CHAPTER-2

2. Literature Review

2.1 Previous work

Badlands are epitome of soil erosion and turning the landmass into a degraded land, which cause heavy damage to the environment, local economy and livelihood of the peoples. The formation ofBadlands is a slow and gradual process, mostly developed on alluvium or soft sedimentary terrain.The processes of formation of the badlands are very diverse viz. slope, upliftment, change in rainfall pattern, land pattern change, deforestation and overgrazing, ill-considered tillage, over- drafting, an incompetent physico-chemical property of the soil, anthropogenic activity, etc, (Kaul,1962; Tejwani, 1959; Haigh, 1984; Bull and Kirkby, 2002; Marzolff et al., 2011 Tignath et al., 2005).

This chapter deals with the details of the previous work done by various researchers on various aspects of Badlands viz morphometry and morphotectonic studies, role of the physico- chemical properties of the badlands affected soils , fractal , multifractal and lacunarity analysis.

The morphometric analysis of landform is the mathematical analysis of earth's configurations, surficial expressions, landforms and dimensions (Clarke et al., 1966; Alqahtani and Qaddah, 2019). The quantitative geomorphological concept has been introduced by Horton (1945) over the idea of landforms as geological features. Later on the methodology was developedby several other workers like (Strahler, 1952, 1957 and 1964; Schumm, 1956; Morisawa, 1958 and 1959; Scheidegger, 1965; Shreve, 1967; Gregory, 1966; Gregory and Walling, 1968 and 1973;Hack, 1973). The methodology (morphometric analysis) becomes more effective by the development of modern remote sensing and GIS (Geographic Information System) techniques (Srtvastava and Mitra, 1995; Nag, 1998; Nag and Chakraborty, 2003; Pandey et al., 2004; Vittala et al., 2004; Sreedevi et al., 2005; Narendra and Rao, 2006; Pike, 2010; Bagyaraj and Gurugnanam, 2011; Magesh et al., 2011; Rawat et al., 2011; Jasmin and Mallikarjuna, 2013; Parasiewicz et al., 2017;Chen et al., 2019)

Smith (1950) has used morphometric analysis to describe the badlands terrain. He definedhighly dissected gullied terrain with ultrafine drainage texture. Schumm (1956) has given a detailed explanation of Pearth Amboy badlands, about its formation and development with the help of mrphometric study. Wood (1980), has explains rilling and gullying activity on the cinder cone of San Francisco, Arizona with the help of morphimetric analysis. Jianjun and Mukang (1994) have studied gully rejuvenation on the basis of drainage density (a component of morphometry analysis) analysis, in the Weihe basin, north-east of China. Mondal (2013) has studied soil degradation, rill and gully erosion in Birbhum District, West Bengal, India with the help of morphometric analysis. Tignath et al. (2014) and Gajbhiye et al. (2014) have applied morphometric analysis to study erosion and prevention technique. Caraballo-Arias (2016), has combine morphometry analysis and hydraulic geometry to study gully in south-west Spain.

Penck (1953) suggested that, upliftment and erosion both act in consecutive manner. Harvey, (1987), Grove and Rackham (2001) and Wainwright and Brazier (2011) have observed that in a regional scale tectonic upliftment is essential for the formation of badlands. Badlands arespecified to the soft sedimentary terrain, with the change of base level, rate of incision gets exceeded, subjected to large gully and badlands system (Begin et al., 1981; Ouchi, 1985; Moreno-de las Heras and Gallart, 2016).

The influence of neotectonic over the badlands formation is recognized by many workers all over the globe. In Mediterranean climate, badlands formation is very often. Many badlands sites like Basilicata badlands (Southern Italy), badlands of Almeria region (South-eastern Spain).In India Chambal ravines are also influenced by neotectonics (Ranga et al., 2015).

In Basilicata badlands, south-eastern Apennine Mountain range del Prete et al. (1997) andPiccarreta et al. (2006) have observed that the badlands is a result of the tectonic intervention of Europe and Africa. This badlands site is characterized by calanchi and biancane and developedof a soft sedimentary terrain of marine clay and silty/sand clay. During Middle to late Pliocene theregion got uplifted at a rate of 0.5- 0.9 mm/yr and the rivers of the region deeply incised into the ground with fast succeeding gully clusters, progressing headward from the river networks (del Prete et al., 1994; Grove and Rackham, 2001; Bentivenga and Piccarreta, 2016). The terrain of south-eastern Spain, particularly the Almeria region is influenced by tectonic activity and this neotectonic activity is linked with badlands initiations (Wise et al., 1982; Harvey, 1987; Alonso- Sarria et al., 2011). Harvey et al. (2014) have noticed that the badlands of this region is developedover the piedmont plain of sedimentary and metamorphic protoliths. The highest uplift rate of theregion has experienced since Pliocene to Recent (0.17mm/yr) (Mather et al., 2002; Braga et al., 2003; Harvey et al., 2014).

