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Investigation of the Physico-Chemical Standards of the Ground Waters around Mai-Bella Area in Asmara

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Abstract

There are many possible sources of ground water contamination and may include wastes from industrial chemical production, domestic wastewater and pesticide run off from agricultural lands. The groundwater is thus susceptible to chemical, physical and/or microbiological contamination and ultimately becomes a cause for diverse diseases borne from the contaminated water. It has been a common practice to cultivate vegetables, crops and animal feed grasses around Asmara using sewage and industrial effluents and there are likelihoods that contaminants in the wastewater used for irrigation would infiltrate to the nearby wells. It is believed that the groundwater around the wastewater irrigated area is not safe for domestic and agricultural applications. Thus, this study was conducted to evaluate the quality of the groundwater in order to safeguard the public health treats caused by using this water. Samples were collected from five locations around Mai-Bella and thus different physico-chemical parameters were investigated. The pH of the samples was measured by pH metric method; electrical conductivity (EC) and salinity by using conductometric method. Hardness was estimated by EDTA method; total alkalinity (TA) and bicarbonate concentrations by titrimetric methods. Chloride concentration was analyzed by titration against mercurial nitrate. Na and K were determined using flame photometric method. Fe, Mn, nitrate, nitrite, sulphates and ammonia were determined using spectrophotometric method. Chemical Oxygen Demand (COD) was determined using photometric method. Moreover, the concentrations of trace, major and heavy metals were analysed using Inductively Coupled Plasma Optical Emission Spectrophotometer (ICP-OES). The suitability of the groundwater for domestic and irrigation purposes was examined using WHO and FAO standards. Most of the physico-chemical parameters, except the temperature, pH, COD, Al, Cd, Cr, Cu and Zn, of the samples were found above the standard limits given by WHO. Similarly, the levels of toxic metals (Pb, As, Hg and Se) in all the water sources and Ni from two water sources were found above the permissible limit. Accordingly, the results signpost that most of the groundwater samples from the study sites are not suitable for drinking and irrigation purposes. Further studies related to the bacterial load would be appropriate to assess the health effects of all the water sources found around Mai-Bella.

Keywords

Mai-Bella, Groundwater, Physico-Chemical, Heavy Metals

1. Introduction

Rapid urbanization and industrialization with improper environmental planning often lead to discharge of industrial and sewage effluents into water bodies (Priyanka et al., 2017; Kumar et al., 2015). Groundwater is used for domestic and industrial water supply and also for irrigation purposes all over the world. In the last few decades, there has been a tremendous increase in the demand for fresh water due to rapid growth of population and the accelerated pace of industrialization. However, groundwater could be chemically, physically or microbiologically contaminated. According to WHO, about 80% of all the diseases in human beings are caused by water (Devendra et al., 2014). Ground water contamination is nearly always the result of human activity. There are many possible sources of chemical contamination which include wastes from industrial chemical production, metal plating operations, domestic wastewater and pesticide runoff from agricultural lands. Application of sewage water and sludge to agricultural soil is a common practice due to easy availability in peri-urban ecosystem, thus heavy metal transfer is rapid in soil profiles and they can pollute ground water supplies also. Movement of heavy metal to ground water is higher where sewage waste is disposed on sandy, acidic and low organic matter soils, receiving high rainfall or irrigation water (Adhena et al., 2015; Kumar et al., 2015). It is known that wastewater, depending on its source, contains dissolved salts, organic matter, oil, grease, detergents and many types of metals including toxic heavy metals (Alnos & Ashraf, 2010).

