Turkish Journal of Engineering & Environmental Sciences

http://journals.tubitak.gov.tr/engineering/

Research Article

Turkish J Eng Env Sci
(2013) 37: 272 – 285

doi:10.3906/muh-1310-8

# Environmental impact of dyeing and printing industry of Sanganer, Rajasthan (India)

**Ikbal HUSAIN**[1], **Jakir HUSAIN**[2], **Mohammed ARIF**[3,*]
[1]Public Health Engineering Department Laboratory, Bhilwara, Rajasthan, India
[2]National River Water Quality Laboratory, Central Water Commission, New Delhi, India
[3]Department of Chemistry, Banasthali University, Niwai, District Tonk, Rajasthan, India

**Received:** 20.10.2013 • **Accepted:** 08.01.2014 • **Published Online:** 03.02.2014 • **Printed:** 28.02.2014

**Abstract:** Wastewater and groundwater samples of Sanganer were studied to find out the pollution load of wastewater generated from dyeing and printing units and its impact on the quality of domestic wastewater of the Amanishah Nallah and groundwater. The wastewater of these units was found to have high concentrations of sodium, chloride, and sulfate. It has remarkable concentrations of copper, chromium, and iron with low chemical oxygen demand and nearly 7-fold biochemical oxygen demand. The wastewater of these units, discharged on land without any treatment, comes into the Amanishah Nallah through small watercourses. The quality of the domestic wastewater of Nallah deteriorates with the mixing of wastewater from these units. Maximum concentrations of physicochemical parameters were found at the Sanganer Road bridge sampling point. Eleven groundwater samples, collected from various locations of Sanganer, were found polluted due to percolation of wastewater into the ground. Copper and chromium were recorded from some groundwater sources while iron was recorded from almost all sources. Sodium and chloride are the major cation and anion in the groundwater, which is identical to the wastewater of dyeing and printing units. Source $\mathbf{G}_5$, near the small watercourse carrying the wastewater of these units, had maximum impact and maximum values of physicochemical parameters.

**Key words:** Dyeing and printing industry, wastewater, groundwater pollution, heavy metals, drinking water quality, irrigation quality

## 1. Introduction

Since the beginning of human civilization, cloth has been among the 3 basic needs of mankind (i.e. food, clothing, and shelter). Natural products like cotton, silk, wool, and jute are reported to be used for manufacturing of cloth. Due to high consumer demand, presently synthetic fibers like nylon, rayon, polyester, and acrylic are being used to fulfill requirements for natural fibers. Color has always been a special necessity and so, in every civilization from remote ages to the present day, the art of dyeing has played an important role in adding beauty to the world. At present, approximately 15% of total world production of colorants is lost daily during their synthesis and use for coloring fabrics, which corresponds to almost 128 t/day around the world [1]. The production of printed textiles in India dates back to the fourth century BC [2]. Today the textile industry is the single largest organized sector in the country, earning one-third of total national export profits [3–7].

Sanganer, near Jaipur (Rajasthan, India), is famous for its traditional dyeing and printing of cloth used

*Correspondence: dr.arifmohammed@gmail.com

for a variety of purposes. The world-famous art of cloth printing began developing in Sanganer during the 18th century and attained its peak in the 19th century due to the Cheepas, a particular caste who mastered this art from infancy. The natural dyes that were used in the early period have now been replaced by synthetic dyes.

Dyeing and printing industrial wastes disposed both in liquid and solid forms in land and water bodies percolate into the groundwater and get transported in the direction of the groundwater flow. The rate of percolation and transportation of pollutants in the groundwater flow increases in arid and semiarid conditions due to high permeability of soil. As a result, different pollutants reach the groundwater system and pose a threat to groundwater quality, which ultimately affects the socioeconomic life of the people who depend on the groundwater for various purposes [8–14]. As per an unpublished survey conducted by the Rajasthan State Pollution Control Board, in Jaipur 75% of total wastewater from dyeing and printing units is directly drained into the Amanishah Nallah, while the remaining 25% accumulates in the surrounding areas of the printing and dyeing units and along roadsides, forming pools and puddles. The accumulation of wastewater in the pools adversely affects the groundwater of the area on account of the high porosity of the sandy soil of Sanganer. This study was carried out to characterize the wastewater and to learn its impact on groundwater.

### 1.1. Dyeing and printing process in Sanganer

In Sanganer, 3-step dyeing and printing is carried out, which involves bleaching, dyeing, and printing processes. Bleaching removes natural coloring materials from the gray cloth and makes it suitable for dyeing and printing. In the process, cloth is first dipped in turkey oil (caustic soda slurry) to remove starch and is then passed through a solution of bleaching powder followed by a washing. This process makes the cloth alkaline; the cloth is then heated with dilute acid and sodium sulfate. After heating, the cloth is washed with detergent and whitening agent and dried in the open air. Before dyeing, the cloth is wound on a roller and passed through a tray of color dye solutions. The process is repeated several times and chemicals are added to fix the color. After dyeing, the cloth is again washed.

In Sanganer, 2 basic types of printing process are in use: block printing and screen printing. Block printing is traditional printing in which wood blocks are dipped in color and impressions are made on the cloth. In screen printing, designs are prepared on a screen using a solution of polyvinyl alcohol and potassium dichromate. The cloth that is to be printed is fixed, and the screen is placed on it carefully and lifted again and again until the printing is completed. After printing, the process of color fixing starts. At present, the 3 commonly used dye-fixing processes in Sanganer are as follows:

1. **Diazotization process**: The indigo and rapid dyes used for dyeing and printing are fixed by keeping the cloths in a dilute solution of either sulfuric acid or hydrochloric acid and sodium nitrite for 20 min, commonly by continuous passing. The acid most commonly used in Sanganer is sulfuric acid, on account of its low cost. The cloth is then washed 3 times with fresh water in separate tanks to remove chemicals and avoid bleeding of dyes.

