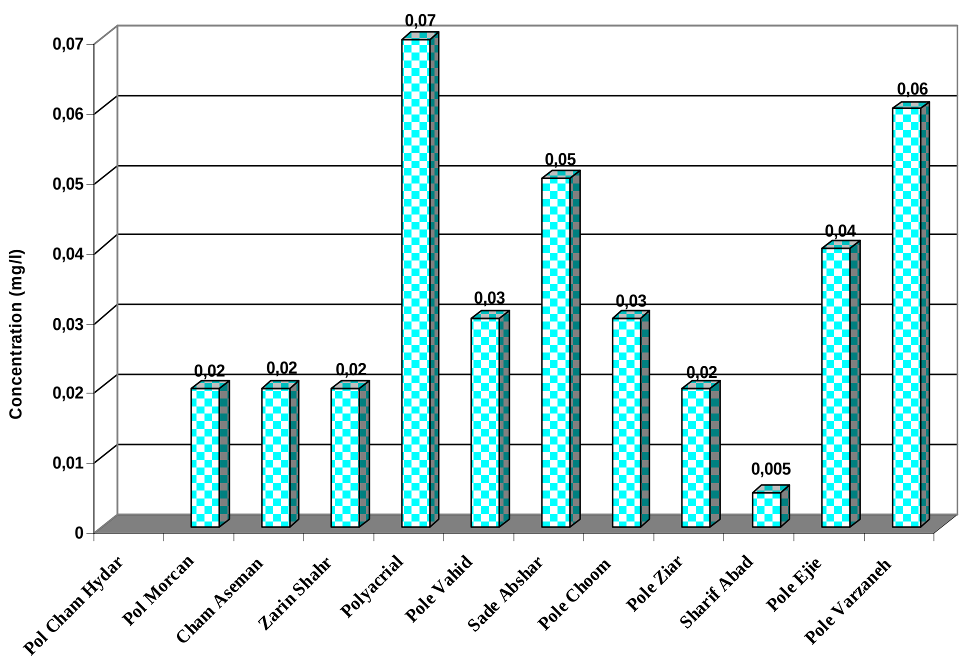

Figure 19: The Average Concentration Of Zn In Zayanderud River At Different Stations

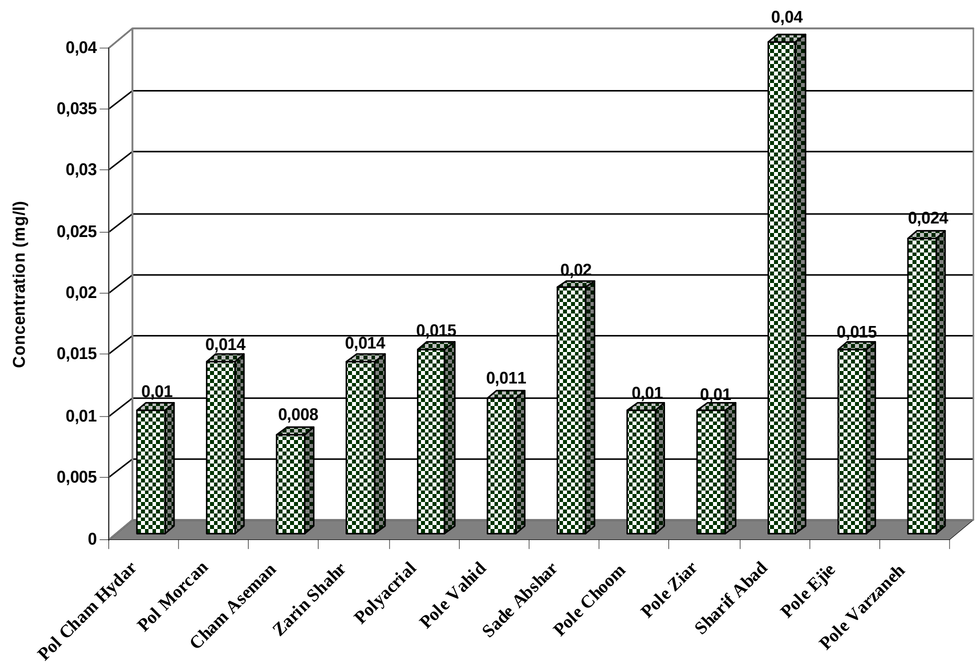

Fig. 20: The Average Concentration Of Ni In Zayanderud River At Different Stations

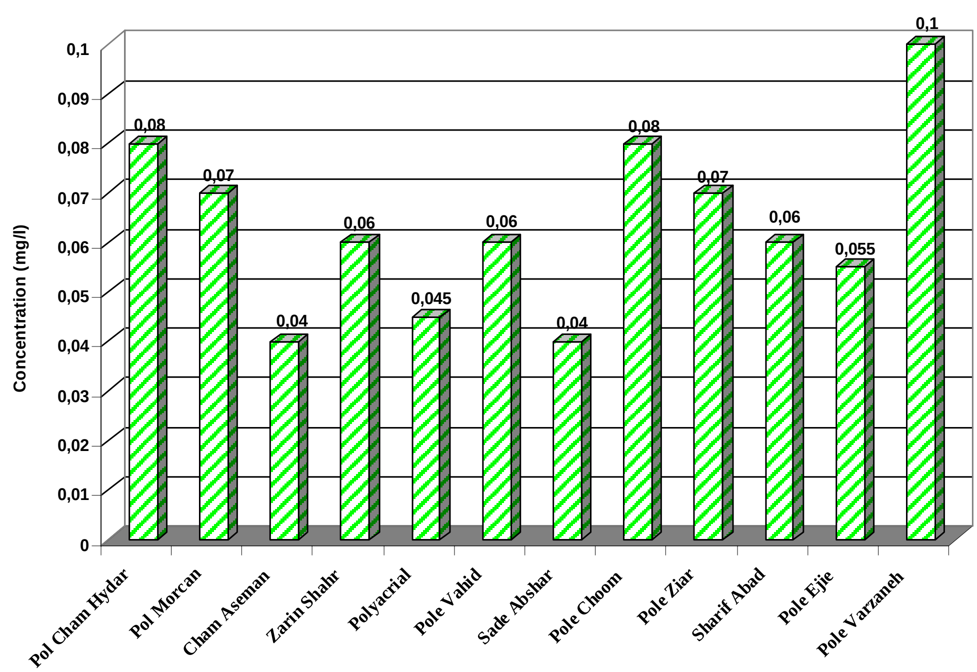

Figure 21: The Average Concentration Of Fe In Zayanderud River At Different Stations