Toxic metal ions contamination in the groundwater, Kingdom of Saudi Arabia

Imran Ali⁹, Mohd Abul Hasan⁵ and Omar M. L. Alharbi⁶

¹Department of Chemistry, College of Sciences, Taibah University, Al-Medina Al-Munawara, Kingdom of Saudi Arabia; ²Department of Chemistry, Jamia Millia Islamia (Central University), New Delhi, India; ³Department of Civil Engineering, College of Engineering, King Khalid University, Abha, Kingdom of Saudi Arabia; ⁴Department of Biology, College of Sciences, Taibah University, Al-Medina Al-Munawara, Kingdom of Saudi Arabia

ABSTRACT

The Kingdom of Saudi Arabia (KSA) is one of the rising countries in the Gulf region but always scared of water; being present in the arid desert. Among some water resources groundwater is one of the most significant ones in this country but unfortunately is being contaminated by the toxic metal ions. The present article describes the status of groundwater contamination by toxic metal ions. The metal ions analysed in the groundwater of KSA are Al, Cr, As, Cd, Ba, Co, Cu, Fe, Li, Hg, Mn, Ni, Se, Pb, V and Zn. This article describes the different groundwater resources in KSA, toxicities of the metal ions, metal ions contamination in the groundwater and sources of metal ions pollution. Besides, efforts are made to discuss the future challenges and the remediation measures; needed to protect the groundwater resources. This article will be important to the academicians, researchers, industry persons and the regulatory authorities.

1. Introduction

The Kingdom of Saudi Arabia (KSA) is one of the rising countries in the Gulf region with much industrial growth such as petrochemical, oil and gas, agriculture, pharmaceuticals, etc. This development led to the growth of urbanization and population; with the growing demand for many needs. All these have a direct impact on the natural assets of the country where water resources are the most important ones. KSA is the biggest nation in the Arabian Peninsula with around 2.15 million km² area. The country has borders with Kuwait, Jordan and Iraq in the north, Qatar in the southeast, Oman, United Arab Emirates and Yemen in the south, the Persian Gulf in the east and the Red Sea in the west. KSA has a maximum arid desert with a mountain range along with the western side and divides the desert from the Red Sea coastal region. KSA is situated in the arid region (Latitude 16.5–32.5 N; Longitude 33.75–56.25 E) [1]. It is supposed as one of the reduced water countries globally because of its limited water resources with about 59 mm rainfall [2]. The weather is arid with a semi-arid situation along the Red Sea coast. There is no river in the country.

The water availability is an important issue in KSA because of the limited available surface water. The main water sources in KSA are groundwater, desalinated sea water, surface water and wastewater. In KSA, about 80% of its water supply is completed from groundwater for various purposes. Generally, the amount of water withdrawn exceeds the recharge amount of the shallow groundwater reservoirs [3]. This leads to the decline of the water quality of the groundwater. The water quality of the groundwater is deteriorating due to the excess of groundwater withdrawn; leading to the mixing of the metal ions in the groundwater aquifers. Besides, man-made activities are also responsible for groundwater quality deterioration. It is important to mention that groundwater contamination owing to toxic metal ions is the major problem because of the susceptibility of groundwater contamination by the toxic metal ions. Besides, the presence of the toxic metal ions in the groundwater is a serious health threat to human beings because the metal ions are toxic and, sometimes, carcinogenic too. During our research on water quality and water treatment, we realize that the shallow groundwater aquifers are being polluted owing to the toxic metal ions. Because of these facts, efforts are made to analyse the contamination of the toxic metal ions in the shallow groundwater aquifers. Besides, the attempts are made to discuss the future challenges and the management measures required. This article will be important to the academicians, researchers, industry persons and the regulatory authorities.

2. Groundwater in KSA

The main groundwater sources in Saudi Arabia are of two sorts. The first category is of the renewable groundwater in splintered Precambrian basement and low alluvial aquifers situated typically in the western and...
south-western parts of the nation. These are present in greater than 20 layers of main and secondary aquifers of dissimilar geology ages. The second types are deep non-renewable groundwater in aquifers situated typically in sedimentary covering swamping the Arabian shield – also called fossil water. The shallow alluvial aquifers are limited chiefly to the major Wadis. These are the main sources of water in the west part of Saudi Arabia. Nevertheless, these aquifers are subtle to man actions and the vicinity of the aquifers to chief cities and towns with a big population. Consequently, groundwater pollution is continuously an option in shallow alluvial aquifers in the neighbourhood of major cities [4]. The deep rock aquifers are sedimentary in nature, typically limestone and sandstone, spreading about thousands of km² with reduced normal recharge via upland and hill zones. The aquifers are present in carbonate or arenaceous constructions, with main formations of Tabuk, Saq and Wajid of Paleozoic age (250–542 million years ago), Biyadh-Wasia and Minjur-Dhurma of Mesozoic age (65–250 million years ago) and Dammam-Neogene and Umm Er Radhuma of the tertiary age (1.8–65 million years ago). Amongst these aquifers, Wajid, Saq, Minjur-Dhurma, Biyadh-Wasia, Tabuk and Dammam-Neogene and Umm Er Radhuma are identified to be the main aquifers [5]. The amount of water and the thicknesses are 600–258,400 MCM and 300–1200 m in these fossil water reservoirs. The area of these reservoirs ranged from 48,000–300,000 km². The estimated positions of these aquifers are given in Figure 1.