2. **Silicate process**: The reactive dyes used in dyeing are fixed by soaking the cloth in a solution of sodium silicate for about 12 h. The cloth is then washed 3 times, similar to the diazotization process.

3. **Patri Process**: The Patri process is basically used for black aniline dyeing and printing. It is commonly used in combination with the diazotization process. The cloth is washed in water containing sodium bicarbonate and then in plain water.

## 2. Materials and methods

Wastewater and groundwater samples were collected in precleaned 5-L and 1-L polypropylene containers for chemical and heavy metal analysis, respectively. The heavy metal sample was acidified with ultrapure $HNO_3$. The necessary precautions were adopted during sampling [15]. All physicochemical parameters were analyzed in the laboratory by standard methods. The heavy metals were estimated by atomic absorption spectrophotometer using standard methods [16].

## 3. Results and discussion

### 3.1. Characteristics of wastewater in Sanganer

For the characterization of wastewater of dyeing and printing units, 11 wastewater samples from different sites were collected and analyzed for physicochemical parameters. The physicochemical results of the wastewater are shown in Table 1.

**Table 1.** Physicochemical results of wastewater.

| Parameter | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Site 8 | Site 9 | Site 10 | Site 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 7.2 | 7.1 | 7.1 | 6.9 | 7.0 | 6.8 | 7.2 | 7.0 | 7.3 | 7.1 | 7.1 |
| Electrical conductivity ($\mu$mho/cm) | 2590 | 2670 | 2860 | 2530 | 3660 | 2220 | 2490 | 2760 | 2850 | 3250 | 3560 |
| TDS | 1554 | 1665 | 1742 | 1489 | 2217 | 1386 | 1525 | 1663 | 1742 | 2008 | 2147 |
| Total hardness | 350 | 360 | 390 | 340 | 500 | 300 | 330 | 350 | 370 | 500 | 510 |
| Bicarbonate | 212 | 256 | 240 | 210 | 341 | 272 | 409 | 312 | 358 | 541 | 320 |
| Chloride | 500 | 550 | 570 | 460 | 700 | 430 | 480 | 550 | 590 | 680 | 720 |
| Sulfate | 190 | 200 | 220 | 180 | 290 | 150 | 130 | 170 | 160 | 200 | 260 |
| Nitrate | 62 | 45 | 56 | 58 | 90 | 24 | 53 | 64 | 58 | 86 | 102 |
| Fluoride | 0.7 | 0.5 | 0.6 | 0.8 | 1.2 | 1.3 | 0.6 | 0.5 | 0.9 | 1.0 | 0.6 |
| Calcium | 60 | 56 | 64 | 76 | 80 | 64 | 60 | 48 | 72 | 80 | 104 |
| Magnesium | 48 | 53 | 55 | 36 | 72 | 34 | 43 | 55 | 46 | 72 | 60 |
| Sodium | 440 | 480 | 500 | 420 | 600 | 330 | 310 | 420 | 410 | 280 | 480 |
| Potassium | 11 | 15 | 9 | 13 | 32 | 18 | 22 | 13 | 22 | 15 | 46 |
| Copper | 0.45 | 0.28 | 0.15 | 0.32 | 0.24 | 1.08 | 0.32 | 0.68 | 0.31 | 0.34 | 0.24 |
| Chromium | 0.13 | 0.09 | 0.06 | 0.08 | 0.16 | 0.08 | 0.04 | 0.06 | 0.07 | 0.03 | 0.02 |
| Iron | 0.96 | 1.66 | 1.34 | 0.89 | 2.75 | 1.07 | 0.76 | 1.15 | 0.68 | 1.23 | 1.34 |
| BOD | 25.3 | 26.9 | 35.1 | 26.3 | 32.5 | 31.2 | 28.6 | 22.4 | 21.7 | 32.7 | 26.9 |
| COD | 150.8 | 190.3 | 181.6 | 203.1 | 345.1 | 156.2 | 147.8 | 120.6 | 253.8 | 212.0 | 147.5 |

All parameter excepts pH and EC are in mg/L.

The pH of the wastewater was found close to natural levels, ranging from 6.8 to 7.3. The pH of wastewater from 3 units was below 7.0, while 2 units had 7.0 pH values and the remaining had pH levels above 7.0. Although sulfuric and hydrochloric acid are used in the color-fixing diazotization process, the use of other salt and caustic slurry in other steps gives it a neutral nature.

The electrical conductance (EC) of the wastewater was between 2220 and 3660 $\mu$mho/cm. The high conductance indicates high contents of ions in the wastewater, which was confirmed by the high total dissolved solids (TDS). TDS of the wastewater was found in the range of 1386 to 2217 mg/L.

The hardness of the wastewater was between 300 mg/L and 510 mg/L. Most of the hardness was due to the hardness of the initial fresh water used in the process. Maximums of 700 mg/L chloride and 290 mg/L sulfate was recorded in the area. From Figure 1 and 2, it is clear that these are the major anions. The higher concentrations of these ions are due to the salts used in the process. The concentration of nitrate (minimum 24 mg/L and maximum 102 mg/L) was comparatively low.