Asmara, the capital city of Eritrea, has a large number of textile industries, and thus various industrial sectors dispose their effluent directly to the natural drainage known as Mai-Bella and become a serious threat to water supply sources located along the banks of the stream. It has been a common practice to cultivate vegetables, crops and animal feed grasses around Asmara using sewage and industrial effluents and there are likelihoods that contaminants in the wastewater used for irrigation would infiltrate to the nearby wells used for drinking and other activities (Anghesom et al., 2017). It is believed that the groundwater wells are contaminated with inorganic and organic pollutants (Mihretab & Taibao, 2018). The use of pesticides and fertilizers in growing the wastewater irrigated vegetation is also frequent. Though the amount of contaminants in wastewater discharges are comparatively low, long-term watering of land with such wastewater can finally cause contaminant build-up in the soil and thus there is probability of leaching of contaminants to ground water depending on the type, pH and organic content of the soil (Kumar et al., 2015). Moreover, large tank trucker's usually transport and sell water from the ground water wells around the wastewater irrigated areas to the people in and around Asmara. The people use this water for drinking, washing their closes, quenching their domestic and pet animals as well as for small scale home gardening and thus ground water sources around Mai-Bella are serious threats of water borne diseases. Therefore there is a need for continuous monitoring of the pollutants load in these ground waters so as to safeguard the public health problems that may arise from using this water. However, there has been no published document to assess the effect of wastewater irrigation on groundwater contamination in that area. Therefore, this preliminary investigation aims to see the effect of wastewater seepage on the physico-chemical properties of groundwater around Mai-Bella area to predict its suitability and acceptability for agricultural, industrial and domestic usages. The findings of this study would also be used as a base line information for further studies, and will motivate the Ministry of Land, Water and Environment to draw basic recommendations related to the ground water sources around Mai-Bella.

2. Materials and Methods

2.1. Study Area

The water samples were collected from five wells located around Mai-Bella. As shown in **Figure 1**, four of the wells (MB1, MB2, MB4 and MB5) are located in wastewater irrigated agricultural areas and the fifth one (MB3) is located 115 meters from the stream closer to the residential areas within the wastewater irrigated agricultural area. The water sources represent different distances from the flow of the Mai-Bella River. The locations, GPS, altitude, distance of the samples from the direction of flow of the river are displayed in **Table 1**.

2.2. Sample Collection

The ground water samples from each site were collected using polyethylene bottles with necessary care. The bottles were thoroughly washed with detergent, distilled water and finally rinsed with nitric acid and made ready for sampling. For Physico-chemical analysis, groundwater samples were collected in polyethylene containers of one litters capacity and after pumping out sufficient quantity of water from the source the sample collected served as a representative sample. For the heavy metal analysis, each water sample was acidified by adding concentrated HNO_3 (1 ml of conc. HNO_3 per 100 ml water sample). The acid treated water samples were then placed in refrigerator at 4˚C.

