Studies on heavy metal contamination in Godavari river basin

Jakir Hussain1 · Ikbal Husain2 · Mohammed Arif3 · Nidhi Gupta4

Abstract Surface water samples from Godavari river basin was analyzed quantitatively for the concentration of eight heavy metals such as arsenic, cadmium, chromium, copper, iron, lead, nickel and zinc using atomic absorption spectrophotometer. The analyzed data revealed that iron and zinc metals were found to be the most abundant metals in the river Godavari and its tributaries. Iron (Fe) recorded the highest, while cadmium (Cd) had the least concentration. Arsenic, cadmium, chromium, iron and zinc metals are within the acceptable limit of BIS (Bureau of Indian Standards (BIS) 1050 (2012) Specification for drinking water, pp 1–5). The analysis of Godavari river and its tributary’s water samples reveals that the water is contaminated at selected points which are not suitable for drinking. Nickel and Copper concentration is above acceptable limit and other metal concentration is within the acceptable limit. Comprehensive study of the results reveals that out of 18 water quality stations monitored, water samples collected at 7 water quality stations are found to be within the permissible limit for all purposes. While Rajegaon, Tekra, Nandgaon, P. G. Bridge, Bhatpalli, Kumhari, Pauni, Hivra, Ashti, Bamini, and Jagda stations were beyond the desirable limit due to presence of copper and nickel metals. The contents of copper metal ions were higher at some water quality stations on Wunna river (Nandgaon); Wardha river (Hivra) and Wainganga river (Kumhari, Pauni, Ashti) during Feb. 2012, while nickel concentration during Feb. 2012, June 2012, March 2013 and Aug. 2013 at some water quality stations on rivers Bagh, Indravati, Pranhita, Wunna, Penganga, Peddavagu, Wainganga and Wardha. It can be concluded that rapid population growth and industrialization have brought about resource degradation and a decline in environmental quality.

Keywords Water quality · Heavy metal · Copper · Nickel · Arsenic · Cadmium · Zinc · Iron · Pollution

Introduction

Heavy metals are elements with a specific gravity that is at least four to five times the specific gravity of water at the same temperature and pressure (Duruibe et al. 2007; Garbarino et al. 1995). These elements have with positive valances and occupy group I to III in the periodic table. Out of thirty five elements including cadmium, antimony, arsenic, bismuth, cerium, chromium, copper, gallium, gold, iron, lead, manganese, mercury, cobalt, nickel, platinum, silver, tellurium, thallium, zinc, tin, uranium and vanadium are considered as heavy metals (Glanze 1996). Worldwide, pollution created by heavy metals in aquatic environment is
a growing problem and it has reached an alarming rate currently. Surface water receives metals from natural and anthropogenic sources in natural condition. The concentration of metals in sediments depends on types of rocks or soils present along the watershed. As after the industrial revolution, point sources from mining, municipal waste, industries and non-point sources from both agriculture and urban storm water runoff have collected in the water bodies. Due to heavy metals such as lead, arsenic, selenium, cadmium, copper, zinc, uranium, mercury, and nickel serious health hazards are caused due to transfer of these contaminants into food chain. Due to changing environmental conditions and extreme use of agrochemical heavy metals are being accumulated in soils which are transferred to water system by leaching. This poses a serious threat to human life (Nicholson et al. 2003; Wong et al. 2003). Heavy metals being toxic in nature are affecting plant growth. Thus, it is essential to protect the soil and to make it free of heavy metal contamination so that it cannot enter into food chain. In industrial areas, soil contamination is of great concern (Hussain et al. 2014).

However, the rivers play a major role in transporting municipal and industrial wastewater and runoff from agricultural and mining land. The present study aimed to envisage the water quality status of river Godavari and its tributaries with respect to its heavy metal concentrations. The research work was carried during Sept. 2011 to Aug. 2013.

Metal toxicity

Out of 106 identified elements, about 80 of them are called metals. Heavy metals or trace elements are among the most harmful of the elemental pollutants. Higher concentration of some heavy metals such as Pb, Sn, Hg, Zn and Cu are toxic to the system (Central Water Commission (CWC) 2014; Bhatia and Jaiswal 2006). Trace metals include essential elements such as Fe as well as toxic metals such as Cd and Hg. Most of these have a strong affinity for sulphur and disrupt enzyme function by forming bonds with sulphydryl groups in enzymes (Central Water Commission (CWC) 2014; Hussain et al. 2014). Heavy metals are persistent and easily enter the food chain and accumulate until they reach toxic levels (Abah et al. 2013). These may eventually kill fish, birds and mammals (Abah et al. 2013). Many countries in the world have experienced menace of metal pollution in water, and a large number of people have been affected. Causes of this pollution have been well documented by (Voutsa et al. 1995; Newchurch and Kahwa 1984; Tariq et al. 1993; Chukwujindu et al. 2012; Samanidou and Papadoyannis 1992; Sharma et al. 1992; Valová et al. 2010). However, the primary sources of metal toxicity in surface water have been thought to be the natural occurrence and subsequent degradation of the environment (Jessica et al. 2011).

