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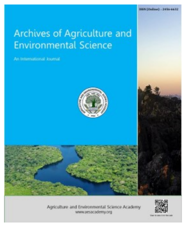

ORIGINAL RESEARCH ARTICLE

Impacts of coal mine water and Damodar River water irrigation on soil and maize (*Zea mays* L.) in a coalfield area of Damodar Valley, India

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ABSTRACT

The present investigation was carried out to assess the environmental and biochemical impacts due to irrigation of coal mine water and Damodar River water on Kharif crop, maize (*Zea mays* L.) in a coalfield area of Damodar Valley, India. Coal mine water and Damodar River water samples were collected for the monitoring of its quality from a coalfield area of Damodar Valley. The samples were analyzed for various parameters and compared with prescribed standard, which revealed that the total suspended solids of coal mine water were higher as Damodar River water. A pot experiment with *Z. mays* was conducted to study the suitability of this coal mine water for irrigation. The plants of *Z. mays* in the pots were irrigated with coal mine water and Damodar River water in two concentrations (100% and 50% dilution with double distilled water) and pure double distilled water was used for control. There was 100% germination of *Z. mays* in all the treatments. The plant growth, chlorophyll content of *Z. mays* and soil quality parameters were significantly better in coal mine water and Damodar River water treated pots. However, the Damodar River water and coal mine water could be successfully used for irrigation. In general, coal mine water and Damodar River water can be used after mixing with good quality of water has shown better growth of *Z. mays*.

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INTRODUCTION

The coal mine water (CMW) can vary greatly in the concentration of contaminants present and some CMW discharges can be a potential water resource, where the local water demands for industrial, irrigation, and even drinking and domestic uses can be fulfilled by effective utilization (Cidu *et al.,* 2007; Singh, 1994). Mining's impacts on the natural water environment may be observed throughout the life cycle of a mine and even long after mine closure (Younger *et al.,* 2002). The potential impacts of mining on the water environment are: (1) disruption of hydrological pathways; (2) seepage of contaminated leachates into aquifers; (3) disposal of CMW, and; (4) depression of the water table around the dewatered zone. Disposal of CMW is a worldwide problem, at both underground and opencast workings (Pulles *et al.,* 1995). The quality of the CMW depends on a series of geological, hydrological and mining conditions, which vary significantly from mine to mine (Younger *et al.,* 2002). The discharged CMW varies greatly in the concentration of contaminants and in some cases it may even meet the drinking water specifications (Singh *et al.,* 2010). Many times, the discharged CMW as such is not usable and may contain unacceptable levels of heavy metals, toxic anions, organic and biological contaminants (Khan *et al.,* 2005; Gupta, 1999). The CMW resource may act as a potential water source in the water scare mining areas and by adopting a suitable water management strategy and treatment process, the CMW generated during mining operations may be harnessed and utilized to meet the regional water demand for domestic, industrial and irrigation uses (Singh, 1994; Tiwary and Dhar, 1994). The CMW may contain large amounts of suspended and dissolved solids, dirty materials and impurities associated with raw coal and they create serious problems of deterioration of water quality of the river or water bodies into which they are discharged (Ghose, 1999). The Damodar River in Durgapur-Asansol region receives waste waters from steel plant, coke oven and coal based chemical industries besides distilleries and paper mills (Chakraborti, 1994). Regulations of Government of India severely restrict the methods of disposal of the effluent loaded with fine material, usually produced in the form of slurry (Bandopadhyay, 1995).

