Hydrogeochemical factors governing the origin and transport of Cr from ophiolitic complex to water resources in the Pangi area (Kadkan, NW Torbat Hydarieh, Iran)

Ghasemi1, A. Razmara2, M

1-MSc Student Environmental Geology, Department of Geology, Ferdowsi University of Mashhad, Mashhad, Iran.
2-Associate Professor of Mineralogy, Department of Geology, Ferdowsi University of Mashhad, Mashhad, Iran.

Abstract—The hydrochemistry of the water resources in Pangi area (Kadkan, NW Torbat Hydarieh), has revealed high concentrations of Cr and heavy metals (Cd, Ni, As) exceeding maximum permissible limit. The result of measurement by GFAAS showed that the highest Cr concentrations were found in waters in the vicinity of chromite mines. The high levels of Mg\(^{2+}\), Na\(^{+}\), Cl\(^{-}\), SO\(_4^{2-}\), HCO\(_3^{-}\) and Cr in the stream sediments often exceed the thresholds of the WHO standards. The water samples of the study area display pH with a mean 8.5, TDS with a mean of 1259 mg/l and EC showed 1978 µs/cm. Hydrochemical facies using Piper trilinear plot delineated two water samples as Na-Cl facies with Ca-SO\(_4\), Mg-Cl, Na-HCO\(_3\) and Mg-HCO\(_3\) facies as minor types. Local ophiolitic rocks, especially serpentinites and ultramafic units, are Cr-rich and represent a Cr source for groundwaters. Hydrogeological investigations confirmed high total Cr contents in soils and waters related to ultramafic rocks from northern ophiolitic zone. Cr(III) concentrations in resulting soils and sediments are magnified by weathering reactions, as a consequence of selective alteration of silicate minerals relative to chromite. The high concentrations of Cl\(^{-}\), Mg\(^{2+}\), Ca\(^{2+}\) and HCO\(_3^{-}\) well as high values of EC, pH and TDS in studied samples are related to weathering reactions of ferromagnesian rocks of ophiolitic complex. The abundance of Mn and Fe oxy-hydroxide (as electron acceptor) with Cr rich spinels in the study area, creates a chemical systems potentially able to increase the Cr(III) to Cr(VI) oxidation. Cr(III) is highly concentrated in areas where the dissolved oxygen content of less than 1 mg/l and pH is in the neutral range. The rate and amount of Cr(VI) in environment increases with increasing chromium concentrations and decreasing pH. As in the ophiolitic zone, pH is greater than neutral range (pH> 7.9) and DO>7.67 mg/l, Therefore, given the values of DO, Eh and alkaline pH of the water sample in the area, chromium in water resources area must contain significant amounts of Cr(VI) and is in the form of chromate (CrO\(_4^{2-}\)). The hydrochemical data demonstrate that serpentinites and serpentine soils are main potential source of non-anthropogenic Cr(VI).The enrichment and variability of Cr in serpentinites and serpentine soils is directly related to the abundance and weathering of multicomponent spinel system.