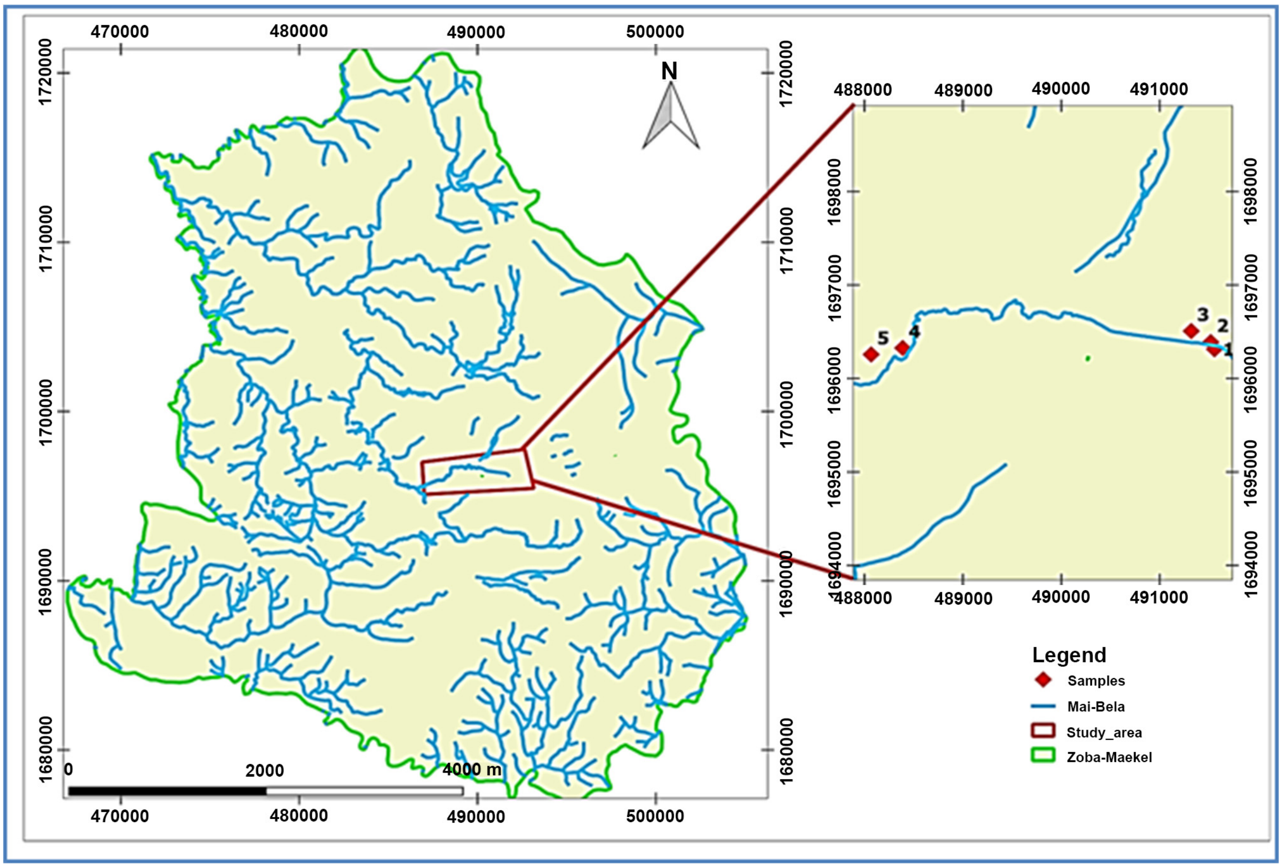

Figure 1. Geographical locations of the samples collected.

Table 1. Locations of the water sources around Mai-Bella area.

Sample Code	Place	GPS Location (Easting)	GPS Location (Northing)	Altitude (m)	Distance from the flow (m)
MB1	Vilajo	37P0491554	1696312	2291	27
MB2	Vilajo	37P0491517	1696389	2290	33
MB3	Paradiso	37P0491318	1696507	2297	115
MB4	Adi-Segdo	37P0488387	1696326	2306	64
MB5	Para-Duba	37P0488067	1696257	2308	200

MB refers to Mai-Bella.

2.3. Water Quality Analysis

The water samples were analysed adopting standard methods in the Environmental Laboratory, Department of Land and Water, Ministry of Land Water and Environment, Asmara. All the chemicals and standards used during preparation and analysis were of the highest purity analytical grade available. De-ionized water was used throughout the analysis wherever applicable. pH was measured by pH metric method; electrical conductivity and salinity were determined by using conductometric method. Hardness estimations were carried out by EDTA method; total alkalinity (TA) and bicarbonate concentrations were estimated by titrimetric methods using phenolphthalein and methyl orange as indicator and sulphuric acid as a titrant. Chloride concentration was analyzed by titration against mercurial nitrate.

To measure total dissolved solid (TDS), the filtered samples were initially weighed and then evaporated in a hot oven at 180˚C ± 2˚C. After the whole sample was evaporated, the evaporated dish was cooled and the final weight was measured and computed with the initial weight measured. Sodium and potassium were determined by flame photometric method. Iron, manganese, nitrate, nitrite, sulphates and ammonia, were determined by spectrophotometric method. Chemical Oxygen Demand (COD) was determined by using photometric method. Each analysis was carried out in triplicate and then the mean value was taken. The overall data were subjected to basic statistical parameters.

2.4. Heavy Metal Analysis

Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) was used for measuring the concentration of trace and heavy metals.

2.4.1. Chemicals and Reagents

Analytical grade chemicals and reagents were purchased from Sigma-Aldrich Company. Nitric acid (65% HNO_3) and Hydrochloric acid (32% HCl) were used for digestion purposes. Ultrapure-deionized water (18Ω) was used throughout the study. The glassware was soaked in HNO_3 (3M) for the whole night and washed and rinsed with deionized water to minimize the chances of interferences. All the chemical analyses were conducted under extractor hood and a digital IR Vortex Mixer (S/N296058 made in Italy) was used for mixing of the solutions.

