Chapter-10

10. Summary and Conclusions

10.1 Summary and Conclusions of the Work

Badlands are multivariate, self-enhancing systems of erosive processes which are characterized byintensely dissected topography with iterative patterns of rill-gully-channel networks having deteriorated soil properties, reduced soil fertility and sparse vegetation. Badlands' formation is a challenging problem globally and such erosive systems may initiate due to varieties of factors related to natural or anthropogenic causes. Almost 30% of India's geographical area (97.85 Mha)is degraded. In that 80% of land degradation is caused by soil erosion; making soil erosion a matterof serious concern.

There are four main badlands hot spots found in India viz; Yamuna-Chambal ravine zone,Gujrat ravine zone, Chhota Nagpur ravine zone and Western Himalayan foothills. All these four regions 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). Furthermore, the investigation work done in these four badlands is very less. Most of the work was done in the Chambal sector of the Yamuna-Chambal ravine zone and there also an integrated approach to encountering badlands generation and process was missing. There is no standard methodology and guideline procedure to revive the eco-system of badlands. Generally, soil conservation civil engineering structures are constructed to check soil losses whichare usually not effective over a long time and the processes of erosion and soil losses resume theirmenacing momentum again. This was due to lack of holistic understanding of the various interdependent aspects of the problem of badlands. Hence, there exists a research gap in the field of badlands study.

The present work focuses on a holistic approach to developing understanding regarding the badlands process in and around Chitrakoot town along the bank of the Mandakini River. The Mandakini River is the southernmost tributary of the Yamuna River system and the badlands system is an extended part of the Yamuna-Chambal ravine zone. The Chitrakoot area has deep historical and religious importance. The place is one of the prime pilgrimage centers in India. It has very special importance in Indian history or mythology; Lord Ram, his wife Sita and brother Lakshmana spanned about 11 or 12 years in Chitrakoot of their14 years' banishment from Ayodhya. The knowledge of the surrounding area, from the old accounts, shows luxuriant forestsand plenty of wetlands in the region. Though the area is still far from proper urbanisation and hasa mixed nature lacking typical characteristics of a modern city, there has been a shift of activitiesin the region in the past few centuries, which may have resulted in badlands formation in the study area.

The study represents detailed investigations of the rill-gully-channel morphology and the intrinsically related characteristic details of the badlands systems. It throws light on the complex and sensitive behaviour of these system owing to multiple causative factors and conditions thereofand puts forth a suggestive reclamation plan. In fact, the definition above incorporates that the badland processes change the entire physico-chemical, biological and topographical status of the land to such a state where these processes further accelerate in rate of their action and the land conditions deteriorate spreading over the safe belts. This detailed study on badlands covers (a) geological and lithological setting (b) general physical conditions of topography, soils, calcrete horizons, nature of slopes of gullies, vegetation, (c) analysis of climate/ precipitation, d) hydrogeological conditions, (f) digitization and characterisation of the badlands affected part of the Mandakini River watershed and sub watersheds, (g) morphometric analysis, (h) the role of soil's physico-chemical properties in the badlands formation and (i) study of nature of forms and patterns of badlands and their characteristics mathematical properties by multifractal and lacunarity analysis, (j) study of imprints and impacts of neo tectonism. Geologically the area has a stable basement of Bundelkhand Granite Gneissic Complex, overlain by Vindhyan sedimentarysequences of limestone, dolomites, Shale and sandstone. Moreover, a vast area of the study area iscovered by the recent alluvium, which is derived from Vindhyan sediments over which badlands are formed in the study area. The geomorphology of the area has a topography of scarped highlandsand plateaus along the margins, valleys opening into the general low plains of the area having dissected isolated hills surrounded by pediment and pediplain complexes of recent alluviums showing badlands. The climate of the region is sub-humid, receiving annual precipitation of about750 to 1100 mm; it has dry summer and chilling winters.

The Hydrogeomorphological study of form, patterns and processes of formation of the Badlands commences with a detailed morphometric analysis of the Mandakini watershed. The study deals with the delineation of the watershed, followed by extraction of the derived morphometric parameters, which helps to characterize the watershed. The morphometric study further extends to sub-watersheds level, identifying various critical zones prone to erosion. Furthermore, a statistical analysis like Pearson Correlation Coefficient was used to interpret the voluminous data and their interdependence. The morphometric study indicates that the majority and cumulative length of the first-order streams are quite very high (50%). First-order streams andtheir headward erosion play a significant part in the badlands formation. The badlands system canoperate with a high correlation of the total number of the streams (Nu) with length parameters of the streams of the watershed, and the drainage texture and the area (80.31% and 98.23%respectively). All these primary parameters should be strongly correlated with the stream number. This indicates the badlands process, which goes on with stream bifurcation upwards. Relief parameters and the bifurcation number (Rb 1&2) (3.61) showed an imprint of tectonic activity over the area that may provide the necessary ignition to initiate the erosional process. Some of theareal parameters give a very clear picture of the processes controlling the entire process. The onset of low infiltration (high If) and high drainage density (4.5), stream frequency (15.16), and drainagetexture (25.32) progressively develop a rugged terrain hence badlands. High drainage texture is also a key governing factor for developing the badlands in the study area.