It is significant to comment here that water quantity in the shallow water reservoirs may change during the period because of the withdrawal of the groundwater. Besides, the recharge during the rainy season also changes the water budget of these reservoirs. According to the Ministry of Planning [5], the normal recharge of aquifers is about 1.28 BCM/year. On the other hand, about 394 MCM has withdrawn annually in KSA. Some aquifers displayed important drips in the water level. For instance, the piezometric level in Minjur decreased from 45.0 to 170.0 m below the surface between 1956 and 1980 [7]. An alike degeneration in water level was stated for the Wasia aquifer (MAW, 184). As per the Ministry of Planning and Water Atlas [5], the major water resources are given in Table 1. This Table describes the location, formation, depth, yield, water quality and reserves.

Of course, groundwater is the chief resource of water supply worldwide including KSA. It is unfortunate to mention here that the groundwater at some places of the world is contaminating during the last few decades; especially in shallow aquifers. The reason is geological and human activities. The various contaminants of organic and inorganic nature were reported in the groundwater at different places in the world. Among these, the toxic metal ions pollution is the most susceptible due to the close vicinity of the rocks with aquifers.
Table 1. Summary of major aquifers for groundwater in Saudi Arabia ([6], with permission).

| Aquifers            | Locations                                                                 | Formations                                                                 | Water quality                      | Yields                  | Depths                  | Reserves (BCM) a, b, c |
|---------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------------------|------------------------------------|-------------------------|-------------------------|------------------------|
| Wajid               | Spreads for a minimum 200 km beneath Rub Al-Khali. Visible for ~ 300 km from the south of Wadi Dawasir to the Wadi Habaunah and for about 100 km to the west | Fine to coarse-grained sandstone, Homogeneous, poorly cemented porous rocks | TDS less than 1000 ppm            | Wadi Dawasir: (10–100 L/s) Rub Al-Khali: (5–15 L/s) | Width 200–400 m         | 30, 50, 100            |
| Saq                 | Spreads from eastern part to 1200 km northward nearby the Jordanian borders | 10–30 km varied narrow band for 820 km from Haddar excluding the break at the Wadi Brik and Wadi Rimah. Spreads from Wadi Brik south to the Rub Al-Khali | Average to coarse-grained sandstone, Locally contain finer material | Tabuk: (9–228 L/s) Hail: (13–19 L/s) Qasim: (10–100 L/s) | Around 2000m; Width: 400–800 m | 65, 100, 200 |
| Minjur/Dhurma       | Spreads from eastern part to 1200 km northward nearby the Jordanian borders | Average to coarse-grained sandstone, Coarse quartzitic sandstone with thin layers of limestone, shale, conglomerate and gypsum | Moderately mineralized. TDS less than 1000 ppm | The normal potentiometric head dropped from 45 m below land surface in 1956–170 m in 1980 | Deepness: 1200–1500 m Thickness: Minjur: 310–400 m; Dhurma: 100–110 m | 17.5, 35, 85 |
| Tabuk               | Spreads south and west from the Jordanian border to south of Wadi Rimah | Marine to continental sequences of the cross and inter bedded sandstone, shale and siltstone | TDS: 500–600 ppm (Tabuk); 2500–4000 ppm (in north); 600–3500 ppm (east) | 5.6–15 L/s                | Width: About 1070 m    | 5.6, 5.6, 5.6          |
| Umm er Radhuma      | Spreads from Iraq border to Jordan border. 50–100 km wide, south for 1200 km to afar Wadi Dawasir | Formed in shallow sea. Light coloured, dense limestones, dolomitic limestones and dolomites | Salinity increases with depth. -TDS: 1200–15,000 ppm; 1000–5800 ppm (near Haddar) | 4–32 L/s | The deepness varies from 240–700 m | 16, 4, 75 |
|Wasia-Biyadh and Cretaceous sands Aquifers | Biyadh: from Wadi Dawasir to closely 650 km. Wasia: Nearly 1450 km from the Rub Al-Khali | Sandstone and shale | Severely mineralized | Dissolved solids: ∼ 150,000 ppm | The potentiometric varies 210–300 m | 120, 180, 290 |
| Dammam-Neogene      | The rock of Dammam aquifer spreads above most of northeast Saudi Arabia and Rub al Khali | Five sections: Midra Shale, Saila Shale, Alveolina Shale aquicludes, Khobar limestone and Atat limestone | - | - | Deepness: 80 m (Atal); 20 m (Khobar) | 5, 5, 5 |

(a: proven; b: probable; c: possible).
It is also important to mention that toxic metal ions pollution is a serious concern as the metal ions are toxic in nature. The groundwater in KSA at some places has also been found polluted due to the toxic metal ions.