Keywords—Chrome, Hydrochemistry, Ophiolite, Pangi

I. INTRODUCTION

Chromium, the 17 th most abundant element in the earth’s crust [16]. Chromium is a group VIB transition metal with an average crustal abundance of 100 ppm. In basaltic and ultramafic rocks its average concentration is 200 and 2400 ppm, respectively [23]. The most common Cr-containing mineral is chromite (Fe\(^{2+}\)Cr\(^{3+}\)O\(_4\)) in which Cr occurs in the +3 oxidation state. This element (Cr) is found in spinels, garnets, amphiboles and pyroxenes [31]. Chromium persists in the environment as Cr(III), a non-hazardous species or as Cr(VI), a toxin to living cells and is a danger to human health, it is carcinogenic. Chromium was demonstrated to occur naturally in waters and soils during dissolution and weathering of rocks, especially in ophiolitic zones (e.g. north of Torbat Hydarieh and south east of Birjand) [13]-[19]. The extensive use of Cr in industrial activities (e.g. tanning, electroplating, steel, paint) and mining has resulted in thousands of soil and groundwater contaminated sites in Iran [27]. Leaching from topsoil and rocks (especially serpentinitized rocks of ophiolitic zones) is the most important natural source of chromium entry into bodies of water [10]. Chromium is present in ground water in either the trivalent (Cr\(^{3+}\)) or the hexavalent (Cr\(^{VI}\)) oxidation state. Cr(III) has a low solubility in natural water and is thus rather immobile, whereas Cr(VI) is quite soluble in water and is comparatively much more mobile [28]. The presence of Cr(III) in majority of the studied samples from ophiolitic zones, may be related to the ultramafic rocks [24] but their concentration of Cr(VI) is low and is about 0.06 ppm [34]. EPA has set an enforceable regulation for total chromium, called a maximum contaminant level (MCL), at 100 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. The permissible limit of Cr(VI) in the drinking water is 0.06 ppb [8]-[37]-[39]. A multidisciplinary approach combining field parameter...
measurements, analytical techniques and laboratory studies
was undertaken to determine whether or not mining activities,
serpentinites and serpentine soils are sources of Cr
contaminations in the study area.

II. GEOLOGICAL SETTING

Remote sensing (RS), Field and petrographic studies in the
ophiolic zone, implies the existence of a complete ophiolite
sequence (peridotite, gabbro, diabase and basalt) in the region.
The ophiolite complex is composed of several units and
associated volcano-sedimentary units. The lowest part of
the sequence consists of the ultramafic complex, which is overlain
by a thick gabbro complex. The complex comprises layered to
massive rocks of which consists of melanocratic to meocratic
and finally pillow lava rocks [29]. This is overlain by the
volcano-sedimentary sequences, which is in turn overlain by
plagic sediments, radiolarites, shale, sandstone, conglomerates
and thick evaporate sediments Fig. 1. The main part of the
ultramafic complex comprises largely lherzolite and
harzburgite, with minor dunite, pyroxenite, serpentinite and
serpentinite breccia Fig. 1. The ultramafic complex hosts
sporadic podiform chromite mineralization [30].

III. SAMPELIG METODS

Six samples were collected to determine the concentration
of heavy metals and measuring physical and chemical
properties of water samples. Measured physical parameters
were dissolved O2 concentrations (DO), pH, electrical
conductivity (EC), redox potential (Eh), temperature and total
dissolved solid (TDS). To determine the chemical properties
of water resources, 250 CC water were taken by a
polyethylene container. After filtering, 5 CC nitric acid was
added to stabilize heavy metals in the water samples. These
Samples were analyzed by graphite furnace atomic absorption
spectrometry (GFAAS, GTA-110 model) for Cr (total), heavy
metal cations as well as anions concentrations determinations
in the Geological Survey of Mashhad. The bicarbonate ion
concentration was measured by titration method (using 0.1
HCl m), then the concentration of anions in samples was
determined by Ion chromatograph but cations concentrations
were measured by Flame photometery method.

IV. RESULTS AND DISCUSSION

A. Study of chromium concentrations in water samples

The area consists mainly of partially serpentinized
peridotites, consisting of various mafic and ultramafic rocks.
The mineralogical studies of the peridotites have shown
various units containing olivine, clinopyroxene,
orthopyroxene, spinel ± chromite and other opaque phases.
Weathering of peridotite and pyroxenite rocks in the Targhi
complex of Torbat Hydariieh produces serpentinites and
serpentine soils containing high concentrations of Cr as well
as other potentially toxic elements including As, Cd and Ni.
Chromium concentrations in serpentinite soil profiles fluctuate
between 2340 to 7754 ppm (Table I). Serpentine soils in the
area have varying pH (7-9), contain a variety of Mn and
Fe(III) oxides as well as contain concentrations of Cr (>2400
ppm), Fe (>8600 ppm), Ni (>1200 ppm), and Mn (>750 ppm).
The enrichment and variability of Cr in serpentinites and
serpentine soils is directly related to the abundance and

Fig. 1 Geological map of Pangl area (modified from Torbat Hydariieh 1:250000 map) and location of water samples