2.4.2. Instrumental Analysis

A dual viewing ICP-OES (Perkin Elmer Optima 8300, made in Singapore) coupled to an ultrasonic nebulizer CETAC 6000AT + (CETAC, Omaha, NE, USA) was employed for the analysis of the trace and other elements. The Windows 7 compatible S/W provided by Perkin Elmer was used to process the spectral data for calculating sample concentrations by comparing light intensities measured at various wavelengths for standard solutions with intensities from the sample solutions.

3. Results and Discussion

Water possesses a range of particular physico-chemical properties which are of fundamental relevance for the matter and energy budgets of our ecosystems. Therefore, any factor that affects the standard of the physico-chemical parameters of water will affect the quality of the water. Therefore, to assess the quality of water some standard physico-chemical parameters recommended by the WHO are used (WHO, 2004). Comparisons on the levels of EC, TDS, TH, TA and major elements are shown in **Figure 2** and **Figure 3**.

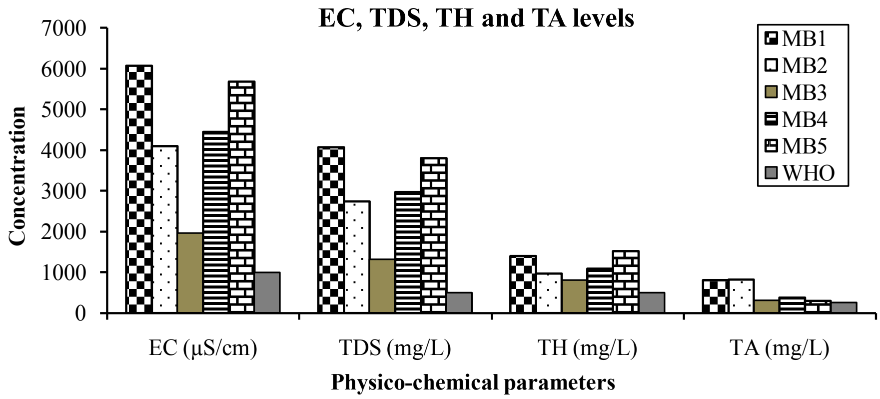

Figure 2. Comparison of the levels of EC, TDS, TH and TA with the WHO standard.

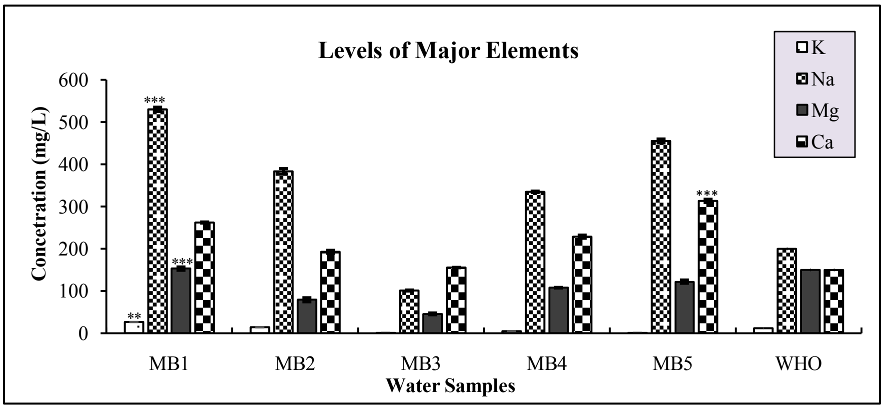

Figure 3. Comparison of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} concentration levels with WHO standard for various water samples. NB: The levels of K ($P < 0.01$), Na ($P < 0.001$), Mg ($P < 0.001$) and Ca ($P < 0.001$) were significantly different among the different water sources around Mai-Bella.

3.1. pH

The values obtained varied from 7.21 to 7.93 with a range of 0.72. A range of 0.72 indicated that the wastewater had not affected the acidity/bascity of the groundwater (Parvez et al., 2013). The pH values are also within the recommended limits (6.50 - 8.50) given by WHO (WHO, 2004) for drinking water. Although the values indicate that the groundwater samples are slightly basic, it is in agreement with what was reported by (Devendra et al., 2014) and slightly higher than those reported by (Kumar et al., 2015) and similar with those reported by (Vinod et al., 2012) in similar studies. The measurement of alkalinity or acidity of pH is required to determine the corrosiveness of the water (Janardhana et al., 2013).