Arsenic

Arsenic (As) is an element found everywhere that is comparatively rare but extensively distributed in the soil, atmosphere, rocks, natural waters and organisms. It is organized in the environment through a combination of natural processes such as biological activities, weathering reactions and volcanic emissions as well as through a range of anthropogenic activities (Kinniburgh and Smedley 2001; Kapaj et al. 2006; Walter and Carter 1995). Most environmental arsenic problems are the recruitment under natural conditions, but the man has a significant impact through mining activity, combustion of fossil fuels, the use of arsenical pesticides, herbicides and crop desiccants and the use of arsenic as an additive in livestock feed, particularly for poultry (Welch 2003; Karthikeyan and Hirata 2003). In the last few decades, although the use of arsenical products such as pesticides and herbicides has decreased significantly but their use for wood preservation is still common. The impact on the environment of the use of arsenical compounds will remain for some years (Nadeem and Shafiq 2007; Faust et al. 1983).

Cadmium

Cadmium is widely distributed in the earth’s crust in a very small amount. In the earth’s crust, it is uniformly distribute but normally estimated to be present at an average concentration of between 0.15 and 0.2 mg/kg. Cadmium may be present in the aquatic environment at relatively low levels as inorganic complexes such as carbonates, hydroxides, chlorides or sulphates (Hiatt and Huff 1975). Even in polluted rivers, the cadmium levels in the aqueous phase may be significantly low and even sometimes below the detection limit. A maximum acceptable concentration of cadmium in drinking water has been established on the basis of health considerations. BIS (2012) proposed that the maximum desirable limit of cadmium is 3 μg/L without any relaxation in the absence of another source. Surface waters have been contaminated by industrial wastes, plating works, plants manufacturing cadmium pigments, textile operations, cadmium-stabilized plastics, or nickel–cadmium batteries, or by effluents from sewage treatment plants (Rani et al. 2014).

Chromium

Chromium is used to call as metal with two faces, that it can be either beneficial or toxic to humans and animals
depending on its concentrations and oxidation state (Zayed et al. 1998). Cr(III) is considered to be a trace element essential for the proper functioning of living organisms (Wang et al. 2009). Nutritionally, at lower concentrations, Cr(III) is an essential component of a balanced human and animal diet for preventing adverse effects in the metabolism of glucose and lipids, e.g., impaired glucose tolerance, increased fasting insulin, increased cholesterol and triglycerides, and hypoglycemic symptoms (Zayed and Terry 2003). Cr(III) at increased concentrations can interfere with several metabolic processes because of its high capability to coordinate various organic compounds resulting in inhibition of some metalloenzyme systems (Zayed et al. 1998). Chromium is widely used in industries, such as electroplating, paint and pigment manufacturing, textile, fertilizer and leather tanning (Ganguli and Tripathi 2002). These industries discharge trivalent and hexavalent chromium with waste effluent to the soil and surface water. Chromium is generated by various industries, occurs in different oxidation states but Cr(III) and Cr(VI) are the most significant. Hexavalent chromium is highly toxic, mutagenic, and carcinogenic (Lee et al. 2008). In addition, Cr(VI) is highly mobile in most environments, mainly due to its soluble nature (Fukai 1967). In spite of that, heavy metals are highly toxic to most microbes; there are metal-tolerant bacteria. Long-term exposure to metals imposes a selection pressure that favors the proliferation of microbes that are tolerant/resistant to this stress (Duruibe et al. 2007).

**Copper**

Copper is an element commonly found in the nature and widely used by humans. The sources of copper in watercourse are copper mining and smelting, chemical weathering, steel production, electrical industry, agriculture and sewer sludge. Copper is an essential trace element for all organisms and can be used in metabolic pathways. If new pipes are used, as adult humans can tolerate up to 12 mg/day, young children are easily toxicated by copper. There have been records of kidney failure in young children exposed to elevated copper concentrations. The Swedish recommendation of a maximum concentration of 2 mg/L in drinking water (Livsmedelsverket författningssamling 2005) prevents acute toxic symptoms such as diarrhea in adults. BIS 10500 (2012) has recommended an acceptable limit of 50 μg/L of copper in drinking water; this concentration limit can be extended to 1500 μg/L of copper in case no alternative source of water with desirable concentration is available.