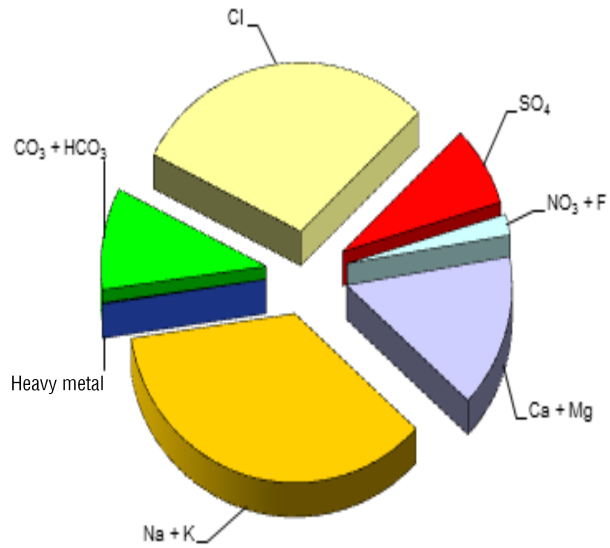


**Figure 1.** Composition of textile industrial effluent.

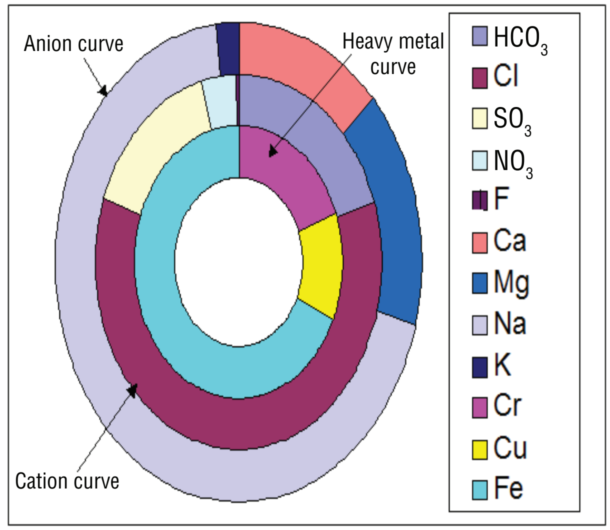


**Figure 2.** Ionic composition of textile effluent (individual ions).

Sodium was recorded to be the major cation as it is extensively used in the process (Figure 1). It was found between 280 and 600 mg/L. Sodium dominates in dyeing and printing industrial effluent. Calcium and magnesium ions are precipitated as carbonates and bicarbonates and sodium chloride, being highly soluble, becomes the major component in the effluent [17]. From Figure 2 it is clear that in the heavy metal iron and copper concentrations are higher. The concentration of iron ranged from 0.68 to 2.75 mg/L while the concentration of copper ranged from 0.15 to 1.08 mg/L. The chemical oxygen demand (COD) of the wastewater was higher than the biochemical oxygen demand (BOD). The average COD and BOD were 192 and 28 mg/L, respectively. Having a higher COD than BOD indicates that the wastewater is richer in chemical pollutants than biological pollutants. This wastewater can cause serious environmental problems due to its color, large amount of suspended solids, and high COD [18].

From the above discussion, it is clear that the physicochemical characteristics of the wastewater from various units fluctuate very much. The characteristics were found to depend primarily on the kind of process used and the kind of discharge released from washing tanks. The wastewaters from various processes have different concentrations of pollutants; the concentration of pollutants is maximum in the first wash and decreases in the subsequent washes, as a result of which there is a decrease in concentration of pollutants in wastewater.

### 3.2. Impact of wastewater on Amanishah Nallah

For the study of the impact of wastewater of dyeing and printing units on the Amanishah Nallah body of water, samples were collected from 3 points:

1. **Upstream of the polluted zone:** Sample from the Ajmer Road Bridge on the Amanishah Nallah was collected.

2. **Polluted zone:** Sample from Sanganer Road Bridge on the Amanishah Nallah was collected.

3. **Downstream of the polluted zone:** Sample from Tonk Road Bridge on the Amanishah Nallah was collected.

These samples were analyzed for physicochemical characteristics. The results of these 3 sample points are shown in Table 2.

**Table 2.** Characteristics of wastewater of Amanishah Nallah.

| Parameter | At Ajmer Road Bridge | At Sanganer Road Bridge | At Tonk Road Bridge |
|---|---|---|---|
| pH | 7.9 | 7.2 | 7.6 |
| Electrical conductivity ($\mu$mho/cm) | 1180 | 1760 | 1540 |
| TDS | 810 | 1241 | 1004 |
| Total hardness | 240 | 240 | 200 |
| Bicarbonate | 210 | 240 | 230 |
| Chloride | 240 | 380 | 310 |
| Sulfate | 80 | 140 | 100 |
| Nitrate | 70 | 80 | 70 |
| Fluoride | 1.1 | 1.0 | 1.1 |
| Calcium | 48 | 60 | 44 |
| Magnesium | 29 | 22 | 22 |
| Sodium | 130 | 270 | 210 |
| Potassium | 11 | 15 | 10 |
| Copper | 0.12 | 0.58 | 0.16 |
| Chromium | 0.14 | 0.16 | 0.10 |
| Iron | 1.9 | 1.6 | 1.8 |
| COD | 120 | 280 | 230 |
| SAR | 3.66 | 7.60 | 6.48 |

All parameters are in mg/L except pH, EC, and SAR.

The Amanishah Nallah mainly carries the domestic wastewater of a part of Jaipur before the mixing of wastewater of the dyeing and printing units of Sanganer in the polluted zone. Therefore, the wastewater of the Amanishah Nallah at this point represents the nature of domestic wastewater. TDS and other parameters were comparatively lower here than in the other 2 sampling sites. The wastewater was being used for agriculture purposes in this area. The wastewater had a low sodium adsorption ratio (SAR) and EC (4.35 mEq/L and 1180 $\mu$mho/cm, respectively) and was rich in nutrients; hence, it is helpful in good growth of plants.