3.2. Temperature

Temperature is basically important for the chemical and biological reactions of organisms in water. The temperature of the samples lies between 19.20˚C and 24.10˚C. The values reported in this work are within the range recommended by

WHO (25˚C) but the slight difference in the range can be due to the location of the wells and time of measurement (Okweye, 2013).

3.3. Electrical Conductivity (EC)

Electrical Conductivity for the ground water samples ranged from 1964.00 - 6070.00 μS/cm. The most desirable limit of EC in drinking water is prescribed as 1000 μS/cm by WHO. EC of the sample of MB3 is lower than the other sample sites, maybe because of the treatment of water well by the people living near that study site. The EC values of the other samples are far higher than the permissible limit proposed by WHO. Significantly, the EC values of samples from area codes MB1 and MB5 are greater than the others. This trend has been supported by the total dissolved salts (TDS) values. The source of EC may be due to an abundance of dissolved salts due to poor irrigation management, minerals from rain water runoff and municipal discharges (Sankpal & Naikwade, 2012). The EC values in this study are much higher than those reported by (Vinod et al., 2012) in similar studies which ranged from 556 to 977 μS/cm. High electrical conductivity affects the germination of crops and it may result in much reduced yield (Janardhana et al., 2013).

3.4. Total Dissolved Solid (TDS)

The TDS values of the water samples varied from 1315.88 to 4066.90 mg/L, which exceed the maximum permissible limits of WHO (500 mg/L) value prescribed for drinking purpose. The results are supported by findings of (Parvez et al., 2013) who reported that 100% wastewater irrigation contaminated the groundwater as compared to canal water irrigation. The presence of excessive solids in water may be due to intensive agricultural activities and discharged domestic wastewater from the capital city of Asmara and geological parameters. Kumar et al. (2015) and Vinod et al. (2012) reported TDS values ranged from 407 to 1948 mg/L and 226 to 321 mg/L respectively. The quality of ground water varies from place to place, from season to season, with the depth of water table, and is primarily governed by the extent and composition of dissolved solids present in it (Vinod et al., 2012). Excessive soluble solid materials or solutes in water indicate pollution which can lead to a laxative effect (Bhatia, 2010).

3.5. Total Hardness (TH)

Hardness is the property of water which prevents the lather formation with soap and increases the boiling points of water. Hardness although have no health effects it can make water unsuitable for domestic and industrial use (Janardhana et al., 2013). The total hardness values which ranged from 800.00 to 1520.00 mg/L are higher than the permissible limit of WHO (500 mg/L). This trend indicates that the water from all the sites is unsuitable for drinking purpose. The TH values in this study are higher than those reported by (Kumar et al., 2015) in similar studies which ranged from 234 to 1030 mg/L. High concentration of calcium above the permissible value may lead to the precipitation and hyper absorption of oxalates to the blood stream in human and cause renal kidney stone accumulation and also create heart diseases (Suresh et al., 2016).

3.6. Total Alkalinity (TA)

Alkalinity value in water provides an idea of natural salts present in water (Janardhana et al., 2013). Alkalinity is a measure of the buffering capacity of the water, and since pH has a direct effect on organisms as well as an indirect effect on the toxicity of certain other pollutants in the water, the buffering capacity is important to water quality. Commonly occurring materials in water that increase alkalinity are carbonates, bicarbonates, phosphates and hydroxides (Gorde & Jadhav, 2013). The total alkalinity of water samples were found in the range of 296.00 to 828.00 mg/L. In all the samples, the alkalinity exceeded the permissible limit set by WHO (250 mg/L). The alkalinity, of the water samples of MB1 and MB2, is higher than the other samples. In a similar study, higher TA values than the accepted values were reported by Soni et al. (2013). High alkalinity in water bodies leads to sour taste and salinity. The high level of TA may be due to the soil background, waste discharge in to the drainage and microbial decomposition of organic matter in the ground water.