**Iron**

Iron is the most abundant element in the earth’s crust and the most abundant heavy metal; it is present in the environment mainly as Fe²⁺ or Fe³⁺. Iron is an essential element in human nutrition, is an integral component of cytochromes, porphyrins and metalloenzymes. The ingestion of large quantities of iron results in hemochromatosis. It is a condition in which normal regulatory mechanisms do not operate effectively which leads to tissue damage as a result of the accumulation of iron. In some cases of alcoholism, tissue damage has occurred with excessive intake of iron from alcoholic beverages (Central Water Commission (CWC) 2014; Mesías et al. 2013). Iron is generally present in surface waters as salts containing Fe(III) when the pH is above 7.

**Lead**

Lead is a most common heavy element and commonly distributed throughout the environment (Greenwood and Earnshaw 1984). Lead is the most toxic heavy metal, and the inorganic forms are absorbed through food and water, and inhalation (Ferner 2001). Lead poisoning causes teratogenic effect, inhibition of the synthesis of hemoglobin, dysfunctions in the kidneys, joints, reproductive systems, cardiovascular system, chronic damage to the central nervous system and peripheral nervous system (Ogwuegbu and Muhanga 2005). And some other effects such as damage to the gastrointestinal tract, urinary tract resulting in bloody urine, neurological disorder and permanent brain damage. As inorganic forms of lead affect central nervous system, peripheral nervous system, gastrointestinal tract and organic forms, mostly affect the central nervous system (McCullogh 1991; Ferner 2001; Institute of Environmental Conservation and Research INECAR 2000; Lentech Water Treatment and Air Purification 2004). Most important lead affects children on the brain and results in poor intelligence quotient (Udedi 2003). Its absorption in the body is increased by calcium and zinc deficiencies.

**Nickel**

Nickel is an essential metal for several animal species, micro-organisms and plants, and toxicity symptoms can occur when too little or too much nickel is taken up (Cempel and Niel 2005). The average abundance of nickel in the earth’s crust is 1.2 mg/L, in soils it is 2.5 mg/L, in streams it is 1 μg/L and in groundwater it is <0.1 mg/L. Nickel is obtained chiefly from pyrrhotite and garnierite. Nickel concentration is increasing in certain areas by human activities such as mining works, emission of smelters, burning of coal and oil, sewage, phosphate fertilizers
and pesticides (Gimeno-García et al. 1996). It is assumed that nickel is an essential element for some plants and animals. Nickel is a ubiquitous metal frequently responsible for allergic skin reactions and has been reported to be one of the most common causes of allergic contact dermatitis, as reflected by positive dermal patch tests (Cavani 2005; Kitaura et al. 2003; Clarkson 1988).

Zinc

Zinc is a necessary element for all living things as well as for human beings. Zinc containing proteins and enzymes are involved in replication and translation of genetic material (Galdes and Vallee 1983). Zinc is an essential element for human diet that is 4 and 10 mg/day is required depending on age and pregnant women require up to 16 mg/day. Food constitutes the most important source of zinc. Zinc is considered to be comparatively non-toxic if taken orally but excess amount can cause system dysfunctions that result in impairment of growth and reproduction (Institute of Environmental Conservation and Research INECAR 2000; Nolan 2003). The clinical signs of zinc toxicosis have been reported as vomiting, diarrhea, bloody urine, icterus (yellow mucus membrane), liver failure, kidney failure and anemia (Fosmire 2001).

Drinking water standards

In view of the direct consumption of water by humans, the domestic water supply is considered to be the most important use of water and drinking use has been given priority on utilization of water resource in the National Water Policy. Bureau of Indian Standards (BIS) 10500 (2012) and Indian Council of Medical Research (ICMR) agencies have formulated drinking water standards in India while World Health Organization (WHO) has considered international drinking water standards. According to BIS 10500 (2012), the requirement (acceptable limit) and permissible limit in the absence of alternative source is given in Table 1.

### Study area

Godavari basin extends over states of Maharashtra, Andhra Pradesh, Chhattisgarh and Odisha including smaller parts in Madhya Pradesh, Karnataka and Union territory of Puducherry having an area of 3,12,812 km² which is nearly 9.5% of the total geographical area of the country. The total maximum length and width of the Godavari river is 995 and 583 km. It lies between 73°24′–83°4′ east longitudes and 16°19′–22°34′ north latitudes (Fig. 1). It is bounded by Satmala hills, the Ajanta range and the Mahadeo hills on the north, by the Eastern Ghats on the south and the east and by the Western Ghats on the west. It rises from Trimbakeshwar in the Nashik district of Maharashtra about 80 km from the Arabian Sea, at an elevation of 1067 m. The total length of Godavari from its origin to outfall into the Bay of Bengal is 1465 km. Its important tributaries joining from right are the Pravara and the Manjra, while the Purna, the Penganga, the Wardha, the Wainganga, the Indravati and the Kolab joins from left. The upper reaches of the Godavari drainage basin are occupied by the Deccan Traps containing minerals, hypersthene, augite, diopside, enstatite, magnetite, epidote, biotite, zircon, rutile, apatite and chlorite. The middle part of the basin is principally Archean granites and Dharwars composed of phyllites, quartzites, amphiboles and granites. The downstream part of the middle basin is occupied mainly by the Cuddapah and Vindhyan metasediments and rocks of the Gondwana group. The Cuddapah and