3. Toxocities of the metal ions

The metal ions are vital constituents of living systems; yet, even important elements may have poisonous or cancer-causing features. The heavy metals found in the environment in dissimilar physico-chemical forms. Amongst them, merely hydrated metal ions are measured to be most poisonous, whereas robust complexes and species linked with colloidal particles are typically expected to be non-toxic. One of the most hazardous features of heavy metals is their accumulation in the animals; even when in the adjacent environment their amounts are relatively little, and over some time these amounts can reach hazardous levels. Among various metal ions, antimony, arsenic, chromium, lead, mercury, selenium, etc. are toxic. Though high amounts of other metal ions like copper, aluminium, platinum, vanadium, rhodium, zinc, etc. may be poisonous [8].

Aluminium is not toxic but a high concentration may produce coarse tremors, mental status deviations, speech disturbances, abnormal brain functioning and learning disabilities. Arsenic is recognized as the oldest toxins utilized by humans. The deadliness of the water-soluble arsenic species differs in arsenite [As(III)] > arsenate [As(V)] > monomethylarsonate (MMA) > dimethylarsinate (DMA) order. The outcomes of clinical conclusions for arsenic harming from arsenic contaminated water display the occurrence of nearly all the phases of arsenic clinical appearance [9]. Long time contact of arsenic contaminated water may create numerous illnesses such as hyperpigmentation, conjunctivitis, cardiovascular diseases, hyperkeratosis, nervous systems, disturbance in the peripheral vascular, leukomelanos, cancer of the skin and gangrene, non-pitting swelling, splenomegaly and hepatomegaly [10]; [11]. The marks on the uterus, lungs, genitourinary tract and additional portions of the body have been noticed in the progressive phase of arsenic poisonousness. Also, a high concentration of arsenic may outcome in the rise of spontaneous abortions and stillbirths [12]. The additional side effects of arsenic pollution are visual turbulences, fatigue, sensory turbulences, coma, loss of energy, convulsions, shock, blindness, muscles paralyzes, kidney damage, atrophy, etc.

Cadmium is considered to be a poisonous metal ion with vomiting and nausea at a high amount. It is a severe poisonous metal ion but not deadly. The kidneys are the serious goal of cadmium pollution. The syndromes related to the kidneys are renal hypertension, anaemia and dysfunction. The additional side effects of cadmium are irritability, restlessness, headache, increased salivation, choking, chest pain, diarrhea, abdominal pain, throat dryness, tenesmus, pneumonitis and cough. Trivalent chromium [Cr(III)] is important for animals and humans at trace amount; with a nontoxic and relative harmless dose of 0.20 mg/day while hexavalent chromium [Cr(VI)] is a strong poison and very poisonous to humans and animals. The chief tarnished effects of Cr(VI) are on respiratory organs, liver, kidney, haemorrhagic effects, skin ulceration and dermatitis for long-lasting and subcronic exposure. Lead is a significant poison among heavy metals with neurotoxic and toxicological natures that have brain damage. Inorganic lead naturally affects the peripheral nervous, renal, central nervous systems, haematopoietic, cardiovascular, reproductive and gastrointestinal systems. Organic lead poisonousness inclines to predominately affect the central nervous system. The inorganic mercury complexes are poisonous to the kidney creating renal and neurological disorders. The organic mercury complexes are poisonous to the central nervous system. Likewise, irritability, discouragement, learning incapacities, personality changes, jerky gait, muscle tremors, inflammation of mouth and gums, spasms of extremities, swelling of salivary glands, loosening of teeth and excessive flow of saliva are the dangerous effects of mercury harming.

4. Metal ions contamination in the groundwater

Generally, the toxic metal ions contamination to the groundwater is a worldwide problem because the geological rocks are in direct contact with aquifer water and the metal ions tend to dissolve in aquifer water. It is important to mention here that the metal ions behaviour in the groundwater is complex and connected to the water resource and the bio-geochemical procedure in the rocks. Some authors studied the water quality at different parts of KSA and these studies indicated that the groundwater of KSA is being contaminated by toxic metal ions. The metal ions found in the groundwater of KSA are Al, Ba, As, Cd, Cr, Co, Fe, Cu, Hg, Mn, Ni, Li, Se, Pb, V and Zn. The presence of the various metal ions in the groundwater of KSA is discussed in the following paragraphs.