The tectonic influence over the formation of badlands can also be observed in India.

Rangaet al. (2015) and Sharma and Pani (2017) have found that the neotectonism plays a significant rolein the development of Chambal badlands.

Ahmed (1968 and 1973), Singh (1996) and Ghosh et al. (2018) suggested that, incised valley and deep gullies formed along the northern slope of Vindhyan mountain range in due to the neotectonic uplift. The northern edge of Indian shield bulges due to the subduction of Indian plateinto Eurasian plate. On the basic of the study of sedimentary fill, the southward migration of the Ganga Plain during the Late Quaternary is recognized as the major cause of the peripheral bulge in reply to the last thrusting event in the Himalaya (Singh and Bajpai, 1989).

Many workers like Bull and McFadden (1977), Keller and Pinter (1996 and 2002), Chen et al., 2003; Das and Mukherjee (2005), Baioni (2007), Raju and Babu (2012), Dar et al. (2013), Zhong et al. (2018), Prakash et al. (2017), Bhatt et al. (2020) have found morphotectonic indicatorsplay a significant role in indicating active tectonic zones in concealed basins. Joshi and Nagare (2013) have worked out the morphotectonic parameters of the badlands formed on the western pediment plain of the Deccan plateau.

Badlands predominantly develops over soft sedimentary terrain and these materials are subject to high dispersion risk. Schumn (1956) and Moreno-de las Heras and Gallart (2016) exhibited that lithology plays a major in the spatial distribution of badlands, in a large scale. Erosive processes involved in forming badlands act on the soil lithologies differently in varied environmental conditions (Bryan and Yair, 1982; Pinna and Vittorini, 1989; Martínez-Murillo andNadal-Romero, 2018). Causative factors that initiate processes of deterioration of soils are quite diverse and area-specific. These factors may be overgrazing, anthropogenic stress, land use/land cover change, deforestation, change in slope of the terrain, change in precipitation pattern with time, earthquakes etc. that form such initial conditions which may trigger variations in the physico-chemical properties of soils in the fluvial environment in the direction where soils gradually lose their stability (Faulkner et al., 2003, 2004; Moreno-de las Heras and Gallart, 2018; Raiesi and Salek-Gilani, 2020; Romero-Díaz et al., 2020; Darama et al., 2021; Wang et al., 2021). The physical properties like bulk density and total porosity of soils have been found to influence the runoff and plant growth, which in turn affect soil erosion (Czyz et al., 2001; Pagliai et al., 2003, 2004; Czyz, 2004). Atterberg limits of soils have been studied in relation to soil stabilities and general characteristics by several researchers (Sharmeen and Willgoose, 2006; Deng et al., 2017;Parmar et al., 2021). Chemical properties and available nutrients present in the soil determine vegetation growth, which indirectly relates to erosion (Thornes, 1985; Alexander, 1982; Campbell,1997; Battaglia et al., 2003; Summa and Giannossi, 2013; Gaspar et al., 2020).

In this context physicochemical property provides a brief knowledge about the depressiveness of the soil. Soils having poor physicochemical properties are prone to erosion. Genetically sand and silt grains have less cohesion in comparison to clay (Schmidt, 1996 and Romero et al., 2007). Furthermore, younger soil or sediment which has lesser organic matter has high erosional property. Pioneer work by Vittorini (1977) , Imeson et al. (1982), Alexander (1982), Lopez-Bermudez and Romero-Diaz (1989), Benito et al. (1993), Alexander et al. (1994), Regüés et al. (1995), Pardini et al. (1996), Gutierrez et al. (1997), Sole-Benet et al. (1997), Cerdàand Garcìa-Fayos (1997), Torri and Bryan (1997), Phillips and Robinson (1998), Farifteh and Soeters (1999), Faulkner et al. (2000), (2003), (2004), Cantón et al. (2001a), Robinson and Phillips(2001), Piccarreta et al. (2006), Díaz et al. (2007), Desir and Marín (2013), Diaz-Hernandez et al.(2015) shows mineralogical and physicochemical properties of soil is a significantly important parameter for soil erosion and badlands formation.

