

CHARACTERIZATION OF SOILS AS INFLUENCED BY GEOMORPHOLOGY IN MAILI WATERSHED OF HOSHIARPUR DISTRICT, PUNJAB

Thesis

**Submitted to the Punjab Agricultural University
in partial fulfilment of the requirements
for the degree of**

**MASTER OF SCIENCE
in
SOIL SCIENCE
(Minor Subject: Chemistry)**

By

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(L-2014-A-131-M)**

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CERTIFICATE – I

This is to certify that the thesis entitled, “**Characterization of soils as influenced by Geomorphology in Maili watershed of Hoshiarpur district, Punjab**” submitted for the degree of **Master of Science**, in the subject of **Soil Science** (Minor Subject: **Chemistry**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Mr. Gaurav Arora (L-2014-A-131-M)** under my supervision and no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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This is to certify that the thesis entitled, “**Characterization of soils as influenced by Geomorphology in Maili watershed of Hoshiarpur district, Punjab**” submitted by **Mr. Gaurav Arora (L-2014-A-131-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **Master of Science** in the subject of **Soil Science** (Minor Subject: **Chemistry**) has been approved by the Student’s Advisory Committee along with External Examiner after an oral examination on the same.

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ABSTRACT

The soils of Maili watershed of Hoshiarpur district (Punjab) were studied for morphological, physico-chemical and fertility aspects relation to geomorphology. The remote sensing data and GIS tool were used geomorphic and morphometric analysis of the watershed. A total of 194 streams of 1st to 4th orders of moderate texture (5.639 stream/ km) followed the dendritic/sub-dendritic pattern. Six land use cover classes were recognized with 74.6% area in forest and 17.6% under cropland. A total of seventeen profiles from different geomorphic units such as hill tops, hill slopes, hill terraces, choe beds and piedmont plains were studied for morphological, physico-chemical characteristics, fertility aspects, taxonomic and land capability classification. The soils of watershed varied in texture from silt loam through loam, sandy loam, loamy sand to sand. The soils were slightly acidic to alkaline having pH from 6.5 to 9.4. The exchange complex dominated with calcium and magnesium cations. The immature soils from hill tops, hill slopes and choe beds were classified as Typic Ustorthents or Typic Ustipsamments whereas weakly developed soils as Udic Haplusteps or Typic Haplusteps. The soils were medium to high in available N (250.9 to 652.3 kg ha⁻¹) and K (39.2 to 336 kg ha⁻¹), deficient in available P (0.5 to 6.0 kg ha⁻¹). The available Zn content ranged from 0.03 to 1.25 mg kg⁻¹, Mn from 0.13 to 19.42 mg kg⁻¹ and Fe from 0.48 to 8.11 mg kg⁻¹. Except for copper, the deficiency of zinc, iron and manganese were nearly 90 per cent. Geomorphologically, the piedmont plain soils contained the highest contents of nutrients whereas hill tops or hill terraces the lowest. The watershed soils in the hills belong to classes IV to VII whereas from piedmont plains in class III of land capability classification.

Key words: Watershed, Geomorphology, Morphometry, Soil Characteristics, Classification

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ਭੂ-ਆਕ੍ਰਿਤਕ ਵਿਗਿਆਨ ਦੇ ਸੰਦਰਭ ਵਿੱਚ ਪੰਜਾਬ ਦੇ ਹੁਸ਼ਿਆਰਪੁਰ ਜ਼ਿਲ੍ਹੇ ਦੇ ਮੈਲੀ ਜਲਵਿਭਾਜਕ ਦੀਆਂ ਮਿੱਟੀਆਂ ਦਾ ਆਕ੍ਰਿਤਕ, ਭੌਤਿਕ-ਰਸਾਇਣਕ ਅਤੇ ਪ੍ਰਜਨਣਤਾ ਦੇ ਲਿਹਾਜ਼ ਨਾਲ ਵਿਸ਼ਲੇਸ਼ਣ ਕੀਤਾ ਗਿਆ। ਜਲਵਿਭਾਜਕ ਦੇ ਭੂ-ਆਕ੍ਰਿਤਕ ਅਤੇ ਆਕ੍ਰਿਤਕ ਮੁਲਾਂਕਣ ਕਰਨ ਲਈ ਰਿਮੋਟ ਸੈਂਸਿੰਗ ਆਂਕੜੇ ਅਤੇ ਜੀ.ਆਈ.ਐਸ. ਯੰਤਰ ਦੀ ਵਰਤੋਂ ਕੀਤੀ ਗਈ। ਦਰਮਿਆਨੀ ਸੰਰਚਨਾ (5.639 ਧਾਰਾ/ਕਿ.ਮੀ.) ਵਾਲੀਆਂ ਪਹਿਲੇ ਤੋਂ ਚੌਥੇ ਕ੍ਰਮ ਦੀਆਂ ਕੁੱਲ 194 ਜਲ ਧਾਰਾਵਾਂ, ਰੁੱਖ/ਉਪ-ਰੁੱਖ ਬਣਤਰ ਵਾਲੀਆਂ ਸਨ। 74.6% ਵਣਾਂ ਅਤੇ 17.6% ਫਸਲਾਂ ਅਧੀਨ ਖੇਤਰ ਸਹਿਤ ਕੁੱਲ ਛੇ ਲੈਂਡ ਯੂਜ਼ ਕਵਰ ਸ਼੍ਰੇਣੀਆਂ ਵਜੋਂ ਪਹਿਚਾਣ ਕੀਤੀ ਗਈ। ਆਕ੍ਰਿਤਕ, ਭੌਤਿਕ-ਰਸਾਇਣਕ ਗੁਣਾਂ, ਪ੍ਰਜਨਣਤਾ ਪਹਿਲੂਆਂ ਅਤੇ ਟੈਕਸਟੋਮਿਕ ਅਤੇ ਭੂਮੀ ਸਮਰੱਥਾ ਵਰਗੀਕਰਣ ਲਈ ਵੱਖੋ-ਵੱਖਰੀਆਂ ਸਤਾਰਾਂ ਭੂ-ਆਕ੍ਰਿਤਕ ਥਾਵਾਂ ਜਿਵੇਂ ਕਿ ਪਹਾੜੀ ਦੀਆਂ ਚੋਟੀਆਂ, ਪਹਾੜੀ ਢਲਾਣਾਂ, ਪਹਾੜੀ ਛੱਤਾਂ, ਚੋਆਂ ਦੇ ਤਾਲ ਅਤੇ ਨੀਮ ਪਹਾੜੀ ਮੈਦਾਨਾਂ ਦਾ ਅਧਿਐਨ ਕੀਤਾ ਗਿਆ। ਜਲਵਿਭਾਜਕ ਦੀ ਮਿੱਟੀਆਂ ਦੀ ਸੰਰਚਨਾ ਦੋਮਟ ਤੋਂ ਚਿਕਨੀ, ਰੇਤਲੀ ਦੋਮਟ, ਚਿਕਨੀ ਬੁਲਈ ਤੋਂ ਰੇਤਲੀ ਸੀ। ਮਿੱਟੀਆਂ ਐਸਡਿਕ ਤੋਂ ਐਲਕੇਲਾਈਨ ਸਨ ਅਤੇ ਇਹਨਾਂ ਦੀ ਪੀ.ਐਚ. 6.5 ਤੋਂ 9.4 ਸੀ। ਐਕਸਚੈਂਜ ਕੰਪਲੈਕਸ ਵਿੱਚ ਕੈਲਸ਼ੀਅਮ ਅਤੇ ਮੈਗਨੀਸ਼ੀਅਮ ਕੈਟਾਇਨਾਂ ਦੀ ਭਰਮਾਰ ਸੀ। ਪਹਾੜੀ ਚੋਟੀਆਂ, ਪਹਾੜੀ ਢਲਾਣਾਂ ਅਤੇ ਚੋਆ ਸਤ੍ਹਾ ਦੀਆਂ ਅਪੂਰਨ ਮਿੱਟੀਆਂ Typic Ustorthents ਜਾਂ Typic Ustipsamments ਸ਼੍ਰੇਣੀ ਨਾਲ ਸਬੰਧਤ ਸਨ ਜਦੋਂਕਿ ਹਲਕੀਆਂ ਮਿੱਟੀਆਂ Udic Haplusteps ਜਾਂ Typic Haplusteps ਕਿਸਮ ਦੀਆਂ ਸਨ। ਮਿੱਟੀਆਂ ਵਿੱਚ ਉਪਲਬਧ ਨਾਈਟ੍ਰੋਜਨ (250.9 ਤੋਂ 652.3 ਕਿ.ਗ੍ਰਾ. ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ) ਅਤੇ ਪੋਟਾਸ਼ੀਅਮ (39.2 ਤੋਂ 336 ਕਿ.ਗ੍ਰਾ. ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ) ਦੀ ਮਿਕਦਾਰ ਉੱਚ ਦਰਜੇ ਦੀ ਅਤੇ ਉਪਲਬਧ ਫਾਸਫੋਰਸ ਦੀ ਮਿਕਦਾਰ ਘੱਟ (0.5 ਤੋਂ 6.0 ਕਿ.ਗ੍ਰਾ. ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ) ਸੀ। ਉਪਲਬਧ ਜ਼ਿੰਕ ਦੀ ਮਿਕਦਾਰ 0.03 ਤੋਂ 1.25 ਮਿ.ਗ੍ਰਾ. ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ, ਮੈਂਗਨੀਜ਼ ਦੀ ਮਿਕਦਾਰ 0.13 ਤੋਂ 19.42 ਮਿ.ਗ੍ਰਾ. ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਅਤੇ ਆਇਰਨ ਦੀ ਮਿਕਦਾਰ 0.48 ਤੋਂ 8.11 ਮਿ.ਗ੍ਰਾ. ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਤੱਕ ਦਰਜ ਕੀਤੀ ਗਈ। ਕਾਪਰ ਤੋਂ ਇਲਾਵਾ, ਮਿੱਟੀਆਂ ਵਿੱਚ ਜ਼ਿੰਕ, ਆਇਰਨ ਅਤੇ ਮੈਂਗਨੀਜ਼ ਦੀ ਮਿਕਦਾਰ ਲੋੜੀਂਦੀ ਮਿਕਦਾਰ ਤੋਂ ਲਗਭਗ 90 ਪ੍ਰਤੀਸ਼ਤ ਤੱਕ ਘੱਟ ਸੀ। ਭੂ-ਆਕ੍ਰਿਤਕ ਲਿਹਾਜ਼ ਨਾਲ, ਨੀਮ-ਪਹਾੜੀ ਮੈਦਾਨੀ ਇਲਾਕਿਆਂ ਦੀਆਂ ਮਿੱਟੀਆਂ ਵਿੱਚ ਪੌਸ਼ਕ ਤੱਤਾਂ ਦੀ ਬਹੁਤਾਤ ਸੀ ਜਦੋਂਕਿ ਪਹਾੜੀ ਚੋਟੀਆਂ ਜਾਂ ਪਹਾੜੀ ਛੱਤਾਂ ਦੀ ਮਿੱਟੀ ਵਿੱਚ ਪੌਸ਼ਕ ਤੱਤਾਂ ਦੀ ਕਮੀ ਦਰਜ ਕੀਤੀ ਗਈ। ਪਹਾੜੀਆਂ ਵਿੱਚ ਜਲਵਿਭਾਜਕ ਦੀ ਮਿੱਟੀਆਂ ਸ਼੍ਰੇਣੀ IV ਤੋਂ VII ਨਾਲ ਸਬੰਧਤ ਸੀ ਜਦੋਂਕਿ ਨੀਮ-ਪਹਾੜੀ ਮੈਦਾਨੀ ਇਲਾਕਿਆਂ ਦੀਆਂ ਮਿੱਟੀਆਂ ਸ਼੍ਰੇਣੀ III ਨਾਲ ਸਬੰਧਤ ਸਨ।

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CHAPTER I

INTRODUCTION

Watersheds are natural hydrological entities that cover a specific areal extent of land surface from which the run-off flows to a defined drain, channel and stream at any particular point. Watershed is a drainage basin with references to run off outlet point where all living things are completely linked and settled through their basic water course (Anonymous 2014). The physical features such as hills, mountains or ridges define the boundaries of watershed which ultimately set the course of movement of water in valleys. Geography might be perceived at different scales, as a few acres of land drain to a small stream and large area drain to rivers and in turn to a sea.

Watershed, as an ideal hydrologic unit, requires multidisciplinary approach for management of natural resources for insuring continuous benefits on sustainable basis. A watershed having defined hydrological area coordinates the management of water resources. The watershed approach includes all those activities within its perimeter that affects watershed health. Watershed approach, ideally, integrates biology, earth science, social and economic aspects in planning and decision making. Watershed approach has been turned out to be most imperative in providing livelihood security in rural areas and attracting people's participation in watershed programmes.

Optimum utilization of natural resources, resource conservation and development along with the quality improvement of the people lives are the primary goals of watershed management. A watershed approach is an effective framework and offers a blueprint to address the difficulties of characteristics resources management (Anonymous 2011).

Many resources, for example, as livestock production, fisheries and open water supplies are depend upon healthy and productive watershed regions. Often, the management purposes of watershed are to balance out and conserve soils, increase vegetative production, enhance surface and groundwater quality, and protect or enhance wetlands, floodplains and riparian areas. Watershed soils impact numerous aspects of management. Not only soil type, vegetation cover, slopes and catchments type all affects the occurrence and volume of runoff (Bhange *et al* 2005), and thus influence watershed management. Soils of watershed play salient role in moving water through the landscape above or below the ground, make it is possible to estimate its response in a particular watershed. These management plan are based on knowledge of the soil's texture, structure, organic matter, density, and soil horizons. Some of these interpretations include permeability, depth to bedrock, depth of water table, and hydrologic group.

The demarcation of basin is of most important in study of hydrological system, planning and its effective management. Quantitative morphometric parameters of watershed provide important information on the hydrological nature of the rocks in the watershed. Quantitative morphometric parameters explain the configuration, dimension and shape of landforms on the earth's surface (Agarwal 1998). A drainage map furnishes index of permeability of rocks and their relationship. So for proper management and execution plan for conservation measures, the information on topography, drainage pattern, water divide, stream length, geomorphologic and geological setup are the most important (Sreedevi *et al* 2013).

The drainage analysis is help to perception the geological, topographic and structural setup of a basin and their inter relationship. The integrated approach of geospatial technology (GIS, GPS and remote sensing) is now being recognized universally as unique, highly effective and extremely flexible technology for evaluation and management. Spatial data application requires a precise inventory of the premise for watershed characteristics and management. Remote sensing and GIS based drainage basin assement has been carried out by number for various territories and it is proved to be scientific tool for characterization of drainage basin parameters. (Grohmann 2004, Korkalainen *et al* 2007, Pankaj and Kumar 2009). Kar *et al* (2009) use multi-spectral IRS-P6, LISS IV data (5.8 m resolution) along with ground information for soil and other natural resources mapping to develop different land use plans of a rainfed watershed. Moreover, the combination of SRS and remote sensing was observed to be an exceptionally helpful system for land suitability classification and in planning new alternative land use options.

Soils form a continuum over the earth's surface forming an interface of atmospheric, biological, and geological processes. Soils are, thus, more than a veneer of surface alteration on landscapes or sediments, and evolve through the interaction of weathering as against erosion and deposition. So, soil as the unconsolidated material on the immediate surface of the earth has been influenced and evolved by genetic and environmental factorfs (Gulati and Rai 2013). The soil is very valuable, diverse and degradable natural resource at the earth's surface that provides life support. Soils form the base for every production systems and apprehension on their properties, degree and spatial distribution at watershed level are extremely important (Sarkar *et al* 2006).

The spatial variability in soil properties is largely influenced by environmental factors as climate, vegetation, parent material and landscape features like landscape position and slope (Ollinger *et al* 2002). Soil geomorphology is, therefore important to comprehend the relationships amongst soils, landscapes, and sediments, and in turn understand soil-landscapes to predict soil occurrence, anticipates soil behavior and internal water movement. In a

toposequence, the soil attributes are determined by soil's position on landform, pedological processes and their relationships (Birkeland 1990, Moore *et al* 1993a and Reddy *et al* 1999). The geomorphic position on a toposequence has an important role in characterization and classification of soils. Often landform units are used as important descriptors as a part of soil mapping (Speight 1990). It is a known fact that topography influences microclimates by effect of temperature, relative humidity and precipitation (Yimer *et al* 2006), and thus significantly affects some soil properties.

Soil survey provides a scientific inventory of one of our most important natural resources—The soil. The soil survey reports furnish information in the form soil description, data tables, figures, photographs and soil maps help variety of people about how to manage them properly for agricultural, forestry and urban uses. Each soil exhibit different properties and studying these properties, soil scientists and other professionals can predict its respond to specific management. The soil survey information may be interpreted for limitations and hazards inherent in soils.

Small land holdings, no irrigation facility, traditional agricultural practices, and low crop productivity are the characteristic features of agriculture in the lower and upper Himalayan regions. The production is barely sufficient to meet even half of the demands of the region. Often, families are sustained from remittances received from migrated members to other areas (Samra *et al* 1999). The mountains and hilly areas of the Himalayas, including Siwaliks, are undermined by cultivation of marginal lands due to expanding population, excessive grazing, deforestation, loss of vegetative cover and biodiversity (Grewal *et al* 2001). The land management approach as suggested by FAO (1989) is important for minimizing and rehabilitating degraded lands, and ensuring optimal utilization of land resources for the sustainable management. It requires coordinated effort and association of land user, organizer and policy makers to ensure that land use systems and practices are suitably identified and properly implemented. In this regards, soil, terrain and socio-economic factors form the basis for sustainable land use planning. Soil and climate are the crucial factors determining the soil-site suitability for optimum land use. Since climate cannot be manipulated, therefore detailed information about soils regarding their extent, distribution, characteristics and potential use is indeed important for effective planning.

In Punjab, about 10.6% of the total geographical area of the state including foothills and piedmont plains is known as Kandi area. The kandi area has undulating topography, steep slopes, poor vegetative cover, and coarse-textured sediments and often infested by chos causing flash-floods which in turn damage crops. Most of the population of this area depends on agriculture either as farmers or as agriculture laborer. Maili watershed is the part of Maili

village, Garhshankar tehsil of Hoshiarpur district in Punjab, India. The annual rainfall ranges from 850 mm to 1200 mm and the area fall in dry sub humid agro-climatic zone. The soils on a region are not equally productive as their properties vary depending on their landscape position. The soils therefore, need to be scientifically studied and judiciously managed to meet food, fiber and fuel requirements. Increasing agriculture production in rainfed areas by adopting efficient use of natural resources within the development area is the major goal of the watershed management (Singh *et al* 2014). An effective planning and management of watershed, there is imperative to identify soil resources and land capability classes.

Considering the vast significance of soils, their properties, degree and spatial distribution at watershed level for every production system and developing land use, an attempt has been made to examine the soils of Maili watershed of Hoshiarpur district of Punjab (India).

