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Soils of the Indo-Gangetic Plains: a pedogenic response to landscape stability, climatic variability and anthropogenic activity during the Holocene

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ABSTRACT

Bound by the Himalaya in the north and the Craton in the south, the Indo-Gangetic Plains (IGP) is one of the largest fluvial plains of the world. The IGP is monotonously flat with a spread of surface soils in hot arid conditions of Rajasthan in west to per-humid conditions in West Bengal. The soil-geomorphology of the IGP detailed during the last few decades is useful in determining the interrelationship among the pedogenesis, the climate, and the landscape evolution during the Holocene. These studies demonstrate that the IGP soils developed on five geomorphic surfaces with varying degree of development. Soils occurring on older geomorphic surfaces (>2.5 ka) are polygenetic with a distinct record of climatic changes and neotectonics.

The present synthesis is based on recent developments in pedology achieved through macro- and micromorphology, clay mineralogy, pedogenic calcrete, and polygenetic pedogenic features of the IGP soils. A critical evaluation of the IGP soils has helped to comprehend the subtle nuances of the pedogenic processes that were also influenced by anthropogenic activities and cultivation over this vast agricultural tract during the Holocene. We provide state-of-the-art information on the pedology, polygenesis, and soil degradation (natural and anthropogenic) over the last 10 ka. The review has potential as a reference for critical assessment of the pedosphere for health and quality in different parts of the world. In addition, it facilitates developing a suitable management practices for the food security in the 21st century.

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1. Introduction

The Indo-Gangetic Plains (IGP) is a "foredeep" depression between the Indian Peninsula to the south and the Himalaya in the north (Wadia, 1966). Geological studies, geophysical surveys and deep drillings by the Oil and Natural Gas Commission of India reveal that the IGP is a vast asymmetric trough with maximum thickness of about 10 km in the foothills to the north and a minimum of few meters in the south towards craton (Wadia, 1966; Sastri et al., 1971; Rao, 1973; Raiverman et al., 1983; Parkash and Kumar, 1991). Origin of the foredeep is linked to the Himalayan orogeny caused by the collision of Indian and Tibetan plates at ca 50 Ma (Klootwijk et al., 1992; Gaina et al., 2007; Kumar et al., 2007; Kent and Muttoni, 2008). The Indian Plate is still moving at the rate of 2–5 cm/y towards the north and the compression generated throughout the plate ensures that it is continuously under stress providing the basic source of strain in the fractured zones (Gaur, 1994).

The fluvial deposits and landforms of the IGP have been influenced by the neotectonics during the Holocene. The major rivers of the IGP have changed their courses and, at present, are flowing towards southeast and easterly directions with convexity towards the southwest under the influence of major thrusts bordering the IGP (Parkash et al., 2000). The IGP is mainly drained by Himalayan Rivers such as the Indus, the Yamuna, the Ganga, the Ramganga, the Ghaghara, the Rapti, the Gandak, the Bhagirathi, the Silai, the Damodar, the Ajay, the Kosi, and the Brahmaputra rivers and also by the rivers originating in the Craton from the south such as the Chambal, the Betwa, and the Son rivers (Fig. 1). The overall topography of the IGP is remarkably flat with a gradient of <0.02% from the Punjab (300 m msl) in the west to the eastern delta of West Bengal (1.5–9.0 m msl) (Fig. 2).

The IGP is one of the most extensive fluvial plains of the world with an aerial extent of about 5.0 x 10^5 km^2. It accounts for the one third cultivable lands and a major contributor of the food supply for the Indian population. The evidence from many archaeological sites of the IGP show considerable changes from incipient agricultural activities to well developed agricultural practices in the IGP during the last 10,000 years (Sharma et al., 1980; Kumar et al., 1996; Misra, 2001; Fuller, 2006; Saxena et al., 2006; Williams et al., 2006). Agriculture was the mainstay of the people of ancient India and the agriculturists were aware of variations in productivity of different types of soils (Raychaudhuri, 1975; Velayutham and Pal, 2004). Archaeological lines of evidence further indicate that western parts of the IGP were the ancient agricultural centres (~10 ka) from where dispersal of domestication and anthropogenic activities took place towards the eastern and the southern parts of India (Fuller, 2006; Chen et al., 2010).

The surface soil remains the firm foundation of human life thriving on it. However, modern use and abuse of soils has made it one of the most degraded and least understood ecosystems in terms of its relationship with people. The knowledge of the IGP soils is important for understanding the long-term human interactions (Williams and Clarke, 1984, 1995; Williams et al., 2006; Gibling et al., 2008). The ancient literature of India ('*Vishnu Purana*' from the first century C.E.) suggests that the early farmers had the knowledge of soils, landforms, erosion, flooding, sedimentation, vegetation, land use, water and human health (McNeill and Winiwarter, 2004; Wasson, 2006). Scientific characterization of the the IGP soils can be traced back to the first half of 19th century when the Geological Survey of India started studying the soils and the underlying strata in 1846 (Raychaudhuri, 1975; Velayutham et al., 2002). The IGP soils were defined as one of the four major soils groups in India (Voelcker, 1893; Leather, 1898). Wadia et al. (1935) note that soil group boundaries were nearly co-incident with the major lithotectonic boundaries. During the past five decades various soil-forming processes such as calcification, leaching, lessivage, salinization and alkalinization, gleization and homogenization have been identified in the IGP (Shankarnarayana and Sarma, 1982). These processes lead to the formation of a variety of soils in the IGP that represent mainly three soil orders – Entisols, Inceptisols and Alfisols (Shankarnarayana and Sarma, 1982). Recent studies, however, indicate that Mollisols, Aridisols, and Vertisols are also present in the IGP (Bhattacharyya et al., 2004; Ray et al., 2006).

The intimate relationship of soils and landforms forms the sound basis for the use of soils in geological studies (Ruhe, 1956, 1960, 1964; Richmond, 1962; Morrisson, 1964, 1965). The critical factors that influence soil-formation are climate, biotic activity, relief, parent material, and the age of the geomorphic surface (Jenny, 1941). The application of soils in geomorphic research is now a well-established approach as "soil-geomorphology" for understanding the genetic relationships between the soils and the landscape elements (Birkeland, 1990; McFadden and Knuepfer, 1990). It is due to the fact that soils form an essential component of any landscape and the history of any landscape evolution is intimately tied with the history of soil development (Birkeland, 1990). The application of a soil geomorphic approach to soil landscape studies has led to a more quantitative evaluation of the geomorphic processes operating over different time scales ranging from 10^3 to 10^5 years (Ritter, 1986). Soil-geomorphic studies over the last three decades have demonstrated that soil development "functions" help in determining the interrelationship among time, climate, landscape development and the soil-forming processes (Birkeland, 1990; Harden, 1990; McFadden and Knuepfer, 1990).

The soil-chronosequences are potentially useful to estimate rates of soil development and landscape evolution over different time