Schumm (1956), Kasanin-Grubin (2013), Vergari et al. (2013), Moreno de las Heras and Gallart (2016) have quoted that, badlands is lithology driven. Hydrogeomorphological features like rill and gully are mostly developed in terrains predominantly composed of marl, limestone, shale, soft sandstone etc. (Faulkner 2013). But badlands can be initiated and developed in the alluvial derived from igneous and metamorphic rocks also.

Joshi and Nagare (2013) have reported badlands in western pediment plain of the Deccan plateau, India. Aown and Kar (2016) have reported badlands develops in lateritic surface in Bankura district, India.

So, distinctively the initiation of badlands depends on the mineralogy, geochemistry, texture of grains, clay mineralogy, weathering process and mechanisms. Clay size particles and clay minerals have an assertive contribution in the initiation and formation of rill and gully. The gullied terrain having less clay size particles in the soil, experiences only surface erosion due to lack in cohesion, produces rill and gully. Terrains having high percentage of clay particles and a considerably higher swelling and dispersive clay minerals (Bridge and Tunny, 1973) can producesubsurface erosion in the form of piping, cavities. This gets eventually collapse and form gullies. In the case study of Zin badlands, Israel, Yair et al. (1980) identifies the role of gypsum is significant in swelling up the mudrock. In Tabernas badlands, Spain, dissolution of moderately soluble gypsum which fills the cracks is responsible for mudrock breakdown (Cantón et al., 2001b).

In the Ebro basin, Benito et al. (1993) and Gutierrez et al. (1997) found that the physico- chemical properties of materials were diagnostic of badlands morphology, with divalent cation- dominated sites being non-dispersive and dominated by overland flow processes and monovalentcation-dominated sites being characterized by a more chaotic morphology and extensive subsurface pipe formation.

Romero-Díaz et al. (2020) have analyzed three badlands of Spain, Abanilla, Gebas and Mula in their study they have found that, the basic distribution of grain size in these areas are loamy-silt, i.e. majority of the grains are silt. Schmidt (1996) and Romero et al. (2007), in their study, they have found that silty and fine sandy textured soil are very prone to erosion in comparison to clayeyand coarse-grained sandy soil. However it does not mean that badlands cannot be form in clayey terrain.

Erosional action in Dinosaur park badlands is highly influenced by clay content in soil andamount of swelling clay (smectite) (Kašanin-Grubin, 2018). Smectite in contacts with sodium richwater, rapidly lose its strength than kaolinite owing to the high CEC (Shainberg et al., 1988; Taylorand Eggleton, 2001).

Percentage of clay is positively influenced the Atterberg limits (liquid and plastic limit). So, soil low in clay content generally has higher the dispersion rate in water saturation condition;this also indicates low compressibility and low porosity (Wagner, 2013). The low porosity of soilalso encourages surface runoff, so as relatively higher erosion. Thus these parameters form a positive feedback loop in badlands ecosystem and gradually enhancing the process.

Just like clay minerals and clay particles, organic matter is a significant physicochemical property which controls or influence erosion of soil. Very significantly organic matter is acts as adhesive to form the soil structure. Morgan, (1986), Brady and Weil (2002) have found that soil having less than 2% organic matter content are prone to erosion. Except this organic acids neutralize the topsoil, providing some stability to the materials (Faulkner, 2007). Soil organic matter is a critical factor for the soil health, soil aggregate, porosity and stability (Chaney and Swift, 1984). Organic matter is essential for water retention, soil structure and cation exchange capacity and also the source of a large portion of many nutrients. Moreover, ninety-five percent ofthe nitrogen in the surface soil and 15- 80% of the phosphorus are found in organic matter (Allison,1973). The soil in gullied and ravenous terrain generally has low content of organic matter.

The percentage of organic matter in soil depends on several factors, among those soil porosity and soil bulk density are two vital parameters. Soil having low bulk density contains more porosity, better aeration, generally got high organic matter content, consequently better soil structure and water storage capacity (Puigdefábregas, 2005; Cantón et al., 2011). Moreover, the growth of plant's root is also hindered in higher soil bulk density terrain. According to USDA- NRCS (Technical Bulletin No.1355), soil bulk density >1.75 (gm/cm^3) restricts plant root growthin silts and silt loam textured soil.