The present study was attempted with the following objectives:

- (i) To identify and study geomorphic units of Maili watershed
- (ii) Morphological and physico-chemical characterization of soils
- (iii) To evaluate soils for land capability classification

CHAPTER II

REVIEW OF LITERATURE

The literature pertinent to the present study has been reviewed under the following heads:

- 2.1 Remote sensing and watershed studies
- 2.2 Soil-landscape relationships
- 2.3 Soil characteristics and formation
- 2.4 Soil classification
- 2.5 Land evaluation for land use

2.1 Remote sensing and watershed studies

A watershed is the land area that drains to a single water body such as stream, river, lake or ocean. A watershed is the surface area drained by a part or the totality of one or several given water course and can be taken as a basic erosion and landscape element where land and water resources interact in a perceptible manner (Biswas *et al* 1999). The drainage network analysis is generally performed to understand the prevailing geological variation, topographic information and structural set of a basin and their interrelationship. Watershed characterization and management requires detail information for topography, drainage network, water divide, channel length, geomorphologic and geological setup of the area for proper watershed management and implementation plan for water conservation measures (Sreedevi *et al* 2013).

Remote sensing techniques provide information about the surface of soils, rocks or vegetation by obtaining pictures or other forms of electromagnetic records of Earth's surface from a distance without being in physical contact with them (Aronoff 1995). Remote sensing and GIS based drainage basin evaluation has been carried out by number of researchers for different terrains and it is proved to be a very scientific tool for generation of precise and updated information for characterization of drainage basin parameters (Grohmann 2004, Korkalainen *et al* 2007, Pankaj and Kumar 2009). Drainage parameter extractions from last two decades are more popular from digital topographical information which is called as digital elevation models (DEM), which is more fast, precise, updated and inexpensive way of watershed analysis (Moore *et al* 1991 and Maathuis 2006). Bastawesy *et al* (2013) recently utilized remote sensing data and digital elevation models to extract the catchment hydrological parameters to delineate storage areas for the Uganda Equatorial Lakes region.

They concluded that digital elevation models (DEMs) are very accurate tool for morphometrical parameter evaluation and watershed delineation for management.

The watershed topography and geomorphology influence base flow by affecting the storage properties and rates of water transmission within a catchment. The influence of factors of slope, relief, and drainage density are particularly noteworthy. Chopra (2005) carried out morphometric analysis of two sub-watersheds in Gurdaspur district using latest IRS-1D PAN sharpened LISS-III analog remote sensing data and GIS techniques. Detailed updated drainage maps were used for the morphometric analysis of the two sub-watersheds. Both the sub-watersheds show dendritic to sub-dendritic drainage pattern with moderate drainage texture. High bifurcation ratio indicates a strong structural control on the drainage. Logarithm of number of stream vs. stream order showed deviation from straight line indicating regional upliftment. In spite of mountainous relief, low drainage density values indicate that the area is underlain by impermeable sub-surface material. Circulatory and elongation ratios show that both the sub-watersheds have elongated shape.

Barnett *et al* (2008) reported that relative influences of watershed geomorphology and land use within a given natural template to develop consistent methodologies for watershed characterization and base flow quantification. However, it remains unclear whether these factors are themselves strong drivers of base flow, or whether they instead correlate to other aquifer properties that more directly control base flow. More research is needed to understand the role of subsurface topography on base flow, and very little is known about water storage in varied geomorphic units (e.g. colluvial deposits and alluvial bottomlands) and their linkages to base flow (Price *et al* 2011).

Sreedevi (2009) attempted to study drainage morphometry and its influence on hydrology of Wailapalli watershed, South India. For this study, Shuttle Radar Topographic Mission (SRTM) data was used for preparing Digital Elevation Model (DEM), aspect grid and slope maps whereas geographical information system (GIS) was used for evaluation of linear, areal and relief aspects of morphometric parameters. The study reveals that the elongated shape of the basin is mainly due to the guiding effect of thrusting and faulting. The lower order streams are mostly dominating the basin. The development of stream segments in the basin area is more or less affected by rainfall. The study was found to be very useful for planning rainwater harvesting and watershed management.

Pareta and Pareta (2011) studied the detail morphometric characteristics of Karawan watershed in Dhasan basin, which itself is part of the mega Yamuna basin in Sagar district, Madhya Pradesh. For detailed study, ASTER data was used for preparing digital elevation model (DEM), and geographical information system (GIS) was used for evaluation of linear,

areal and relief aspects of the watershed. Watershed boundary, flow accumulation, flow direction, flow length, stream ordering have been prepared using ArcHydro Tool whereas and contour, slope-aspect, hill-shade have been prepared using Surface Tool in ArcGIS-10 software and ASTER (DEM). Different thematic maps, i.e. drainage density, slope, relief, superimposed profile, and longitudinal profiles have been prepared by using ArcGIS software.

Lopez-Granados *et al* (2005) demonstrated that sparse and expensive soil measurements combined with secondary information, such as remotely sensed data from aerial photograph, and geostatistical techniques to map soil properties accurately. Mulder *et al* (2011) demonstrated that soil properties that have been measured using remote or proximal sensing approaches include mineralogy, texture, soil iron, soil moisture, soil organic carbon and carbonate content.

Paul and Inayathulla (2012) studied the nine sub-watersheds of Hebbal valley located in Bangalore district of Karnataka state using Remote Sensing and GIS techniques. The morphometric parameters considered were stream order, stream length, bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circulatory ratio, elongation ratio, relief ratio, length of overland flow and basin shape. They found the dendritic drainage pattern in the watershed. The bifurcation ratio varies from 1.89 to 3.03 and all sub-watersheds fall under normal basin category. The circularity ratio ranges from 0.42 to 0.78 indicating that all the sub-watersheds except SWD9 are more or less circular. The sub-watershed with lowest compound parameter value is given the highest priority. The sub-watershed SWD3 is likely to be subjected to maximum soil erosion hence it should be provided with immediate soil conservation measures.

The morphometric analysis carried out by Sharma *et al* (2012) in the Tangri watershed in the lower Siwalik and Piedmont zone of Haryana revealed that the terrain is comprised of undulating topography composed of sand, silt, clay and conglomerate in the northern part, and deposits of rich alluvium in the middle and southern parts. Mostly, the streams of lower order dominate the watershed. The drainage density, frequency and texture revealed that the watershed have low relief and underlain by highly permeable rocks. Bifurcation ratio indicated that it has not been affected by structural disturbances and tectonic control. The computation of various shape factors indicated that the Tangri watershed has low peak flows for longer duration. Moreover, the result of ruggedness and dissection index was found to be almost in agreement and corroborated with each other.

Ali and Khan (2013) prepared the detailed drainage map from SOI (Survey of India) toposheets (45h/5 and 45h/9) and updated using IRS-P6, LISS-III data and ARC GIS

software. Further, the data from Shuttle Radar Topographic Mission (SRTM) was used for delineating watershed boundary using SAGA GIS software. The GIS analysis techniques were used to evaluate linear and areal morphometric parameters of the basin. The study revealed that the drainage patterns are mainly dendritic to sub-dendritic with fifth order drainage. The Banas river basin possesses high drainage density which is indicative of less permeable material, sparse vegetative cover and moderate to high relief.

Geomorphometric analysis of Um Shipra watershed in north east India was attempted by Lama *et al* (2014) using Survey of India toposheets and GIS techniques. The drainage map generated from the Survey of India toposheets was used for morphometric analysis of the watershed in terms of stream order, stream length, bifurcation ratio, relief ratio, drainage density, stream frequency, drainage texture, form factor, circulatory ratio, elongation ratio, infiltration number and ruggedness number. The watershed is a fifth order watershed having dendritic drainage pattern with high drainage density (6.22 km/km²).

Aouragh and Essahlaoui (2014) in their study found that the Guigou sub-watershed is susceptible to hydrologic processes like flooding, erosion and landslide. Form factor (Ff), circulatory ratio (Rc) and elongation ratio (Re) indicates elongated shape of the drainage watershed. High drainage density and stream frequency in a basin, the flow is faster, and therefore is high likely flooding (plain Guigou). The texture ratio (Rt) value of the present study is 6.77, which indicates an intermediate texture for the study area drained by a network of dendritic to sub-dendritic type evenly distributed in the highest Collins of Guigou plain characterized by Basaltic Plio-Quaternary deposits. Relief ratio Rr is 0.025 indicates moderate relief and steep to moderate slope. Dissection index (Dis) value is 0.72 indicated moderate dissected Guigou sub-watershed. The ruggedness number is 3.44, which indicates both relief and drainage density are high. The study has proved that the remote sensing coupled with GIS techniques are the efficient tool for the morphometric analysis of watersheds.

Kaur *et al* (2014) carried out for quantitative description and characterization of drainage of two sub-watersheds namely Kukar Suha and Ratewal of district Shahid Bhagat Singh Nagar, Punjab, India. They identified drainage pattern of Kukar Suha and Ratewal as dendritic. The agriculture and settlements came up along the drainage network caused the pattern disturbance in the watershed. The land use/land cover change was extracted from LISS IV Mx + Cartosat1 PAN data whereas ASTER data was used to prepare DEM (digital elevation model) with geographical information system (GIS) ArcGIS10 software to evaluate various morphometric parameters.

2.2 Soil-landscape relationships

Topography is one of the factors of soil formation. Geomorphology and geology, combined with time and climate, are the main factors that influence soil distribution.

Understanding geomorphology is useful in understanding soil patterns. The landscape evolution usually leads to the juxtaposition of different types of landforms and therefore different types of soils (Zinck 2013). So, there is a close relationship between the kind of soil and landform. The geographical distribution of soils on landscape is called soil-landscape relationship. At a detailed level there may be a close relationship between soil characteristics and its position on a hillslope – the catena concept of Milne (1936). At a broader scale, different landform types are formed of different materials and are of different ages, and thus result in different soil types. Ata Rezaei and Gilkes (2005) shown that landscape attributes including slope, aspect, and elevation affected plant growth through indirect influences involving soil properties.

Not only the topographic factors directly influence pedogenic processes (Beckett and Webster 1971) but variations in landform may reflect underlying changes in parent material and differences in age of the soil profile. Sidhu and Sharma (1990) studied the arid zone of Punjab in north-west India. The soils developed on sand dunes were coarser in texture and lacked sub-surface diagnostic horizons. The soils developed on alluvial terraces were relatively fine textured and showed the development of a structural B horizon. The soils of interdunal areas were intermediate in texture. Sawhney *et al* (1991) described the soils occurring in different physiography in semi-arid and arid tract of Punjab, and found the three distinct stages of pedogenic development as A-C, A-Bw-C and A-Bt-C profiles. Genesis of these soils was mainly attributed to the influence of climate as conditioned by relief over a period of time. Yair (1990) studied the role of topography and surface cover upon soil formation along hillslopes in arid climates. The Pearson correlation analyses performed between soil properties and terrain attributes have shown significant relationships differences in soil properties are due largely to the topographic variability, which influences water redistribution within soil units, being overland flow the main agent for water redistribution, erosion and deposition in arid environments. Moore *et al* (1993b) found strong interrelationships between topographic characteristics (slope gradient, contribution area) and soil development amongst others, like topography and hydrological and erosive behavior. From upper to down-slope positions, the soil development as well as plant covers increase.

The detailed soil surveys of the Walnut Gulch Experimental Watershed, Arizona have demonstrated that soil types are functions of local geomorphic features, and that many soils are immature owing to semiarid climate, slow biochemical weathering, and rampant post-settlement rill and gully erosion in fan deposits north and east of Tombstone. Where accelerated erosion of the last century has not stripped the upper horizons, soils tend to be thick, mature loams rich in sand and gravel and of high carbonate (calcrete) content. Virtually all of the soils reflect the underlying rocks from which they developed (Breckenfeld 1994).

There have been several attempts to relate soil properties to landscape position as it plays the influencing role in runoff, soil erosion and hence soil formation (Babalola *et al* 2007). Soil properties such as soil organic matter has been shown to vary with topographic position (Miller *et al* 1988) while clay content has been found highly correlated with topographic position (Wang *et al* 2001).

Fu *et al* (2000) studied the relationships between land use and soil conditions in the hilly area of the loess plateau in northern Shaanxi, China. In the Yangjuangou catchment, which has typical hill area and steep topography, the effects of land use changes on soil erosion and the distribution of soil nutrients and moisture were studied at the three spatial scales of total catchment, transect and land use type. The amounts of total N, total P, available N, available P and organic matter of surface soil 0–20 cm is different from hill foot to hill top, and has a better capacity for soil conservation and retention of nutrients than other land use structures. They suggested that inappropriate land use is one of the main reasons for soil erosion and nutrient loss in the hilly area.

Conton *et al* (2003) showed that altitude is positively correlated with sand content and negatively correlated with silt and clay. A negative correlation exists between elevation and sodium adsorption ration (SAR) values. The length slope factor (LSF) is positively correlated to the sand content and negatively correlated to silt and clay. As the LSF is related to sediment transport capacity, the higher the transport capacity, the higher the removal of finer particles, and the higher the sand content.

Diack *et al* (2010) studied total carbon content that varies between 3.14 and 25.20 g/kg under lowland condition. In the colluvium, total carbon varies between 1.29 and 3.14 g/kg whereas under terrace condition it varies between 1.21 and 3.00 g/kg. Compared to the colluvium and terrace soils, the lowland soil presents the highest values for total carbon content within the watershed. With high soil moisture content from rainfall and the presence of diverse vegetation, the soil carbon content tends to accumulate over time, which contributes to an establishment of a good soil fertility level. Total soil nitrogen content varies between 0.32 and 1.50 g/kg under lowland condition, between 0.18 and 0.32 g/kg under colluvium, and 0.18 and 0.22 g/kg under terrace conditions. Similar to the total soil carbon, total nitrogen has the highest content under lowland conditions as compared to colluvium and terrace.

Jassal *et al* (2012) studied some soils of central Punjab and found that the alluvium soils have developed on two different physiographic positions, viz. flood plains and alluvial terraces. The soils from the flood plains exhibit immature profile (A-C), poor to moderately drained, and medium in permeability whereas soils from terraces have weakly developed

profile having horizon sequence A-Bw-C, moderate to well drained and low in permeability. Flood plain soils had light brownish gray to olive brown matrix colour in lower horizons and presence of mottles indicated their fluctuating drainage condition but the soils from the terraces had the dark brown color in the surface horizons and dark yellowish brown to olive brown in subsurface horizons indicated their better drainage condition than flood plain soils. The terrace soils frequently contain calcium carbonate nodules whereas flood plain soils do not contain calcium carbonate nodules.

Dahdwal *et al* (2012) compare the soil properties of the different land uses in various landscape positions in lower Himalayan watershed of India. The soil properties such as bulk density showed lowest value in forest land use with mean value of 1.15 Mg m^{-3} . Sand and silt contents were more in *nala* bed and agriculture-fallow land use respectively in lower landscape whereas clay content ranged from 6.7 to 27.2% in whole watershed. The organic carbon content was found in the order of forest > degraded forest > scrub > orchard > agriculture > *nala* bed. The total nitrogen (Total N) content was higher in forest land use of upper landscape (0.13 to 0.22 % with mean value of 0.16%) than other land use systems. Available P varied from 0.8 to 31.2 kg ha⁻¹ in the entire watershed with higher values in agriculture land use (mean value of 19.5 kg ha⁻¹) due to continuous application of phosphatic fertilizer. Available K was higher in forest land use (158 kg ha⁻¹) than the other land use in the watershed. The present investigation revealed that land use has a great influence on soil properties mostly through its effect on soil organic matter and total N. It was evident from the study that cultivation on the various landscape positions have resulted in a significant deterioration in physical and chemical soil properties.

Heshmati *et al* (2013) studied the effects of soil and rock mineralogy on soil erosion features in the Merek Watershed in Iran and found that the accelerated soil erosion is an anthropogenic phenomenon and a major worldwide environmental problem. The soil erosion mainly leads to removal of the clay minerals and soil nutrients and thereby reduces soil fertility because of mineralogical influence on the soil. The study helped to identify the dominant soil and rock minerals and the influences of mineralogical properties on soil erosion features.

Ofori *et al* (2013) conducted at a Sawah site in Ghana to examine the relationship between landscape position and some selected soil properties with the aim of generating adequate data for modeling landscape relationships and to aid both researchers and farmers in taking critical management decisions. They analyzed soil properties namely total porosity, moisture content, infiltration rates, hydraulic conductivity, sand content, silt content, clay content, gravel concentration, bulk density, soil pH, total nitrogen, soil organic matter and

cation exchange capacity for soils collected from the foot slopes, middle slopes and at the upper slopes under four major land uses (maize, oil palm, natural vegetation and plantain). Simple statistical parameters such as mean and standard deviation were used to analyze the data revealed that moisture content, total porosity, soil pH, organic matter and carbon and total nitrogen increased down-slope whereas sand content, clay content, bulk density occurred at upper slopes decreased downslope. Management practices appeared to have influenced infiltration rate, hydraulic conductivity and silt content.

Conforti *et al* (2016) found the results of different behavior of physical-chemical properties and carbon storage for coarse-textured soils and fine-textured soils. The soil types and topographic features such as slope gradient, landscape position and slope curvature controlled SOC stored in mineral horizons through changes in variability of SOC concentration and profile thickness. The higher SOC stocks were recorded in flat areas than on steep slopes. The study showed Inceptisols developed on slopes with concave morphology exhibited higher SOC values than Entisols located on convex slope.

2.3 Soil characteristics and formation

Plants require definite soil and site conditions for its optimum growth. Although some plants may be found to grow under different soils and extreme agro-ecological conditions, yet not all plants can grow on the same soil and under the same environment. Since the availability of both water and plant nutrients is largely controlled by the physico-chemical and micro environment of soils, the success and/or failure of crops, in a particular area, is largely determined by these factors. Soils vary in quality based on their physical, chemical and biological characteristics and their interaction with one another. The major emphasis on soil quality investigations has been given on the determination of physical and chemical attributes of soil (Arshad and Coen 1992). The wide knowledge about soils' morphologic and physico-chemical characteristics helps us for improve land use management and soil conservation practices (Emadi *et al* 2008).

The soils of Punjab differ greatly in their morphological, physical and chemical, characteristics and belong to four orders of Soil Taxonomy viz Inceptisols, Entosols, Aridisols and Alfisols (Deka *et al* 1996). It is well recognized that the parent material, topography, climate, time and organisms are five basic soil formation processes that impress soil characteristics (Soil Survey Staff 2006). There have been many attempts to correlate soil properties with various factors, such as parent material and topography (Mahmoodi *et al* 2007). Two vital soil forming factors which affect the genesis, development and classification of soils are the climate and topography. Numerous soil characteristics and pedogenic features like calcium carbonate are depend on climate and may record paleo-climate data (Srivastava,

2001). Differences in physical, chemical and mineralogical properties of soils are related primarily to parent material (Irmak and Surucu 2007). The parent material from which soils develop is a key factor that in many cases determines the kinds and contents of secondary minerals of soils; therefore, determines its texture and chemical properties (Nkongolo and Plassmeyer 2010).

Patagundi *et al* (1996) characterized the some salt affected soils of Tungabhadra Left Bank Command, Karnataka and found the soil pH ranging from 7.3 to 7.5 in hill side slope, 8.0 to 8.5 in undulating pediments, 7.5 to 9.4 in pediplains and stream bank. Nayak *et al* (2002) observed the variation of pH with depth may be due to intensive weathering and subsequent leaching of bases in the soils of sloping landforms of Central Research Station, Bhubaneswar.