India supports more than 16% of the world's population with only 4% of the world's fresh water resources (Singh, 2003). Although agriculture sector in this country has been major user of water, share of water allocated to irrigation is likely to be decreased by 10-15% in next two decades (CWC, 2000). In this changing scenario, reuse of domestic and industrial waste water in agriculture for irrigating crops appears to be a lucrative option (Rattan *et al.,* 2005; Kumar and Chopra, 2013, 2014; Kumar, 2014). Disposal of waste water to agricultural sites offers an economic alternative to disposal into surface waters and it contributes to nutrient cycling. Effluent wastewater can be used for the restoration of degraded land, and for the growth of vegetation having commercial and environmental value (Dighton and Jones, 1991; Kumar, 2014). The performance of few crops irrigated with waste waters discharged from several sources has been studied by earlier researchers. Foliar damages of landscape trees (*Quercus virginiana*, *Chilopsis linearis*, *Prunus cerasifera* and *Pistacia chinensis*) irrigated with reclaimed wastewater have been reported by Barnett *et al.* (1994). For utilization and management of available water resources in mining areas, a baseline water quality data and continuous monitoring of water quality of the mining regions is prerequisite. Though, some information on the aspects of CMW quality and impact of mining activities on water regimes are available for Jharia, Raniganj, West Bokaro, Singrauli, Pench and Neyveli coalfield areas (Mondal *et al.,* 2013). However, till date no work is done on the potential of CMW for irrigation purpose in the study area. The objective of the present investigation is to characterize the CMW and to study of the effects and biochemical changes of CMW and Damodar River water (DRW) on *Zea mays* L. and soil health.

MATERIALS AND METHODS

Description of study area: The study carried out in East Bokaro Coalfield, located in the Bokaro district of Jharkhand State. This is the third coalfield from East within the chain of coalfields lying in the Damodar Valley. The Coalfield is one of the major repositories of medium-coking, metallurgical coal in Peninsular Gondwana Basins in India, occupying an area of about 237 sq. Km. The East Bokaro Coalfield lies between 23°45’ N to 23° 50’ N latitude and 85° 30’ E to 86° 03’ E longitude. It spreads 65 km from East to West and 10 to 16 km from North to South. The East Bokaro coalfield is part of Chhotanagpur Plateau. It is highly undulating and hilly all over the area. The regional slope of the area is towards east and controlled the alignment of the tributaries of Damodar River. The northern and western part of the area is having hilly ranges. The coalfield is drained by three prominent rivers viz. the Bokaro River in the Central part, the Konar River in the Eastern and the Damodar River in the Southern. The climate of the study area is humid and sub-tropical. It is characterized by hot and dry summer from March to October and cold winter from November to February.

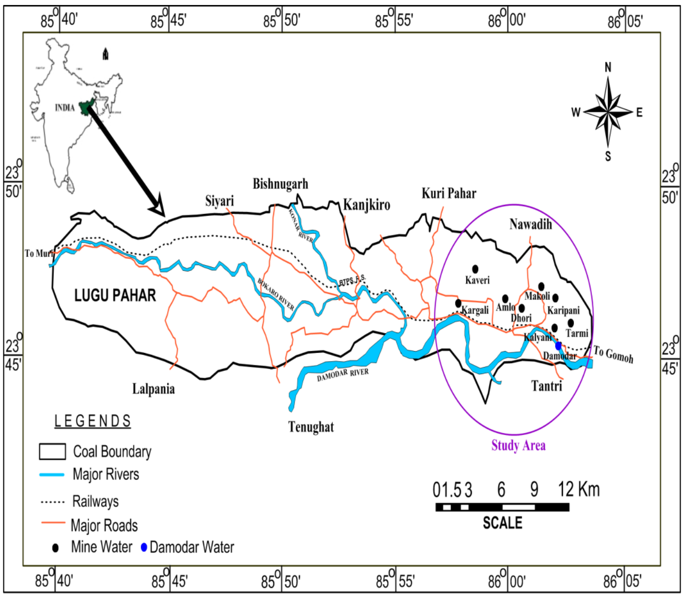

Figure 1. *Map of the East Bokaro Coalfield showing the sampling locations.*

Sampling and analysis of water samples: Coal mine water (CMW) samples were collected during November 2016 from different collieries (*viz.,* Tarmi, Kalyani, Karipani, Makoli, Amlo, Dhori, and Kargali) and composite the samples and Damodar River Water (DRW) was collected from Phusro, near to the coal mining area. The sampling locations are shown in Figure 1. Samples were collected in two litre pre-washed high density polyethylene containers. At the sampling sites, before collecting the samples, bottles were washed with the double distilled water (DDW) and then taken up water samples. Suspended sediments were separated from the water samples in the laboratory by using 0.45 µm Millipore membrane filters and preserved 100 ml separately by adjusting the pH<2 with 6 N ultrapure nitric acid (Radojevic and Bashkin, 1999) for analysis of heavy metal.