3.7. Salinity

The salinity values obtained (ranged from 0.80‰ to 3.30‰) exceeded the WHO permissible limit (0.5‰). The increased level of salinity may be due to pollution caused by industrial waste and discharge of domestic sewage containing a large amount of chlorides. The higher salinity in all the water samples is also supported by higher TDS, TA and Cl^- ion values. High salinity content in water bodies harms metallic pipes and structure as well as agricultural crops (Suresh et al., 1992).

3.8. Calcium and Magnesium

Calcium and magnesium are among the most common constituents present in natural water and their salts are important contributors to the hardness of water. In this study, calcium and magnesium contents (in mg/L) ranged from 140.80 - 355.20 and 55.68 - 151.68 respectively. The Ca and Mg values in this study are similar with those reported by (Kumar et al., 2015) in similar studies. The recorded value for calcium, except the sample MB3, is higher than the permissible limit of WHO and magnesium concentrations, except the sample from MB5, lie within the approved limits of WHO (150 mg/L for each) and MB5 displayed the highest level of Ca and Mg. The levels of Mg and Ca were significantly different ($P < 0.001$) among the different water sources around Mai-Bella. Higher values for calcium are related to sewage and weathering of calcium rich rocks or cementing materials (Gebreyohannes et al., 2015).

3.9. Sodium and Potassium

Sodium and potassium concentration lied in the range of 79.12 - 737.15 mg/L and 7.90 - 22.40 mg/L respectively. All the samples have high amount of sodium and potassium which exceeded the permissible limit of WHO (200 mg/L and 12 mg/L respectively), except sample MB3. Especially for sodium, the results have a very wide range of concentration among the lowest and highest values obtained, may be due to the poor groundwater management and protection from external contaminants of the people using it. MB1 relatively showed the highest levels of Na and K. The levels of Na and K in this study are slightly higher than those reported by (Kumar et al., 2015). The levels of K ($P < 0.01$) and Na ($P < 0.001$) were significantly different among the different water sources.

3.10. Iron and Manganese

The iron and manganese concentration lie in the range from 0.02 to 0.06 mg/L and 0.20 to 0.90 mg/L respectively. The amount of iron except in samples MB2 and MB5, and the amounts of Mn except in MB1 and MB3 exceeded the limits set by WHO (0.30 and 0.50 mg/L respectively). After Fe, Mn is the second most abundant heavy metal. The adequate daily intake of Mn has been set by the National Academy of Sciences (NAS) at 2.3 mg/day for men and 1.8 mg/day for women. However, elevated Mn levels can cause human neurotoxicity (Goitom et al., 2018).

3.11. Chlorides, Sulphates and Bicarbonates

The chloride concentration serves as an indicator of pollution by sewage. Chloride, a major anion in potable and industrial water, has no adverse effect on health, but imparts bad taste to drinking water (Janardhana et al., 2013). The chloride ion concentration found in the study areas ranged from 220.00 - 1168.00 mg/L. The permissible limit of chloride is 600.00 mg/L according to WHO. The samples from MB2 and MB3 were within the permissible limit but the samples from MB1, MB4 and MB5 were above the permissible limit, and water sample from MB5 showed significantly higher values when compared to the other samples. The chloride values in this study are higher than those reported by (Kumar et al., 2015). High level of chloride in water bodies harms metallic pipes and structure as well as agricultural crops (Suresh et al., 1992). Sulphate ion concentration of the samples lied in the range of 330.00 to 675.00 mg/L. Samples represented as MB1, MB2, MB4 and MB5 have moderately high levels of sulphate and exceeded the permissible limit of WHO, except MB3. Sulphate may come into ground water by industrial or anthropogenic additions in the form of Sulphate fertilizers (Janardhana et al., 2013). High concentration of sulphate has laxative effect and causes gastro-intestinal irritation (Bhatia, 2010). The sulphate ion, one of the important anions present in natural water, produces cathartic effect upon human beings when it is present in excess (Vinod et al., 2012). The bicarbonate values which ranged from 361.12 to 1010.16 mg/L exceeded the WHO permissible limit of 300 mg/L. The bicarbonate concentration of MB1 and MB2 was significantly higher than the other samples. High content of bicarbonate in water bodies leads to alkalinity and salinity.