### Table 1 Drinking water standards for trace and toxic metals (BIS-10500-2012)

| Toxic metal            | WHO 1993 Health-based guideline by WHO (mg/L) | BIS 10500-2012 Requirement (acceptable limit) (mg/L) | Permissible limit in the absence of alternative source (mg/L) |
|------------------------|---------------------------------------------|-----------------------------------------------------|-------------------------------------------------------------|
| Total arsenic as As    | 0.01                                        | 0.01                                               | 0.05                                                        |
| Cadmium as Cd          | 0.003                                       | 0.003                                              | No relaxation                                               |
| Total chromium as Cr   | 0.05                                        | 0.05                                               | No relaxation                                               |
| Copper as Cu           | 2.0                                         | 0.05                                               | 1.5                                                         |
| Iron as Fe             | No guideline                                | 0.3                                                | No relaxation                                               |
| Lead as Pb             | 0.01                                        | 0.01                                               | No relaxation                                               |
| Nickel as Ni           | 0.02                                        | 0.02                                               | No relaxation                                               |
| Zinc as Zn             | 3.0                                         | 5                                                  | 15                                                          |

Appl Water Sci (2017) 7:4539–4548 4542
Table 2 Water quality stations on river Godavari and its tributaries

| Sr. no. | Name of water quality site | Name of river | Catchment area (km²) | Latitude and longitude | State          |
|---------|----------------------------|---------------|----------------------|------------------------|----------------|
| 1       | Bhadrachalam               | Godavari      | 280,505              | N17°40'05"E80°52'38"   | Andhra Pradesh |
| 2       | Jagdalpur                  | Indravati     | 7380                 | N19°06'29"E82°01'22"   | Chhatisgarh    |
| 3       | Konta                      | Sabari        | 19,550               | N17°47'56"E81°23'34"   | Chhatisgarh    |
| 4       | Pathagudem                 | Indravati     | 40,000               | N18°51'09"E80°20'58"   | Chhatisgarh    |
| 5       | Perur                      | Godavari      | 268,200              | N18°35'14"E80°23'45"   | Andhra Pradesh |
| 6       | Polavaram                  | Godavari      | 307,800              | N17°15'07"E81°39'23"   | Andhra Pradesh |
| 7       | Mancherial                 | Godavari      | 102,900              | N18°50'09"E79°26'41"   | Andhra Pradesh |
| 8       | Ashri                      | Wainganga     | 50,990               | N19°41'12"E79°47'08"   | Maharashtra    |
| 9       | Bami                       | Wardha        | 46,020               | N19°48'50"E79°22'46"   | Maharashtra    |
| 10      | Bhatpalli                  | Peddagavu     | 3100                 | N19°19'49"E79°30'15"   | Andhra Pradesh |
| 11      | Kumhari                    | Wainganga     | 8070                 | N21°53'03"E80°10'30"   | Madhya Pradesh |
| 12      | Rajegaon                   | Bagh          | 5380                 | N21°37'32"E80°15'14"   | Madhya Pradesh |
| 13      | Hivra                      | Wardha        | 10,240               | N20°32'50"E78°19'29"   | Maharashtra    |
| 14      | Nandgaon                   | Wunna         | 4580                 | N19°49'03"E78°34'40"   | Maharashtra    |
| 15      | P. G. Bridge               | Penganga      | 18,441               | N19°49'03"E78°34'40"   | Maharashtra    |
| 16      | Pauni                      | Wainganga     | 35,520               | N20°47'41"E79°38'52"   | Maharashtra    |
| 17      | Satrapur                   | Kanhan        | 11,100               | N21°13'00"E79°13'59"   | Maharashtra    |
| 18      | Tekra                      | Pranhita      | 108,700              | N18°58'42"E79°56'49"   | Maharashtra    |
Vindhyan are quartzites, sandstones, shales, lime stones and conglomerates. The Gondwanas are principally detritals with some thick coal seams. The Eastern Ghats dominate the lower part of the drainage basin and are formed mainly from the Khondalites which include quartz–feldspar–garnet–sillimanite gneisses, quartzite, calc-granulites and charnockites. In the coastal region, the tertiary Rajahmundry sandstones crop out.