To know the formation of badlands in the study area, probable causative factors like physico-chemical property of the soil, neotectonics impacts and climatic control were studied. Thestudy area has several surficial features like high cliffs (10-40m), the steep slope along the bank, elongated shaped drumlins like structures with a length of 300–1200 m and a relief of 5–20 m, indicating an influence of neotectonic over the region. These claims were further investigated by morphotectonic analysis. The morphotectonic study incorporates the parameters like elongation ratio (Re), hypsometric integral (HI), basin shape index (Bs), channel sinuosity (S) and basin asymmetric factor (AF). The results show that the Mandakini River watershed has less elongated (Re= 0.7) shape with a moderate hypsometric integral value (HI = 0.48), the basin shape index (Bs = 1.6) and the windy channel are indicative of moderately active tectonism in the watershed. Although the watershed is more or less symmetrical in some parts, the basin asymmetry factor (AF) is 55.24, which again indicates there is a partial impact of low active tectonics on the watershed. The GIS-based overlay analysis conducted on the basis of significant values of the morphotectonic parameters, indicates neotectonic and spatial discord of the sub-watershed. It shows a degree of neotectonic interference during the sustained erosive phase of badlandsformations. The values are found to be ranging from High Tectonic to Low tectonic signatures ofdifferent tectonic activity phases and the spatial signatures of tectonic events have been named asthe High Tectonic Activity Phase (HTAP), Moderate Tectonic Activity Phase (MTAP), and Low Tectonic Activity Phase (LTAP). The present work offers assumptions for sequencing the events.The MTAP is currently the dominant phase, whereas HTAP and LTAP are relicts of older phases.Although the tectonic influence in the watershed is moderate, it is the soil erosion that is prominentprocess in the watershed. The overland flow has shrunk in many sub-watersheds and restricting headward extension but the width of the gullies may be further widened at a few sites. This may be because most of the horizons in the watershed are alluvium, consisting of sand-silt. Thus, it canbe comprehended that a joint act of neo-tectonics and geology plays over the region, emphasizingits extensive soil erosion activity.

To study the intrinsic properties of soil and its proneness to erosion, the grain size analysis, clay mineralogy, physical properties, Atterberg limit, chemical property and nutrient value of soilwere analysed. The study deciphers that soil texture (silt loam), Atterberg limits with the values aslow plastic limit (14.80%) and low liquid limit (17.44%)), high bulk density (1.95) and soil pH (>7.5), have a central role in soil degradation and badlands formation. The presence of calcrete insoil horizons and illite as a clay mineral seems to have choked the pore spaces, reduced permeability and enhanced runoff over the area. An increase in runoff led to the loss of fine particles and organic matter from the soils. This loss resulted in the destruction of the soil profile and soil structure which limited the vegetation growth and increased the bulk density. Higher bulkdensity, in turn, restricted microbial activity and hampered the replenishment of organic matter inthe soils. In such conditions as unstable soils, deteriorated ground, the higher pH and moderate to low nutrient contents limited vegetation growth and further accelerated erosion. Furthermore, the prevailing dry period (reflects in isotopic analysis) in past may have hampered the carbon pool ofthe soil caused low occurrence of organic matter in soil. This series of interactions changed the plastic and liquid limits of the soils. Lowered plasticity index promoted cavity and piping in the ground, which led to subsurface erosion also. Hence the soil system turned into the site of surfaceerosion through rills and gullying, making headward growth supported by subsurface piping and collapsing of grounds.

The growth pattern of the gully and its development in space and time was studied using multifractal and lacunarity analysis. The results of these analysis on the badlands of the study area show high values of fractal dimension (Dq) (>1.59) with sigmoidal shape decreasing towards higher values of Q (Q>0) and low values of lacunarity (λg or Λg) (< 0.47), indicating that the badlands are multifractally patterned and are densely dissected. Right skewed graphs and negativeDf (α) values show that gullying processes are active on a finer scale through rill networking. Thegreater values of the ($\Delta\alpha$) show greater complexity in the study area and the decrease in ($\Delta\alpha$) maybe indicative of adjustment of forms. Multifractal analysis showed that the badlands complexity ishighly sensitive and changes in a short span of time. Conservation measures were found to have lowered the complexity as reflected in the decrease in the value of fractal dimension. This is a verysignificant finding that the badlands system responded quickly and if proper measures are taken, they may be controlled relatively quickly.

The self-sustainable reclamation approach was discussed based on the comprehensive knowledge of the ground. The sustainability in reclamation attempts can only be produced with proper participation of government and public sector. The central plan of the reclamation project is to enhance the economic activity of the area by restoring the native ecosystem with the help of various process like, reshaping the land with indigenous vegetation support, plantation of herbal and fruits gardens, aquaculture, water conservation structures etc. This may help an agro-industryto flourish, which will assist the land to get stable by the retention of more water through the contentment structures and helps to improve the carbon pool of the soil. Likewise, the area has also a potential to grow as a geotourism hub; natural gallery and sports and training centres such as Rock climbing etc. can attract tourist and contribute to the local economy.

Therefore, the holistic plan may be undertaken and local people may be led to resolve for the overall development programme, of course, under the guidance of experts and with initial funding supports from the government.

10.2 Future Prospects

The future prospects of the study may include:

I. Study of the laboratory-based physical models of various badlands.

II. Uses modern technologies like Unmanned Aerial Vehicle (UAV), drones, LIDAR etc, forhigh resolution mapping of the badlands of India.

III. It is a big challenge to improve the index properties of the badland soils because it will require large scale interference, which may itself be dangerous in its impacts and may generate environmental issues. Of course, natural restoration of these index properties andthe chemistry of the soils is the only safe way but it may be a very long-term solution. Thisis a major challenge area for future research work.