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Impact of the disposal and re-use of fly ash on water quality: The case of the Koradi and Khaperkheda thermal power plants (Maharashtra, India)

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HIGHLIGHTS

- Coal power plants produce low-lime F-type ash (Mul + Qtz + Al–Si glass).
- Mo, As, B and F are high in stream waters and originated by ash leaching.
- Groundwater may exceed drinking limits for Mg^{2+}, Ca^{2+}, NO_3^-, SO_4^{2-}, TDS, B, Mn and U.
- Groundwater SO_4^{2-} are released by brick factories mixing ashes with gypsum and lime.
- Groundwater U is due to the interaction with the U-rich Gondwana rocks.

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ABSTRACT

An increasing amount of fly ash from thermal power plants is produced in India every year. Its disposal is generally done in ponds after it is mixed together in suitable proportion of water to form a slurry. Fly ash from Koradi and Khaperkheda thermal power plants (Nagpur, Maharashtra) is commonly disposed in an area characterized by the presence of many small villages where the population uses the groundwater for drinking and domestic purposes. Here, the groundwater locally exceeds the concentration limits recommended by the Bureau of Indian Standards (BIS, 2005) and by the World Health Organization (WHO, 2008) for Mg^{2+}, Ca^{2+}, NO_3^-, SO_4^{2-}, Total Dissolved Solids (TDS) and for some minor elements like As, Mo, V and U.

A new geological map of the study area has been prepared to understand the possible water–rock interactions. An extensive geochemical survey of groundwater, stream water and fly ash was also carried out to clarify the possible origin of the pollutants by discriminating between geogenic and anthropogenic sources and to assess the influence of the ash ponds on water quality. The analytical results suggest that a large part of the sulfates in the groundwater of the villages of Masada, Khairi and Kawatha originate from the infiltration of industrial water from tens of factories that mix fly ash with relatively high quantities of gypsum and lime for the production of bricks. In addition, the interaction with the relatively U-rich Gondwana units, like Talchir formation, is probably the cause of the high concentration of this element. Results showed how the relatively high concentrations of Mo, As, B and F in circulating waters are linked to the leaching from fly ash, also pointing out a direct spatial correlation between the concentration of fluorides in the groundwater and their closeness to the ash ponds.

1. Introduction

During the last few decades the disposal of fly ash generated by coal based thermal power plants has been a matter of concern on a worldwide scale. Huge amounts of this by-product are usually deposited in ash ponds which have a remarkable environmental impact by consuming vast areas of land and releasing dusts and leachates prone to contaminate the aquifers (e.g. Pandeya et al., 2011; Carlson and Adriano, 1993; Sajwan et al., 2006). This is a particular problem in India where thermal power accounts for roughly two-thirds of the overall power generated in the country (Central Statistics Office, 2013). Here, a series of studies, often carried out or funded by thermal power plant operating companies, tried to highlight the many possible usages of fly ash and their possible benefits to the economy and environment (e.g. NTPC, 2013a, 2013b). In fact, thanks to its pozzolanic and mineralogical properties, the use of this material is often possible for the production of cement, bricks and road embankments (e.g. Kim et al.,

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2005) while a series of code quality requirements has been formulated by the Bureau of Indian Standards. Other usages of fly ash have been also proposed in agriculture as soil amendment (Basu et al., 2009) or for environmental restoration actions such as the backfilling of mines. The possibility of using a significant amount of this material in some industrial processes has a relevant economic importance since it can reduce the disposal costs, minimize the consumption of land and, at the same time, boost the local economies. Following this approach, in 2008, India reused about 38% of the 112 million tonnes of fly ash produced in that year by the power plants installed in the country (Basu et al., 2009). This percentage has increased over the following years according to the national guidelines and local policies. In particular 100% of the fly ash produced in 2012 by the Khaperkheda thermal power plants, near Nagpur, has been reused (http://www.khaperkhedatps.com) mainly for the production of bricks (44.3%), landfills (35.7%) and cement (16.0%).

The coal based thermal power plants of Koradi[1] and Khaperkheda[2], operated by the Maharashtra State Power Generation Company Limited (MahaGenco), have been in operation since 1974 and 1989 in the district of Nagpur (Maharashtra, India) with an effective total power generation capacity of 620 MW and 880 MW (Fig. 1a).

A significant part of the coal for these two power plants is extracted from the Gondegaon mine (Fig. 1a), in the Ghatrohan area, within the so called Kamptee coalfield of the Gondwana geological supergroup, while variable shares of fuel also come from other coal fields and especially from those mined in Odisha.