Materials and methods

Grab samples were collected from the Godavari river basin at a depth of about 0.3 m from 18 sampling locations. The sampling locations with their coordinates are shown in Table 2. Sampling was carried out six times from Sept. 2011 to Aug. 2013. The sample bottles were soaked in 10% HNO₃ for 24 h and rinsed several times with double-distilled water (DW) prior to use. Water samples (500 mL) were collected and immediately acidified with 2-mL ultra pure nitric acid (1:1 or 50-mL concentrated HNO₃ + 50 mL DW) and 2-mL HCl for arsenic to lower pH to <2. The samples thus preserved were stored at 4 °C in sampling kits and brought to the lab for metal analysis. In the lab, water samples were filtered through 0.45 μm membrane filter. Samples were collected in the months of Sept. 2011, Feb. 2012, June 2012, Oct. 2012, March 2013 and Aug. 2013. All chemicals and reagents were purchased from Merck, India and standard solutions of metals were obtained from Merck, Germany. Deionized water was used during the study. All glassware and other containers were cleaned with deionized water prior to use. Trace metal analysis was carried out using Atomic Absorption Spectrometer (AAS) following standard methods given in APHA (2012).

Results and discussion

Heavy metal concentration ranges in the study area during Sept. 2011 to Aug. 2013 are shown in Table 3. The minimum–maximum values of metals with 25 and 75% are shown in Box Whisker diagram (Fig. 2).

Table 3 Heavy metal distribution in river Godavari and its tributaries (Sept. 2011 to Aug. 2013)

| Rivers   | Arsenic (μg/L) | Cadmium (μg/L) | Chromium (μg/L) | Copper (μg/L) | Nickel (μg/L) | Lead (μg/L) | Zinc (mg/L) | Iron (mg/L) |
|----------|----------------|----------------|-----------------|---------------|---------------|-------------|-------------|-------------|
| Wunna    | 0.04–9.30      | 0.25–1.12      | 1.08–5.07       | 2.83–54.58    | 0.40–4.30     | 0.003–0.03  | 0.03–0.22   |
| Wardha   | 0.59–8.12      | 0.03–1.10      | 0.34–6.06       | 2.70–71.81    | 0.36–4.93     | 0.0028–0.021| 0.009–0.230 |
| Wainganga| 0.14–5.62      | 0.01–1.59      | 0.17–9.26       | 0.82–114.8    | 0.09–5.24     | 0.0003–0.057| 0.001–0.240 |
| Pranhita  | 0.43–4.28      | 0.004–1.21     | 1.22–7.52       | 0.78–12.18    | 8.87–71.50    | 0.15–4.53   | 0.002–0.078 | 0.006–0.180 |
| Sabari   | 0.05–3.31      | 0.001–0.44     | 0.25–3.43       | 0.16–18.23    | 1.34–10.90    | 0.51–6.28   | 0.003–0.029 | 0.01–0.169  |
| Peddavagu| 0.24–3.69      | 0.002–0.95     | 0.13–6.26       | 0.08–27.57    | 0.37–4.98     | 0.002–0.040 | 0.003–0.170 |
| Penganga | 0.16–4.51      | 0.039–1.56     | 0.25–4.20       | 2.70–38.69    | 1.54–35.00    | 0.37–7.41   | 0.003–0.032 | 0.013–0.240 |
| Bagh     | 0.34–6.06      | 0.02–1.45      | 0.52–2.93       | 0.29–25.09    | 0.92–48.37    | 0.62–6.77   | 0.0002–0.046| 0.016–0.140 |
| Kanhan   | 1.30–5.19      | 0.002–1.29     | 0.58–13.67      | 0.29–39.80    | 1.40–18.25    | 0.58–4.20   | 0.003–0.040 | 0.027–0.140 |
| Indravati| 0.16–9.18      | 0.01–0.79      | 0.16–8.98       | 0.05–27.36    | 0.89–20.77    | 0.41–5.35   | 0.0009–0.078| 0.01–0.170  |
| Godavari | 0.05–7.61      | 0.002–0.99     | 0.36–10.12      | 0.19–42.80    | 1.47–17.29    | 0.45–4.11   | 0.0006–0.094| 0.008–0.180 |

Fig. 2 Box Whisker diagram (Sept. 2011 to Aug. 2013)
Arsenic

BIS has recommended 0.01 mg/L (10 μg/L) as acceptable concentration of arsenic in drinking water. The arsenic concentration varies from 0.04 to 9.31 μg/L. Maximum arsenic concentration (9.31 μg/L) was observed at Nandgaon on river Wunnain in Oct. 2012. In the study area, all the river water quality samples are reported to have arsenic concentration within the acceptable limits of Bureau of Indian Standards (BIS) and no toxicity of arsenic in the rivers Wunna, Wardha, Wainganga, Pranhita, Peddavagu, Penganga, Sabari, Kanhan, Indravati, Bagh and Godavari are observed during the study period.

