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Detection of illegal mine voids using electrical resistivity tomography: The case-study of Raniganj coalfield (India)

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ABSTRACT

Unauthorised coal mining activities may result in development of hidden hollows, rat holes, galleries, goafs, shafts etc., which pose great threats of land subsidence, fire, water flooding leading to severe environmental hazards, health problems and safety issues to the local people. Present study deals with delineation and mapping of unauthorised coal mine voids/galleries over an abandoned old mine around Khudia open cast mine, Nirsa, Raniganj coalfield, India. Electrical resistivity tomography (ERT) study comprising Wenner, Schlumberger, Dipole-Dipole, and Gradient arrays has been carried out along three parallel profiles over the affected area. Further joint inversion of all combined arrays has also been carried out using 2.5D resistivity inversion program, to combine the relative advantages of all the arrays, for producing superior results. 2D ERT sections have been generated for the filtered data sets with a constant quality factors and two different current thresholds. The best results have been obtained, from joint inversion of all combine arrays for the filtered data with higher current threshold. The observed resistivity anomalies are well correlated with the depth of coal seam occurrences as observed in the borehole litholog of nearby area. Finally, a geoelectric model of four unauthorised coal mine galleries has been established with their extension and orientation over the study area. The results demonstrate the suitability of the ERT technique through joint inversion of all combined arrays for characterization of illegal coal mine workings.

1. Introduction

India is one of the biggest coal producing countries in the world with an annual production of ~600 million tonnes. Initially, coal mining in India started over Raniganj coalfields during eighteenth century in a random manner and regular mining started in early nineteenth century. The collieries in Raniganj coalfield were owned by several companies and owners. These were nationalized in 1973. Prohibited mining of coal has been serious matter of concern for a long period of time. Generally, abandoned mines are the main source of prohibited coal mining activities. Subsequent to the economic coal extraction, the remaining coal in an abandoned mine is stolen by coal mafias and illegal miners which leads to roof falling, water flooding, poisonous gas leaking and further results in loss of land, property and life. Generally, illegal miners dig rat holes in abandoned mining areas. Over the time, the underground hollows are left unfilled and diggers enter inside with ease and excavates unscrupulously. The mining cavities collapse due to natural alteration processes in the course of time. About 200 miners died in Mahavir Collieries, Raniganj coalfield, India in 2001. Illegal mining may also take place on fresh land in small patches in haphazard manner which always keep on changing in different direction and depth. Sometimes miners burst small explosives after the first entry point which is called as foxhole. The illegal mining may hamper the legal mining activities as the illegal tunnels are made in a random and unscientific manner. Other concern that may arise is the damage of the foundation of buildings located in these mining areas. The local roads and railway tracks may also be severely damaged due to potholes, sinkholes and land subsidence which cause inconvenience to the transportation. Sometimes, during illegal mining oxygen seeps into the underground methane-charged coal seam which leads combustion of the coal and spread of coal fire in the vicinity (Prakash et al., 1995, 1997; Prakash and Gupta, 1998, 1999; Vaish and Pal, 2013, 2015a, 2015b, 2016; Pal and Vaish, 2014; Pal et al., 2016; Singh et al., 2015; Kumar et al., 2014, 2015a; Singh and Pal, 2015; Bharti et al., 2014, 2016; Srivardhan et al., 2016). Such kind of coal fire incidents occurred four times between December 2007 and February 2008 near Nimcha village, Raniganj coalfield. The burning of coal leads to the formation of voids due to reduction of volume by the transformation of coal into ashes (Bharti et al., 2016). The term subsurface cavity in coal mining area is used to denote all subsurface features, such as mining galleries, goafs, rat holes, foxholes, caves, caverns, voids, potholes and sinkholes etc. caused by different coal mining and coal fire activities. The delineation and mapping of these subsurface cavities are

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essential over Raniganj coalfield, India for safety of the local environment, agricultural land, ecology and health of the people.

Different geophysical methods used for detection of subsurface cavity/cave/void/goaf/gallery, sinkhole, karst topography etc. are i) electrical resistivity tomography (Cardarelli et al., 2006; Pánek et al., 2010; Cardarelli et al., 2010; Gómez-Ortiz and Martín-Crespo, 2012; Martínez-Pagán et al., 2013; Metwaly and AlFouzan, 2013; Satitpittakul et al., 2013; Cardarelli et al., 2014; Kumar et al., 2015b; Bharti et al., 2016; Bhattacharya and Shalivahan, 2016 among others), ii) Vertical Electrical Soundings (Rodríguez Castillo and Reyes Gutierrez, 1992) iii) Induced Polarization Tomography (Brown et al., 2011; Martínez-Moreno et al., 2014), iv) Self-Potential (Lange, 1999), v) Ground Penetration Radar (Leucci and De Giorgi, 2010; Brown et al., 2011; Gómez-Ortiz and Martín-Crespo, 2012 among others), vi) Electromagnetic (Lange, 1999), vii) Seismic Refraction Tomography (Cardarelli et al., 2010, 2014), viii) Multichannel Analysis of Surface Waves (Debeglia et al., 2006), ix) Microgravity methods (Gambetta et al., 2011; Reynolds, 2011; Martínez-Moreno et al., 2014 among others), and x) Magnetic (Mochales et al., 2008). Among the various geophysical methods, electrical resistivity tomography (ERT) method has been established to be a very effective tool for characterization of cavities (Van Schoor, 2005; Ezersky, 2008; Cardarelli et al., 2006, 2010, 2014; Metwaly and AlFouzan, 2013; Martínez-Pagán et al., 2013; Singh, 2013; Singh et al., 2016; Martínez-Moreno et al., 2014; Bharti et al., 2016). In recent years, ERT technique is becoming more popular as a key technique for environmental, mining engineering, civil engineering and shallow subsurface investigations (Morelli and LaBrecque, 1996; Cardarelli et al., 2006, 2010; Santarato et al., 2011 among others), including void/cave detection (Van Schoor, 2002; Zhou et al., 2004; Abu-Shariah, 2009; Ortega et al., 2010; Pánek et al., 2010; Ravbar and Kovačič, 2010; Martínez-Moreno et al., 2014; Satitpittakul et al., 2013; Bharti et al., 2016). This is mainly due to its cost effectiveness, simplicity in automated data-acquisition, efficient user-friendly inversion of acquired data with highly reliable geoelectric model of subsurface features (Van Schoor, 2005; Athanasiou et al., 2007; Loke et al., 2013; Revil et al., 2013; Martínez-Moreno et al., 2014; Singh et al., 2016; Bharti et al., 2016; Bhattacharya and Shalivahan, 2016). The subsurface resistivity distribution is determined by making measurements on the ground