Large quantities of ash originate as the by-product of the burning of powdered coal in the boiler furnace. In particular, the finer particles, the *fly ash*, mobilize along with hot flue gases which pass through electrostatic precipitators before being taken out pneumatically, while larger particles, the *bottom ash*, fall to the bottom of the furnace. The amount of fly ash generated by the two thermal power plants is relevant and has been estimated to be more than 17 MT for the Khaperkheda power plant alone over the last 10 years (http://www.khaperkhedatps.com). Fly and bottom ash, with a relative abundance ratio of about 80% to 20% by weight, are mixed together in suitable proportion of water to form a slurry and are subsequently transported for deposition in three large ash ponds (K1, K2, K3, Fig. 1a) to the west of Kamptee village (VV.AA., 2008). These ponds have a size of 2.5–3.5 km^2, an estimated average thickness of the fly ash deposits of about 12–15 m and do not have liners at the bottom as well as the flanks. The disposal is currently active only in the easternmost pond (K3) while the other two ponds are substantially filled.

The water in the ponds and in the outflow streams follows a complex path during which water coming from the Pench dam, about 25 km to the north, is brought to the power plant thanks to some pumping stations. Here, water is treated with chemicals like HCl, caustic lye, lime alum (aluminium sulfate), hydrazine and salt and then used for cooling, water vapor generation and to transform the fly ash into a slurry. After this cycle, water is sent back to the pond where it mixes with other waters coming from the Pench dam and/or with the meteoric ones before being pumped again to the power plant (VV.AA., 2008).

A series of hydrogeochemical surveys, carried out in the period 2008–2009 in the villages of the Koradi area close to the ash ponds, highlighted TDS (total dissolved solids) rising up to 2700 mg/l and concentrations of sulfates that reach about 1100 mg/l in some of the water wells which are used for drinking purposes (Ramya et al., 2013). The proximity of the villages to the ponds raised the suspicion that the latter are directly responsible for the deterioration of water quality. Nevertheless in such a complex environment characterized by high anthropogenic impact, the unambiguous discrimination of the multiple pollution sources is a difficult task. This work aims to discriminate the pollution source of groundwater, to identify useful tracers to apportion their relative contribution and to provide useful suggestions and guidelines to improve the water quality in the study area.

1.1. Geological, hydrological and geomorphological setting of the Kanhan–Kolar area

The Kanhan and Kolar river area (Fig. 1a) is characterized by a gently eastward sloping topography whose altitude ranges between 320 and 280 m a.m.s.l (above mean sea level). The only significant relief is represented by the Suradevi Hills which extend for about 5 km along a WNW–ESE direction south of the Kolar river and just before its confluence in the Kanhan river. These two rivers have a markedly seasonal regime and deeply cut their alluvial deposits and the basement rocks, keeping their beds lowered to about 10 m below the surrounding topographic surface. Several artificial water basins, with sizes ranging from a few hundred m^2 to about 1.5 km^2, are dispersed in this area due to the presence of small dams or excavations and act as reservoirs for agriculture and factories. The overall morphology is nowadays dominated by three wide basins (ash ponds K1, K2, K3), used for the disposal of fly ash produced by the Koradi and Khaparkheda Power Plants.

The geological succession is here characterized by formations of different ages, origins and compositions. The most complete and accurate modern geological map available which includes the area of Koradi has been published by Dhote et al. (2001) at an approximate scale of 1:250,000. A geological map at a 1:250,000 scale, mainly obtained from satellite data interpretation, was also published by Gawande et al. (2002) but totally fails to identify formations and alluvial coverage. Focus on the composition of the pre-Cambrian basement and its pegmatitic intrusions is finally given by Gwalani et al. (1999). A complete description of the Gondwana supergroup in the relatively near and lithologically similar Prahita–Godavary valley is given by Vaidyanadhan and Ramakrishnan (2008).

The local geological succession includes:

Alluvium (*Holocene*)

Alluvial terraces of the Kolar and Kanhan rivers.

Infratrap formations (Upper Cretaceous–Lower Cretaceous)

The presence of the infratrap formations has been found in different localities within and around the city of Nagpur even though they are not present in our study area.

a) *Lametas formation* (Upper Cretaceous) is made of hard cherty limestones and calcareous conglomerates deposited in a fresh water environment.

Unconformity

Lower Gondwana (Upper Carboniferous–Permian)

a) *Kamthi* (Upper Permian), medium grained brown, ferruginous sandstone and micaceous and carbonaceous shales.
b) *Barren Measures* (Middle Permian), moderately hard ferruginous, grayish sandstone, occasional gray shales, laminated siltstone and red mottled clays.
c) *Barakar* (Middle Permian–Lower Permian), sandstones with alternation of shale, siltstone and thick coal seams and carbonaceous shale.
d) *Karhabari* (Lower Permian), mottled ferruginous, hard sandstone, carbonaceous shales with occasional coal seams.
e) *Talchir* (Lower Permian), basal boulder bed in clay/silty matrix (which are not present in the study area) followed by alternation of shales, siltstones and sandstones.

Sausar Super Group (Archean)

a) *Chorbaoli formation*, made of quartzites and quartz mica schists which outcrop along the WNW-ESE oriented structure of the Suradevi hills.

[1] The Koradi Thermal Power Station comprises four 105 MW units, one 200 MW unit 1 and two 210 MW units.

[2] The Khaperkheda Thermal Power Station comprises four 210 MW units. Construction of three new 500 MW units is in progress.