Cadmium

Data reveal that cadmium concentration varies from 0.001 to 1.59 μg/L. The highest cadmium concentration (1.59 μg/L) was observed at Pauni in Wainganga river during Oct. 2012. Data reveal that during study period, cadmium concentration at all stations is within the acceptable limit prescribed by BIS 10500 (2012).

Chromium

BIS (Bureau of Indian Standard) 10500 (2012) has recommended an acceptable limit of 0.05 mg/L (50 μg/L) of chromium in drinking water. Data reveal that chromium concentration varies from 0.13 to 13.67 μg/L. Water quality station Satrapur on river Kanhan have maximum 13.67 μg/L concentration in Feb. 2012.

Lead

Bureau of Indian Standard (10500, 2012) has recommended an acceptable limit of 0.01 mg/L (10 μg/L) for lead in drinking water. Lead concentration is maximum (7.41 μg/L) at P. G. Bridge water quality station on Pen-ganga river in March 2013.

Zinc

BIS has recommended 5 mg/L (5000 μg/L) acceptable concentration of zinc in drinking water, which can be extended to 15 mg/L (15,000 μg/L) in the absence of an alternate source. Zinc concentration varies from 0.2 to 94.23 μg/L. Maximum zinc concentration is in Oct. 2012 at Perur on river Godavari. In the study area, all the water quality samples having zinc concentration is well within the acceptable and permissible limits of Bureau of Indian Standard (BIS) 10500 (2012) and there is no toxicity of Zn in the river water.

Iron

According to BIS, the acceptable limit of iron is 0.3 mg/L (300 μg/L). The occurrence of iron in river water ranges 1–240 μg/L. All the samples are within the acceptable limit
prescribed by BIS. Iron concentration was maximum 0.24 mg/L (240 μg/L) in Feb. 2012 at Pauni on river Wainganga.

**Nickel**

BIS (Bureau of Indian Standard) 10500 (2012) has recommended acceptable limit of 0.02 mg/L (20 μg/L) of nickel in drinking water. The highest nickel concentration 75.25 μg/L is observed in Feb. 2012. Eight water quality stations in Feb. 2012 Rajegaon (45.75 μg/L); Tekra (71.50 μg/L); Nandgaon (58.00 μg/L); P. G. Bridge (35.00 μg/L); Bhatpalli (40.25 μg/L); Kumhari (44.50 μg/L); Pauni (75.25 μg/L); Hivra (54.00 μg/L); and ten water quality stations in June 2012 Rajegaon (48.37 μg/L); Tekra (50.25 μg/L); Nandgaon (74.26 μg/L); P. G. Bridge (32.69 μg/L); Bhatpalli (20.35 μg/L); Kumhari (24.26 μg/L); Pauni (51.38 μg/L); Ashti (64.66 μg/L); Hivra (45.26 μg/L); Bamini (64.35 μg/L) have nickel concentrations above standards. Four water quality station Jagdalpur (20.77 μg/L); Nandgaon (26.12 μg/L); P. G. Bridge (29.45 μg/L); Bamini (61.02 μg/L) in March 2013 and Bamini (28.98 μg/L) water quality station in Aug. 2013 have nickel concentrations above the acceptable limits.

WHO guidelines propose 0.07 mg/L (70 μg/L) of nickel in drinking water. This is more than that of the guidelines of BIS. As per WHO guidelines, only three stations have nickel concentrations beyond limit during the study period. A contour map (Fig. 3) is plotted by taking average nickel concentration for the whole study period.

**Copper**

Copper concentration of the Godavari and its tributary rivers were found between 0.05 and 114.84 μg/L. The low values of Cu indicate that there is no significant source of
pollution. The maximum Cu concentration was found 114.84 µg/L at Pauni on river Wainganga in Feb. 2012 and minimum (0.05 µg/L) at Jagdalpur on river Indravati in March 2013. It may be attributed to domestic sewage and runoff from extensive farmed areas (Wang et al. 2009). Five water quality samples Nandgaon (54.58 µg/L); Kumhari (78.94 µg/L); Pauni (114.84 µg/L); Ashti (111.53 µg/L) and Hivra (71.81 µg/L) have copper concentration above the acceptable limits but within the permissible limit of Bureau of Indian Standard (BIS) 10500 (2012). A contour map (Fig. 3) is plotted by taking average copper concentration for the whole study period.