Characterization and fertility assessment of soils of Markapur mandal, Prakasm district, Andhra Pradesh for sustainable land use planning showed the available nitrogen, phosphorus and potassium in all the physiographic divisions of the mandal ranged from 87.8 to 376.3 kg ha⁻¹, 8.7 to 28.4 kg ha⁻¹ and 62.7 to 257.6 kg ha⁻¹ respectively. The low nitrogen, phosphorus and potassium content in these soils was attributed to low organic carbon content (Prasuna Rani *et al* 1992), fixation of released phosphorus by clay minerals and oxides of Fe and Al (Vijay-Kumar *et al* 1994), medium to high content of potassium due to weathering of K bearing minerals and releasing of K from organic residues (Sharma and Kumar 2003 and Rao *et al* 2008).

Sidhu *et al* (2000) studied the pedological variability of Aravallies-Yamuna river transect in Haryana and found that the soils of old floodplains had weak to moderate, medium to coarse subangular blocky structure whereas recent and active flood plain soils did not exhibit any structural development. Sharma *et al* (2004) studied six typical pedons representing cultivated soils of Neogal watershed in North-West Himalayas occurring on river terraces and hill slopes viz. Baun, Talinu, Phata, Gopalpur, Bhattu and Mahadev for their morphological characteristics, physico-chemical properties and suitability for locally preferred crops. The soils are acidic in reaction, non-calcareous, coarse to fine loamy in particle size class, mixed in mineralogy and medium to very deep and have thermic soil temperature and udic soil moisture regimes. The soil texture, pH (1:2.5), organic carbon, CEC, base saturation, water retention at 33 and 1500 kPa ranged from loamy sand to clay loam, 5.2 to 6.2, 3.2 to 9.5 g kg⁻¹, 4.9 to 14.3 cmol (p⁺) kg⁻¹, 46 to 77%, 4.2 to 31.2% and 2.6 to 16.8%, respectively.

Conton *et al* (2003) observed weak or moderately fine to medium subangular blocky structure in the catchment soils except where there is regolith. Their surface is frequently

formed by either physical or biological crusts with inherent hydrological and pedogenetic consequences as reduced infiltration and limited soil development. Most of the soils are light grey (2.5Y 7/2) when dry and grayish brown (2.5Y4/2) when wet. Some of the more developed soils may attain a 10YR hue. Organic matter content is low in horizons near the parent material (0.15% to 1.4%), moderate in some surface horizons (0.4% to 2.4%), and under perennial plants it is still higher (up to 3.5%).

Kumar *et al* (2005) studied the Aridisols of Punjab and showed that the soils developed on inter-dunal areas and alluvial terraces were yellowish brown in colour in the surface horizons, however underlying horizons were mostly dark yellowish brown. Texture of the inter-dunal soils varied from loamy sand in surface to sandy loam in lower horizons. In soils of alluvial terraces the texture varied from sandy loam to clay loam with depth. B horizons of both the soils showed the presence of weak, fine to medium sub-angular blocky structure. These soils are calcareous throughout but lack a regular trend of CaCO_3 distribution. However, C horizon of both the soils had high CaCO_3 content than the overlying horizons. The irregular distribution of CaCO_3 with depth, may either be due to variable nature of geological material that contributed to these Aeolian/alluvial soils or to rapid leaching of carbonates from the porous sandy soils. Sawhney *et al* (2005) studied the soils of semi-arid tract of Punjab and showed that the hue of Munsell colour was 10YR, the value ranged from 3 to 5 and chroma was 6 or less. The soils developed on the upper piedmont were sandy loam throughout the depth except in surface horizon, the middle piedmont soils varied from loam to sandy clay loam, and the lower piedmont soils were comparatively finer in texture. The textural variations in these soils were due to the heterogeneous nature of the parent material and topographical differences. Sharma *et al* (2008) found that soils developed on sand dunes from semi-arid and arid zone are generally light in colour due to low content of organic matter and other colouring agents like hydrous oxides of iron and manganese. The soils invariably showed 10YR hue throughout the depth except in few subsurface horizons which had 7.5YR hue. The texture of these soils varied from sandy loam to sand. The lack of textural differences in coarse-textured soils suggested the prevalence of aeolian process in these areas.

Hedge *et al* (2008) studied Soils in Lingnahalli microwatershed under Amani Shivpurkere watershed, Doddaballapur taluk, Bangalore Rural District, Karnataka for their properties and classification. The soil texture ranged from sandy loam, sandy clay loam through sandy loam and loamy sand to sand in the surface horizons. The pH of surface soils ranged from 5.0 to 7.3, EC from 0.20 to 1.23 dS m, organic carbon from 1.2 to 6.0 g/kg and

CEC from 1.0 to 11.8 c mol kg⁻¹ at surface layer. The OC, pH, EC, CEC and exchangeable bases did not follow a regular trend with depth. Most of the soils in the study area were free from major constraints and suitable for major adopted crops of the region.

Bali *et al* (2010) characterized the soils of different agro-eco-sub-regions of Punjab and indicated that the pH varied from 6.77 to 9.3 whereas electrical conductivity (EC) ranged from 0.14 to 4.57 dS m⁻¹. The organic carbon (OC) ranged from nil to 1.55 per cent and calcium carbonate from 0.5 to 10.46 per cent. Available K ranged from 33.6 to 1192 kg ha⁻¹ and available P from 1.12 to 238 kg ha⁻¹. The exchangeable Ca²⁺⁺Mg²⁺ ranged from 1.2 to 14, Na⁺ ranged from 0.12 to 3.06 cmol(p⁺)kg⁻¹ and K⁺ ranged from 0.05 to 3.65 cmol(p⁺)kg⁻¹. Cation exchange capacity (CEC) ranged from 1.87 to 15.5 cmol(p⁺)kg⁻¹. Exchangeable sodium per centage (ESP) varied from 0.03 to 33.13. The DTPA-Zn ranged from 0.07 to 3.06 mg kg⁻¹ suggesting deficient to sufficient available Zn. The availability of Zn was found to be controlled by such factors as OC, silt content, EC and pH.

Likhar and Prasad (2011) studied the soils developed from different parent materials in Nagpur district, Maharashtra and observed Munsell colour in the hue of 10YR, 2.5Y, 7.5YR and 5YR. The Ap horizon had dark brown colour whereas others had very dark grayish brown colour including surface and sub-surface horizons. The surface and sub-surface horizons had sub-angular to angular blocky structure of varying grades and sizes but angular blocky structure associated with slickenside in sub-soils.

Dahdwal *et al* (2012) studied the different land use systems, particularly at the soil surface level. In croplands, soil pH, OC, total N and available P were affected due to intensive cultivation. The soils of the region are acidic in nature. The highest sand and silt content was distributed in *nala* bed and agriculture land use, respectively at lower landscape position. The soil nutrients are mainly stored in the top-soil, together with the organic matter. Land-use systems significantly affect the clay, silt and sand fractions. High proportions of clay are found in soils of forests land use. The clay content ranged from 6.7 % in *nala* bed to 27.2 % in forest land. Soil pH, organic carbon, available P, exchangeable K is significantly changed with the land-use systems. Soils of the forest presented the higher fertility level than other land use.

Jassal *et al* (2012) studied some soils of central Punjab and found that the sand, silt and clay contents of these soils vary from 12.6 to 88.6 per cent, 7.4 to 72.6 per cent and 4.0 to 25 per cent, respectively. The particle size distribution suggested relatively coarser nature of flood plain soils and finer nature of terrace soils. The soils are moderately alkaline to strongly alkaline in reaction having pH varying from 8.28 to 10.9 in different horizons. Electrical conductivity ranges from 0.06 to 1.30 dSm⁻¹ in different soils. Organic carbon content ranged from 0.02 to 0.65 per cent in different horizons of the soils having higher content in the

surface horizon and lower content in subsurface horizon. The soils contain calcium carbonate both as dispersed particles and as segregated nodules within the profile. Calcium carbonate in floodplain soils varied from nil to 13.8 per cent, whereas in terrace soils it varied from nil to 19.5 per cent suggesting relatively low content in the former. Accumulation of calcium carbonate in lower horizons suggests some eluvial/illuvial processes associated with pedogenesis in the soils. Cation exchange capacity varied from 4.44 to 14.21 cmol(p⁺) kg⁻¹.

Vyshnavi *et al* (2014) studied two rarely well-preserved soil profiles developed on metavolcanic rocks namely Alaknanda soil profile (ASP) and Bhilangna soil profile (BSP) in Alaknanda and Bhilangna watersheds of the Garhwal Himalaya. Geochemical studies were carried out to understand the elemental mobility with reference to the least altered rock (LAR) in both the profiles. Differences in major elements showed depletion of Ca and K in ASP, and depletion of Ca and Na in BSP. This was also reflected in chemical index of alteration values which suggested variation of climatic parameters such as rainfall in the region.

Ram *et al* (2014) found the soils of hill side slope and pediments, having their parental legacy with quartzite and sandstone, are shallow, well drained and permeable, brown (7.5 YR 4/4) to dark brown (7.5 YR 3/4) in colour and have gravelly clay loam texture with fine, weak, subangular blocky structure. These soils generally support forest, open scrub and rainfed crops in patches. The soils occurring on pediplains and stream bank (1-5% slope) developed over quartzite and sandstone are yellowish red (5 YR 4/6) to dark reddish brown (5 YR 3/3) in colour and have clay loam to clay texture with fine, weak to medium, subangular blocky structure. These soils are under rainfed crops in pediplains and waste land in stream bank. The swelling clay soils (pedons 6, 7 and 8) of pediplains (1-5% slope) developed from shale are dark brown (10 YR 4/3) to very dark brown (10 YR 3/2) in colour and have clay texture with fine, medium to strong, subangular blocky to angular blocky structure.

Ande *et al* (2016) attempted to map and characterize floodplain soils of Upper Niger River Basin in Katcha Local Government Area, Niger state, Nigeria, for sustainable land use. Flexible grid method was used for mapping and it was effective for soil examination due to plain terrain. The floodplain geo-morphophysical processes show that the soils which are close to the river levees have high clay in the sub-soils with 68% maximum content. Variable and high sand contents ranging between 80% and 90% were recorded in profiles at distal positions to the levees. The morphological description shows the effect of gleization at the surface soils due to ponding with variation of grayish color. The sub-soils varies from grayish brown to brown which indicates the subsoil are better aerated than the topsoil with weak expression of ferrugination. The variable cation exchange capacity could be attributed to effect of various deposits of soil regoliths from time to time. Higher concentration of some chemical nutrients at the surface is adduced to land preparation and annual flooding.

2.4 Soil classification

Soil classification deals with the systematic categorization of soils based on distinguishing characteristics as well as criteria that dictate choices in use. The grouping of soils into distinct units or taxa based on the measurable morphological and analytical soil properties forms the basis of soil classification (Sehgal 2005). The objective of soil classification is to organize the knowledge about them so that their properties are clearly conceived and their relationship is easily understood. Soil classification is very useful in extrapolating the results of intensive studies on limited areas to other large areas with similar types of soils, and therefore importance in agro-technology transfer. The most important and widely accepted system of soil classification is the Soil Taxonomy (Soil Survey Staff, 1999) which takes into account the field and laboratory properties rather than genetic factors for classification of soils.

The soils of Punjab State belong to four orders of Soil Taxonomy: Inceptisols, Entisols, Aridisols and Alfisols. Beside these, associations of Entisols-Inceptisols and Entisols-Aridisols cover 15 and 4 per cent of total geographical area of Punjab respectively (Deka *et al* 1996 and Kumar *et al* 2010).

The denuded Siwaliks hills have thin forests pertaining to tropical dry deciduous and tropical thorny forests. The moderately to gently sloping topography have Hapludalfs, Hapludolls, Eutrochrepts whereas moderately to steeply sloping pediments at lower elevations are represented by Udorthents, Haplustrepts, Argudolls. The nearly level to level flood plains are mostly calcareous, neutral to slightly alkaline and represent Udifluvents and Haplaquepts (Sidhu *et al* 1987). The dominant soil great group associations covering the area are Ustochrept - Udorthents, Ustochrept - Udorthents -Haplustalfs, Hapludalfs - Entrochrept and Hapludolls in association with glacier. The other great group associations found in pockets are Ustochrepts - Ustorthents and Hapludalfs - Ustochrepts - Ustochrepts - Ustorthents, Ustorthents- Ustorthents with gullied land (Sehgal *et al* 1993).

Sidhu and Sharma (1990) studied the soils of the arid zone of Punjab in north-west India and classified the soils developed on sand dunes as Ustic Torripsamments whereas soils on alluvial terraces and interdunes as Ustochreptic Camborthids. Based on criteria proposed in Soil Taxonomy, Sawhney *et al* (1991) classified the soils from different physiographic units in arid and semi-arid parts of Punjab. The soils located on sand bars, rivulet and flood plains due to their young and stratified nature were classified as Typic Ustipsamments and Typic Ustifluvents. The soils from old channel fill, due to limited profile development were classified as Aquic Ustochrepts. Dhaliwal *et al* (1996) did not find any profile development in the flood plain soils of Punjab and as such the soils were classified into Entisols order. They

differentiated Orthents, Fluvents and Psamment based upon their profile characteristics. The soils were generally coarse loamy mixed hyperthermic at family level under different subgroups.

Sidhu *et al* (2000) studied the soils of Aravallies-Yammuna river transect in semi arid tract of Haryana and classified the soils from active flood plains as Typic Ustipsamments, from recent flood plains as Typic Ustifluvents and old flood plain as Typic Haplaquepts.

Raj-Kumar *et al* (2005) on assessing the actual and potential productivity of Kandi soils of Punjab found that fine loamy calcareous Fluventic Ustochrepts, Typic Ustorthents and Typic Ustipsamments have poor to extremely poor productivity for pasture and forest. Taking into account of actual productivity, potential productivity, coefficient of improvement and cost of improvement, it is concluded that forest and pasture should be encouraged only on fine loamy calcareous Fluventic Ustochrept soils.

Harsh and Tewari (2007) observed that like climate, there is a great variability in soil characteristics in hot arid regions of India. In hyper arid zone of western Rajasthan, the soils associated with dunes and sandy waste are classified as Torripsamments whereas the soils of lower topographic positions associated with interdunal plains as Typic Calciorthids, Typic Palaorthids and Typic Salorthids. Raj-Kumar *et al* (2008) while discussing the planning for precision farming, gave the classification of the soils of different agro-ecological sub-regions of Punjab. The soils of south-western agro-eco-subregion which includes parts of Firozpur, Muktsar, Faridkot, Bathinda and Mansa were classified as Ustic Torripsamments from sand dunes, and Ustic Haplocambids or Ustic Haplocalcids from inter-dunes and terraces. Sharma *et al* (2008) studied the sand dune soils of semi-arid and arid agroecological sub-regions of Punjab and classified the soils from semiarid sub-region as mixed, hyperthermic family of Typic Ustipsamments whereas that of arid sub-region as mixed, calcareous, hyperthermic family of Ustic Torripsamments since the moisture regime is weak aridic bordering with ustic moisture regime.

Ram *et al* (2014) indicated that the clay content varied from 23 to 25% in hill side slope, 25 to 26% in undulating pediments, 18 to 37% in pediplains and stream bank under Inceptisols and 37 to 53% in pediplains under Vertisols respectively. The high clay content in soils of pediplains and alluvial plains was due to deposition of finer fractions from hill side slope and undulating pediments (Rao *et al* 2008 and Ram *et al* 2010). The enrichment of clay content in lower horizon was due to illuviation or vertical migration of clay (Sarkar *et al* 2002). Sand and silt content in all the pedons ranged from 33 to 65% and 11 to 21% respectively. Sand content in soils of higher altitude was higher and decreased with depth whereas silt content in the pedons have irregular trend with the depth.

Ande *et al* (2016) characterize floodplain soils of Southern Guinea Savanna in North Central Nigeria for sustainable land use. The flexible grid method was adopted to identify the soil units. Soil map was produced in a GIS environment, using morpho-physical and soil chemical properties. The major morphological expressions are ferrolyses and gleization. The variation in cation exchange capacity recorded ($1.29\text{--}21.64\text{ cmol kg}^{-1}$) could be attributed to effects of various deposits of soil regoliths from time to time. The phosphorus distribution is generally low ($0.8\text{--}11.8\text{ mg kg}^{-1}$) while nitrogen content is $\text{N}0.15\%$ at the surface. The major pedogenetic processes include cummulization, ferrolyses and gleization. The soil units identified were classified as Fluvaquentic Epiaquept, Aquertic Ustifluvent, Kandic Ustifluvent, and Aeris Ustipsamment. The mapping units suggest two possible management units based on texture and chemical properties. The soils are generally suitable for rice production due to epi-saturation.

Sarmast *et al* (2016) studies the two types of soil classification that are soil taxonomy 2014 and world reference base 2015. Latest editions of Soil Taxonomy (2014) and WRB (world reference base) (2015) were compared for classification of calcareous and gypsiferous soils of southern Kerman in the present research. Eleven pedons were described and sampled along Jiroft-Kahnooj transect having ustic moisture regime and hyperthermic temperature regime. Based on physical and chemical analyses the soils were classified according to Soil Taxonomy (2014) and WRB (2015) systems. The calcic, gypsic, anhydritic, salic, argillic (argic), and cambic diagnostic horizons were studied in field and for laboratory analysis. Based on the findings, it is recommended that new Calciustalfs and Saliustepts great groups and Salic Anhydritic Calciustepts, Salic Calciustepts, Anhydritic Calciustepts, and Anhydritic Saliustepts subgroups need to be added to Soil Taxonomy (2014) classification system. Anhydritic diagnostic horizon, property, or material and paralithic qualifier were also suggested for WRB (2015) classification system. Results of the study showed that WRB (2015) classification system using various qualifiers and specifiers could classify soils of the area, especially saline soils, more efficiently than Soil Taxonomy.

Han *et al* (2016) believed that the soil type is a key indicator in field survey, but the current soil classification method largely depends on personal experiences of operators. Because different soils have different soil colors, soil can be classified by measuring soil colors. In this paper, they compared and analyzed the roles of the visible spectrum and machine vision adopted in soil classification and proposed a new smartphone-based, low-cost, and miniaturized soil color classification sensor.

2.5 Land evaluation for land use

Land may be evaluated directly, by trial e.g. through growing crops, collection and processing of crop-yield data, and to see what happens. The most land evaluation systems are

indirect based on soil and site properties that influence the success of a particular land use. A land may be assessed in different ways as land suitability, land capability and land value. Indirect evaluation systems assume that a number of properties influence land performance in a reasonably predictable manner, and that this performance can be deducted from the observation of those properties. It further involves the interpretation of surveys and studies of landforms, soils, vegetation, climate and other aspects of land in order to identify and make comparisons of promising kinds of land use applicable to the objectives of the evaluation. The values allocated to those properties can then be integrated into either in to a categoric or a parametric system (McRae and Burnham 1981).

The land capability classification (LCC) system was developed by the Soil Conservation Service, USDA in 1930 as part of programme to control soil erosion. The grouping of soil-units into capability classes and subclasses is done on the basis of their capability to produce crops and pasture. Klingebiel and Montgomery (1961) established criteria for placing soils in different capability classes. The land capability classification is interpretative grouping of the soils based on (i) inherent soil characteristics (ii) external land features, and (iii) environmental factors that limit the use of land. Guidelines for land capability classification (LCC) were elaborated in the Soil Survey Manual (Anonymous 1970). The All India Soil and Land Use Survey, then a central soil survey organization, and many state soil survey organizations adopted the land capability classification system to interpret the soil survey data.