There are some studies on the hydrochemical and general water quality in KSA, which are published in the scientific Journal but Khashogji et al., in 2012, defined the analysis of toxic metal ions in the groundwater of Abar Al Mashi and south Al-Madinah Al-Munawarah areas of Saudi Arabia. The authors collected 36 water samples from wells. The metal ions detected were As, Mn, Fe, Pb, Cd, Cu, Ni Cr, and Zn with concentrations ranges 0.001-0.01, 0.001-0.003, 0.01-0.037, 0.01-0.01, 0.001-0.003, 0.001-0.008, 0.001-0.07 0.001-0.125, and 0.011-0.335 mg/L. Later on, two studies were carried in south Al-Madinah Al-Munawarah city in 2013 by Maghraby et al. [13] and Sharim et al. [14]. Maghraby...
et al [13] carried out a quality evaluation of groundwater at the south of Al-Madinah Al-Munawarah area, Saudi Arabia. The authors selected about 20.0 km south to Madinah on Madinah-Mekka highway neighbouring to Wadi al Aqqiq as the study area and collected 29 water samples. The metal ions detected were As, Cd, Cu, Fe, Cr, Ni Mn, and Zn with concentrations of 1–2, 1–4, 2–8, 1–37, 1–146, 1–18, 1–39, and 22–475 µg/L. As per the authors, the concentrations of Pb, Mn, Ni, Cu, As and Zn were under permissible limits while Cd and Cr showed elevated concentrations. Sharim et al. [14] carried out water quality analysis in Al-Madinah Al-Munawarah by collecting 6 samples from the city wells. The concentrations of arsenic (12.0–29.0 µg/L), iron (320–589 µg/L) and manganese (159–210 mg/L) were higher than the permissible limit in some samples. On the other hand, the concentrations of chromium, copper, nickel, cadmium, barium, lead and zinc were under the permissible limit. In 2014, Bob et al. carried out a multi-objective evaluation of groundwater quality in Al-Madinah Al-Munawarah city of Saudi Arabia to study the groundwater quality by collecting 20 water samples. The concentration of iron and strontium were 0.015–4.580 and 0.04–7.86 mg/L. However, some metal ions like As, Cd, Cu, Cr and Se were present at trace levels. Later on, in 2016, Bamouo and El-Maghrawy carried out a quality valuation, and sources of contamination in Al-Madinah Al-Munawarah, Saudi Arabia. The authors collected 32 groundwater samples in Uhdh, Quba, Al Aqool areas and around the Prophet’s Holy Mosque area. The reported metal ions were Fe, Pb, Mn, Zn, Ni, Cu, Cr, Cd, Se, As, V, Hg, Al and Co with concentrations of 0.046–0.67, 0.0015–0.027, 0.011–0.48, 0.011–0.29, 0.001–0.18, 0.0023–0.0087, 0.011–0.11, 0.0014–0.083, 0.0001–0.017, 0.0001–0.045, 0.002–0.044, 0.0001–0.0007, 0.0001–0.11 and 0.0001–0.0014 mg/L. The authors reported normal concentrations of Fe, Cu, Mn, Se, Zn, Hg, Co and V metal ions in the water while the concentrations of Al, As, Cd, Pb, Ni, and Cr were shown to be high in some samples located in the southwestern area; as per WHO [15]. The authors reported this pollution due to human happenings in an industrial area in the south western parts of Madinah. Recently, in 2018 a study was carried out by Alghamdi et al., which described the hydrochemical and quality evaluation of groundwater sources in Al-Madinah Al-Munawarah city, Saudi Arabia by collecting 54 samples from the Hamra Alasad region. The authors reported the presence of Pb, As, Cd, Cu, Zn, Co, Ni, Mn, Fe and Cr metal ions with concentrations under the permissible limits. It is clear from these studies that several metal ions are present in the groundwater of Al-Madinah Al-Munawarah city of KSA. The amounts of these metal ions are varied from place to place. It is also significant to note that the concentrations of these metal ions changed year wise i.e. changed over time (2012–2018). The concentrations of some metal ions were higher than permissible limits while the concentrations of some metal ions were under permissible limits. Overall, it is concluded that the shallow aquifer in Al-Madinah Al-Munawarah city of KSA is contaminating due to the toxic metal ions.

Aly et al., in 2013, reported a hydro-chemical and water quality assessment in Riyadh and Al-Ahsa regions by collecting a total of 62 samples. The authors reported Co, Cd, Cu, Cr, Mn, Fe, Pb Ni, and Zn with concentration ranges of 0.01–2.0 mg/L. Al-Omran et al. (2015) carried out water quality valuation and presented a water quality index in the city of Riyadh, Saudi Arabia. The authors collected 180 water samples from five zones of Riyadh governorate i.e. Riyadh main zone, Bidadah, Nassim, Shifa, and Ulia zones. The metal ions reported were Fe, Mn, Zn, Cu, Al, Cr and Pb with concentrations of 0.01–0.13, 0.01–0.02, 0.01–0.24, 0.01–0.11, 0.01–0.10, 0.01–0.02 and 0.01–0.12 mg/L. The authors reported that all these toxic metal ions were within safe limits.