Conclusion

The analyzed data revealed that iron and zinc metals were found to be the most abundant metals in the river Godavari and its tributaries. Iron (Fe) recorded the highest, while cadmium (Cd) had the least concentration. Arsenic, cadmium, chromium, iron and zinc metals are within the permissible limit of BIS 10500 (2012). It can be concluded that rapid population growth and industrialization have brought about resource degradation and a decline in environmental quality. The analysis of Godavari river and its tributary’s water samples reveals that the water is contaminated at selected points which are not suitable for drinking. Nickel and copper concentrations are above acceptable limit and other metal concentration is within the acceptable limit. Comprehensive study of the results reveals that out of 18 water quality stations monitored, water samples collected at 7 water quality stations are found to be within the permissible limit for all purposes. While Rajegaon, Tekra, Nandgaon, P. G. Bridge, Bhatpalli, Kumhari, Pauni, Hivra, Ashti, Bamini, and Jagda stations were found to have nickel concentration beyond the permissible limit and copper concentration above acceptable limit as proposed in BIS 2012. The contents of copper metal ions were higher at some water quality stations on Wunna river (Nandgaon); Wardha river (Hivra) and Wainganga river (Kumhari, Pauni, Ashti) in Feb. 2012, while nickel concentration in Feb. 2012, June 2012, March 2013 and Aug. 2013 at some water quality stations on rivers Bagh, Indravati, Pranhita, Wunna, Penganga, Peddagug, Wainganga and Wardha is high (Fig. 4). The major source of copper and nickel pollution on rivers is the anthropogenic municipal solid waste and sewage from nearby towns/habitations, agricultural runoff and native soil erosion. The quality of the rivers is degraded due to the municipal and industrial discharges from the catchment.

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References

Abah J, Ubwa ST, Onyejefu DI, Nomor SA (2013) Assessment of some trace metals content of orehocromis niloticus obtained from river Okpokwu, Apa Benue State, Nigeria. Res J Chem Sci 3(3):70–75
American Public Health Association (APHA) (2012) Standard methods for the examination of water and wastewater, 22nd edn. American Public Health Association, Washington
Bhatia KKS, Jaiswal R (2006) Water quality conservation and need for publication awareness. Proceeding of seminar on water conservation and public awareness. Institute of Engineers, Roorkee, pp 276–280
Bureau of Indian Standards (BIS) 10500 (2012) Specification for drinking water. Indian Standards Institution, New Delhi, pp 1–5
Cavani A (2005) Breaking tolerance to nickel. Toxicology 209(2):119
Cempel M, Nikel G (2005) Nickel: a review of its sources and environmental toxicology. Pol J Environ Stud 13(3):375–382
Central Water Commission (CWC) (2014) Status of trace and toxic metals in Indian rivers. Ministry of Water Resources, New Delhi, pp 1–185
Chukwuindu MAI, Arimoro FO, Nwajei GE, Osayonmo IE (2012) Concentrations and distribution of trace metals in water and streambed sediments of Orogodo river, Southern Nigeria. Soil Sediment Contam 21(3):382–406
Clarkson TW (1988) Biological monitoring of toxic metals. Plenum Press, New York, pp 265–282
Duruibe JO, Ogwuegbu MOC, Egwurugwu JN (2007) Heavy metal pollution and human biotoxic effects. Int J Phys Sci 2(5):112–118
Faust SD, Winka A, Belton T, Tucker R (1983) Assessment of the chemical and biological significance of arsenical compounds in a heavily contaminated watershed part II. Analysis and distribution of several arsenical species. J Environ Sci Health A 18(3):389–411
Fernier DJ (2001) Toxicity, heavy metals. eMed J 2(5):1
Fosmire GJ (2001) Zinc toxicity. Am J Clin Nutr 51(2):225–227
Fukai R (1967) Valency state of chromium in seawater. Nature 213:901
Galdes A, Vallee BL (1983) Categories of zinc metalloenzymes. Metal Ions Biol Syst 15(2):1–54
Ganguli A, Tripathi AK (2002) Bioremediation of toxic chromium from electroplating effluent by chromate-reducing Pseudomonas aeruginosa A2Chr in two bioreactors. Appl Microbiol Biotechnol 58:416–420
Garbarino JR, Hayes H, Roth D, Antweider R, Brinton TI, Taylor H (1995) Contaminants in the Mississippi river. US Geological Survey Circular 1133, Virginia, USA
Gimeno-Garcı´a E, Andreu V, Boluda R (1996) Heavy metals incidence in the application of inorganic fertilizers and pesticides to rice farming soils. Environ Pollut 92:19–25
Glanze WD (1996) Mosby medical encyclopedia, revised edition. C. V. Mosby, St. Louis
Greenwood NN, Earnshaw A (1984) Chemistry of the elements, 1st edn. Pergamon Press, Oxford, p 248
Hiatt V, Huff JE (1975) The environmental impact of cadmium: an overview. Int J Environ Stud 7:277–285