Analytical methods: Analysis of collected water samples was done as per Standard Methods (APHA, 2012) for water quality parameters. The pH and electrical conductivity was measured by using LABINDIA, EC and pH meter while turbidity of the samples was analyzed by using turbidity meter (EUTECH instruments TN-100). Color was measured as the transmittance at 450 nm (pc Based Double Beam Spectrophotometer 2202). Total solids including suspended, dissolved and volatile solids were determined using hot air oven at 100° C to 105°C. Dissolved oxygen (DO), bio-chemical oxygen demand (BOD), chemical oxygen demand (COD), chlorides, and alkalinity, total hardness as $CaCO_3$, total nitrogen, sulphate, oil and grease were estimated by following prescribed standard procedures (APHA, 2012). Major anions (F^-, NO_3^- and SO_4^{2-} were analyzed by UV Spectrophotometer and Cl^- concentration was estimated by titrimetric method. Major cations Na^+ and K^+ were estimated by Flame photometer. Ca^{2+} and Mg^{2+} concentration were analyzed as $CaCO_3$ by titrimetric method. The concentration of heavy metals in water samples was determined by ICP–MS (Make: Perkin Elmer, Model: ELAN DRCe) at CSIR- Central Institute of Mining and Fuel Research, Dhanbad. Reagent blank determinations were used to correct the instrument readings. For the accuracy of the analysis was checked by analyzing reference standard of water (NIST, 1640a). The precision obtained in most cases was better than 5% RSD with comparable accuracy.

Pot experiments: The effects of irrigating the soil with CMW and DRW on soil quality and biochemical changes of the plant *Z. mays* L. var. Pioneer at seedling stage were studied in the pot experiment. Stock solutions prepared as CMW +DDW (1:1), CMW (100%), DRW + DDW (1:1), DRW (100%) and Control (DDW-100%) and were used for irrigation of *Z. mays.* These treatments were replicated thrice in a completely randomized design. Germination percentage, shoot length, root length, number of leaves and number of roots of *Z. mays* were recorded. Photosynthetic pigment of *Z. mays* analysis including total chlorophyll, chlorophyll a and b was done by following the method (Arnon, 1949). Soil quality parameters like pH, EC, organic carbon and dehydrogenase activity were estimated by following standard procedures (Tandon, 1995; Chhonkar *et al.,* 2007).

RESULTS AND DISCUSSION

Characteristics of CMW and DRW: The results in the Table 1 show that pH of CMW was slightly alkaline (pH 7.98). DRW was more turbid as compared to CMW samples. The electrical conductivity of collected sample of CMW 578 µS/cm while in Damodar river was observed 218 µS/cm. Turbidity is expressed as NTU (Nephelometric turbidity unit). Turbidity of Damodar water was found higher 1.9 NTU. Total solids (275 mg/l), TSS (180 mg/l) and TDS (405 mg/l) were found in CMW. Coals being friable in nature, lots of fines are generated during the coal handling and operation process which increases the TSS in CMW. Oil and grease content was high in CMW (0.77 mg/l) and Damodar River (0.22 mg/l). Total nitrogen and phosphorous were very high in Damodar water than CMW. DO content of DRW was higher (6.3 mg/l) than CMW (5.8 mg/l). BOD was less in CMW (5.9 mg/l) than DRW (3.3 mg/l).