398
weathering of multicomponent spinel system (chromite, Cr-bearing magnetite, and magnesiochromite). Therefore, oxidation of Cr(III) from Cr-spinels by high valent Fe and Mn oxides, oxyhydroxides and dissolved O$_2$ are main potential sources of Cr(VI) in serpentine soils and waters. Cr release and oxidation from mining activities is another potential environmental hazard in sediments, soils and water sources of the area. In the area, mining activities causing release of toxic metal chromium and its compounds in the environment. The highest Cr (total) concentrations were found in waters in the vicinity of chromite mines. This indicates that the sediments in the area are naturally high in Cr and specific geochemical compositions within the ore deposits have allowed greater dissolution of Cr Measured field parameters (DO, pH, EC, Eh, T, TDS) and water analysis are presented in Table II Chromium in different samples, are compared in Fig. 2.

<table>
<thead>
<tr>
<th>Rack name</th>
<th>harzburgite</th>
<th>serpentinite</th>
<th>ultramafic rocks</th>
<th>chromite</th>
<th>gabbro</th>
<th>andesite</th>
<th>diabase</th>
<th>basalt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>38</td>
<td>2340-7754</td>
<td>3550-3920</td>
<td>353000</td>
<td>230-1033</td>
<td>318-400</td>
<td>482-641</td>
<td>170-306</td>
</tr>
</tbody>
</table>

Table II. Results of physical and chemical parameters, (major elements in terms of ppm, chromium and manganese concentration in ppb)

<table>
<thead>
<tr>
<th>Sample</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>WHO (2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na$^+$</td>
<td>82.8</td>
<td>36.8</td>
<td>690</td>
<td>713</td>
<td>23</td>
<td>87.4</td>
<td>50</td>
</tr>
<tr>
<td>Ca$^{2+}$</td>
<td>30</td>
<td>48</td>
<td>88</td>
<td>90</td>
<td>138</td>
<td>44</td>
<td>200</td>
</tr>
<tr>
<td>Mg$^{2+}$</td>
<td>27.6</td>
<td>41.4</td>
<td>110.4</td>
<td>117.6</td>
<td>27.6</td>
<td>20.4</td>
<td>50</td>
</tr>
<tr>
<td>K$^+$</td>
<td>0</td>
<td>0</td>
<td>35.1</td>
<td>35.1</td>
<td>0</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>HCO$_3^-$</td>
<td>207.4</td>
<td>183</td>
<td>463.4</td>
<td>543</td>
<td>292.8</td>
<td>323.3</td>
<td>120</td>
</tr>
<tr>
<td>Cl</td>
<td>51.7</td>
<td>62.1</td>
<td>739</td>
<td>862.5</td>
<td>44.9</td>
<td>44.9</td>
<td>200</td>
</tr>
<tr>
<td>SO$_4^{2-}$</td>
<td>120</td>
<td>57.6</td>
<td>715.2</td>
<td>619.2</td>
<td>201.6</td>
<td>52.8</td>
<td>200</td>
</tr>
<tr>
<td>Cr</td>
<td>97.4</td>
<td>34.8</td>
<td>5.4</td>
<td>54.5</td>
<td>24</td>
<td>12.8</td>
<td>50</td>
</tr>
<tr>
<td>Mn</td>
<td>195</td>
<td>206</td>
<td>130.5</td>
<td>186.6</td>
<td>114</td>
<td>20.6</td>
<td>400</td>
</tr>
<tr>
<td>pH</td>
<td>9.1</td>
<td>8.8</td>
<td>8.1</td>
<td>8.2</td>
<td>8.7</td>
<td>7.9</td>
<td>7-8</td>
</tr>
<tr>
<td>EC (μs/cm)</td>
<td>773</td>
<td>557</td>
<td>4440</td>
<td>4650</td>
<td>995</td>
<td>453</td>
<td>1000</td>
</tr>
<tr>
<td>TDS (mg/l)</td>
<td>471</td>
<td>351</td>
<td>2798</td>
<td>2929</td>
<td>627</td>
<td>341</td>
<td>-</td>
</tr>
<tr>
<td>Eh (V)</td>
<td>0.41</td>
<td>0.37</td>
<td>0.38</td>
<td>0.46</td>
<td>0.43</td>
<td>0.40</td>
<td>-</td>
</tr>
<tr>
<td>DO (mg/l)</td>
<td>10.91</td>
<td>8.43</td>
<td>7.67</td>
<td>9.56</td>
<td>8.45</td>
<td>7.99</td>
<td>-</td>
</tr>
<tr>
<td>T (°C)</td>
<td>11</td>
<td>12</td>
<td>14</td>
<td>10</td>
<td>11</td>
<td>11</td>
<td>-</td>
</tr>
<tr>
<td>Water type</td>
<td>Na-HCO$_3$</td>
<td>Mg-Cl</td>
<td>Na-Cl</td>
<td>Na-Cl</td>
<td>Ca-SO$_4$</td>
<td>Na-HCO$_3$</td>
<td>-</td>
</tr>
</tbody>
</table>