Rehman and Cheema [16] reported the presence of Li, Cr, Al, Fe, Mn, Ba, Ni, Pb and Hg metal ion in groundwater at a sewage waste disposal facility near Jeddah, Saudi Arabia. The authors collected 19 total samples in the Wadi Bani Malik area, Jeddah, Saudi Arabia. The concentrations of Al, Li, Mn, Cr, Ni, Fe, Ba, Pb and Hg were 10–560, 20–100, 20–3480, 10–70, 10–20, 10–910, 20–320, 10–50 and 10–430 µg/L. Hassan et al. [17] studied the effect of dumping of waste and sewage on groundwater quality of Wadi Bani Malik, located in Jed- dah city of Saudi Arabia. The study area was Wadi Bani Malik, east of Jeddah in the upstream of the mountainous range covering 519 square kilometres of alluvial (unconfined) aquifer area. The total samples collected were 20 in number. The authors reported As, Ba and Li with 98–964, 18–377 and 94–1815 µg/L concentrations. These are high concentrations of the reported metal ions. Furthermore, the authors stated a requirement of widespread valuation and workable managing of the groundwater.

Abdullah et al. [18] carried out one study for arsenic contamination and hydro-geochemical parameters in 27 bore-holes in the aquifers in Al-Khajir geothermal fields, Saudi Arabia. Arsenic concentration was 122 µg/L. Abdel-Satar et al. [19] carried out the groundwater quality valuation in the Hail region, Saudi Arabia. The authors collected 60 samples from numerous sites within the Hail area. Most of the samples were from private and farming wells. The authors analysed toxic metal ions along with other parameters. The reported meal ions were Fe, Cu, Zn and Pb with maximum concentrations of 1544, 128, 331 and 26 µg/L. As per the authors, the amounts of Cu and Zn in groundwater were in the permissible range of SASO standards of drinking water while groundwater was found to be commonly polluted by Fe and Pb. Al-Hasawi et al. [20] described the groundwater quality for agricultural and drinking purposes in seven districts, Rabigh governorate, Saudi Arabia by collecting
Table 2. Toxic metal ions present in the groundwater, KSA.

| Study Area         | Metal ions | Concentrations (mg/L)           | Source of water | Refs. |
|--------------------|------------|----------------------------------|----------------|-------|
| Al-Madinah Al-Munawarah | As, Fe, Mn, Pb, Cu, Cd, Cr, Ni & Zn | 0.001-0.01, 0.01-0.037, 0.01-0.003, 0.01-0.01, 0.01-0.008, 0.01-0.003, 0.001-0.125, 0.001-0.07 & 0.001-0.335 mg/L | 36 Water samples | [17] |
| Al-Madinah Al-Munawarah | As, Cu, Cd, Cr, Fe, Mn, Ni & Zn | 1-2, 2-8, 1-4, 1-146, 1-37, 1-39, 1-18 & 22-475 µg/L | 29 Water samples | [9]  |
| Al-Madinah Al-Munawarah | Fe & Sr | 0.015-4.580 & 0.04-7.86 mg/L | 8 Water samples | [13] |
| Al-Madinah Al-Munawarah | Fe, Mn, Pb, Ni, Zn, Cu, Cd, Cr, As, Se, Hg, V, Co & Al | 0.046-0.67, 0.011-0.48, 0.0015-0.027, 0.001-0.18, 0.0011-0.29, 0.0023-0.0087, 0.00004-0.083, 0.011-0.11, 0.0001-0.045, 0.00001-0.017, 0.0001-0.0007, 0.002-0.044, 0.0001-0.0014 & 0.0001-0.011 mg/L | 32 Water samples | [7]  |
| Riyadh              | Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb & Zn | 0.01-2.0 mg/L | 62 Water samples | [5]  |
| Riyadh              | Fe, Mn, Zn, Cu, Al, Cr & Pb | 0.01-0.13, 0.01-0.02, 0.01-0.24, 0.01-0.11, 0.01-0.10, 0.01-0.02 & 0.01-0.12 mg/L | 180 Water samples | [12] |
| Jeddah              | Li, Al, Cr, Mn, Fe, Ni, Hg & Pb | 20-100, 10-560, 10-70, 20-3480, 10-910, 10-20, 20-320, 10-430 & 10-50 µg/L | 19 Water samples | [23] |
| Al-Kharj            | As, Ba & Li | 98-964, 18-377 & 94-1815 µg/L | 20 Water samples | [24] |
| Hail                | As | 122 µg/L | 27 Water samples | [21] |
| Rabigh              | Fe, Cu, Zn & Pb | 1544, 128, 331 & 26 µg/L | 60 Water samples | [10] |
| Taif                | Cu & Pb | 0.02-0.04, 33.61-1611.82, 0.0003-0.012, 0.001-0.005, 0.001-0.088 & 0.0149-0.0899 mg/L | 49 Water samples | [25] |