Some of the shortcomings were realized in grouping of soils while applying the land capability classification in different areas. So modifications in the system and new approaches to meet specific requirements such factors as morphometry of the ravines, slope gradients, distance of table and marginal lands from the gully heads were introduced for different land capability classes for the soils of the Eastern and Western Ghats and Himalayan region (Bali and Khybri 1982). Besides a new parameter soil: stone ratio, Khybri (1979) also pointed out that the soil depth and slopes need to be considered in combination so as to indicate the potential of terrace for cultivation and horticultural development. Tejawani (1987) has reported that in the Himalayan region there is almost no class I and class II lands, little class III land and only some class IV land. Hence, cultivation in the area is being done largely on class VI and VII lands that actually are not suitable for the purpose.

A framework for land evaluation was presented by FAO (1976) defining the concept of land utilization types and suggested the classification for specific use. The different categories of the classification are orders, classes, subclasses and units. Storie (1978) proposed the Storie Index Rating of land productivity in the quantitative term based on four

factors A, B, C and X representing profile development, surface texture, ground slope and miscellaneous properties, respectively.

Sharma *et al* (2002) studied soil–site characteristics and productivity assessment of Nara-Dada-Manjhi watershed of Hoshiarpur district and identified four land productivity grades based on A, B, C and X factors. The soils from lower piedmont plains were belong to grade 2, from upper piedmont plains to grade 3 and from *choes* and hills qualified for grades 5 and 6 respectively. Raj-Kumar *et al* (2005) assessed the actual productivity and potential productivity of soils of the *Kandi* area and it suggested that forests or pastures should be encouraged only on fine loamy calcareous Fluventic Ustrochrepts whereas other lands having Typic Ustipsamments or Typic Ustorthents should not be disturbed to sustain the fragile ecosystem of the Siwaliks.

Surya *et al* (2006) made the soil erosion assessment and conservation based on soil resource data for the Siwaliks area in Balachur tehsil of Nawanshahr district, Punjab. The topography, drainage pattern and inherent characteristics of soils found to be responsible for major problems such as denudation of Shiwaliks, torrents seasonal stream (*choes*) lands, severe erosion, coarse texture; low ground water table due to less recharge of water. Soil conservation measures (like mechanical, terrace trenching, vegetative, etc.) were suggested to restore the eroded area on sustainable basis. Results of case study indicated that six soil series into 21 soil mapping units occupying 35.2% area, experienced problem of moderate erosion, 27.0% area affected by severe to very severe erosion. Leveling, contour bunding, field bunding, cultivation of thick canopy crops like green gram, moth bean and green manuring crops; construction of vegetative and masonry check dams in higher slopes; sowing and planting on degraded lands; terracing of lands, contour trenching, gully plugging; landslide control measures like masonry spill, waltings structure, etc. have been recommended to check the erosion losses. Water harvesting techniques should be encouraged. ‘Choes’ affected sandy and severely eroded soils (0.66%) occurring on moderate slopes with surface boulders are recommended for plantation of erosion resistant grass species like *Saccharum* species. To slow down the dissection of these soils due to overflow of water, cultivation of fodder crops by adopting adequate soil conservation practices has been recommended as preventive measures. Studies further indicated that macro-level soil resource mapping is useful for demarcating the general and potential soils, however, for identifying more specific problems and field-level soil conservation measures micro level mapping is more effective.

Hedge *et al* (2008) studied Soils in Lingnahalli microwatershed under Amani Shivpurkere watershed, Doddaballapur taluk, Bangalore Rural District, Karnataka for their

properties and classification. The soil texture ranged from sandy loam, sandy clay loam through sandy loam and loamy sand to sand in the surface horizons. The pH of surface soils ranged from 5.0 to 7.3, EC from 0.20 to 1.23 dS m, organic carbon from 1.2 to 6.0 g/kg and CEC from 1.0 to 11.8 c mol kg⁻¹ at surface layer. The OC, pH, EC, CEC and exchangeable bases did not follow a regular trend with depth. Most of the soils in the study area were free from major constraints and suitable for major adopted crops of the region.

Srivastava *et al* (2010) studied suitability of soil and water conservation measures for Badri Gad watershed of Tehari Garhwal district of Uttarakhand using geographical information system. The land capability classes were identified considering slope parameter. The dominant slope classes were VI covering 27.2% area followed by class VI covering 26.6% area. More than 50 per cent area was under moderately steep slope and steep sloping classes. Demelash and Stahr (2010) studied on assessment of integrated soil and water conservation measures on key soil properties in South Gonder, north-western highlands of Ethiopia and found that soil organic matter, total N, available phosphorous (P), bulk density, infiltration rate and soil texture found a significant difference between conserved and non-conserved lands. Soil pH and electrical conductivity (EC) did not show significant difference. The non-conserved had the lowest soil organic matter, total N and infiltration rate with highest bulk density, clay content and available P. Soil organic matter content positively correlated with infiltration rate and total N and it negatively correlated with soil bulk density. Cation exchange capacity positively correlated with soil pH and available P. The undulating lands were moderately suitable for rain fed agriculture. Hilly and valley lands found suitable for protective forestry and livestock production for a better sustainable land use.

Bhandari *et al* (2013) conducted a study in the watershed of Tons river to ascertain crop suitability assessment for mango and wheat using land capability classification through appropriate GIS techniques. Based on the slope map, land characteristics of each physiographic unit and land capability criteria for land qualities, land capability classes and sub-classes were assigned. These assignments were translated into a land capability map. From the slope map, a slope suitability map was generated, which was combined with land characteristics and crop suitability criteria to generate crop suitability maps for mango and wheat. The GIS software used was ARCGIS10 and image processing software used was ERDAS9.2.

Sidhu and Surya (2014) studied the soils of North-Western Himalayan eco-system and their land use, constraints and productivity potentials, and observed that about 36 per cent area is affected by severe soil erosion, 49 per cent by moderate and 13 per cent by slight

erosion in the north western Siwaliks. Stoniness covering 25 per cent area is also a major problem in severely eroded areas. These areas should be treated by adopting suitable soil conservation measures to minimize soil erosion losses. These soils need intensive soil conservation measures along with introduction of erosion resistant varieties of grasses like Bhabbar grass which can also be utilized for paper manufacturing. Some of these soils are well suited for raising horticultural crops, protected-pastures, forestry and recreational activities.

CHAPTER III

MATERIAL AND METHODS

Keeping in view of the objectives mentioned in Chapter I, the materials and methods used during the course of the study have been reported under the following heads:

3.1 Geological conditions

3.1.1 Location and extent

Maili watershed is the part of Maili village in Mahilpur block of Garhshankar Tehsil in Hoshiarpur district of Punjab, India. Hoshiarpur district forms the kandi region of Punjab covering the north-eastern wedges of the submontane adjoining Himachal Pradesh. In Punjab, nearly 10.6% of the total geographical area of 5.03 mha comprising of foothills and piedmont, is popularly known as Kandi area. Hoshiarpur district covers an area of 3390 sq. km, out of which forest area is 1090 sq. km (32.2 per cent). Due to steep slopes the area is infested by number of choes causing flash-floods causing erosion and damages to crops. Most of the population of this area depends on agriculture either as farmers or as agriculture labourer. Maili watershed extends between the longitudes of $76^{\circ} 03' 46.8''$ and $76^{\circ} 09' 03.6''$ E and the latitudes of $31^{\circ} 25' 56.4''$ and $31^{\circ} 28' 44.4''$ N. The area fall under the survey of India topo sheet No H43E3 on 1:50000 scale. The watershed has an area of 36.07 sq km. The minimum and altitude is 313 m and maximum 586 m respectively above the mean sea level (Fig. 3.1).

3.1.2 Geology and physiography

The northern part of Hoshiarpur district where Maili watershed is situated, presents distinct geology and physiography. The most characteristic features of the area are the Siwalik hills and piedmont plains. The Siwalik hills comprising of Upper Siwalik formation of Upper Pliocene to Lower Pleistocene age represented by two distinct lithofacies namely the sandstone and conglomerate. The sandstone facies form the lower part of the geological sequence and dominantly composed of thick beds of poorly to moderately indurated light grey to pale brown pebbly sandstones of fine to very fine grain size. The upper part of the sandstone facies frequently alternate with pale brown to reddish brown clays/ silty clays/ sandy clays beddings. The conglomerate facies occupying the upper most part of the geological sequence have composed of pebble, cobble and boulder size fragments of chert, quartzite, sandstone and siltstone. The piedmont plain is composed of the alluvium derived from the Siwalik formations. The deposits originating from sandstones are coarser in texture and those originating from siltstones and shales are finer in texture. The alluvial deposits of piedmont plains are of the Recent age of Quaternary period (Wadia 1979).

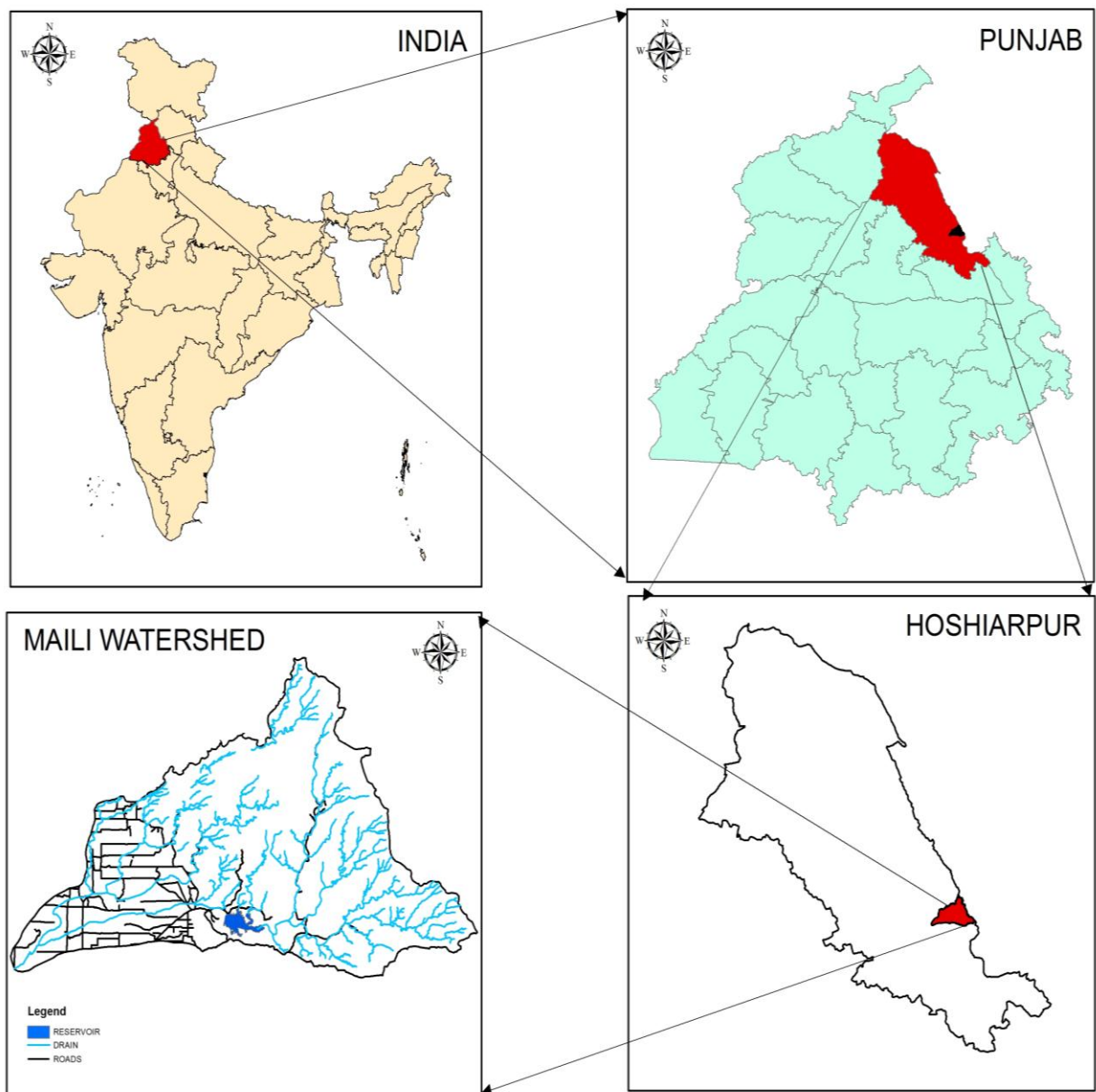


Fig. 3.1: Location map of Maili watershed

3.1.3 Climate

The study area belongs to the semi-arid (submoist) less hot zone of Punjab as reported by Sehgal *et al* (1992). The climate of the region is characterized by humid eco system with mild summers and cold winters. The sub-region receives ample sunshine as such photosynthetic activity is not limited by radiation the mean maximum temperature ranges between 25⁰ C and 34⁰C, and, mean minimum temperature ranges between 9⁰C and 22⁰C in rabi and kharif season respectively. The means annual rainfall ranges from 850 to 1200 mm. The month of July, August and September show peak period of the rainfall. The rainfall of this season are quite heavy resulting in excessive run-off having heavy sediment load .The quality of water in this region is good but it is very deep.

3.2 Remote sensing

Remote sensing is an important tool for watershed characterization and resource mapping. The Punjab Remote Sensing Centre, PAU Campus, Ludhiana has provided all help related to remote sensing work for the present study.

3.2.1 Remote sensing techniques

The remote sensing techniques illustrate the materials required and methodology adopted for the completion of the objectives of the present study. The flow diagram of methodology is presented below:

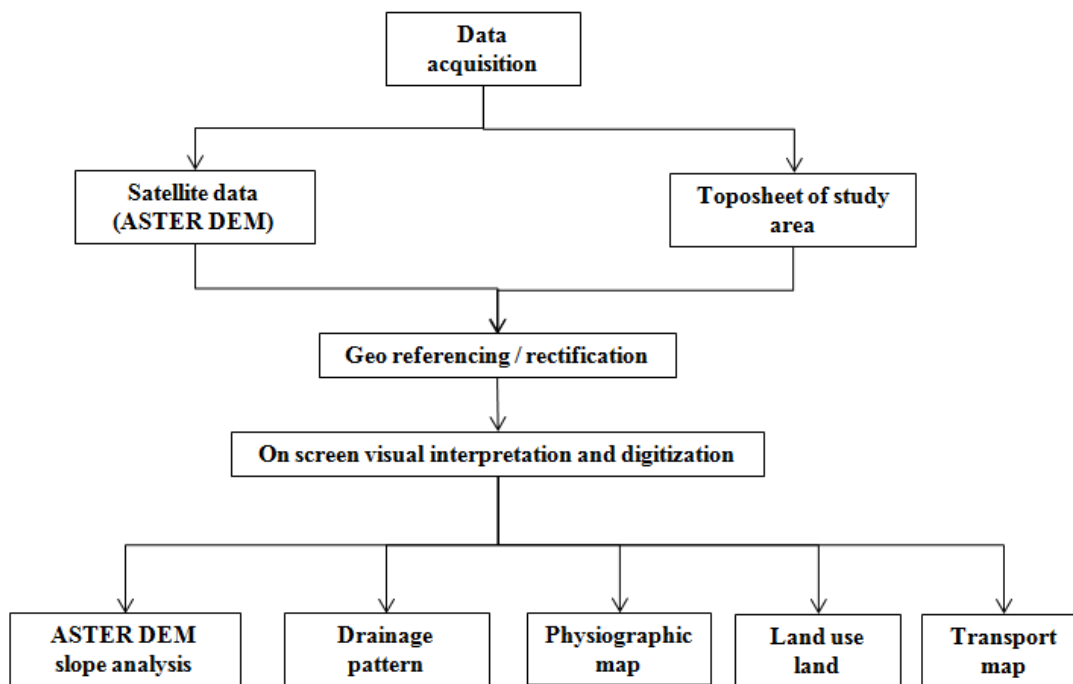


Fig. 3.2: Flow diagram of methodology

3.2.2 Data resource

The following secondary data are used in this study

- I. Topographical sheet no. H43E3 open series updated in 2000-01 on 1:50,000 scales of Maili watershed.
- II. Merged data (LISS IV + CARTOSAT-1 PAN) October (2009), spatial resolution 2.5m (source: PRSC, Ludhiana)
- III. ASTER (aster space borne thermal emission and reflection radiometer) with spatial resolution 30m

3.2.3 Software and tool used

- I. Arc GIS 10 software
- II. Global positioning system (GPS) tool was used for measurement of latitude and longitude of the study area.

3.2.4 Delineation of drainage basin

The locations on the Maili watershed of the study area have been identified with the help of global positioning system (GPS). Topographical sheets on 1:50,000 scale has been used for morphological and relief records and further used in Arc GIS (10) software. Maps and images will be dereferencing in a same projection with the help of software. After dereferencing the data has been overlaid to each other in Arc GIS 10 for the analysis of land use land cover.

The drainage basin of the Maili watershed has been delineated on a base map obtained from survey of India toposheet. The drainage basin would be divided according to surface run-off splits flow away from basin. The watershed boundary will be delineated and drainage network will be derived from toposheet using contours.

The drainage map along with watershed boundaries has been digitized. The digitized map was edited in Arc GIS Software. The morphometric parameters under linear and shape were computed using standards methods

3.2.5 Standards methods for morphometric analysis

There are mainly three different types of morphometric parameters i.e. liner, areal and relief for analyzing.

3.2.5.1 Linear aspects

Computation of the linear aspects such as stream order, stream number for various orders, bifurcation ratio, stream lengths for various stream orders and length ratio are described below.

- I. Stream Number (Nu):** With the application of GIS, the number of streams of each order and total numbers of streams were computed. The total number of streams gradually decreases as the stream order increases.
- II. Stream Order (U):** The channel segment of the drainage basin has been ranked according to Strahler's (1952) stream ordering system. In the system fingertip stream has lowest order while trunk stream through which all discharge of water and sediment passes has highest order.
- III. Stream Length (Lu):** The stream length of various orders of watershed has been measured on digitized map with the help Arc GIS 10.
- IV. Stream Length Ratio (RL):** The length ratio (RL) is defined as the ratio of mean stream length (Lu) of segment of order u, to mean stream segment length (Lu-1) of the next lower order u-1. The stream length ratios (RL) are changing haphazardly at the basin and sub-basin levels.
- V. Mean stream length (Lsm):** The mean stream length of a channel is a dimensional property and calculated by dividing the total stream length of order by the number of streams. Mean stream length reveals the characteristic size of drainage network components and its contributing basin surfaces (Strahler 1964).
- VI. Bifurcation Ratio (Rb):** The ratio of the number of streams of any given order to the number in the next lower order is bifurcation ratio. As indicated by Strahler (1964), the ratio of number of streams of a given order (Nu) to the number of segments of the higher order (Nu+1) is termed as the Rb.

3.2.5.2 Areal aspects

- I. Drainage density (Dd):** Horton (1945) characterized Dd as the total length of channels (Lu) in a catchment divided by the area (A) of the catchment. Slope gradient and relative relief are the principle morphological elements to controlling drainage density.
- II. Stream Frequency (Fs)** The stream frequency (Fs) of a basin may be defined as the number of streams per unit area (Horton, 1945). It mainly depends on the lithology of basin and reflects the texture of drainage network.
- III. Drainage texture (Dt)** Drainage texture is the total number of stream segments of all orders per perimeter of that area (Horton, 1945). Smith (1950) classified drainage density into five classes i.e., very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8).

3.2.5.3 Relief aspects

- I. Relative Relief: Relative relief is the** the maximum vertical distance between the lowest and highest points of basin.