In the polluted zone, the wastewater of dyeing and printing units mixes into the domestic wastewater of the Amanishah Nallah and hence the nature of wastewater changes in this zone. TDS and other parameters were found to be maximum in the wastewater of this zone. The SAR value increased up to 75% and COD increased up to 133%. The pH value and the concentrations of fluoride and iron were recorded to decrease up to 15%. Furthermore, it is clear from Tables 1 and 2 that the TDS and other parameters of wastewater of the Amanishah Nallah are much lower than those of wastewater from dyeing and printing units; hence, the clear impact on the quality of wastewater of the Amanishah Nallah can be visualized with an increase in most of the parameters in the polluted zone.

The total ionic concentration of the Amanishah Nallah at Site 1 is minimum and it reaches maximum at Site 2, where the wastewater of the dyeing and printing units starts to mix. Site 3 has lower TDS and other parameters than Site 2, but higher than Site 1. This is due to dilution by the mixing of the domestic wastewater of Sanganer and seepage occurring thereon. The concentration of sulfate, chloride, calcium, and sodium increases in the wastewater at Site 2. Here the concentration of heavy metal also increases and reaches the maximum value. After this, the concentration of almost all parameters starts to decrease. A very large decrease in heavy metal concentration is seen at Site 2. The concentration of heavy metals decreased due to their accumulation in soil and absorption by crop plants cultivated in the area. Khan et al. reported an increase in the heavy metal contents in the soil and crop plants at Sanganer [4]. Srivastava and Prakash also found increases in levels of heavy metal contents in a wheat crop after its irrigation by textile effluent [19].

### 3.3. Impact of wastewater on the groundwater

For the study of the impact of wastewater of dyeing and printing units on groundwater, 11 sources situated at various locations were marked. All the samples were examined for physicochemical parameters. Table 3 gives the physicochemical results of groundwater samples.

**Table 3.** Physicochemical quality of groundwater.

| Parameter | $G_1$ | $G_2$ | $G_3$ | $G_4$ | $G_5$ | $G_6$ | $G_7$ | $G_8$ | $G_9$ | $G_{10}$ | $G_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 7.8 | 7.6 | 7.8 | 7.4 | 7.6 | 8.0 | 7.2 | 7.8 | 7.3 | 7.4 | 7.7 |
| EC | 1501 | 1420 | 1492 | 1648 | 1861 | 1638 | 1706 | 1498 | 1456 | 1335 | 1360 |
| TDS | 982 | 924 | 972 | 1074 | 1212 | 1068 | 1104 | 968 | 943 | 867 | 860 |
| Alkalinity | 300 | 260 | 220 | 220 | 320 | 250 | 210 | 290 | 400 | 280 | 320 |
| Bicarbonate | 366 | 317.2 | 268.4 | 268.4 | 414.8 | 305 | 256.2 | 353.8 | 488 | 341.6 | 390.4 |
| Chloride | 280 | 260 | 290 | 260 | 310 | 290 | 260 | 270 | 200 | 230 | 160 |
| Sulfate | 104 | 112 | 108 | 122 | 224 | 134 | 142 | 106 | 82 | 70 | 84 |
| Nitrate | 50 | 45 | 40 | 58 | 46 | 50 | 46 | 52 | 44 | 55 | 60 |
| Fluoride | 1.2 | 0.9 | 0.8 | 1 | 1.6 | 0.9 | 0.8 | 1.4 | 1.8 | 0.8 | 1.4 |
| Total hardness | 400 | 370 | 460 | 310 | 300 | 300 | 280 | 270 | 340 | 280 | 250 |
| Calcium | 84 | 72 | 76 | 56 | 52 | 52 | 48 | 44 | 60 | 52 | 48 |
| Magnesium | 45.6 | 45.6 | 45.6 | 40.8 | 40.8 | 40.8 | 38.4 | 38.4 | 45.6 | 36 | 31.2 |
| Sodium | 196 | 184 | 178 | 196 | 326 | 248 | 212 | 262 | 242 | 192 | 192 |
| Potassium | 14 | 8 | 10 | 14 | 30 | 12 | 14 | 10 | 16 | 18 | 12 |
| Copper | 0.007 | 0.010 | 0.019 | 0.002 | 0.080 | 0.034 | 0.028 | 0.010 | 0.040 | 0.030 | 0.008 |
| Chromium | ND | ND | ND | ND | 0.029 | 0.018 | 0.011 | 0.009 | 0.012 | ND | ND |
| Iron | 0.325 | 0.746 | 0.423 | 0.867 | 1.784 | 1.012 | 0.876 | 1.160 | 1.023 | 0.894 | 0.568 |
| Percentage sodium | 52.80 | 52.78 | 51.46 | 59.09 | 71.53 | 65.09 | 63.30 | 68.52 | 61.85 | 61.33 | 63.57 |
| SAR | 4.28 | 4.18 | 3.99 | 4.86 | 8.22 | 6.25 | 5.53 | 6.97 | 5.73 | 5.01 | 5.30 |
| RSC | –1.94 | –2.14 | –3.14 | –1.75 | 0.85 | –0.95 | –1.35 | 0.44 | 1.25 | 0.04 | 1.44 |
| RSBC | 1.81 | 1.61 | 0.61 | 1.60 | 4.20 | 2.40 | 1.80 | 3.60 | 5.00 | 3.00 | 4.00 |

All parameters are in mg/L except pH, EC ($\mu$mho/cm), SAR (epm), RSC (epm), and RSBC (epm).