In general, Cr(III) is soluble in acidic conditions [3] but Cr(VI) compounds are much more soluble than the major Cr(III) oxides under alkaline and natural conditions [21]. Cr(VI) in wastewaters is present as chromate (CrO$_4^{2-}$) and dichromate (Cr$_2$O$_7^{2-}$) forms [4].

Fig. 2. a) The concentration of chromium in water and b) pH-Eh diagram of Cr-OH system in water resources
B. Hydrogeochemical processes governing the origin and transportation of Cr(VI) in Water

Hydrogeochemical processes are governing the origin, Chemical evolution transport and fate of Cr(VI) from ophiolitic complex and mineralized rock to surface and groundwater in the area. Water samples acquire the dissolved solids by reaction of meteoric waters with the minerals in the bedrock. DO and pH are important factors affecting the physical and the presence of chromium species. The concentration of Cr(VI) in water with pH> 7.5 and DO> 0.5 mg/l, is higher than that of Cr(III) [2]. With increasing pH, Cr and other trace elements adsorbed onto Fe oxides and Mn, are released into the solution [20]. Cr(III) is highly concentrated in areas where the dissolved oxygen content of less than 1 mg/l and a pH is in the neutral range [26]. Cr(VI) has direct relationship with DO. From thermodynamically view, Cr(VI) is stable in high concentrated oxygen environment [20]. In the case of the studied ophiolite, the amount of pH> 7.9 and DO is greater than 7.67 mg/l. These values indicate that the soluble chromium is more Cr(VI). In neutral conditions, redox potential of Cr, is directly affected by Mn and oxygen of water content [6]. According to the (1), coating insoluble manganese oxides on soils and sediments in the saturated zone is a transformation factor of Cr(III) to Cr(VI):

$$2Cr^{3+} + 3MnO_2 + 2H_2O \rightarrow 2HCrO_4^- + 3Mn^{2+} + 2H^+ \quad (1)$$

As Cr(VI) adsorbed by cations such as Mn and Manganese compounds are important absorber of Cr, it can be deduced that the chromium in water resources must contain significant amounts of Cr(VI) and is in the form of chromate (CrO_4^{2-}).

C. The distribution of major elements in water resources

Dissolved cations in studied waters are released through geochemical weathering processes. The most abundance of ionic compositions can be described as Na\(^{+}\), Ca\(^{2+}\), Mg\(^{2+}\), K\(^{+}\) cations and Cl\(^{-}\), HCO\(_3\)\(^{-}\) and SO\(_4\)\(^{2-}\) anions trend. The groundwater–mineral interactions in aquifer play an important role in water quality and groundwater contamination. In addition, to investigating the origin and concentration of elements, the concentrations of cations and anions were compared with World Health Organization standards.

Sodium (Na\(^{+}\)): The dominant cation in the stream waters of the study area is Na\(^{+}\). The average value of Na\(^{+}\) in studied samples is 279.1 ppm. The Lowest sodium concentration was found in the sample No 5 (23 ppm), but the highest value was in the sample No 4 (713 ppm). The desirable amount for human consumption is 50 ppm [38]. The main source of sodium in waters is associated with evaporite deposits which their outcrops in the southern mountains of the study area are visible.