II. Relief Ratio: The relief ratio (Rh) of maximum relief to horizontal distance along the longest dimension of basin parallel to the principal drainage line (Schumn 1956).

3.3 Field survey and study of soils

The physiographic map generated from remote sensing technique along with survey of India toposheets is used as base map to select the traverse route for the study of soils. Several traverses were undertaken following kachcha roads and dry drainage courses in the hilly terrain. During the field survey number of excavations, vertical exposures and auger bore were also examined in order to differentiate the soils. The traverses and examination of soils at different random locations form the part of rapid reconnaissance survey. Based on rapid reconnaissance survey and having strong soil-physiographic relationships along with geological control, seventeen locations from different parts of Maili watershed were selected for detailed observations and differentiation of soils of the area. Out of total seventeen representative soil profiles, five profiles are from the hill tops (P1, P11, P13, P14, P15), four from the hill slopes (P3, P4, P9, P16), two from the hill terraces (P12 and P17), three each from the choe beds (P2, P8, P10) and the piedmont plains (P5, P6, P7) (Fig 3.3). These profiles were exposed to different depths depending on thickness of soil solum and presence of bedrock.

The freshly exposed soil profiles were studied for their morphological properties such as horizons, colour, texture, structure, consistence, reaction, concretions, etc. following the standard procedures (Schoeneberger 2012).

3.4 Collections of soil samples

The sampling was carried out from all the seventeen profiles. The soil samples were collected from each of the morphologically differentiated horizon. Four to five samples were collected horizon-wise from each profile. The samples were placed in shade for air drying. The dried samples were crushed gently with a wooden pestle and mortar, and passed through a 2mm sieve for separating coarse fragments, if any. The soil material passed through the sieve was used for laboratory analysis of physio-chemical and other parameters.

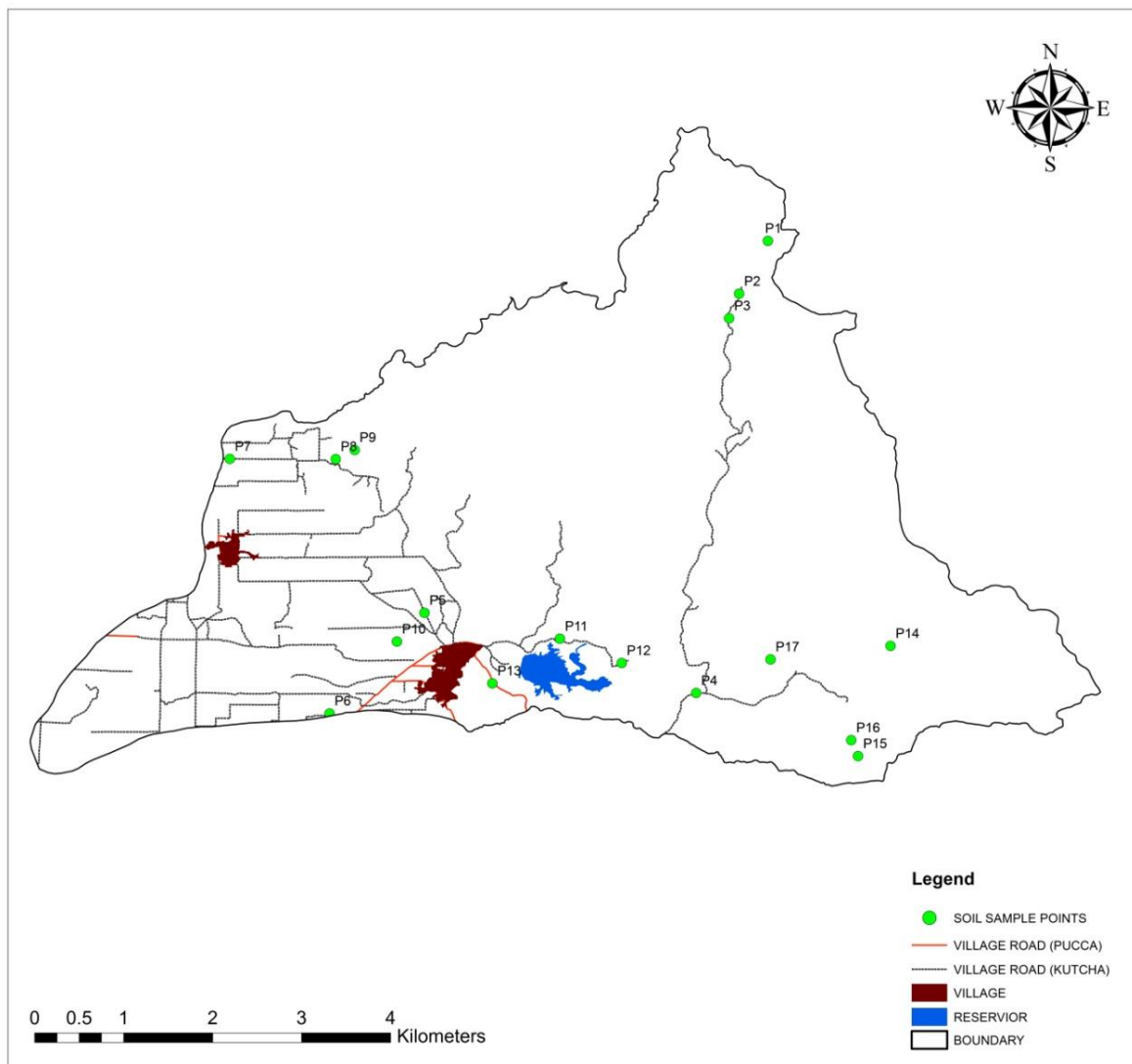


Fig. 3.3: Locations of different profiles in Maili watershed

3.5 Determinations of physico-chemical properties

3.5.1 Particle size distribution (texture)

Particle size distribution was determined by the International Pipette method (Page *et al* 1982). The soil was dispersed by stirring the sample, treated with 1 per cent sodium hexa-metaphosphate. The sand was separated by wet sieving through 300 mesh sieve. The suspensions containing Silt and clay fractions were collected in one liter capacity sedimentation cylinder. Volume of silt plus clay suspension in the cylinder was made to one liter and these contents were thoroughly mixed using a plunger. Twenty five ml of suspension was pipette-out from a depth of 10 cm in the cylinder after a requisite settling time for smaller than 2μ particles. Percentage of clay was calculated from the sample so obtained. Percentage of silt was computed by subtracting sand plus clay percentage from 100. The USDA textural triangle was used for determining textural classes.

3.5.2 Soil reaction (pH)

A soil suspension was prepared with distilled water keeping 1:2 soil to water ratio and the concentration of hydrogen ions in soil suspension (pH) was measured by potentiometric method (Jackson 1973). The pH of the solution being proportional to the potential developed on the glass membrane was measured in conjunction with saturated calomel electrode as reference electrode.

3.5.3 Electrical conductivity (EC)

The soil suspension used for pH determination was also used to measure soluble salts after keeping them overnight to obtain a clear supernatant solution. The soluble salts in soils were measured with a conductivity meter, also known as salt bridge. The conductivity of electric current through soil solution is proportional to the concentration of soluble salts in it (Richard 1954). The EC was expressed as decisiemens per meter (dS m^{-1}).

3.5.4 Organic carbon (OC)

Rapid titration method (wet digestion method) was used for organic carbon determination (Walkley and Black 1934). In this determination 2 gm of dried soil was treated with 10 ml of 1N $\text{K}_2\text{Cr}_2\text{O}_7$ solution in a 250 ml conical flask. A 20 ml of concentrated H_2SO_4 was slowly added to the flask. After 30 minutes, about 0.5 gm of NaF, 100 ml of distilled water and 10 drops of diphenylamine indicator were added to the flask. These contents were titrated against 0.5N ferrous ammonium sulphate solution. The change of colour from violet to bright green through blue color was the end point. The value of ferrous ammonium sulphate used for titration was adopted for calculating organic carbon and was expressed as percentage. In another flask, 10 ml of 1N $\text{K}_2\text{Cr}_2\text{O}_7$ solution was titrated without soil against 0.5N ferrous ammonium sulphate solution to determine blank reading.

3.5.5 Calcium carbonate (CaCO_3)

Rapid titration method of Puri (1930) was employed to determine calcium carbonate equivalent of the soils.

3.5.6 Exchangeable cations and exchange capacity (CEC)

The soil is leached with a sodium acetate solution having pH 8.2 for replacement of exchangeable cations by sodium ions. The excess of salt is washed down by alcohol (95%) and ammonium acetate having pH 7. The sodium ions released, from the exchange complex, measured by flame-photometer (Jackson 1967). For measuring exchangeable cations, soil is washed with repeated washing with ammonium acetate. Ammonium ions get adsorb on exchange complex replacing the cations already sitting on complex. The cations so released into the solution, the extract was analyzed for Na and K using Elico CL22D flame photometer, and Ca and Mg by versenate titration method (Barrows and Simpson 1962).

3.6 Determination of fertility status

3.6.1 Available nitrogen

Available nitrogen was determined by the method described by Subbiah and Asija (1956).

3.6.2 Available phosphorus

Available phosphorus in soil was determined by Olsen *et al* (1954).

3.6.3 Available potassium

Available potassium in soil was determined by ammonium acetate extractable K using flame photometer (Jackson 1973).

3.6.4 DTPA- extractable micronutrients

The DTPA-extractable Zn, Fe, Mn and Cu contents in the soil samples were determined from 1:2 soil-extractant ratio using DTPA-TEA buffer (0.005 M DTPA + 0.001 M CaCl_2 + 0.1 M TEA, pH 7.3), and concentration of Zn, Fe, Mn and Cu were measured on atomic absorption spectrophotometer (Lindsay and Norvel 1978).

3.7 Statistical analysis

Correlation matrix was run to find the relationship among different physico-chemical properties, and between physico-chemical properties and available nutrients of the Maili watershed soils.

CHAPTER IV

RESULTS AND DISCUSSION

The results of the present study are presented and discussed under the following heads:

- 4.1 Geomorphology of the watershed
- 4.2 Watershed characteristics
- 4.3 Land use land cover
- 4.4 Morphological characteristics of soils
- 4.5 Physico-chemical characteristics of soils
- 4.6 Taxonomic classification of soils
- 4.7 Fertility status of soils
- 4.8 Land evaluation and land capability classification

4.1 Geomorphology of the watershed

The geomorphic analysis of the study area has been carried using Survey of India Topo sheet no. H43E3 (open series updated in 2000-01) on 1:50,000 scales along with merged satellite data (LISS IV + CARTOSAT-1 PAN) with help of Arc GIS 10 software. Field survey was also performed for the verification of the geomorphic units of the watershed. Maili watershed falls in Mahilpur block of Garhshankar Tehsil in Hoshiarpur district of Punjab. The north eastern boundary of the watershed is located in the Siwalik hills whereas south western boundary in the piedmont plains. So, the most characteristics physiographic features of the area are the Siwalik hills and piedmont plains. The Siwalik hills form a sharp physiographic and tectonic boundary with undulating piedmont plains lying to the south which marks the presence of Himalayan Frontal Thrust (Gill et al 2004). The various geomorphic units identified in the watershed area are (Fig. 4.1):

- 1. Siwalik hills
- 2. Hill terraces
- 3. Piedmont plains
- 4. Choe beds

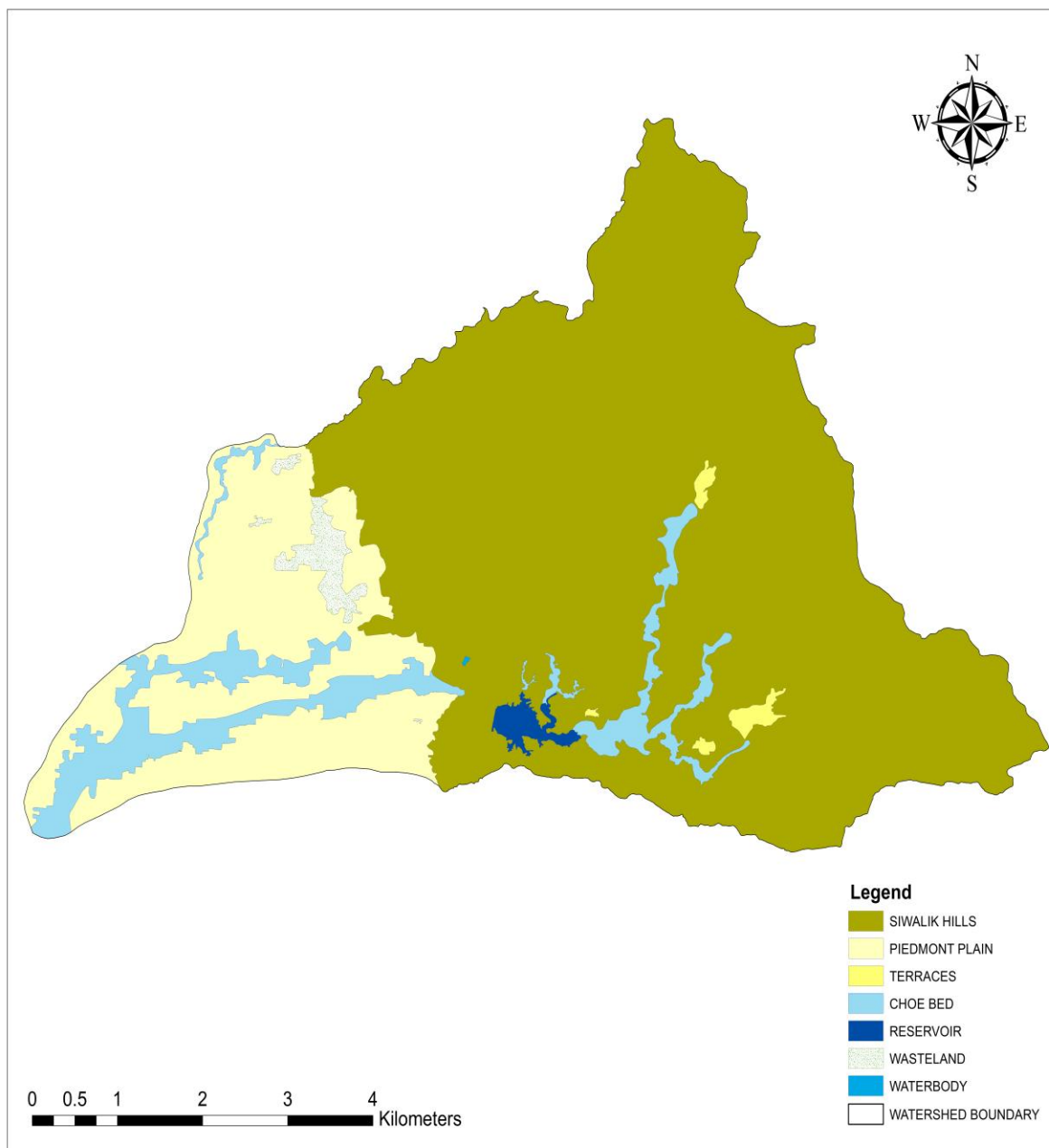


Fig: 4.1: Geomorphologic map of Maili watershed

4.1.1 Siwalik hills

The Shiwalik hills are found in the north-eastern part of the study region which runs from north-west to south-east direction. The Shiwalik hills occupy a sizeable area in Hoshiarpur districts nearly 2.6 per cent in the state. The Siwalik Hills in north-east are steeply sloping. The Siwalik hills have general slope ranging from 25 to 50 per cent. The elevation of Siwaliks hills ranges from 400 meters to 580 meters in the study region from mean sea level. The Siwalik hills of the area are composed mainly of thickly bedded, poorly to moderately indurated light grey to pale brown pebbly sandstones and poorly indurated pale brown to reddish brown clays silty clays, sandy clays or silt stones. The Siwaliks formations have inclined bedding planes suggesting deformation in the past. The area is prone to water erosion due to high slopes and poorly consolidated rocks. The Siwalik hills form a sharp physiographic and tectonic boundary with undulating piedmont plains lying to the south which marks the presence of Himalayan Frontal Thrust (Gill *et al* 2004). The hills have poor to dense to open scrub forest.

4.1.2 Hill terraces

Hill terraces located in the Siwalik hills are either natural or man-made. The natural terraces are formed along the banks of the rivers or rivulets by erosion or sedimentation processes during the course of valley development. The man-made terraces are created artificially along the contour of the hills for the purpose of terrace farming. Maili watershed in the Siwalik hill showed presence of small patches terraces where cultivation is performed. The terrace area is small near the hill tops and higher in foothills. The terrace sediments vary in composition depending on underlying and surrounding rocks, and mode of their formation.

4.1.3 Piedmont plains

The piedmont plains, popularly known as Kandi area is located at the foot of Siwalik Hills. This zone runs along the Siwalik hills in the south from north-west to south-east direction. The piedmont area forms a transitional zone between the Siwalik hills and alluvial plains. The piedmont plain covers large area about 10 to 15 km wide and extends in Gurdaspur, Hoshiarpur, S.B.S. Nagar, Rupnagar and S.A.S Nagar districts. The elevation of this zone varies from 300 to 375 m above MSL. It forms the undulating plain with a slope of 1 to 6 per cent. It is which progressively decreases towards the west side of the district. The piedmont plain is composed of the alluvium derived from the Siwalik formations. The deposits originating from sandstones are coarser in texture and those originating from siltstones and shales are finer in texture. The alluvial deposits of piedmont plains are of the Recent age of Quaternary period (Wadia 1979). Geomorphologically, the piedmont plains can be grouped into 2 units- upper piedmont and lower piedmont plains. The alluvial fans coalesced to form Kandi belt (lower piedmont). These alluvial fans are mainly found in the

foothills deposited by hill torrents. The upper piedmont forming near the hills consist of sand, gravel and pebbles materials which make the plains infertile. The lower piedmont also called Sirowal belt forming the lower part is comprised of sediments containing sand, silt and clay fractions in varying amount.

4.1.4 Choe beds

Choes represents natural streams, which carry excess rain water from Siwalik hills and the sloping piedmont plains during rainy season. These choes originate in Siwalik hills and adopt frequent changes their courses depending upon topography, volumes and velocity of rain water and sediment load. Many of these choes terminate in the area without joining any major stream/river. These seasonal rivulets (choes) dissect and erode the area by storm water and transport the sediments from their catchments. The coarsest of these sediments are deposited in the form of alluvial fans at the foot hills whereas the finer fractions are deposited farther away within the piedmont area. These choes also damages the cultivated land, when they flow in velocity. In dry period, the choes have some water flowing in it feed by springs in the upper reaches in hills. However, water get dry up in the lower reaches of choes in the piedmont because of very permeable strata of the piedmont plains and low volume of water. The deposits in and around these rivulets are sandy in nature in the piedmont and gravelly and pebbly in the hills. The area is partly cultivated and partly under forests and wastelands.

4.2 Watershed characteristics

The study area exhibits complex mountainous environments which are highly susceptibility to natural hazards particular those that are triggered by the action of water such as soil erosion, floods and mass movements. Among all the natural hazards, soil erosion is the most implicit and the devastating hazard affecting the life and property of the millions of people living in these regions. The watershed study provides in-depth assessments of topography, drainage, soils, conservation and other aspects for better understanding of available resources. The information gathered may be used in appropriate models for management of watershed at a finer scale. The watershed study may address specific concern like soil, water quality, animal feeding, drainage management, manure management, wildlife habitat, etc depending on its objective.