It is clear from Table 3 that the pH value in the study area ranges from 7.2 to 8.0. No sources were found to have acidic water. The EC in the area fluctuates from 1335 to 1861 $\mu$mho/cm. The minimum EC was recorded in $\mathbf{G}_{10}$ and the maximum in $\mathbf{G}_5$. The TDS value was below 1213 mg/L. The maximum TDS of 1212 mg/L was found in source $\mathbf{G}_5$ and the minimum of 860 mg/L was recorded from $\mathbf{G}_{11}$. The presence of heavy metals Cu, Cr, and Fe in sources $\mathbf{G}_5$ through $\mathbf{G}_9$ clearly indicates the impact of wastewater on groundwater. In source $\mathbf{G}_5$, the concentration of these heavy metals is maximum. The concentration of iron is above 1.0

mg/L at 4 sources (**G**$_5$, **G**$_6$, **G**$_8$, and **G**$_9$). In these 5 sources (**G**$_5$ to **G**$_9$) the sodium concentration was also above 200 mg/L, while the sulfate concentration in only **G**$_5$ was recorded above 200 mg/L.

From the total ionic concentration graph (Figure 3), it is clear that the total ionic concentration is nearly constant in the first 4 sources (**G**$_1$ to **G**$_4$). These sources are situated along the Amanishah Nallah before the Sanganer Road Bridge. In **G**$_5$ it is maximum and in **G**$_6$ it decreases. Source **G**$_5$ is situated near a small watercourse that carries the wastewater of the dyeing and printing units and hence has maximum impact. The total ionic concentration from **G**$_6$ to **G**$_9$ again remains nearly constant, and after **G**$_9$ it again decreases and becomes nearly constant onward. Sources **G**$_6$ to **G**$_9$ are situated between the Sanganer Road Bridge and the Tonk Road Bridge. In this area, the wastewater of dyeing and printing units and the domestic wastewater mixes and the concentrations of most physicochemical parameters decrease; hence, these source have less impact from the dyeing and printing unit wastewater than does **G**$_5$, which is in direct contact with pure dyeing and printing unit wastewater. The percentage of sodium in all sources is above 50%. In 7 sources, **G**$_5$ to **G**$_{11}$, it is above 60%, which indicates the impact of the wastewater, which is rich in sodium concentration, on the groundwater.

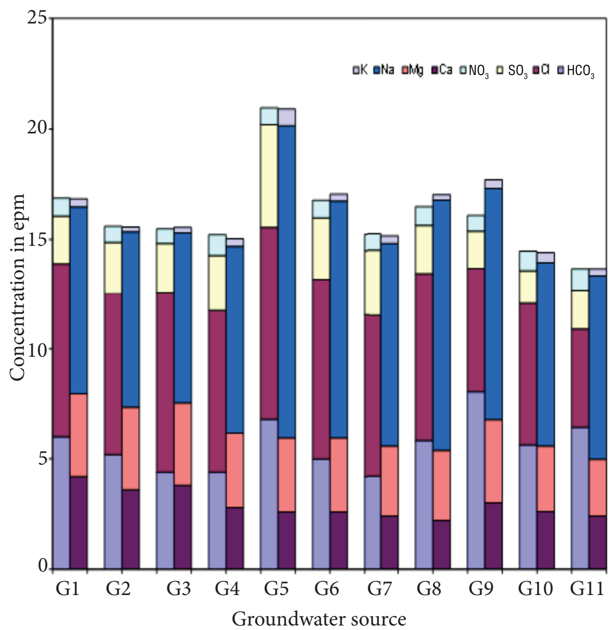


**Figure 3.** Ionic composition of groundwater of study area.

### 3.4. Suitability of groundwater for drinking purposes

Various standards are being used to find the suitability of groundwater for drinking purposes. Limits for safe drinking water are different as the limits depend on environmental conditions because water consumption per day is directly related to them. Hence, Indian Standard IS: 10500 is used for comparing the results. The Bureau of Indian Standards purposed 2 limits for drinking purposes, maximum desirable limit and maximum permissible limit, in their standards [20]. The maximum desirable limit is best for the consumer, but in the absence of such a source of water, the maximum permissible limit may be used. Table 4 presents the classification based on IS: 10500 (1991). In the classification +, ±, and – symbols are used to classify the groundwater. The + sign shows that results are within the maximum desirable limit and the ± sign shows that results are between the maximum desirable and maximum permissible limits. The – sign is used to represent results that are outside of the maximum permissible limit. Details of the parameter qualities of the zone are discussed below.

**Table 4.** Classification of ground water as per IS: 10500 [20].

| Parameter | Maximum desirable limit | Maximum permissible limit | $G_1$ | $G_2$ | $G_3$ | $G_4$ | $G_5$ | $G_6$ | $G_7$ | $G_8$ | $G_9$ | $G_{10}$ | $G_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 6.5–8.5 | 6.5–8.5 | + | + | + | + | + | + | + | + | + | + | + |
| TDS | 500 | 2000 | ± | ± | ± | ± | ± | ± | ± | ± | ± | ± | ± |
| Alkalinity | 200 | 600 | ± | ± | ± | ± | ± | ± | ± | ± | ± | ± | ± |
| Chloride | 250 | 1000 | ± | ± | ± | ± | ± | ± | ± | ± | + | + | + |
| Sulfate | 200 | 400 | + | + | + | + | ± | + | + | + | + | + | + |
| Nitrate | 45 | 100 | ± | + | + | ± | ± | ± | ± | ± | + | ± | ± |
| Fluoride | 1.0 | 1.5 | ± | + | + | + | - | + | + | ± | - | + | ± |
| Total hardness | 300 | 600 | ± | ± | ± | ± | + | + | + | + | ± | + | + |
| Calcium | 75 | 200 | ± | + | ± | + | + | + | + | + | + | + | + |
| Magnesium | 30 | 100 | ± | ± | ± | ± | ± | ± | ± | ± | ± | ± | ± |
| Copper | 0.05 | 1.5 | + | + | + | + | ± | + | + | + | + | + | + |
| Chromium | 0.05 | 0.05 | + | + | + | + | + | + | + | + | + | + | + |
| Iron | 0.3 | 1.0 | ± | ± | ± | ± | - | - | ± | - | - | ± | ± |