49 water samples. The authors reported Fe, Cu, Zn, Al, Mn, and Ba metal ions with concentrations 0.02–0.04, 33.61–1611.82, 0.0003–0.012, 0.001–0.005, 0.001–0.088 and 0.0149–0.0899 mg/L. Qari [21] described heavy metal contamination in the water of the open well in the Taif Region, Saudi Arabia. The ported metal ions were Cu and Pb with 0.10 and 0.11 mg/L concentrations. The metal ions present in the groundwater in KSA are summarized in Table 2.

It is clear from the above study that no systematic analysis of toxic metal ions was carried out in the groundwater of KSA. These are some random studies covering a few areas of KSA. All these studies do not cover all the groundwater aquifers in the country. However, the results of these studies reflect that groundwater in KSA is being contaminated by toxic metal ions. There is a need to plan to carry out an exhaustive study of the groundwater quality in all the groundwater aquifers of the country. During the study of toxic metal ion analysis, the complete water quality should be determined and a data-based should be made ready for further action.

5. Sources of metal ions contamination

Numerous studies have been carried to find out the sources of groundwater pollution with an emphasis on the degree of the contamination, pollution release rates and amount concerning the function of time [27]. It was observed that the main sources of groundwater contamination are natural and man-made activities. The former is the geological activities while the latter includes domestic, industrial and agricultural activities [28]. Generally, solid and liquid wastes are supposed to be responsible for groundwater contamination [29]. Generally, the quality of the groundwater reservoir depends on the geological construction of the strata, size of the aquifer and the geological activities. The deviation in the regional and local geology, aquifers dilution, water-rock interactions are also contributing to the groundwater quality [30]. Besides, the metrological factors and man-made activities also affect the quality of the groundwater. Generally, metal ions get dissolve in the aquifers over time [25]. The human activities responsible for groundwater contamination are mining, agriculture, smelting, fuels and industrial waste disposal [23]. Once the metal ions dissolved in the aquifer these are controlled by several factors such as metal concentration, metal ions oxidation sates, pH of water, temperature, organic carbon amount, cation exchange capability and the redox potential of the whole system. Some studies associated with the water sources contamination are discussed herein.

Anthropogenic action is the key way of inflowing copper into water frames by the domestic and industrial wastes, mining and mineral leaching and metal plating [25]. The common causes of lead pollution in the groundwater may be from agricultural run-off and household sewages, comprising animal and human excreta, phosphate fertilizers and pesticides [31]. Zinc is present in the groundwater in areas where mining is going on and also from industrial wastes; it is assumed as the main component of sludge [26]. Bagousa and El Maghraby et al. described numerous trace component resources in the groundwater of Madinah due to dissolution and leaching processes from rigorous fertilizer utilization for agricultural purposes. Furthermore, the authors reported that several dyes, paints, tannery, etc. manufacturers and car workshops were disposing badly of planned landfills. The wastewater is over-laden with raised amounts of trace constituents, which are the main sources of groundwater pollution. Abdullah et al. [18] used principal component analysis (PCA) to find out the sources of arsenic contamination in the groundwater of Al-Kharj geothermal fields, Saudi Arabia. According to PCA, the local geothermal systems with weathering of minerals are responsible for arsenic contamination. Besides, the authors
described reducing iron oxyhydroxides dissolution as a probable mechanism. The authors also reported that the secondary mechanism of arsenic mobility may be active and correlated with total organic carbon. Abdel-Satar et al. [19] described a relationship among various metal ions to predict the sources of pollution in the Hail region, Saudi Arabia. A close relationship \( (n = 39; p < 0.01) \) between the couples Cu/Pb \( (r = 0.79) \), Zn/Pb \( (r = 0.57) \) and Zn/Cu \( (r = 0.47) \) in Hail groundwater stated a possible common source of the metal ions. In many studies, it was observed that the excessive withdrawal of groundwater is responsible for groundwater contamination. Generally, atmospheric air enters into the aquifers by the excessive withdrawal of groundwater and the oxygen present in the air oxidized the rocks; leading to metal ions dissolution into the groundwater. Such types of studies are not carried out in KSA but this reason for metal ions contamination into groundwater aquifers may not be denied in KSA. To make the contamination concept clear a flow chart of pollution sources is shown in Figure 2.

Figure 2. A flow chart of groundwater pollution sources.