Calcium (Ca\(^{2+}\)): Calcium in waters of studied area varies from 30 to 138 ppm with the mean of 74 ppm (Table II). The desirable and permissible limit of Ca\(^{2+}\) in the drinking water is 75 and 200 ppm [38]. It implies that the drinking water in the study area is within recommended value. The main source of calcium in the area is associated with carbonate rocks. An extensive outcrop of carbonates in the margins of ophiolitic unit is exposed in an east-west trending belt in the southern part of the Fariman - Sabzevar ophiolite complex. Water samples acquire the dissolved calcium by reaction of meteoric waters rich in CO\(_2\) with saussorized plagioclases and ferromagnesian minerals containing calcium of gabbroic, diabasic and basaltic units in the bedrock. For example, the interaction of labradorite in the gabbro, diabase and basalt units in the study area can be expressed as follows (2) [22]:

$$\text{(Ca,Na)}_2\text{Si}_2\text{O}_5 + \text{2CO}_2 + \text{3H}_2\text{O} \rightarrow \text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_2 + \text{Ca}^{2+} + \text{Na}^{+} + \text{2HCO}_3^- \quad (2)$$

The effect of waters containing CO\(_2\) on igneous minerals for the production of clay minerals and soluble ions (Ca\(^{2+}\), Na\(^{+}\) and HCO\(_3^-\)) is shown in this equation. The instability of Ca-silicates leads to an increase the Ca\(^{2+}\) in the fluids along with an increase in pH. Therefore, waters discharging from serpentinites have high pH and are rich in Ca\(^{2+}\).

Magnesium (Mg\(^{2+}\)): The third cation in the water samples of the study area is Mg\(^{2+}\). The average value of Mg\(^{2+}\) in studied samples is 56.7 ppm. The Lowest sodium concentration was found in the sample No 6 (24 ppm), but the highest value was in the sample No 4 (117.6 ppm). Up to 50 ppm Mg\(^{2+}\) concentration in drinking water is considered safe for human health [38]. The presence of CO\(_2\), Fe and Mg\(^{2+}\) catalysts, associated with H\(_2\)O create conditions favorable for the serpentinization of ferromagnesian minerals (olivine, pyroxene and amphiboles). Serpentinization of olivine in peridotite and its interaction with H\(_2\)CO\(_3\), can be described as [12]:

$$\text{Mg,Fe}_2\text{SiO}_4 + \text{4H}_2\text{CO}_3 (aq) \rightarrow \text{Mg}^{2+} + 4\text{HCO}_3^- + \text{Fe}^{3+}\text{H}_2\text{SiO}_3 (aq) \quad (3)$$

The source of magnesium ion in the area can be determined from the ratio of Mg\(^{2+}\)/Ca\(^{2+}\). If the ratio is less than 0.7, the origin of Mg\(^{2+}\) is from limestones, in the range of 0.7 to 0.9 dolomitic, but if it is greater than 1, the origin of Mg\(^{2+}\) is from ophiolitic rocks [17]. As the ratio is higher than 1, therefore, a source of ophiolitic complex can be considered for magnesium ions. The carbon - oxygen isotope data was revealed that the origin of Mg\(^{2+}\) in magnesites was related to ultramafic host rocks during serpentinization reaction time [1]. Therefore, The instability of Mg-silicates leads to an increase of Mg\(^{2+}\) in the fluids along with an increase in pH. Therefore, low-temperature fluids discharging from serpentinite-hosted rocks have characteristically high Mg\(^{2+}\).

Potassium (K\(^{+}\)): In contrast Na\(^{+}\) the amount of K\(^{+}\) in studied samples is very low (average 11.7 ppm). The amount of K\(^{+}\) is in safe limit, set by the WHO. The desirable limit of K\(^{+}\) in the drinking water is 12 ppm [38]. Low levels of potassium in comparison with other cations in the region are related to the lack of potassium-bearing minerals in ophiolitic complex, its greater resistance to chemical weathering and substituting in the crystal structure of some clay minerals[36].