4.2.1 Watershed boundary and extent

Watershed boundaries are topographic divides and delineate area where rainfall and surface-run off drains into common water body such as stream, lake and river. Watershed boundaries follow the highest and lowest ridgeline around the stream drainage area, where water flows out of the watershed. Maili watershed covers an area of 36.07 sq km in Garshankar tehsil of Hoshiarpur district of Punjab. The watershed is triangular in outline

having one arm following ridge line of Siwalik hills in the north east. The main rivulet or choe in the watershed is the Maili choe which drains the whole watershed through its smaller network from hills to plains. Its general flow is in the south west direction.

4.2.2 Drainage characteristics

Morphometric analysis of a watershed provides a quantitative description of the drainage system, which is an important aspect of the characterization of watersheds (Strahler 1964). Drainage pattern refers to spatial relationship among streams or rivers, which may be influenced in their erosion by inequalities of slope, soils, rock resistance, structure and geological history of a region. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms. This analysis can be achieved through measurement of linear, areal and relief aspects of the basin and slope contribution (Nag and Chakraborty 2003).

4.2.2.1 Linear aspects of watershed

The linear aspects of a watershed deals with the quantitative analysis of a watershed area, where running water has been acted for a long period which modified the surface geometry of the watershed. The stream order, stream number for various orders, bifurcation ratio, stream lengths for various stream orders and length ratio are some of the linear aspects of the watershed. The computation and description of these linear aspects are as under.

4.2.2.1.1 Stream order and stream number

In the present study, the channel segment of watershed has been ranked according to Strahler's (1964) stream ordering system. With the application of GIS, the number of streams (Nu) of each order and the total numbers of streams were computed. The whole drainage in the watersheds is differentiated in four orders. The streams of various orders (U) and drainage pattern of Maili watershed are presented in Fig 4.2. The data in Table 4.1 depict that the total 194 streams were identified out of which 132, 46, 14 and 2 streams belong to 1st, 2nd, 3rd and 4th order respectively in Maili watershed. Total number of streams gradually decreases as the stream order increases.

4.2.2.1.2 Stream length

The stream length of micro watershed of various orders has been measured on digitized map with the help Arc GIS 10. The length of each stream is presented in Table 4.1. Then after adding each stream for a given order, the total stream length of each order (Lu) has computed. The stream length is higher for first order and decreases as stream order increases. The total length of the streams of the watershed is 109.40 km.

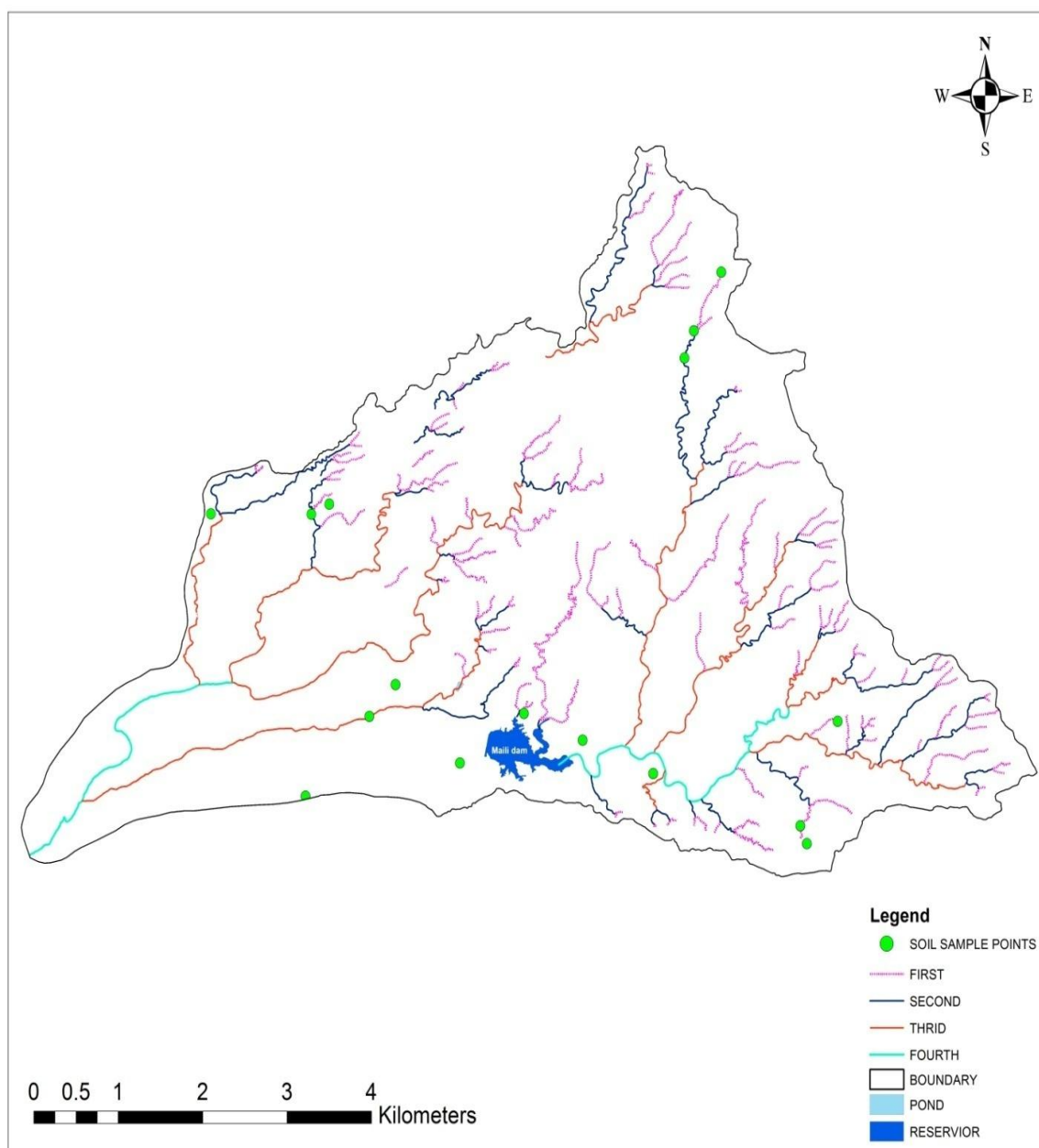


Fig. 4.2: Stream order and Stream number of Maili watershed

4.2.2.1.3 Mean stream length

The mean stream length of a channel is a dimensional property and reveals the characteristic size of drainage network components and its contributing basin surfaces (Strahler 1964). The mean stream length (Lsm) is calculated by dividing the total stream length of a given order by number of stream in the same given order. The mean stream length calculated for Maili watershed ranges from 0.323 to 3.715 km for streams of 1st to 4th orders. The mean stream length of the given order is higher than the previous order and lower than the next successive order (Table 4.1).

Table 4.1 Linear morphometric parameters of Maili watershed

Stream order	Stream in order (No)	Stream length (Km)	Mean stream length (Km)	Bifurcation ratio	Stream length ratio
1	132	42.68	0.323	2.809	1.786
2	46	26.57	0.578	3.067	4.046
3	14	32.72	2.337	4.667	1.590
4	2	7.43	3.715	--	--
	$\Sigma = 194$	$\Sigma = 109.40$			

4.2.2.1.4 Stream length ratio

The stream length ratio (RL) is defined as the ratio of the mean length of the given order of the stream to the next lower order. The stream length ratios (RL) are changing haphazardly at the basin and sub-basin levels. The values of the stream length ratio vary from 1.590 to 4.046 from basin. The stream length ratio has an important relationship with the surface flow discharge and erosion stage of the basin. The changes in the stream length ratio of various orders indicate their late youth stage of geomorphic development.

4.2.2.1.5 Bifurcation ratio

The term 'bifurcation ratio' (Rb) was introduced by Horton (1932) to express the ratio of the number of streams of any given order to the number in the next higher order. According to Strahler (1964), the ratio of number of streams of a given order (Nu) to the number of segments of the higher order (Nu+1) is termed as bifurcation ratio. In the study area, mean bifurcation ratio varies from 2.809 to 4.667. Usually these values are common in the areas where geologic structures do not exercise a dominant influence on the drainage pattern. The bifurcation ratio values of a basin ranging between 3 and 5 are considered to be characteristics of the basin which have experienced minimum structural disturbances (Strahler 1964) and geologic structure does not exercise a dominant influence on the drainage pattern (Chow 1964). In the study area it is noted that bifurcation ratios of different order streams are generally near to 3 or more indicating erosionally controlled stream pattern. The lower bifurcation ratio (<3) for first order streams indicates some geologic structural control in the

drainage in the watershed. The higher bifurcation ratio for sub-basins is the result of large variation in frequencies between successive orders and indicates the mature topography.

4.2.2.2 Areal aspects of watershed

The areal aspects of the watershed include drainage density, drainage frequency, drainage texture, etc which are discussed as under (Table 4.2).

4.2.2.2.1 Drainage density

The drainage density (Dd) is a significant factor to understand land forms element in stream eroded topography. The two main morphological factors controlling drainage density are the slope gradient and relative relief. Strahler (1964) noted that the lower drainage density is favoured where basin relief is low whereas higher drainage density is favoured where basin relief is high. Horton (1945) defined drainage density as the total length of channels (Lu) in a catchment divided by the area (A) of the catchment. Drainage density gives an idea about the physical properties of the underlying rocks in the study area. In general, higher the drainage density faster is the runoff. The high drainage density is the resultant of weak or impermeable sub surface material, thin vegetation and high (mountainous) relief. The low drainage density of the watershed reveals that they are composed of permeable subsurface material, good vegetation cover, and low relief which results in more infiltration capacity in the watershed (Singh *et al* 2014). The drainage density of Maili watershed is 3.033 km/km² indicating that the region has permeable subsoil, good vegetation cover and has moderate relief.

4.2.2.2.2 Stream frequency

The stream frequency (Fs) is obtained by dividing the total number of streams segment of all order by the total drainage area (Horton 1932). The stream frequency exhibits a positive correlation with drainage density. With increase in stream population, there is increase in the drainage density. The stream frequency of Maili watershed is calculated to be 5.379. The stream frequency is mainly depend on the lithology and reflects the texture of the drainage network of the basin.

4.2.2.2.3 Drainage texture

Drainage texture is the total number of stream segments of all orders per perimeter of that area (Horton, 1945). It is one of the important concepts of geomorphology which means that the relative spacing of drainage lines. The variation in the value of drainage texture (Dt) depends upon a number of natural factors such as climate, rainfall, vegetation, rock, soil type and their infiltration capacity and relief of the basin. Smith (1950) has classified drainage density into five different textures. The Drainage density less than 2 indicates very coarse, between 2 and 4 is related to coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture. The drainage texture of Maili watershed is 5.639 which indicate moderate drainage texture.

4.2.2.3 Relief aspects of watershed

4.2.2.3.1 Basin relief

It is the maximum vertical distance between the lowest elevation and the highest elevation points of the basin. The minimum height is 313 m and maximum height is 586 m of the basin. The relief of the basin is 273 m. The relative relief was calculated as percentage by dividing the basin relief with perimeter and multiplying by hundred as suggested by Melton (1957). Using the basin relief and perimeter the relative relief for Maili watershed comes out as 0.8 per cent.

4.2.2.3.2 Relief ratio

The relief ratio is defined as the ratio between the basin relief and the horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumn 1956). The length of the principal drainage stream in the area is 8.531 km. It measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion processes operating on the slopes of the basin. The relief ratio of Maili watershed has come to 0.032.

4.2.2.3.3 Slope

Slope is the measure of change in surface value over distance and can be expressed in degrees or as a percentage. Any two points on the grid will be sufficient to ascertain a slope. Once the slopes have been calculated, then the maximum difference can be found and the gradient can be determined. The slope of Maili watershed was computed using Arc GIS 10 software. The slope was found in the range of 0 to 45 degree, which are further categories as level (0-1), very gentle (1-3), moderate (3-8), strong (8-15), extreme (15-30), steep (30-45) and very steep (> 45) slopes as shown in Figure 4.3. A major part of Siwalik hills present slope in the range from 15 to more than 45 degree suggesting extreme to very steep slopes. The piedmont area, however, exhibits less than 15 degree slope suggesting level to strong slopes. The slope of the watershed is affected by many factors like geological structures, absolute and relative relief, vegetation cover, drainage characteristics, climate, etc.

Table 4.2 Areal and relief parameters of Maili watershed

Area of watershed (km ²)	Perimeter of watershed (km)	Drainage density (km/km ²)	Drainage frequency (streams/km ²)	Drainage texture (streams/km)	Basin relief (km)	Relative relief (%)	Relief ratio
36.068	34.402	3.033	5.379	5.639	0.273	0.8	0.032

The study suggested that the area is drained by a network of drainages distributed over the Siwalik hills and adjoining piedmont plains consisting moderately consolidated sandstone or clays and coarser alluvial sediments, respectively. The Siwalik hills have higher relief and steep slopes whereas piedmont plains have lower relief and gentle undulating

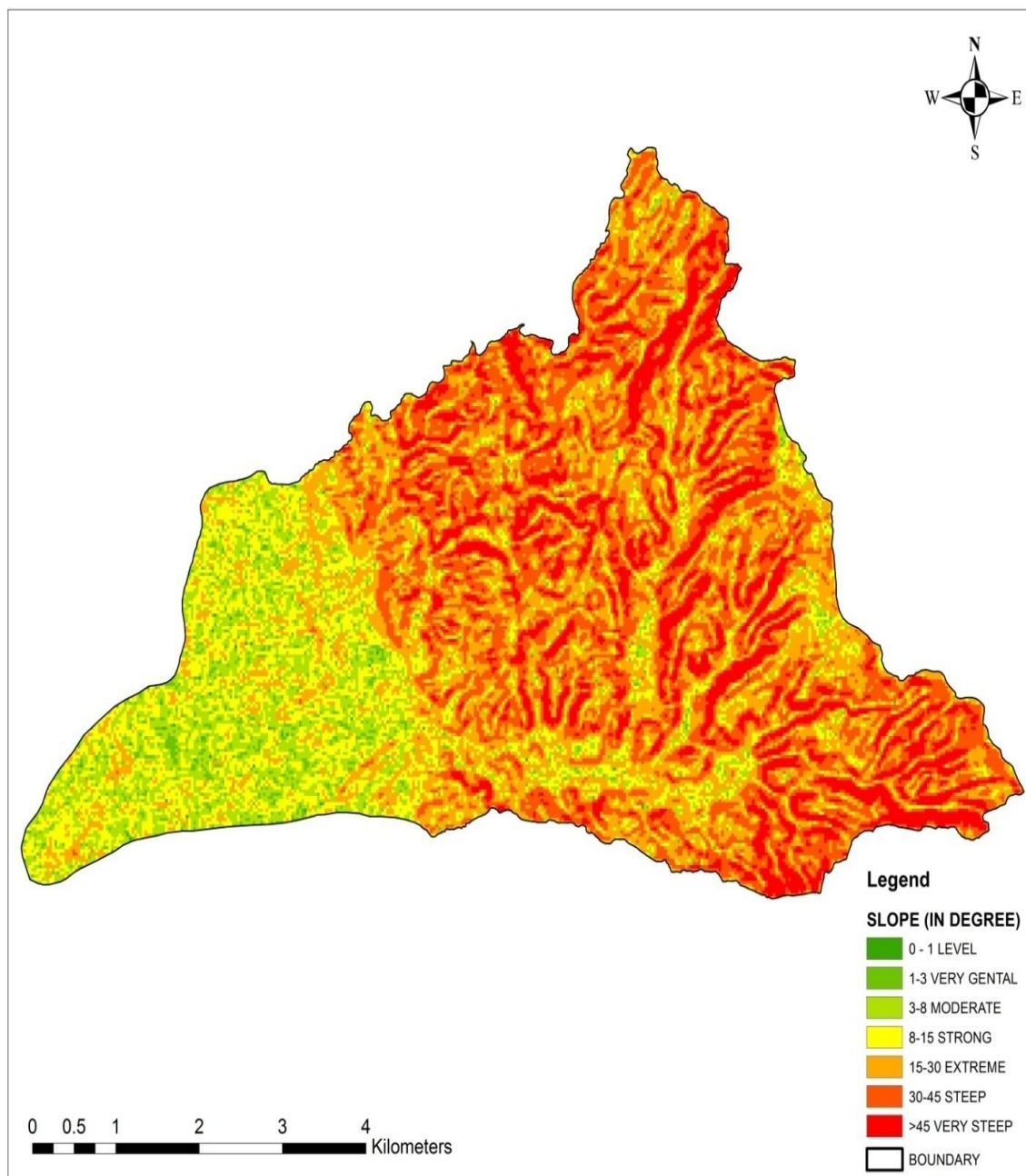


Fig. 4.3: The slope map of Maili watershed

slopes. Under the condition, the drainage has adopted the dendritic/ sub-dendritic drainage pattern as seen from the fact that the tributary systems are subdivided headway like the limbs of a tree. The tributaries in the steep terrains, i.e. in the upper and lower parts of the Maili watershed, tend to be somewhat subparallel and are joining at acute angles (Fig 4.2). Presence of any marked structural feature (joints, faulting) tends to interfere with the development of the dendritic drainage pattern. Although the Siwalik rocks showing marked bedding planes and steep dip, however due to their relatively soft nature these structures are not showed much influencing effect on drainage pattern.

4.3 Land use and land cover

Land use and land cover pattern describe the utilization of land resource by manmade activities particularly agriculture and urbanization (Singh *et al* 2012). The study of land use and land cover pattern help to assess the changes in the pattern with time and in turn help to evaluate available resources and constraints. The soil and water resources are under severe pressure due to land use practices.

The land use land cover is controlled by physiography, parent material and climate of the watershed. The classification is however is not permanent but changes with time as land use changes. The land use and land cover analysis of the study area has also been carried out from merged satellite data (LISS IV + CARTOSAT-1 PAN). Field survey was also performed to finalize the land use/land cover map of the watershed for verification of classes. Six common categories of land use land cover classes identified in the study area are cropland, plantation, forest, reservoir/lake, built-up area and scrubland. The assessment of land use pattern of the watershed reveals that most part of the area comes under forest cover followed by cropland which will directly or indirectly supports the future for watershed development and management (Table 4.3). The land use land cover map of Maili watershed is presented in Fig.4.4.