6. Future challenges and remediation

It is clear from above the discussed studies that groundwater contamination by the toxic metal ions in KSA is going to be continued. There may be a problem in the future due to the toxic nature of the metal ion in the groundwater. The main problems will be for humans, animals and agriculture and horticulture plants. The rigorous use of fertilizers, inadequate well construction, uncontrolled irrigation, industrialization and urbanization are causing groundwater quality degradation. As stated above, excess withdrawal of groundwater is a major problem since every year water demand is increasing due to 2.5% increase in the population annually. In this way, there may be a problem in the coming years. It is important to mention here that; augmented from 260 to 325 MCM in 2004–2009 [32]; water sources in Saudi Arabia are limited. These sources are related to improbability and can be affected by climatic alteration in the future [33]. The low rain-fall is a major drawback in this area and the chances of groundwater recharge are poor. Therefore, there is a great need for conserving groundwater quality.

The groundwater contamination may be controlled by several conservation measures steps such as the proper functioning of agriculture, industrial and municipal sectors. Besides, improving irrigation efficiency, decreasing demand for water, observing and keeping groundwater resources, and supply increase via desalination are required to conserve groundwater resources in KSA. The water bore should be constructed at appropriate places for groundwater recharge; when rain has
occurred. Even a single drop of rain-water should not be wasted; rather should be used to recharge the groundwater aquifers. The awareness of the groundwater importance among the public should be created. This may be achieved by organizing scientific conferences and public meetings. Another attractive way of awareness is advertisements on national television programmes.

7. Conclusion
KSA is the biggest country in the Arabian Peninsula with around 2.15 million km² area. It is situated in the arid desert and always has a problem for a good quality of water. About 80% water is achieved from shallow aquifer groundwater, but unfortunately, groundwater is being contaminated by the toxic metal ions. During the write up of this article, it was perceived that As, Al, Cd, Ba, Cr, Co, Fe, Cu, Li, Hg, Ni, Mn, Se, Pb, V and Zn are the metal ions present in the groundwater of KSA. The concentrations of these metal ions ranged from under limit to up limit of WHO recommendation for drinking water. Therefore, it was concluded the situation of groundwater contamination may be alarming in the coming years. It is because of the rapid industrialization and urbanization in this country. It was also observed that the metal ions contamination is limited to shallow aquifers only while the deeper aquifers are safe. Besides, it is important to emphasize here that only a few and scattered studies are available on the metal ions analysis in the groundwater. Therefore, there is a need to carry out a systematic and exhaustive study of the toxic metal ions analysis in the groundwater of the country. In this article, the efforts are made to describe the groundwater in KSA, toxicities of the metal ions, metal ions contamination in the groundwater, sources of metal ions contamination and the future challenges and the remediation measures needed to protect groundwater resources. Certainly, this article will be important to the academicians, researchers, industry persons and the regulatory authorities.

Acknowledgment
The authors thankfully acknowledge the Deanship of Scientific Research, King Khalid University, Abha, for providing administrative and financial supports. Funding for this work has been provided by the Deanship of Scientific Research, KKU, Abha, Kingdom of Saudi Arabia, under research grant award number R.G.P2/85/41.

Disclosure statement
No potential conflict of interest was reported by the author(s).