Bicarbonate (HCO\(_3^-\)): HCO\(_3^-\) as the dominant anion in the water samples of study area ranged between 183-543 ppm. The mean value (355 ppm) of HCO\(_3^-\) ions is less than maximum permissible limit (120 ppm) [38] in the waters of study area. An important factor in creating the bicarbonate ion is related with alteration of ferromagnesian silicates and plagioclase (based on the interaction of 2 and 3). Due to the significant bicarbonate anion in waters of the area, the probable origin is weathering of silicate minerals (such as olivine and plagioclase) [11].
Chlorine (Cl\textsuperscript-): The chloride concentration in the groundwater of the study area ranged 44.9-862.5 ppm. The amount is higher than desirable limit (250 ppm) [38]. Serpentinite as carriers of chloride in subduction zones have high levels of chlorine [5]-[32]. Chlorine is present in two forms in serpentinitized rocks [36]. In addition, the main source of Cl in waters is associated with evaporite deposits which their outcrops in the southern mountains of the study area are visible.

Sulfate (SO\textsubscript{4}\textsuperscript{2-}): The values range from 52.8 to 715 ppm with a mean concentration of 294.8 ppm. WHO [38] has established 200 and 600 ppm as desirable and permissible limit in the drinking water respectively. The main source of SO\textsubscript{4}\textsuperscript{2-} in the area can be related with evaporite deposits in the southern mountains of the study area.

V. Chemical processes affecting water

Gibbs diagram [14] has been used extensively in water resource studies to understand hydrochemical trends. The diagram provides a simple tool to identify waters that are dominated by rock weathering, evaporation-crystallization or precipitation. In order to evaluate the effect of hydrochemical processes, Gibbs diagram was used. Waters affected by high evaporative deposits are generally expected to present high TDS and Na\textsuperscript+/Ca\textsuperscript{2+} +Na\textsuperscript{+} ratios. Most of points in the diagram fall between the regions, which indicate rock weathering. According to Gibbs diagram Fig. 3., it can be deduced that the weathering of abundant ferromagnesian minerals in ophiolite complexes have a significant impact on local water chemistry in the environment.

Diagrams of [Na\textsuperscript{+}+K\textsuperscript{+}]/[HCO\textsubscript{3}\textsuperscript{-}] versus [HCO\textsubscript{3}\textsuperscript{-}]/[Ca\textsuperscript{2+}+Mg\textsuperscript{2+}] which are based on chemical stoichiometry [15], may indicated the origin of the dissolution of minerals in water (Fig. 4). The weathering process deduced from water situations on the above diagram. The [HCO\textsubscript{3}\textsuperscript{-}]/[Na\textsuperscript{+}+K\textsuperscript{+}] ratio (0.1-1.5), indicating the dissolution of Na\textsuperscript{+} and K\textsuperscript{+} bearing minerals in the study area. These points can also be deduced from [HCO\textsubscript{3}\textsuperscript{-}+SO\textsubscript{4}\textsubscript{2-}] anions ratio to [Ca\textsuperscript{2+}+Mg\textsuperscript{2+}] cations. The above ratio in water samples are always higher than 1 (about 1.2) which indicates the necessity of dissolution of minerals containing Na\textsuperscript{+} and K\textsuperscript{+} cations (in the ionic balance) between cations and anions in water samples.
Diagram of Ca$^{2+}$/Mg$^{2+}$ versus Na$^+$/Ca$^{2+}$ in water samples, shows lithologic units which affecting water quality. Based on the above diagram, the water chemistry is influenced by silicate, evaporite and carbonate units, but the influence of silicate unit in water is more than of carbonate and sulfate units.

**VI. FIELD PARAMETERS**

**pH:** The normal pH range is from 6.5 to 8.5 [39]. The pH is one of the most important parameters concerning Cr mobility. The water samples of the Ophiolite springs and groundwaters are within a range of 7.9 to 9.1 with a mean 8.5 (Table II). Because Mg$^{2+}$ and Ca$^{2+}$ hydroxides are strong bases, their presence in the environment causes high pH alkaline water character [7]. In this study, only Al and Ca are found to be strongly correlated with pH.