3.12. Nitrogen-Nitrate, Nitrogen-Nitrite and Ammonia

In this study the nitrate-N and nitrite-N concentrations (in mg/L) ranged from 17.71 to 496.00 and 0.15 to 0.89 respectively. High nitrogen content is an indicator of organic pollution, it results from the added nitrogenous fertilizers, decay of dead plants and animals, animal urines feces, etc. They are all oxidized to nitrate by natural process (Janardhana et al., 2013). The nitrate content of all the water samples was found to be higher than the permissible limit (50 mg/L) except sample MB2. Through endogenous nitrosation, nitrate is a precursor in the formation of N-nitroso compounds (NOC); most NOC are carcinogens and teratogens. Thus, exposure to NOC formed after ingestion of nitrate from drinking water and dietary sources may result in cancer, birth defects, or other adverse health effects (Ward et al., 2018). The nitrite content in all the samples was found to be within the limit (3 mg/L). Furthermore, increased nitrite level in drinking water may adversely affect the central nervous system (Janardhana et al., 2013). The comparison of the levels of HCO_3^-, SO_4^{2-}, Cl^- and NO_3^- with WHO standard for various samples is shown in **Figure 4**.

Concentration of ammonia ranged from 0.00 to 1.51 mg/L. The sample MB3 was free from ammonia. The level of ammonia in the remaining samples was almost within the WHO permissible limit of (1.5 mg/L). Ammonia can occur in ground water from agricultural activities, animal manure and wastewater drainage. Ammonia in water is an indicator of possible bacterial, sewage and animal waste pollution.

3.13. Chemical Oxygen Demand (COD)

COD is a measure of pollution in aquatic system. High COD may cause oxygen depletion on account of decomposition by microbes (Janardhana et al., 2013) to a level detrimental to aquatic life. The COD values in this study, ranging from 0 to 130 mg/L, fell below permissible limit WHO (75 mg/L) in all the samples except sample MB5. The value for sample MB5 is significantly higher indicating that the groundwater was highly contaminated with chemically oxidizable inorganic and organic substances. The COD values in this study, except samples from MB3 and MB4, are lower than those reported by Janardhana et al. (2013) which ranged from 5.28 to 10.14 mg/L.

3.14. Heavy Metal Analysis

The results of the heavy metal analysis, given in **Table 2**, showed that the concentrations of arsenic, mercury, lead and selenium were higher than the permissible limit proposed by WHO. Similarly, the level of nickel for MB1 and MB2 were higher than the permissible limit. The major possible sources of these metals to the water system could be due to the entry of municipal and industrial wastes in to the drainage. Few of the heavy metals are essential elements (e.g. Fe, Zn) while some others are toxic (e.g. Hg and Cd). Most heavy metals are extremely toxic, even low concentrations of heavy metals have damaging effects to man and animals because there is no established mechanism for their elimination from the body (Goitom et al., 2018).

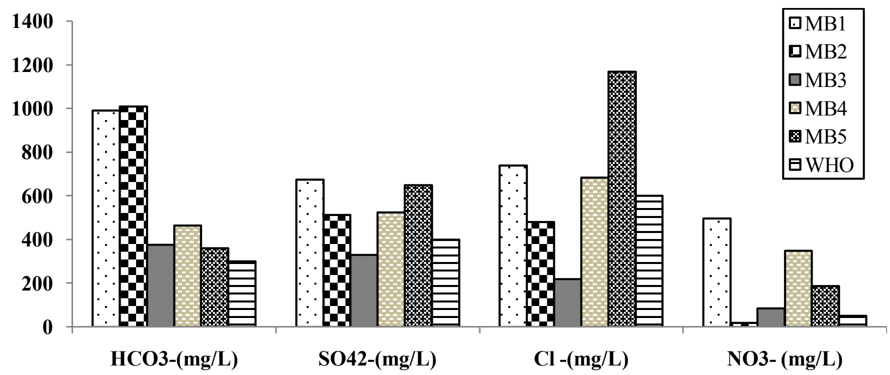

Figure 4. Comparison of HCO_3^-, SO_4^{2-}, Cl^- and NO_3^- concentration levels with WHO standard for various water samples.

Table 2. Heavy metal content of groundwater samples (in μg/L).