References
[1] FAO (Food and Agriculture Organization). Irrigation in the Middle East region in figures. Food and Agriculture Organization of the United Nations. FAO Water Reports 34, Rome; 2009.
[2] World Bank. Average precipitation in depth (data) Available at < http://data.worldbank.org/indicator/AG.LND.PRCP.MM >. (accessed 20/2/2015); 2015.
[3] Abderrahman WA, Rasheeduddin M, Al-Harazin IM, et al. Impacts of management practices on groundwater conditions in Eastern Province, Saudi Arabia. Hydrogeol J. 1995;3:32–41.
[4] Al-Shaibani AM. Hydrogeology and hydrochemistry of a shallow alluvial aquifer, western Saudi Arabia. Hydrogeol J. 2008;16:155–165.
[5] MOP (Ministry of Planning). Fourth Development Plan: 1985-1990. MOP, Riyadh.; FAO (Food and Agriculture Organization), 1998. Proceedings of the Second Expert Consultation on National Water Policy Reform in the Near East, Cairo, Egypt, 24–25 November 1997; 1985.
[6] Shakhawat C, Muhammad A. Characterizing water resources and trends of sector wise water consumptions in Saudi Arabia. J King Saud Univ Eng Sci. 2015;27:68–82.
[7] MAW (Ministry of Agriculture and Water). Census of agriculture according to farm size, 1981–82. MAW, Riyadh; 1982.
[8] Ali I, Aboul-Enein HY. Instrumental methods in metal ions speciation: Chromatography, Capillary Electrophoresis, and Electrochemistry. New York: Taylor & Francis Ltd; 2006.
[9] Hotta N. Clinic aspects of chronic arsenic poisoning due to environmental and occupational pollution in and around a small refining spot. Jpn. J. Const. Med. 1989;53:49–70.
[10] Pershagen G. The Epidemiology of human arsenic exposure, Fowler BA (Ed), Elsevier, Amsterdam; 1983.
[11] Yamamura Y, Yamauchi H. Arsenic metabolites in hairs, blood and urine in workers exposed to arsenic trioxide. Ind Health. 1980;18:203–210.
[12] Csanady M, Straub I. Health damage due to pollution in Hungary, Proceedings of the Rome symposium, September, 1994, IAHS Publ No 233; 1995.
[13] Magdy MS, El M, Ahmad KO, et al. Quality assessment of groundwater at south Al Madinah Al Munawarah area, Saudi Arabia. Env Earth Sci. 2013;70:1525–1538.
[14] Shraim AM, Alsuhaimi AO, Al-Muzaini KO, et al. Quality assessment of groundwater of Almadinah Almunawarah city. Glob NEST J. 2013;15:374–383.
[15] WHO (World Health Organization). Guidelines for drin king-water quality. 4th ed, Geneva 541; 2011.
[16] Rehman F, Cheema T. Boron contamination in groundwater at a sewage waste disposal facility near Jeddah, Saudi Arabia. Env Earth Sci. 2017;76:218.
[17] Hassan M, Saleem AMS, Amro E. Environmental Impacts on groundwater of Wadi Bani Malik, Jeddah, Saudi Arabia. Intl J Sci Eng Res. 2017;8:1658–1662.
[18] Abdullah SA, Mohammed IA, Mohamed HE, et al. Evaluation of groundwater for arsenic contamination using hydrogeochemical properties and multivariate statistical methods in Saudi Arabia. J Chem. 2013;2103:812365.
[19] Abdul-Satar AM, Al-Khabbas MH, Alahmad WR, et al. Quality assessment of groundwater and agricultural soil in Hail region, Saudi Arabia. Egypt J Aqua Res. 2017;43:55–64.
[20] Al-Hasawi Z, Al-Wesabi E, Al-Harbi H, et al. Assessment of groundwater quality for drinking and agricultural purpose in seven districts, Rabigh governorate, Saudi Arabia. J Biosci Appl Res. 2018;4:184–192.
[21] Qari HA. Microbial pathogens and heavy metal contaminations in the open wells water in Taif region, Saudi Arabia. Biomed Pharmacol J. 2018;11:1449–1456.

[22] Huda AQ. Microbial Pathogens and heavy metal Contaminations in the open wells water in Taif region, Saudi Arabia. Biomed Pharmacol J. 2018;11:1449–1456.

[23] Musa OK, Shaibu MM, Kudamnya EA. Heavy metal concentration in groundwater around Obajana and its environs, Kogi State, North Central Nigeria. Am Int J Contemp Res. 2013;3(8):170–177.

[24] Mustafa B, Norhan AR, Saud T, et al. Multi-objective assessment of groundwater quality in Madinah city, Saudi Arabia. Water Qual Expo Health. 2014;7:53–66.

[25] Reddy TB, Ramana CV, Bhaskar C, et al. Assessment of heavy metal study on groundwater in and around Kapuluppada MSW site, Visakhapatnam. AP IJSN. 2012a; 3(2):468–471.

[26] Reddy TB, Ramana CV, Bhaskar C, et al. Assessment of heavy metal study on groundwater in and around Kapuluppada MSW site, Visakhapatnam. AP Intl J Sci Nat. 2012b;3:468–471.

[27] Domenico P, Franklin A, Schwartz W. Physical and chemical hydrogeology. 2nd ed. Chichester: Wiley; 1997.

[28] Taha AA, El-Mahmoudi AS, El-Haddad IM. Pollution sources and related environmental impacts in the new communities southeast Nile Delta, Egypt. Emir J Eng Res. 2004;9(1):35–49.

[29] Ellen M, Akpofure ET. Land-use impacts on the quality of groundwater in Bulawayo. Water SA. 2004;30(4):453–464.

[30] Zaidi FK, Nazzal Y, Jafri MK, et al. Reverse ion exchange as a major process controlling the groundwater chemistry in an arid environment: a case study from northwestern Saudi Arabia. Environ Monit Assess. 2015;187:607.

[31] Sirajudeen J, Abdul Jameel A. Studies on heavy metal pollution of groundwater sources between Tamilnadu and Pondicherry India. J Ecotoxicol Environ Monit. 2006;6:443–446.

[32] MOEP (The Ministry of Economy and Planning). The Ninth Development Plan (2010–2014). The Kingdom of Saudi Arabia; 2010.

[33] Chowdhury S, Al-Zahrani M. Implications of climate change on water resources in Saudi Arabia. Arabian J Sci Eng. 2013;38:1959–1971.