Table 4.3: Area under different land use land cover classes in Maili watershed

Sr. no.	Land use type	Area (km ²)	Area (%)
1	Cropland	6.361	17.64
2	Plantation	0.015	0.04
3	Forest	26.888	74.56
4	Scrubland	2.235	6.20
5	Villages	0.282	0.78
6	Hamlets	0.041	0.11
7	Reservoir	0.236	0.66
8	Lake/Pond	0.004	0.01
	Total	36.061	100.00

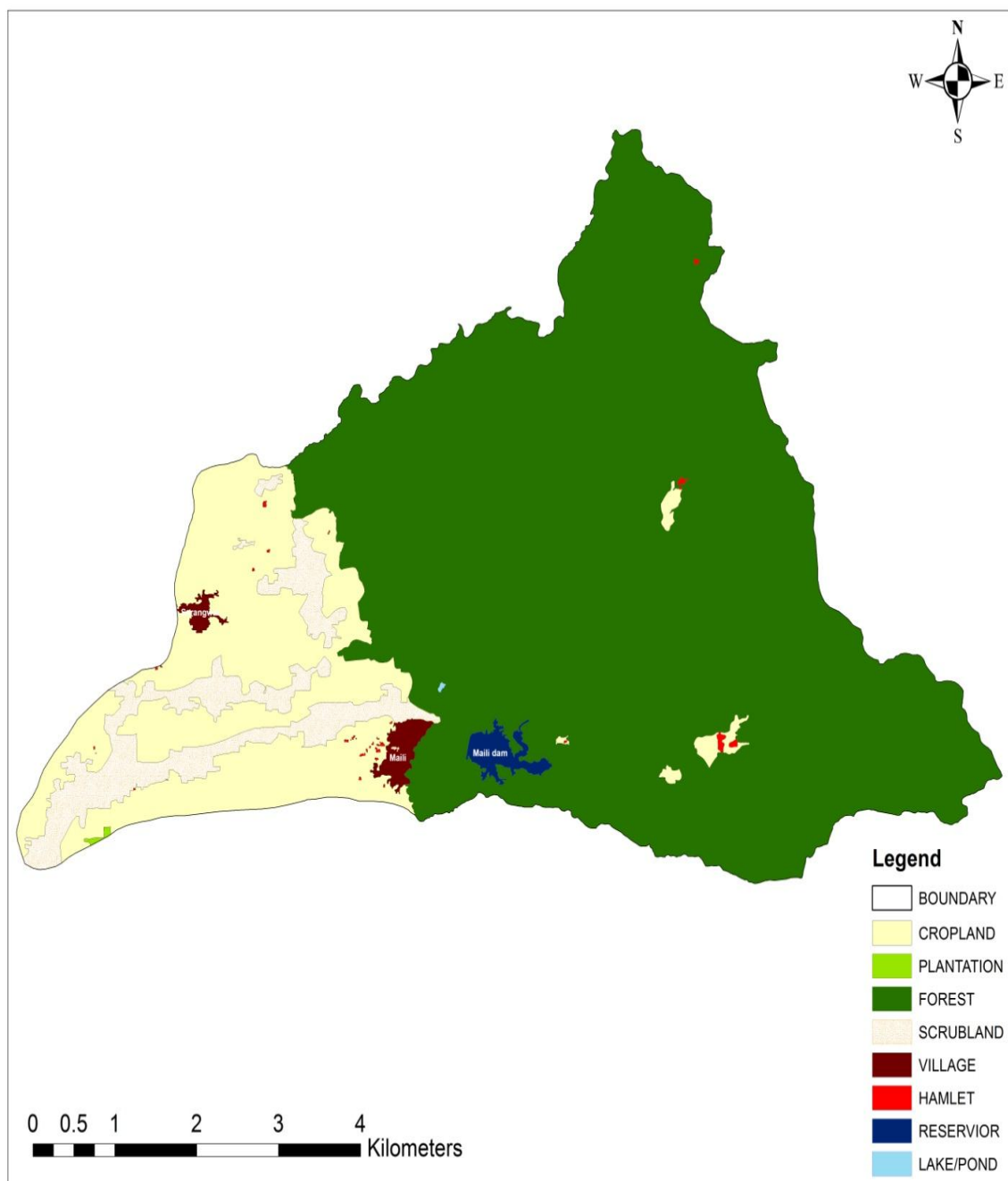


Fig. 4.4: The land use/ land cover map of Maili watershed

4.4 Morphological characteristics of soils

The soils under the study were characterized for their morphological properties in the field and their characteristics are given in Tables 4.3 to 4.7. The detailed descriptions of these morphological properties are given in Appendix I. Morphological characteristics of the soils are discussed in the following sections.

4.4.1 Morphological characteristics of soils of hill tops

The soils of hill top represented by profiles P1, P11, P13, P14 and P15. The soils showed different degree of development due to wide and narrow hill top area. The soil depth varied from 50 to 110 cm in and therefore, hill top soils belong to shallow, moderately deep and deep depth classes (Soil Survey Staff 2004). Soil color of the different horizons of the soils had hue value 10YR throughout the profiles except the subsurface horizon of P13 which showed 7.5YR hue (Table 4.3). The redder hue (7.5 YR) in the lower horizons of the P13 soils suggested better weathering condition and development of altered cambic horizon. The cambic horizon has also seen P14 and P15 soils. The Munsell value varied from 3 to 7 in all profiles and chroma 1 to 8. The slightly developed soils have relatively more chroma in subsurface horizons than the immature soils. The soft sandstone or siltstone rocks in the lower horizons showed very low chroma (P1 and P11). The soils showed varied textural composition of these soils. The texture of the different horizons of these soils varied from silt loam through loam, sandy loam to loamy sand. Except in surface horizon of P11 and P15, the profiles P11, P13, P14 and P15 are texturally similar having sandy loam texture in upper horizons and loamy sand in lower horizons (Table 4.4). The soils are generally coarser texture except P1 soil. The textural composition of these soils is because of the kind of the bed rock on which the soils have developed.

The soils have generally weak, fine, granular structure in the surface horizon of all the hill top profiles. The P1 and P11 soils had structurless massive or single grained in the underlying horizons whereas the profiles P13, P14 and P15 had weak sub angular blocky structure in the subsurface horizons and structurless massive or single grained in the lower horizons. The hill top soils showed friable to loose consistence in moist condition. Textural composition appears to have greater influence on the consistence of the soils. The soils are not consistence regarding presence of free calcium carbonate. The soils of P1 gave slight effervescence in the upper horizons whereas P14 and P15 soils showed slight to strong effervescence in subsurface horizons. The presence of calcium carbonate may be due to nature of parent rocks of the soils. The roots were fine size occurring in common to many quantities in the surface horizons of these soils. The horizons showed clear or gradual smooth boundaries with their immediate underlying horizon.

Table 4.4: Morphological characteristics of soils of hill tops

Horizon	Depth (cm)	Colour (moist)	Texture	Structure	Consistence (moist)	Reaction	Roots	Boundary
Profile 1								
A	0-26	10YR 6/4	L	1,f,gr	m(fr)	SL	2,f	C,S
C	26-50	10YR 7/3	L	0,m	m(fr)	SL	1,f	C,S
Cr1	50-85	10YR 7/1	L	0,m	m(fr)	NE	-	C,S
Cr2	85-110	10YR 7/1	Sil	0,m	m(fr)	NE	-	G,S
Cr3	110-150	10YR 7/2	Sil	0,m	m(fr)	NE	-	-
Profile 11								
A	0-15	10YR 3/4	Ls	1,f,gr	m(fr)	NE	2,f	C,S
C1	15-35	10YR 5/4	Sl	0,m	m(fr)	ST	1,f	G,S
C2	35-60	10YR 5/4	Sl	0,m	m(fr)	ST	-	C,S
C3	60-85	10YR 6/4	Ls	0,sg	m(lo)	ST	-	G,S
Cr	85+	10YR 6/2	Ls	0,sg	m(lo)	ST	-	-
Profile 13								
A	0-18	10YR 4/6	Sl	1,f,gr	m(fr)	NE	3,f	C,S
Bw1	18-40	7.5YR 5/8	Sl	1,f,sbk	m(fr)	SL	2,f	G,S
Bw2	40-80	7.5YR 5/8	Sl	1,f,sbk	m(fr)	SL	1,f	C,S
C	80-110	7.5YR 6/6	Sl	0,m	m(fr)	SL	-	C,S
Cr	110-130	7.5YR 5/6	Ls	0,sg	m(lo)	SL	-	-
Profile 14								
A	0-12	10YR 5/8	Sl	1,f,gr	m(fr)	NE	2,f	C,S
Bw1	12-36	10YR 5/8	Sl	1,f,sbk	m(fr)	NE	2,f	G,S
Bw2	36-70	10YR 5/6	Sl	1,f,sbk	m(fr)	NE	1,f	C,S
Cr	70-125	10YR 5/4	Ls	0,sg	m(lo)	NE	-	-
Profile 15								
A	0-15	10YR 5/6	L	1,f,gr	m(fr)	NE	3,f	C,S
Bw1	15-38	10YR 4/6	Sl	1,f,sbk	m(fr)	NE	2,f	G,S
Bw2	38-65	10YR 5/6	Sl	1,f,sbk	m(fr)	NE	1,f	C,S
Cr	65-125	10YR 5/4	Ls	0,sg	m(lo)	NE	-	-

Abbreviation used as per Schoeneberger (2012)

4.4.2 Morphological characteristics of soils of hill slopes

The profiles P3, P4, P9 and P16 represent the soils of hill slopes of the watershed. The soils showed no to slight profile development due to nature of hill slope. Due to moderate slope, the profile P9 showed slight profile development as indicated by presence of cambic horizon. The profiles P3 and P4 showed paralithic contact with bed rocks at 68 cm and 40 cm depths respectively. The profiles P9 and P16 represented deep soils having more than 120 cm depth. The soils of hill slopes showed invariably 10YR hue throughout the profiles suggesting no appreciable sign of alteration or weathering in the profiles (Table 4.5). The Munsell colour value varied from 3 to 6 and chroma 1 to 8. The soils P3 and P16 have sandy loam texture in the upper horizons and loamy sand in the lowermost horizon. The profiles P4 and P9 are quite variable in texture at different depths suggesting stratified nature of the parent material. Amongst different hill slope soils, P9 soil is relatively finer texture having clay loam, silt loam and loam texture at different depths. The upslope and underlying bed rocks appears to have influenced the textural composition of these soils.

The soils did not show much structural development except in profile P9. The soil structure in the surface horizon was observed to be weak, fine, granular in P3, P4, P9 and P16 profiles. The profiles P3, P4 and P16 had no structural development showing single grained or massive structureless condition in subsurface horizons. The profile P9, however had weak, fine, sub angular blocky structure in the subsurface horizons and structureless massive in the lowermost horizon. The profiles P3, P4 and P16 profiles had moist loose to moist friable consistent due to lower clay, plasticity and stickiness whereas profile P9 had moist friable to firm consistence. The soils P3 and P4 showed presence of free calcium carbonate in upper part of the profile, however it was totally absent in P9 and P16 profiles. The variations in the presence or absence of calcium carbonate in the hill slope soils suggested influence of varied nature of parent rocks. The field observation showed presence of common to many fine roots in the surface horizons but density of roots decreased in the lower horizons. The profiles showed clear to gradual and smooth boundaries.

4.4.3 Morphological characteristics of soils of hill terraces

The soils of hill terraces are represented by P12 and P17 profiles. The terraces being relatively level and stable surfaces showed relatively better developed profiles among the hill soils. The soils showed A-Bw-C horizon sequence. All the horizons of these profiles had 10YR hue whereas value varied from 4 to 6 and chroma from 2 to 4. The soil horizons generally had different shades of brown. The colour variables indicated relatively darker colour in the surface horizons and lighter colour in the lowermost horizons in these soils. The darker colour of the surface horizons was due to the accumulation of more organic carbon at the surface. The textural composition of terrace soils was found to be uniform throughout the depth. These soils invariably had sandy loam texture (Table 4.6).

Table 4.5: Morphological characteristics of soils of hill slopes

Horizon	Depth (cm)	Colour (moist)	Texture	Structure	Consistence (moist)	Reaction	Roots	Boundary
Profile 3								
A	0-17	10YR 4/4	Sl	1,f,gr	m(fr)	SL	2,f	C,S
C1	17-41	10YR 4/3	Sl	0,m	m(fr)	SL	1,f	G,S
C2	41-68	10YR 5/4	Sl	0,m	m(fr)	SL	-	G,S
Cr	68-120	10YR 6/3	Ls	0,sg	m(lo)	SL	-	-
Profile 4								
A	0-20	10YR 3/3	L	1,f,gr	m(fr)	SL	2,f	C,S
AC	20-40	10YR 4/3	L	0,m	m(fr)	SL	1,f	C,S
Cr1	40-65	10YR 5/2	Ls	0,sg	m(lo)	NE	1,f	G,S
Cr2	65-120	10YR 5/1	Ls	0,sg	m(lo)	NE	-	G,S
Cr3	120-150	10YR 6/2	Sl	0,m	m(fr)	NE	-	-
Profile 9								
A	0-21	10YR 3/6	Cl	1,f,gr	m(fm)	NE	3,f	C,S
Bw1	21-47	10YR 4/6	Cl	1,f,sbk	m(fm)	NE	2,f	G,S
Bw2	47-82	10YR 4/4	Cl	1,f,sbk	m(fm)	NE	1,f	C,S
BC	82-115	10YR 5/4	Sil	1,f,sbk	m(fm)	NE	-	C,S
C	115-150	10YR 5/6	L	0,m	m(fr)	NE	-	-
Profile 16								
A	0-16	10YR 4/4	Sl	1,f,gr	m(fr)	NE	2,f	C,S
AC	16-40	10YR 4/6	Sl	0,m	m(fr)	NE	1,f	G,S
C1	40-73	10YR 5/8	Sl	0,m	m(fr)	NE	-	C,S
C2	73-120	10YR 5/8	Ls	0,sg	m(lo)	NE	-	-

Abbreviation used as per Schoeneberger (2012)

Table 4.6: Morphological characteristics of soils of hill terraces

Horizon	Depth (cm)	Colour (moist)	Texture	Structure	Consistence (moist)	Reaction	Roots	Boundary
Profile 12								
Ap	0-20	10YR 4/4	Sl	1,f,gr	m(fr)	SL	3,f	C,S
Bw1	20-35	10YR 5/4	Sl	1,f,sbk	m(fr)	SL	2,f	G,S
Bw2	35-55	10YR 5/3	Sl	1,f,sbk	m(fr)	ST	1,f	G,S
Bw3	55-70	10YR 6/2	Sl	1,f,sbk	m(fr)	ST	-	G,S
C	70-110	10YR 6/2	Sl	0,m	m(fr)	ST	-	-
Profile 17								
Ap	0-18	10YR 5/3	Sl	1,f,gr	m(fr)	NE	3,f	C,S
Bw1	18-31	10YR 6/4	Sl	1,f,sbk	m(fr)	NE	2,f	G,S
Bw2	31-56	10YR 6/3	Sl	1,f,sbk	m(fr)	SL	1,f	G,S
Bw3	56-83	10YR 5/4	Sl	1,f,sbk	m(fr)	SL	-	G,S
C	83-119	10YR 6/3	Sl	0,m	m(fr)	SL	-	-

Abbreviation used as per Schoeneberger (2012)

The structural development of P12 and P17 soils indicated weak, fine granular structure in the surface horizon and weak, fine subangular blocky structure in the subsurface horizons. The structural development in the surface and subsurface horizons indicate some decomposition and reorganization of skeletal grains and pedogenesis. The soils had moist friable consistence. The friable consistence in the horizons suggests low clay and cementing material in the soils. The coarser texture influenced the consistence more than any other property of the soils. The terrace soils showed presence of calcium carbonate throughout of the profile in P12 and in the subsurface horizons in P17 profile. Absence of concretions in all these soils is due to their well drained condition causing free leaching of water. The root distribution was many fine roots in the surface horizon and few to common fine roots in underlying horizons. As usual, the abundance and size of the roots decreased with depth. The successive horizons of the soils showed clear or gradual smooth horizon boundary.

4.4.4 Morphological characteristics of soils of choe beds

The soils of choe bed are represented by P2, P8 and P10 profiles. The soils of choe beds did show any profile development as these undergo frequent flooding and sedimentation or erosion of surfaces. Moreover parent material of choe beds was found to coarser nature and frequently contains gravels. The Textural composition is though variable in different parts of the three profiles but generally coarse-textured. The texture varied from sandy clay loam to sand. The profiles P2 and P8 contained appreciable amounts of gravels however P10 profile was free from such gravels. The high gravel content in profiles P2 and P8 is due the fact that here the choe bed is located in the Siwalik hill. However, the profile P10 is sandy without gravels because here the choe bed is passing through the piedmont plains. The textural composition reflects the kind of material deposited during at the different parts of the geomorphic units. All the horizons of these three profiles had 10YR hue whereas value varied from 3 to 6 and chroma from 2 to 6. The profiles P2 and P8 showed no specific colour pattern with depth suggesting stratification (Table 4.7). The profile P10 however had dark surface horizon and lighter subsurface horizon suggesting admixture of some organic matter at the surface. The lighter colour of the lower horizons of P10 profile is more due to grayish nature of sandstone of the Siwalik hills.

No structural development was observed in the choe bed soils except in the surface horizon. The surface horizon showed weak, fine, granular structure whereas all the underlying horizons were structureless massive (P2 and P8) or single grained (P10). The P2 and P8 profiles had moist friable consistence in all the subsurface horizons because of occurrence of their dry masses. The profile P10, however showed moist loose consistence in all underlying horizons.

Table 4.7: Morphological characteristics of soils of choe beds

Horizon	Depth (cm)	Colour (moist)	Texture	Structure	Consistence (moist)	Reaction	Roots	Boundary
Profile 2								
A	0-22	10YR 6/2	Ls	1,f,gr	m(fr)	SL	2,f	C,S
C1	22-43	10YR 5/3	L	0,m	m(fr)	SL	1,f	G,S
C2	43-75	10YR 5/4	L	0,m	m(fr)	SL	1,f	G,S
C3	75-110	10YR 6/3	L	0,m	m(fr)	SL	-	G,S
C4	110-140	10YR 6/3	Sl	0,m	m(fr)	NE	-	-
Profile 8								
A	0-22	10YR 3/6	Scl	1,f,gr	m(fr)	ST	2,f	C,S
C1	22-40	10YR 4/3	Sl	0,m	m(fr)	ST	1,f	G,S
C2	40-65	10YR 4/4	Sl	0,m	m(fr)	ST	-	G,S
C3	65-110	10YR 5/4	Sl	0,m	m(fr)	ST	-	-
Profile 10								
A	0-20	10YR 3/4	Ls	1,f,gr	m(fr)	NE	2,f	C,S
C1	20-38	10YR 5/2	S	0,sg	m(lo)	NE	1,f	C,S
C2	38-62	10YR 5/4	Sl	0,m	m(lo)	NE	1,f	C,S
C3	62-90	10YR 6/2	S	0,sg	m(lo)	SL	-	G,S
C4	90-140	10YR 4/2	S	0,sg	m(lo)	NE	-	-

Abbreviation used as per Schoeneberger (2012)

The reaction of soil with dilute HCl was more or less missing except in C3 horizon from profile P10 suggesting free from calcium carbonate. The profiles P2 and P8 showed slight to strong effervescence with dilute HCl throughout the profile except in the lowermost horizon of P2. The surface horizons show presence of common, fine roots but density of roots decreased with depth. The choe bed soils showed clear or gradual smooth boundaries in successive horizons.

4.4.5 Morphological characteristics of soils of piedmont plains

The soils developed on piedmont plains were represented by P5, P6 and P7 profiles. The piedmont plains have undulating surfaces with slopes ranging from 1 to 6 per cent. The soils being relatively stable surfaces than of hills have shown relatively better developed profiles than the hill soils. The profiles have shown development of structural or altered subsurface diagnostic horizon distinguished as cambic horizon (Bw). The soils, thus exhibited A-Bw-C horizon sequence (Table 4.8). The Munsell colour charts showed that the horizons of P5, P6 and P7 profiles had 10YR hue throughout the profile. The value varied from 3 to 5 and chroma was in the range of 4 to 6. The surface horizons are darker than the subsurface horizons due to presence of more organic matter content. The subsurface horizons appeared relatively redder than other horizons suggesting some decomposition or weathering. The soil horizons generally had different shades of brown. The piedmont plain soils varied in textural composition depending upon its distance from hills and position from the rivulets. The profile P5 being closer to the hills exhibit coarser texture which varied from sandy loam to loamy sand. The profiles P6 and P7, being away from the hills, have relatively finer texture which varied from silt loam to loam.