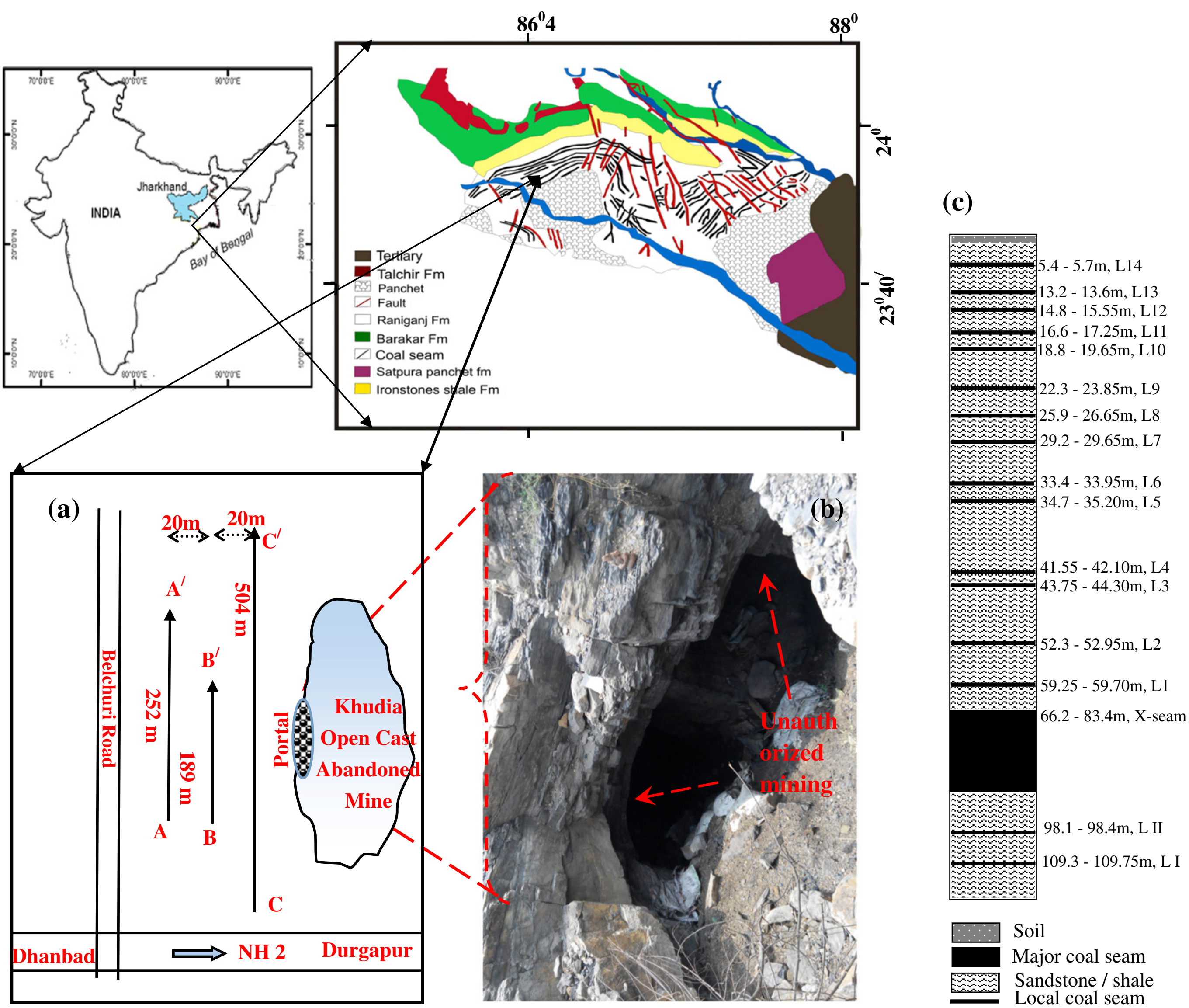

Fig. 1. (a) Map of the study area along with generalized geological map of Raniganj Coal field, showing the location and lengths of ERT sections (b) field photograph showing illegal mining galleries, (c) available borehole litholog of nearby area showing different coal seams (ECL, 1998).