Toxic Metals	MB-1	MB-2	MB-3	MB-4	MB-5	WHO
Al (μg/L)	123.00	60.40	50.20	102.00	106.00	200
As (μg/L)	95.40	10.40	42.80	31.00	27.10	10
Ba(μg/L)	68.60	61.50	90.40	151.00	60.90	700
Cd (μg/L)	2.59	1.02	1.84	1.80	2.75	3
Co (μg/L)	1.22	2.33	0.95	0.83	1.82	-
Cr (μg/L)	22.50	2.57	20.10	22.30	20.60	50
Cu (μg/L)	23.80	8.65	3.28	26.80	31.50	2000
Hg (μg/L)	16.30	12.00	24.20	22.00	12.30	1
Ni (μg/L)	25.72	33.00	13.43	17.30	17.10	20
Pb (μg/L)	39.22	34.90	34.70	32.00	54.40	10
Se (μg/L)	82.74	54.28	141.00	34.00	55.30	10
Sn (μg/L)	24.80	11.30	20.80	10.90	8.76	-
V (μg/L)	10.70	9.11	3.10	7.45	2.20	-
Zn (μg/L)	29.50	20.60	11.70	7.20	1.07	3000

NB: "-" WHO data not available.

In this study, different heavy metals were detected quantitatively in all samples. Some of the heavy metals like As, Hg and Pb are very toxic and were found to be above the WHO limit. Some of the heavy metals including Ni in MB1 and MB2, and Se in all the water sources were above the permissible limit, few of the heavy metals found in the water sources were below the permissible limit and others have no health hazard. The levels of heavy metals such as Pb, Zn, Cd, Ni and Cu are lower than those reported by (Parvez et al, 2013). The main sources for these metals are natural mineral rocks and industrial wastewater seepage to the groundwater (Verma & Dwivedi, 2013). Therefore, continuous assessment and special attention should be done to the water sources containing of the toxic metals.

3.15. Ground Water Quality for Irrigation

The suitability of groundwater for irrigation is determined on the basis of physical, chemical and bacteriological characteristics. The criteria for suitability of groundwater for irrigation are based on Total Dissolved Solids (TDS), Electrical Conductivity (EC), Sodium Salts concentration and other ions like chloride and nitrate (Priyanka et al., 2017). The sodium absorption ratio (*SAR*) values were calculated for all the water samples by using the following formula:

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

The *SAR* values were found to be 48.48, 39.24, 7.101, 35.99, and 38.89 for MB1, MB2, MB3, MB4 and MB5 respectively. Based on the results of SAR calculations, it was observed that all the water samples, except the water sample in MB3, were having high SAR values, which means that these water samples are unfavorable for plant growth because of the sodic nature or sodium richness. Moreover, based on the level of electrical conductivity, hardness and chloride parameters, the water samples were not suitable for irrigation purposes according to the FAO/WHO Joint standards (FAO/WHO, 2008).

4. Conclusion

The present investigation portrays that most of the physico-chemical parameters of the samples, except the source from MB3, were higher than the recommended values set by WHO and FAO. Almost 60% of the studied physico-chemical parameters were found above the standard limits set by WHO. Although the levels of pH, temperature, Mg, Mn, Fe, nitrite, ammonia and COD in almost all the water samples are below the permissible limit, Mg and COD levels in MB5 and the level of ammonia in MB1 were also found to be above the WHO permissible limit. Moreover, the concentrations of Ca, Na, K, Mn, sulphates and chloride in MB3 were found below the permissible limit though their levels in the other four sites are higher than the permissible limit. Similarly, the levels of toxic metals (Pb, As, Hg and Se) in all the water sources and Ni from two water sources (MB1 and MB2) were found above the permissible limit. Therefore, the water samples are not safe for drinking and irrigation purposes unless the water sources are subjected to purification. The present work was undertaken to bring an acute awareness of the quality of water among the people living in and around Asmara. The groundwater contamination can be minimized by introducing wastewater treatment techniques before agricultural applications. Additional assessment on the bacteriological data would be relevant to assess the health effects of all the water sources found around Mai-Bella. The authors of this study recommend the Ministry of Land, Water and Environment to draw some attention to the ground water sources around Mai-Bella.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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