Hussain J, Husain I, Arif M (2014) Occurrence of trace and toxic metals in river Narmada. Environ Qual 14:31–34
Institute of Environmental Conservation and Research INECAR (2000) Position paper against mining in Rapu-Rapu. INECAR, Ateneo de Naga University, Philippines
Jessica H, Andrew MP, McCarter JD (2011) World’s worst pollution problems report, top ten toxic pollution problems. Blacksmith Institute, New York
Kapaj S, Peterson H, Libet K, Bhattacharya P (2006) Human health effects from chronic arsenic poisoning. J Environ Sci Health A 41(10):2399–2428
Karhikkeyan S, Hirata S (2003) Arsenic speciation in environmental samples, Anal Lett 36(11):2355–2366
Kinniburg DG, Smedley PL (2001) Arsenic contamination of groundwater in Bangladesh. Final report of British Geological Survey, vol 2. University of Michigan, Michigan
Kitaura H, Nakao N, Yos Hida N, Yamada T (2003) Induced sensitization to nickel in guinea pigs immunized with mycobacteria by injection of purified protein derivative with nickel. New Microbiol 26(1):101
Lee SE, Lee JU, Chon HT, Lee JS (2008) Microbiological reduction of hexavalent chromium by indigenous chromium-resistant bacteria in sand column experiments. Environ Geochem Health 30:141–145
Lenntech Water Treatment and Air Purification (2004) Water treatment. Lenntech, Rotterdamseweg
Livsmedelsverket författningssamling (2005) Föreskrifter om ändring i Livsmedelsverkets föreskrifter (SLVFS 2001:30) om dricksvatten, vol10
McCluggage D (1991) Heavy metal poisoning, NCS magazine. The Bird Hospital, USA
Mesias M, Seiquer I, Pilar Navarro M (2013) Iron nutrition in adolescence. Crit Rev Food Sci Nutr 53(11):1226–1237
Nadeem A, Shafiq T (2007) Mapping of arsenic contents and distribution in groundwater in some district of Punjab, Pakistan J Sci 58:66–69
Newchurch EJ, Kahwa IA (1984) Heavy metals in the lower Mississippi river. J Environ Sci Health A 19(8):973–988
Nicholson FA, Smith SR, Alloway B (2003) An inventory of heavy metals inputs to agricultural soils in England and Wales. Sci Total Environ 311:205–219
Nolan K (2003) Copper toxicity syndrome. J Orthomol Psychiatry 12(4):270–282
Ogwuegbu MO, Muhanga W (2005) Investigation of lead concentration in the blood of people in the copperbelt province of Zambia. J Environ 1:66–75
Rani A, Kumar A, Lal A, Pant M (2014) Cellular mechanisms of cadmium-induced toxicity: a review. Int J Environ Health Res 24(4):378–399
Samanidou VF, Papadoyannis IN (1992) Study of heavy metal pollution in the waters of Axios and Aliakmon rivers in northern Greece. J Environ Sci Heal A 27(3):587–601
Sharma YC, Prasad G, Rupainwar DC (1992) Heavy metal pollution of river Ganga in Mirzapur, India. Int J Environ Stud 40(1):41–53
Tarq I, Ashraf M, Jaffer M (1993) Assessment of pollution status of rivers Jhelum and sutlej, Pakistan through trace metals in fish, sediment and water. Toxicol Environ Chem 43(3–4):169–174
Udedi SS (2003) From guinea worm scourge to metal toxicity in Ebonyi State. Chem Nigeria New Millenn Unfold 2(2):13–14
Valová Z, Jurajda P, Janáč M, Bernardová I, Hudcová H (2010) Spatiotemporal trends of heavy metal concentrations in fish of the river Morava (Danube basin). J Environ Sci Heal A 45(14):1892–1899
Voutsa D, Zachariadis G, Samar C, Th K (1995) Evaluation of chemical parameters in Aliakmon river/northern Greece. Part II: dissolved and particulate heavy metals. J Environ Sci Health A 30(1):1–13
Walter TK, Carter DE (1995) Arsenic toxicity: chemical and mechanistic implications. J Toxicol Environ Health 46(4):399–409
Wang Y, Xu W, Luo Y, Ma L, Li Y, Yang S, Huang K (2009) Bioeffects of chromium(III) on the growth of Spirulina platensis and its biotransformation. J Sci Food Agric 89(6):947–952
Welch AH (2003) Arsenic in groundwater. Kluwer, Dordrecht
Wong SC, Li XD, Zhang G (2003) Heavy metals in agricultural soils of the Pearl river Delta, South China. Environ Pollut 119:33–44
Zayed AM, Terry N (2003) Chromium in the environment: factors affecting biological remediation. Plant Soil 249:139–156
Zayed A, Gowthaman S, Terry N (1998) Phytoaccumulation of toxic trace elements by wetland plants: I. Duckweed (Lemma minor L.). J Environ Qual 27:715–721