The dispersive nature of badlands can also be documented through chemical analysis of soil. Alexander (1982) has portrait the dispersive behaviour of the materials on the basis of chemical properties of soil like pH, Electric Conductivity (EC), Sodium Absorption Ratio (SAR),Exchangeable Sodium Percentage (ESP) and Cation exchange capacity (CEC).

EC and SAR both represent the degree of salinity in the soil. The soils with EC > 4 dS/m and SAR ≥ 13 are classified as the sodic soils that have poor drainage (Waskom et al., 2007). Imeson et al. in 1982 did a pioneer work to detect the dispersive nature of soil based on EC and SAR, in Moroccan badlands. Letter on in 1984 Rengasamy et al. proposed *domains of dispersivity,*based on the relationship of EC and SAR.

Benito et al., (1993) and Gutierrez et al., (1997) have observed in their study of physicochemical properties of badlands soil of Ebro basin, Spain, that the high salinity and presence of exchangeable sodium percentage significantly causes dispersion of clay soil and subsequently influence subsurface erosion. In clay-rich materials, dispersion can reduce considerable water infiltration, which may prevent extensive pipe enlargement but induce rill formation (Bouma, 2006).

Gutierrez et al. (1997) has found in the badlands of Ebro basin, Spain that the badlands siteis severely eroded from internally as well as externally. The driving agents operating internal erosion are high pH concentration, low organic matter, EC and SAR. In their case study they wereobserved that, the soil of the terrain is alkaline with low organic matter content (<1%) and with high EC and SAR values.

Piccarreta et al. (2006) studied erosion processes in the badlands of Basilicata, southern Italy; they have observed that piping is a common geomorphic feature in clayey soil. Piping playsan important role in badlands morphology, especially in the intermediate and basal part of the slope, favouring the formation and development of calanchi and biancane. Physicochemical properties of materials are holding a major command in the morphological development. Moreover, the badlands consists of high concentration of sodium with high EC, SAR and pH.

Díaz et al. (2007) have analyzed three badlands sites in Spain, Abanilla, Gebas and Mula.Their main objective was to characterize the morphology of the badlands by analyzing mineralogical and physicochemical aspects of parent materials. In Abanilla site popcorn shaped gully and piping process appears with abundant silt content with high salinity and a higher EC, SAR and ESP.

Fractal geometry introduced by Mandelbrot (1967) is mathematical framework to treat complex and irregular geometries with similar patterns at varying scales. Thus, the term fractal isapplied to a pattern that repeats itself again and again to generate a complex ensemble of self- similar forms in nature (Mandelbrot, 1974, 1975 and 1982). By fractal analysis, Mandelbrot measured, the length of very complex coastline of United Kingdom. It has two basic properties like, self-similarity and heavy tails. Self-similarity describes the multiplicative invariance of an object’s structure at multiple scales, while heavy tails illustrate that self-similarity undergoes a power-law. Gully patterns are very resemble to tree pattern and channel networks. The use of fractal analysis in the study of these natural patterns is very vital and efficient to extract empiricalproperties (Milne, 1991; Gaston, 2000; Brown et al., 2002; Makarieva et al., 2005; Wu and Li, 2006). Application of multifractal methods along with lacunarity analysis has been successfully made in the various fields of geosciences (Xie et al., 1999; Montero, 2005; Rodríguez-Lado and Lado, 2017; Kong et al., 2019). Significant contributions on the river network structure have beenmade by earlier researchers (Pandey et al., 1998; Song et al., 2019; Xiang et al., 2019) and on the soil moisture–soil temperature–precipitation relationship (Bai et al., 2019) applying multifractal analysis. Similarly badlands system has also produced self-similar pattern, can be studied with fractal, multifractal and lacunarity analysis (Cao et al., 2020; Real et al., 2020).

Badland topography is driven by the erosive action of surface and subsurface water. Rill, gully, piping etc, are some common features of badland topography. Hydrogeomorphological features like rills and gullies spatially expand in head ward fashion (Yair et al., 1980). In Chambalravine site the common pattern that has been formed by ravine networks, are bulbous, compound and trilles pattern (Pani, 2012).

Jha et al. (2013) have suggested that off shoots of gullies are ultimately form hexagonal pattern. The growth of gully follows a definite patter at every definite stage of its growth. This growth pattern is identifiable and it is detected by ‘Fractal analyses’.