**TDS:** TDS of waters ranges between 341-2929 ppm. TDS of some samples is within the maximum allowed limit, however the most of the sample are above the maximum permissible limit of WHO [39].

**EC:** The range of EC variation is 453 $\mu$s/cm to 4650 $\mu$s/cm.

EC values in the up to 2000 $\mu$s/cm is suitable for irrigation but most the amount of EC 1000 $\mu$s/cm could be indicative of water pollution [39].

**VII. ASSESSMENT OF WATER RESOURCES AND DRINKING WATER FACIES**

The water samples in Rud Shur area exhibit a wide range of water qualities. All the waters are moderate alkaline (pH from 7.9 to 9.1). The waters show a wide range of major cation, anion and trace element concentrations. To show the chemical composition and hydrochemical facies of water resources, Piper diagram [25] Fig. 6 was used. They fit into five broad water types: 1) Mg-Cl 2) Mg-HCO$_3$ 3) Na-HCO$_3$ 4) Na-Cl and 5) Ca-SO$_4$ facies.
To determine the feasibility of using water for drinking, Schuler charts [33] Fig. 7, and its indicators were used. On the basis of Schuler siagram, samples 1 and 6 good, No 5 as acceptable sample but samples 2, 3 and 4 were not-potable. High amounts of Cl\(^-\), Na\(^+\) and Mg\(^{2+}\) in the samples are the main reason of unsuitablity of waters for drinking.

In studies conducted in Italy and Mexico in most areas of ophiolitic area, the waters are Ca-HCO\(_3\) and Mg-HCO\(_3\) types [9]. They produce as a result of weathering of ultramafic rocks and serpentinite containing Cr(VI) and Cr(III). Mg-HCO\(_3\) water types, usually are produced through the interaction of meteoric water with serpentinite and ultramafic rocks. Ca-HCO\(_3\) water types are produced through interaction of meteoric water with gabbro and basalt rocks. Mg-HCO\(_3\) water types are more rich in Cr than Ca-HCO\(_3\) water types. One of samples was Mg-HCO\(_3\) type and had the highest amounts of Cr in Pangi village (with a concentration of 97.4 ppb).

VIII. Conclusion

Hydrochemical variables of water resources in Pangi area were evaluated in order to enhance an understanding of the most significant processes which impact the hydrochemical variations. Major conclusions of this study are drawn as follows:

- As in the ophiolitic zone, pH is greater than neutral range (pH > 7.9) and DO > 7.67 mg/l. Therefore, given the values of DO, Eh and alkaline pH of the water sample in the area, chromium in water resources area must contain significant amounts of Cr(VI) and is in the form of chromate (CrO\(_4^{2-}\)).

- The water chemistry of Pangi area is influenced by complex contamination sources and geochemical processes. In the area, rock–water interaction, carbonate mineral dissolution, silicate weathering and ion exchange reactions are the major hydrogeochemical processes responsible for contamination of water resources.

- Geochemical and hydrological processes controlling the concentration and speciation of chromium in water resources in the study area. The mean value of Cr cation (38.2 ppb) is higher than maximum permissible limit (ppb) in the waters of studied samples.

- An investigation of water resources associated with the ophiolite rocks of Pangi area shows five broad water types: 1) Mg-Cl (2 Mg-HCO\(_3\)) 3) Na-HCO\(_3\) 4) Na-Cl, and 5) Ca-SO\(_4\) facies.

- Important processes affecting the hydrochemistry of water resources as well as high amounts of Cl\(^-\), Na\(^+\), Ca\(^{2+}\), HCO\(_3\)-, TDS, EC and pH in waters are related to weathering of multicomponent spinel systems in ophiolitic complex. Therefore, oxidation of Cr(III) from Cr-spinels by high valent Fe and Mn oxides is main potential source of Cr(VI) contamination in serpentine soils and waters.

REFERENCES


ISSN (Online): 2305-0225
Issue 15(2), July 2014, pp. 397-406