In the standards, pH of 6.5 to 8.5 was suggested as safe for drinking purposes. No relaxation was given in the limit. The pH levels of all sources of the study area are within the standard limit. TDS, alkalinity, and magnesium concentrations in the study area are between the maximum desirable limits (i.e. 500, 200, and 30 mg/L, respectively) and maximum permissible limits (i.e. 2000, 600, and 100 mg/L, respectively).

Chloride concentrations in the study area were found between the maximum desirable limit and maximum permissible limit, except from the last 3 sources ($\mathbf{G}_9$ to $\mathbf{G}_{11}$). Chloride toxicity has been observed in such cases where it is impaired with sodium. When an excess chloride concentration is present with excess sodium, it may cause congestive heart failure and hypertension [21]. In sources $\mathbf{G}_5$ to $\mathbf{G}_8$, chloride and sodium concentrations are high; therefore, such health effects may occur. The sulfate concentration in the study area is within the maximum desirable limit, except for source $\mathbf{G}_5$, which has maximum impact. Fingl reported dehydration as a common side effect of high sulfate consumption [22].

Total hardness in 5 sources ($\mathbf{G}_1$ to $\mathbf{G}_4$ and $\mathbf{G}_9$) was found between the maximum desirable limit (300 mg/L) and maximum permissible limit (600 mg/L). In the remaining 6 sources, it was within the maximum desirable limit. These standards are not set from a drinking point of view because there are no effects on health associated with total hardness. However, the use of hard water may cause problems in domestic usage. It may scale in pipes and obstruct lather from soap during washing. The calcium concentration in only 2 sources ($\mathbf{G}_1$ and $\mathbf{G}_3$) was between the maximum desirable limit and maximum permissible limit, as shown in Table 4. In the remaining 9 sources, the calcium concentration was within the maximum desirable limit (75 mg/L). Consumption of water containing up to 1.8 g/L calcium has been reported harmless. In the case of suspected kidney or bladder stones, high contents of calcium and magnesium in drinking water should be avoided [23]. Magnesium concentration in all sources was found between the maximum desirable limit (30 mg/L) and maximum permissible limit (100 mg/L). Magnesium has been considered as nontoxic to humans at the concentration expected in water. Magnesium salt has a laxative and diuretic effect, particularly for individuals not accustomed to high dosages [23].

Nitrate concentration in only 3 sources ($\mathbf{G}_2$, $\mathbf{G}_3$, and $\mathbf{G}_9$) was within the maximum desirable limit (45 mg/L), while in the remaining sources it was between the maximum desirable limit and maximum permissible limit (100 mg/L). Nitrate itself does not show toxic effects, but in human body, when it is reduced to nitrite, it creates various serious unhealthy effects. Nitrate has been found to react with nitro-stable compounds to form N-nitroso compounds. Most of these compounds have been found to be carcinogenic [24]. The US National Research Council found an association between high nitrate intake and gastric and or esophageal cancer. The major biological effect of nitrite in humans is its involvement in the oxidation of normal hemoglobin to methemoglobin, which is unable to transport oxygen. When the concentration of methemoglobin reaches 10% of that of hemoglobin, the condition called methemoglobinemia or blue baby syndrome causes cyanosis and, at higher concentrations, asphyxia [25,26].

Fluoride concentration in 6 sources ($\mathbf{G}_2$ to $\mathbf{G}_4$, $\mathbf{G}_6$, $\mathbf{G}_7$, and $\mathbf{G}_{10}$) was within the maximum desirable limit (1.0 mg/L), while in 3 sources ($\mathbf{G}_1$, $\mathbf{G}_8$, and $\mathbf{G}_{11}$) it is between the maximum desirable limit and maximum permissible limit (1.5 mg/L). In 2 sources ($\mathbf{G}_5$ and $\mathbf{G}_9$) it is above the maximum permissible limit. Intake of high fluoride water causes various types of fluorosis problems, from dental to skeleton [27,28]. The type of fluorosis depends on fluoride concentration as well as on environmental conditions and consumers' diets. The long-term use of groundwater from sources $\mathbf{G}_5$ and $\mathbf{G}_9$ may cause dental fluorosis.