The problem of release of metals from coal into water has been reported in earlier studies. The metals reported in coal were Al, Ca, Co, Cu, Fe, Mg, Mn, Ni, Pb and Zn and the order of leaching rate was Mn>Ca>Mg>Zn>Pb>Fe>Ni>Cu>Co>Al (Vlado, 1983). In the present study, amongst the parameters analyzed, the maximum value was observed for Fe = 224.2 µg/l in CMW followed by 188.4 µg/l in Damodar water. Na, K, Ca and Mg present in coal have also been found to dissolve in water (Orhan, 1994). Thus, Ca, Mg, Na and K were high in CMW (Table 1). Chlorine is probably both organically and inorganically bound to coal (Swaine, 1990). The chloride content was high in CMW (15.7 mg/l). Among all parameters, only the TSS of CMW (180 mg/l) and Damodar River (102 mg/l) exceeds the prescribed limit (100 mg/l) for industrial effluents, rest all are well within the prescribed limits.

Impact of CMW and DRW on plant and soil health: During the present study, cent percent germination of *Z. mays* was observed in all treatments which revealed that plant can establish in soils irrigated with CMW (Table 2). In line with germination percentage, plant shoot and root length of *Z. mays* was more in CMW than control (double distilled water). The enhanced growth of *Z. mays* was observed in present study is probably due to the nutrients added from CMW. In contrast to present study found that germination of wheat was not affected by the mine effluent (Kaushik *et al.,* 1996), while Kumar (2014) reported that the concentrations (up to 50%) supported the seed germination of *Z. mays*. However, the seedling growth of wheat was reduced significantly by the effluent in aqueous medium, but not in soil. Effluent water from oil and detergent factories exhibited significant inhibition on shoot growth but root growth was significantly enhanced in sunflower. The number of leaves, number of roots, root and shoot length of *Z. mays* was significantly lower in 100%

Table 1. Characteristics of CMW and DRW of east Bokaro coalfield.

Parameters	CMW	DRW	BIS Effluent irrigation standard (2010)
pH	7.98	8.31	5.5–9
Temperature (°C)	27	29.4	–
Electrical Conductivity (µS/cm)	578	218	–
Turbidity (NTU)	0.75	1.9	5
Colour (T 450 nm)	90.5	89	–
Total solids (mg/l)	275	240	–
TSS (mg/l)	180	108	100
TDS (mg/l)	405	152	2,100
Alkalinity (bicarbonate) (mg/l)	132	92	–
Total hardness (mg/l)	347.8	114	–
F^- (mg/l)	0.73	0.61	–
Cl^- (mg/l)	15.7	6.7	1,000
NO_3- (mg/l)	23.6	24.2	--
HCO_3^- (mg/l)	140.1	82	--
SO_4^{2-} (mg/l)	191	29.1	1,000
Ca^{2+} (mg/l)	59.4	32.6	–
Mg^{2+} (mg/l)	48.5	7.8	–
Na^+ (mg/l)	17	12.3	–
K^+ (mg/l)	6	1.62	–
Oil and grease (mg/l)	0.77	0.22	10
Total nitrogen (mg/l)	0.31	12.95	100
Phosphorous (mg/l)	0.0007	0.00034	5
DO (mg/l)	5.8	6.3	–
BOD (mg/l)	1.3	3.1	30
COD (mg/l)	5.9	3.3	250
Pb (µg/l)	0.44	0.99	0.1
Cd (µg/l)	0.12	0.08	2
Fe (µg/l)	224.2	188.4	–
Mn (µg/l)	1.95	1.98	–
Cu (µg/l)	2.67	5.82	3
Zn (µg/l)	5.06	7.69	5
Ni (µg/l)	8.14	1.26	3
Cr (µg/l)	3.75	2.89	2
Co (µg/l)	0.09	0.04	–

Values are the means of three samples; BIS-Bureau of Indian Standards; CMW-Coal mine water; DRW-Damodar river water.

Table 2. Effect of CMW and DRW on seed germination and the morphology of *Z. mays* L. var. Pioneer.

S.N.	Treatments	Germination percent	Shoot length (cm)	Root length (cm)	No. of roots	No. of leaves
1	CMW+DDW (1:1)	100	7.87	6.40	4.0	3.0
2	CMW (100%)	100	9.93	10.80	5.0	3.0
3	DRW+DDW (1:1)	100	9.03	19.77	6.0	3.0
4	DRW (100%)	100	7.33	25.93	6.0	4.0
5	Control (DDW)	100	7.50	14.77	4.0	3.0

CMW: Coal mine water, DRW: Damodar River water, DDW: Double distilled water.