Clarke and Schweizer (1991) considered fractal geometry as a milestone achievement forthe scientific community in the Twentieth century. The concept has a very wide spread applicationsin the field of oceanography (Malinverno, 1989), astronomy (Coleman and Pietronero, 1992), geophysics (Schertzer and Lovejoy, 1991), geology (Turcotte 1992; Sahoo and Jain, 2017), meteorology (Lovejoy and Schertzer, 1986; Olsson et al., 1992 and 1993; Svensson et al., 1996). Various fields of physics (Mandelbrot 1983; Feder 1988; Vicsek 1992), microbiology (Veselá et al. 2002).

There are basically two fractal methods to study river channels the divider method (Richardson, 1961) and the box-counting method (Grassberger, 1983). Richardson (1961) used thedivider method for the first time; latter on Mandelbrot (1967) has used this method to estimate thefractal dimension of the coast line of United Kingdom.

Snow (1989) more accurately advanced the divider method and by this method he definedfractal sinuosity of twelve single channel stream segments and recommended that at scales close to river meandering length, river traces behaved as reasonable fractals.

Box counting method is most adopted and simplifies version to evaluate fractal geometry. Tarboton, et al. (1988), has used both the Divider (Richardson's) method and the box counting method to evaluate the fractal dimension of a DEM extracted channel networks. They found out that channel network is a kind of fractal, in which individual channel segment has a different fractaldimension than that of the channel network as a whole.

La Barbera and Rosso (1989) did fractal analysis of channel networks based of Horton's law (1945) of stream ordering and bifurcation and length ratio to derive fractal dimensions. Letteron in 1990's innovation in geomorphological study with fractal analysis significantly rises with the evolution of remote sensing and Digital Elevation Model (DEM) (Rosso, et al., 1991). More specifically, Agnese, et al. (1996) projected that the fractal dimension of channel networks as a function of basin diameter and magnitude within the framework of the link magnitude ordering system.

However, set of fractal objects like gully or cluster of gully, with scaling behaviour dependency and self-similarity are not sufficient to study with single fractal, rather Multifractal analysis (Cencini et al., 2010). Multifractal dimension has multiple singularities, there for the fractal value of each single component and their union can also be determined individually (Feder,1988; Vicsek, 1992).

Ariza-Villaverde et al. (2015) has used multifractal analysis to recognize the self-similaritypatterns of drainage network extracted from Photogrammetric and ArcHydro Tool.

Cao et al. (2020) used Multifractal detrended fluctuation analysis (MF-DFA) to detect gully erosion in Loess Plateau, China. They have used a digital elevation model of 5 m resolution to extract gully shoulder lines.

Real et al. (2020) has performed their study in the gullies of Palmital stream watershed inMinas Gerais state, Brazil. They have analyzes the temporal change in the gully pattern during thetime of 2003 to 2016, with the help of multifractal analysis and lacunarity analysis.

Information regarding details of the water conservation structures was gathered from the Agr. Handbook No. 61, USDA. SCS and Michael and Ojha, 1966, which was helpful for the generationof the eco-restoration plan of the study area. Extensive study of these literatures and its findings have helped me in understanding the problems of badlands during my research work.

2.2 Research Gap

Significant work has been done on the badlands in global context, but in-depth studies of badlandsare lacking in Indian scenario. Four major badlands hot spots identified in India are Yamuna- Chambal ravine zone, Gujrat ravine zone, Chhota Nagpur ravine zone and Western Himalayan foothills. They have a unique perspective of erosion and soil loss. But there is no documentation on the initiation of Indian badlands, though it is estimated to have started in pre-Mughal period (before the 15th Century). The investigation work done in these four badlands is very less. Most ofthe work was done in the Chambal sector of the Yamuna-Chambal ravine zone and there also a holistic approach to encountering badlands generation and process was missing.

Most of the earlier research in badlands area was focused on the identification and mapping of the badlands, instead of processes responsible for the badland formation. There is a lack of study which shows a link between the intrinsic property of the soil and the processes of the badland formation. Furthermore, there is no standard methodology and guideline procedure to revive the eco-system of badlands. This was due to lack of holistic approach to the problem of badlands. Hence, there exists a research gap in the field of badlands study. Thus, the present work focuses on a holistic approach in developing understanding regarding the badlands process in and around Chitrakoot town along the bank of the Mandakini River.