Iron concentration of 0.3 mg/L is proposed as the maximum desirable limit and 1.0 mg/L is proposed as the maximum permissible limit by Indian standards for drinking water. In the study area, no source has an iron concentration within the maximum desirable limit, while in 4 sources ($\mathbf{G}_5$, $\mathbf{G}_6$, $\mathbf{G}_8$, and $\mathbf{G}_9$) its concentration is above the maximum permissible limit. The remaining 7 sources have iron concentrations between these 2 limits, as shown in Table 4. Although 10 to 50 mg/day of iron is essential for humans, such concentrations in water may cause problems in the domestic use of water. Iron above 0.3 mg/L may create a noticeable change in taste, color, and turbidity. The use of water with high iron concentrate in laundry and sanitation may stain cloths and utensils [23]. Meanwhile, a 0.05 mg/L concentration of copper is proposed as a maximum desirable limit, while 1.5 mg/L is proposed as the maximum permissible limit in the absence of a more suitable source. In the study area, only source $\mathbf{G}_\mathbf{5}$ had copper concentrations between the maximum desirable limit and maximum permissible limit. Prolonged use of such groundwater may cause Wilson disease [29]. Chromium was found in 5 sources, but its concentration was below the maximum desirable limit (0.05 mg/L)

### 3.5. Suitability of groundwater for irrigation purpose

To find the suitability of groundwater for irrigation purposes, various factors have been used. Most classifications are based on EC, sodium, calcium, magnesium and bicarbonates. On the basis of these parameters, the groundwater of the study area was classified as follows.

#### 3.5.1. Sodium adsorption ratio

The sodium concentration is one of the major parameters of groundwater. Its concentration in irrigation water affects the quality for irrigation purposes. A higher sodium concentration than that of calcium and magnesium in water may clog the soil, reducing the soil permeability. Therefore, the effect caused by sodium is called the sodium hazard. Considering the effects of sodium on soil, the US Salinity Laboratory introduced SAR based on the concentrations of sodium, calcium, and magnesium [30]. The SAR is calculated by using following formula:

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

On the basis of SAR values, irrigation water is classified into 4 sodium hazard classes: low ($<10$), medium (10–18), high (18–26), and very high ($>26$). SAR values in the studied area are below 10 and therefore the groundwater of the study area has a very low sodium hazard. The maximum SAR of the area was 8.22 from source $\mathbf{G}_5$.

#### 3.5.2. Electrical conductance

The EC of water is due to the conductivity of dissolved ions. The presence of an excess of dissolved salts in water has an effect on the soil quality as well as crop yield. As the EC is due to dissolved matter, the effect created by EC is called the salinity hazard. A salinity problem occurs if the total quantity of salts in the irrigation water is high enough to cause salt accumulation in the crop root zone to the extent that yields are affected adversely. If an excessive quantity of soluble salts accumulates in the root zone, the plant will experience extra difficulty in extracting enough water from the salty soil solution. This reduced water uptake by the plant can result in slow or stunted growth and may also present with symptoms similar in appearance to those of drought, such as early wilting. Therefore, the US Salinity Laboratory proposed a classification based on EC values. They classified water into 4 classes, low ($<750$ $\mu$mho/cm), medium (750–2250 $\mu$mho/cm), high (2250–5000 $\mu$mho/cm), and very high ($>5000$ $\mu$mho/cm) [30]. No source in the studied area had an EC below 750 $\mu$mho/cm. The groundwater of the area had EC values between 1335 $\mu$mho/cm and 1806 $\mu$mho/cm; hence, all sources belong to the medium salinity hazard group. Such water can be used if a moderate amount of leaching occurs.

#### 3.5.3. Residual sodium carbonate

Eaton introduced the concept of residual sodium carbonate (RSC) [31]. He calculated the relation of excess carbonate and bicarbonate concentration to calcium and magnesium concentration using following formula:

$$RSC=(CO_3^{2-}+HCO_3^{-})-(Ca^{2+}+Mg^{2+})$$

The excess carbonate and bicarbonate concentration tends to precipitate as $CaCO_3$, producing a white layer of $CaCO_3$ on the soil surface. Such a layer reduces the permeability of the soil, resulting in reduction in the crop yield. According to this classification, irrigation water may be classified into 3 classes: safe ($<1.25$), marginal (1.25–2.50), and unsafe ($>2.50$). In the study area, all 11 sources had RSCs below 1.25 and hence are safe for irrigation purposes.

#### 3.5.4. Residual sodium bicarbonate

Groundwater contains a very low or nil carbonate concentration and only precipitates with calcium only. Hence, a new hypothesis based on only bicarbonate and sodium concentration was introduced, called residual sodium bicarbonate (RSBC) [32]. It is calculated as excessive carbonate concentration to calcium concentration by using following formula:

$$RSBC=HCO_3^{-}-Ca^{+2}$$

The RSBC values classify water into 3 classes: safe ($<5.0$), marginal (5.0–10), and unsafe ($>10$). In the study area, no sources have RSBC values above 5.0, and hence all sources are safe for irrigation purpose.

#### 3.5.5. SAR and EC classification

SAR and EC represent sodium and salinity hazard, respectively. Considering both types of hazards, the US Salinity Laboratory proposed a classification that combined both hazards to determine the integrated effect on quality [30]. For the classification a graph was plotted as shown in Figure 4. The curves were given a negative slope to take into account the dependence of sodium hazard on total salt concentration. In the curve, the sodium class changes with a change in the EC of water. Although this classification classifies water into 16 classes, the groundwater of the study area belongs to 2 classes, as shown in Table 5. It is clear that 3 sources (**G**$_1$ to **G**$_3$) of the area belong to the **C**$_3$S$_1$ (high salinity, low sodium hazard) class, while the remaining 8 sources belong to the **C**$_3$S$_2$ (high salinity, medium sodium hazard) class.