Table 3. Effect of CMW and DRW on the chlorophyll content of *Z. mays* L. var. Pioneer.

S.N.	Treatments	Total chlorophyll (mg/g)	Chlorophyll-a (mg/g)	Chlorophyll-b (mg/g)
1	CMW+DDW (1:1)	1.36	0.64	0.72
2	CMW (100%)	1.2	0.52	0.68
3	DRW+DDW (1:1)	1.43	0.63	0.80
4	DRW (100%)	0.67	0.15	0.52
5	Control (DDW)	0.66	0.13	0.53

MW: CMW, DR: Damodar River, DW: double distilled water.

Table 4. Impact of CMW and DRW on soil quality parameters.

S.N.	Treatments	pH	EC (µS/cm)	Organic C (%)	Dehydrogenase activity (µg TPF/g/h)
1	CMW+DDW (1:1)	6.46	150	2.05	12.81
2	CMW (100%)	6.67	173	1.58	10.85
3	DRW+DDW (1:1)	6.63	231	1.89	12.11
4	DRW (100%)	6.47	218	1.15	11.15
5	Control (DDW)	6.72	223	1.88	11.78

CMW: Coal mine water, DRW: Damodar River water, DDW: Double distilled water.

CMW than control. CMW has significantly increased the plant growth parameters of *Z. mays*; diluting the CMW with good quality water is more effective than unmixed CMW. Total chlorophyll, chlorophyll a and b contents of *Z. mays* significantly increased in all the treatments maximum being at Damodar River (50% dilution) followed by CMW (Table 3). Similarly it was found that the effluent treatment increased the concentrations of various pigments of wheat (Kaushik *et al.,* 1996). Kumar and Chopra (2013, 2014) reported that the sugar mill effluent irrigation supports the seedling growth of sorghum and pearl millet. Higher oil content and favorable photosynthesis were observed in mustard crops irrigated with waste water, due to better utilization of nutrients (Aziz *et al.,* 1994). The nutrient content of the effluent was able to maintain good plant growth for most of the tested species (Claudio *et al.,* 2004).

In the present study, the soil quality was studied at 30 days after the treatment with CMW/Damodar water. It is evinced from Table 4 that soil pH was not affected due to irrigation with CMW. Conductivity was high (0.231 dS/m) in Damodar water with 50% treatment and the least was observed at CMW (0.150 dS/m). Continuous irrigation with untreated paper mill effluent having high EC resulted in the development of sodicity and soluble salts in the soil (Narwal *et al.,* 2006). Similar findings were also reported by (Chonnkar *et al.,* 2000; Raverkar *et al.,* 2000). Organic carbon was high in 50% of CMW and low in 100% of Damodar water. Dehydrogenase activity in the soil environment considered to be a major contributor of overall soil microbial activity and soil quality (Masto *et al.,* 2006), was significantly higher in CMW (12.81 µg TPF/g/h). In general, there was no adverse effect on plant or soil quality by irrigating with CMW. Therefore, dilution of CMW enhanced the plant growth parameters, chlorophyll content of *Z. mays* and soil enzyme activity.

Conclusions

This study concluded that characterization of CMW and DRW revealed that only total suspended solids of DRW and CMW exceeds the prescribed Indian standards. Mine waters emanating from the coal mines could be used for irrigation. The absolute CMW showed adverse effect on plant chlorophyll content of *Z. mays* and soil enzyme activity while dilution of CMW enhanced the plant growth parameters, chlorophyll content of *Z. mays* and soil enzyme activity. The CMW and DRM could be successfully used for irrigation. Mixing of CMW with DRW may enhance the quality of water. Thus, this study provided the irrigation water availability in the study area. This may be helpful in the future for the sustainable irrigation management of the water resources in these mining areas.

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