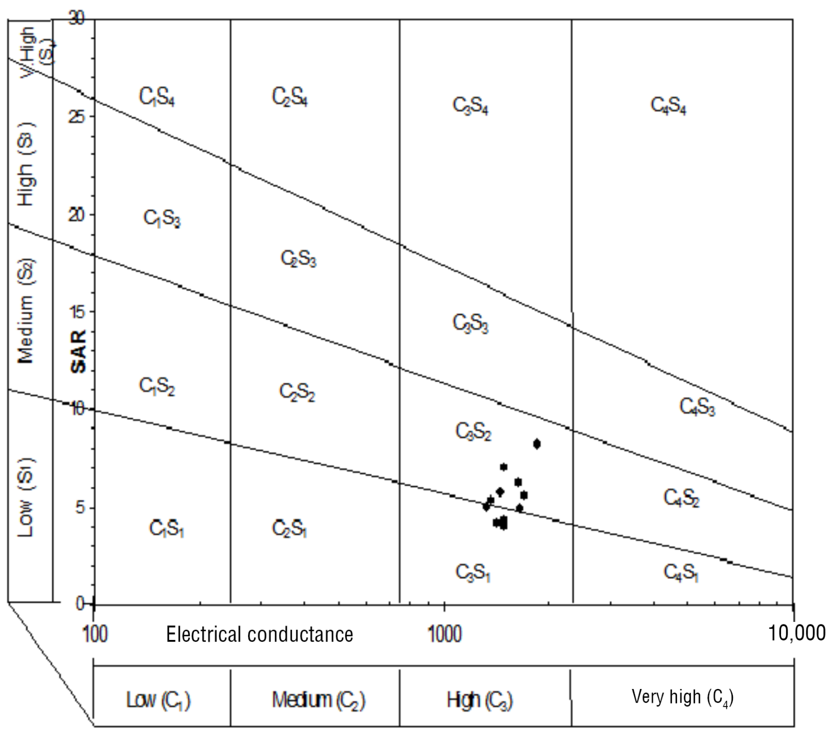


**Figure 4.** Sodium and salinity hazard relationship for irrigation water classification.

**Table 5.** Classification based on SAR and EC curve [30].

| Category | Type of water | No. of samples | Detail of samples |
|---|---|---|---|
| $C_3S_1$ | High salinity and low sodium | 3 | $G_1$ to $G_3$ |
| $C_3S_2$ | High salinity and medium sodium | 8 | $G_4$ to $G_{11}$ |

#### 3.5.6. Percentage sodium and EC

Percentage sodium is the percentage of sodium concentration against all cationic concentrations related to sodium hazard. Therefore, Wilcox used a classification based on these 2 factors, i.e. percentage sodium and electrical conductance [33]. For this purpose the percentage sodium (% Na) against EC was plotted as shown in Figure 5. This classification demarcates irrigation water into 5 classes, but the groundwater of the study area belongs to 2 classes, as shown in Table 6.

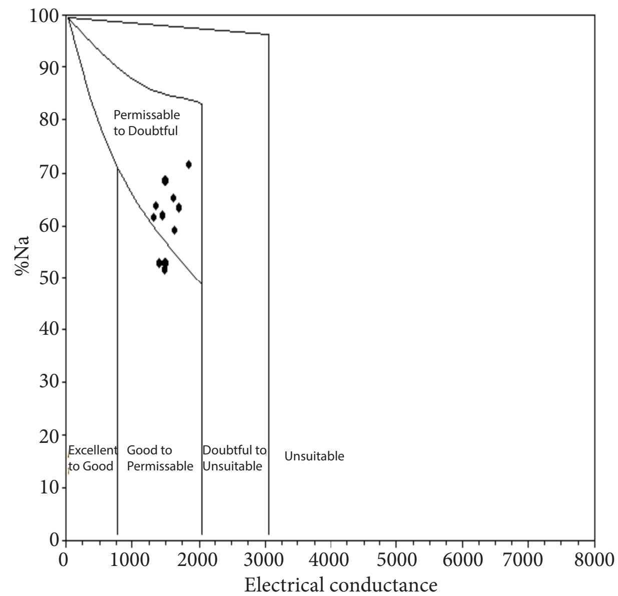


**Figure 5.** Water classification in relation to % sodium and EC.

**Table 6.** Classification based on % sodium and EC.

| Class | No. of samples | Detail of samples |
|---|---|---|
| Excellent to good | - | - |
| Good to Permissible | 3 | $G_1$ to $G_3$ |
| Permissible to Doubtful | 8 | $G_4$ to $G_{11}$ |
| Doubtful to Unsuitable | - | |
| Unsuitable | - | |

No source in the study area belongs to the 'excellent to good' class, while 3 sources ($\mathbf{G}_1$ to $\mathbf{G}_3$) belong to the 'good to permissible' class. The remaining 8 sources of the study area are permissible to doubtful.

## 4. Conclusion

From this study it is clear that the wastewater of the printing and dyeing units has high concentrations of sodium, chloride, and sulfate. The wastewater also has remarkable concentrations of copper, chromium, and iron. The wastewater has low COD and a BOD of nearly 7 time higher. The wastewater of the dyeing and printing units is discharged on land, which comes into the Amanishah Nallah through small watercourses. The quality of wastewater of the Amanishah Nallah deteriorates with the mixing of dyeing and printing wastewater. The physicochemical results of the Amanishah Nallah wastewater are maximum at the Sanganer Road Bridge point. The groundwater of the study area was also polluted due to percolation of wastewater. Copper and chromium were recorded in some groundwater sources, while iron was recorded in almost all sources. Sodium and chloride are the major cation and anion in the groundwater, which is identical to the wastewater of dyeing and printing units. Source $\mathbf{G}_5$, near the small watercourse carrying the dyeing and printing wastewater, has maximum impact. The physicochemical parameters of this source are maximal in the study area.

The industries in the area are small-scale industries and by law there is no need to establish an effluent treatment plant. In such circumstances, there is a need to establish a common effluent treatment plant. There is a need to collect waste through a channel to stop percolation of waste water.

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