The structure of all profiles (P5, P6 and P7) was weak, fine granular in the surface horizon and weak, fine sub angular blocky in subsurface horizons except in C horizon of P5 profile, which had structureless massive. The soil consistence varied from moist friable to moist firm in different soils. The soil horizons having silt loam texture showed firm consistence due to higher clay content, plasticity and stickiness. The profiles P5 and P6 generally had friable consistence whereas profile P7 profile had firm consistence. The soils of piedmont plains, except for slight presence in profile P5, were generally free of calcium carbonate. The traces of calcium carbonate in some horizon of P5 profile may be expected as remains of parent material transported and deposited from the hills lying closer to the site. The absence of calcium carbonate in P6 and P7 soils suggested complete dissolution and leaching from the profile. The different horizons showed presence of common to many fine roots in the surface horizon, and few to common fine roots in the lower horizons to a maximum depth of 120 cm. The soils' successive horizons showed clear or gradual smooth boundaries.

Table 4.8: Morphological characteristics of soils of piedmont plains

Horizon	Depth (cm)	Colour (moist)	Texture	Structure	Consistence (moist)	Reaction	Roots	Boundary
Profile 5								
Ap	0-18	10YR 3/4	Sl	1,f,gr	m(fr)	NE	3,f	C,S
Bw1	18-34	10YR 4/4	Sl	1,f,sbk	m(fr)	NE	2,f	G,S
Bw2	34-65	10YR 5/4	Sl	1,f,sbk	m(fr)	SL	1,f	C,S
BC	65-105	10YR 5/6	Ls	1,f,bk	m(fr)	NE	-	C,S
C	105-140	10YR 5/6	Sl	0,m	m(fr)	SL	-	-
Profile 6								
Ap	0-20	10YR 4/4	L	1,f,gr	m(fr)	NE	2,f	C,S
Bw1	20-40	10YR 4/4	L	1,f,sbk	m(fr)	NE	2,f	C,S
Bw2	40-78	10YR 3/4	Sil	1,f,sbk	m(fm)	NE	1,f	C,S
BC	78-120	10YR 3/6	L	1,f,bk	m(fr)	NE	-	-
Profile 7								
Ap	0-20	10YR 3/6	Sil	1,f,gr	m(fr)	NE	2,f	C,S
Bw1	20-48	10YR 4/6	Sil	1,f,sbk	m(fm)	NE	1,f	G,S
Bw2	48-80	10YR 5/6	Sil	1,f,sbk	m(fm)	NE	1,f	G,S
Bw3	80-120	10YR 4/4	Sil	1,f,sbk	m(fm)	NE	1,f	C,S
BC	120-150	10YR 5/6	L	1,f,sbk	m(fr)	NE	-	-

Abbreviation used as per Schoeneberger (2012)

4.5 Physico-chemical characteristics of soils

The physico-chemical characteristics of the soils of different geomorphic units of Maili watershed are discussed under the following sections:

4.5.1 Physico-chemical characteristics of soils of hill tops

The physico-chemical characteristics of the soils of hill tops are presented in Table 4.9. The particle size distribution data indicated the dominance of silt fraction in P1 profile and dominance of sand fraction in P11, P13, P14 and P15 profiles (Table 4.9). The hill top soils varied in sand content from 19.2 to 83.8 per cent (AM=64.6%), silt content from 5.6 to 62.0 per cent (AM=24.8 %) and clay content 3.2 to 24.2 per cent (AM= 10.6%). The sand content was the lowest in P1 profile (AM = 32.0%) and the highest in P11 profile (AM = 80.0%) (Fig 4.5). The clay content was the lowest in the P15 soils (AM = 8.9%) and the highest in P1 soil (AM = 17.1%). The variation in sand, silt and clay contents with depth is due primarily to geologic causes responsible for parent material subsequently by pedogenic processes (Nayak *et al* 2002). The soils were alkaline in reaction with pH ranging from 7.3 to 9.4 (AM= 8.3). No definite trend of pH with depth was observed in these soils (Fig 4.5). The high pH in some of the horizon of these soils may be due to the presence of calcium carbonate liberating OH⁻ ions on hydrolysis and desiccation (Lloyd and Peterson 1964) and due to residual salts. Raj-Kumar *et al* (1995) reported occurrence of alkali soils (having pH varying from 8.8 to 9.7) though having udic moisture regime from the steeply sloping Siwalik hills of Satluj-Yamuna divide in north-west India. Electrical conductivity varied from 0.03 to 0.34 dS m⁻¹ having the highest in P1 profile and lowest in P11 profile. The depth pattern of electrical conductivity was irregular in these profiles suggesting dominance of not any soil forming factor.

The hill top soils were low to high in organic carbon content which varied ranging from 0.08 to 1.42 per cent. The lowest organic carbon content was observed in P13 and the highest content in P14 profile. The large variation of organic carbon in these soils may be due to varying conditions of leaf litter accumulation and its assimilation under forest cover. In all the soils, organic carbon content was relatively higher in the surface horizon than in the subsurface horizon. Calcium carbonate was not present in all profiles from the hill tops. The profiles P1, P11 and P13 varied in calcium carbonate content from nil to 2.1 per cent (AM = 0.87%) whereas the profiles P14 and P15 had no calcium carbonate. Sawhney *et al* (2000) also reported calcium carbonate in the Siwalik hill soils from Ropar district of Punjab. No specific distribution trend of calcium carbonate with depth was observed in P1, P11 and P13 profiles.

Table 4.9: Physico-chemical characteristics of soils of hill tops

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH (2:1)	EC (dS m ⁻¹)	OC (%)	CaCO ₃ (%)	Exchangeable cations			CEC (cmol kg ⁻¹)
								(cmol(+)kg ⁻¹)			
								Ca ²⁺ + Mg ²⁺	Na ⁺	K ⁺	
Profile 1											
0-26	42.5	49.6	7.9	7.9	0.21	0.85	0.9	8.4	0.04	0.03	5.4
26-50	43.9	37.1	19.0	8.4	0.25	0.78	0.6	6.2	0.13	0.02	6.8
50-85	29.7	46.1	24.2	8.8	0.31	0.47	Nil	4.8	0.17	0.02	6.0
85-110	19.2	59.8	21.0	8.8	0.34	0.41	Nil	5.2	0.20	0.06	4.3
110-150	24.6	62.0	13.4	8.9	0.28	0.39	Nil	3.6	0.18	0.01	3.6
Avg. Mean	32.0	50.9	17.1	8.6	0.28	0.58	0.3	5.6	0.14	0.03	5.2
Profile 11											
0-15	83.8	5.6	10.6	8.8	0.17	0.65	Nil	8.8	0.05	0.03	7.2
15-35	76.5	11.7	11.8	8.6	0.16	0.54	1.8	5.4	0.03	0.04	9.5
35-60	78.0	12.4	9.6	8.8	0.03	0.39	2.1	3.4	0.05	0.04	3.0
60-85	80.3	9.5	10.2	9.4	0.06	0.21	1.2	3.0	0.04	0.02	7.4
85+	81.5	8.9	9.6	8.7	0.10	0.13	1.4	3.6	0.01	0.01	3.0
Avg. Mean	80.0	9.6	10.4	8.9	0.10	0.38	1.3	4.8	0.04	0.03	6.0
Profile 13											
0-18	73.0	18.3	8.7	7.8	0.07	0.44	Nil	8.4	0.02	0.03	7.4
18-40	74.2	17.7	8.1	7.8	0.11	0.36	1.3	7.0	0.03	0.02	6.3
40-80	70.8	20.8	8.4	8.2	0.12	0.26	1.5	6.4	0.05	0.02	8.9

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH (2:1)	EC (dS m ⁻¹)	OC (%)	CaCO ₃ (%)	Exchangeable cations (cmol(+)kg ⁻¹)			CEC (cmol kg ⁻¹)
								Ca ²⁺ + Mg ²⁺	Na ⁺	K ⁺	
80-110	72.2	18.8	9.0	8.7	0.07	0.13	0.8	5.6	0.21	0.02	7.6
110-130	80.5	11.6	7.9	8.7	0.16	0.08	1.6	4.2	0.10	0.02	8.2
Avg. Mean	74.1	17.5	8.4	8.2	0.11	0.25	1.0	6.3	0.08	0.02	7.7
Profile 14											
0-12	70.3	21.3	8.4	7.3	0.08	1.42	Nil	6.0	0.04	0.08	6.8
12-36	70.8	21.6	7.6	8.1	0.11	0.88	Nil	5.0	0.05	0.01	3.9
36-70	72.3	19.3	8.4	7.7	0.15	1.14	Nil	5.8	0.01	0.01	5.5
70-125	82.3	9.5	8.2	7.9	0.15	1.11	Nil	4.8	0.03	0.03	6.2
Avg. Mean	73.9	17.9	8.2	7.8	0.12	1.14	Nil	5.4	0.03	0.03	5.6
Profile 15											
0-15	43.3	33.9	22.8	7.9	0.13	0.54	Nil	10.0	0.03	0.02	10.9
15-38	63.6	33.2	3.2	8.4	0.13	0.18	Nil	8.0	0.01	0.01	5.7
38-65	62.3	33.7	4.0	7.8	0.16	0.21	Nil	6.0	0.02	0.02	5.9
65-125	83.6	11.0	5.4	8.1	0.15	0.10	Nil	3.8	0.01	0.01	4.3
Avg. Mean	63.2	27.9	8.9	8.1	0.14	0.26	Nil	7.0	0.02	0.02	6.7

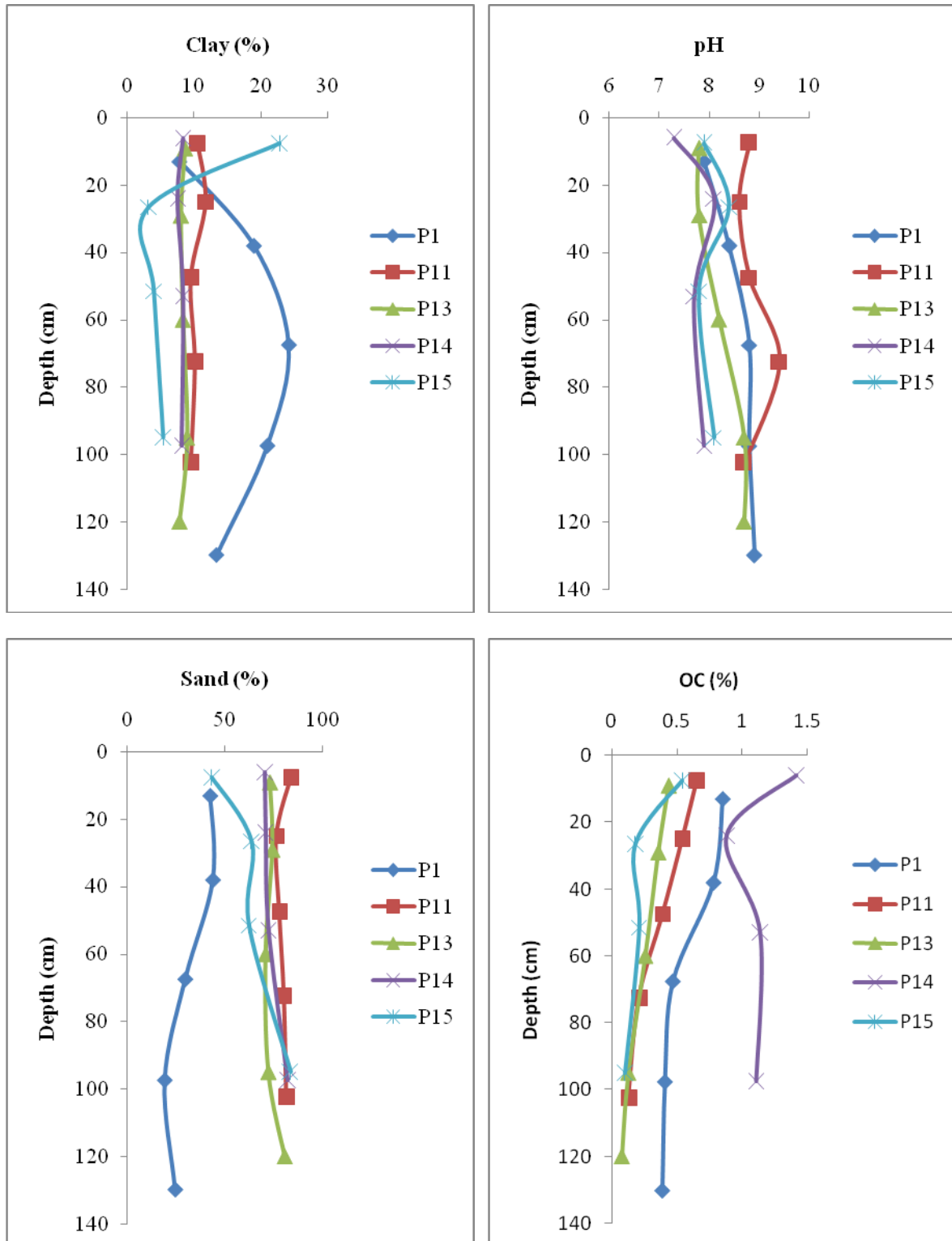


Fig. 4.5: Depth-wise distribution of Sand, Clay, pH and OC in soils of hill tops

Cation exchange capacity varied from 3.0 to 10.9 cmol (+) kg⁻¹ having the lowest in P1 and the highest in P13 profile. Relatively low CEC is the reflection of parent material and depletion of bases in the higher rainfall area. Further, it may be due to dominance of clay minerals with low CEC such illite and kaolinite (Visalakshi Devi and Naidu 2016). Cation exchange capacity was found to be significantly positively correlated ($r = 0.54$) with clay content (Table 4.10) due to location of exchange ions mainly on clay particles and low content of organic matter in the soils (Sidhu and Sharma 1990). Calcium and magnesium cations ($\text{Ca}^{2+} + \text{Mg}^{2+}$) were dominated on the exchange complex and their content varied from 3.0 to 10.0 cmol(+)/kg⁻¹. The exchangeable Na^+ and K^+ varied from 0.01 to 0.21 and 0.01 to 0.08 cmol (+) kg⁻¹ respectively.

Table 4.10: Correlation coefficient among physico-chemical properties

	Sand	Silt	Clay	pH	EC	OC	CaCO₃
Silt	-0.96						
Clay	-0.58	0.34					
pH	0.25	-0.27	-0.07				
EC	-0.25	0.24	0.16	-0.01			
OC	-0.16	0.10	0.27	-0.25	-0.02		
CaCO ₃	0.19	-0.20	-0.05	-0.05	0.12	-0.22	
CEC	-0.52	0.41	0.54	-0.04	0.08	0.23	-0.07

For df 78 the significance value of r at 5% = 0.21

4.5.2 Physico-chemical characteristics of soils of hill slopes

The physico-chemical characteristics of the soils of hill slopes are presented in Table 4.11. The particle size distribution data indicated the dominance of silt fraction in P9 profile and dominance of sand fraction in P3, P4, and P16 profiles (Table 4.11). Even silt and clay contents together were not exceeded the content of sand fraction in P3, P4 and P16 profiles suggesting coarser nature of these soils. The sand content was the highest in P3 soil (AM= 73.4 %) and lowest in P9 soil (AM= 29.0 %). Like silt fraction, clay content was also highest in P9 soil (AM= 27.0%).

The hill slope soils varied in sand, silt and clay contents from 23.1 to 86.5 per cent (AM= 59.7 %), 6.3 to 50.7 per cent (AM= 26.5 %) and 5.4 to 27.8 per cent (AM= 13.8 %), respectively (Table 4.11). Distribution of sand, silt and clay fractions was irregular with depth. The variation in sand, silt and clay contents with depth is primarily due to the nature of

exposed rocks in hills supplying parent material on down slopes. The common exposed rocks are sandstones and clay-beds. The soils were alkaline in reaction with pH ranging from 7.5 to 8.8 (AM= 8.1). The alkaline reaction suggested presence of sufficient bases in the soils. No definite trend of pH with depth was observed in these soils. The soil pH increases with depth in P3 and P4 soils, however no definite trend was observed in P9 and P16 soils. The soil pH seems to not affected by presence of calcium carbonate in the soils contrary to what observed by Lloyed and Peterson (1964). The electrical conductivity ranged from 0.12 to 0.33 dS m⁻¹. The electric conductivity which indicates salt content, varied in the soils depending on accumulation and/or leaching of salts. The profile P4 soils have higher EC value (AM= 0.19 dSm⁻¹) whereas profile P9 had lower EC value (AM= 0.17 dS m⁻¹). The electrical conductivity was generally higher in surface horizon and then decrease to certain depth. The higher EC value at the surface may be due to addition of fresh sediments from rocks of upper slopes.

Organic carbon content varied very widely and ranged from 0.23 to 0.96 per cent suggesting its low to high content in hill slope soils. Organic carbon content was the lowest in P4 profile and highest in P16 profile. The large variation of organic carbon in these soils may due to the varying conditions of leaf litter accumulation and its assimilation under forest cover. Organic carbon content was the highest in the surface horizon and generally decreased with depth (Fig 4.6). All the profiles of the hill slope soils did not contain calcium carbonate as in case of hill top soils. The profiles P3 and P4 varied in calcium carbonate content from nil to 2.6 per cent (AM = 1.5%) whereas profiles P9 and P16 had no calcium carbonate. Calcium carbonate was also reported in the Siwalik hill soils from Ropar district of Punjab by Sawhney *et al* (2000). No specific trend in distribution of calcium carbonate with depth was observed in hill slope profiles. Cation exchange capacity varied from 3.3 to 15.1 cmol(+)kg⁻¹ having the lowest in P3 and highest in P9 profile. Relatively low CEC is the reflection of parent material and depletion of bases and dominance of clay minerals with low CEC such illite and kaolinite (Visalakshi Devi and Naidu 2016). The relatively finer textured soils had higher CEC than coarser texture soils suggesting positive correlation with clay content ($r = 0.54$). The clay particles thus have dominating influence on CEC than organic matter in the soils as also noted by Sidhu and Sharma (1990). Calcium and magnesium cations (Ca²⁺ + Mg²⁺) were dominated on the exchange complex and their content varied from 2.8 to 8.4 cmol(+) kg⁻¹. The content of exchangeable Na⁺ and K⁺ varied from 0.01 to 0.04 and 0.01 to 0.05 cmol(+)kg⁻¹, respectively.

Table 4.11: Physico-chemical characteristics of soils of hill slopes

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH (2:1)	EC (dS m ⁻¹)	OC (%)	CaCO ₃ (%)	Exchangeable cations			CEC (cmol kg ⁻¹)
								(cmol(+)kg ⁻¹)			
								Ca ²⁺ + Mg ²⁺	Na ⁺	K ⁺	
Profile 3											
0-17	72.0	18.2	9.8	7.5	0.20	0.62	2.3	5.6	0.01	0.03	3.9
17-41	66.0	23.8	10.2	7.8	0.19	0.52	2.2	5.2	0.02	0.02	4.2
41-68	69.0	21.0	10.0	8.0	0.18	0.47	1.6	5.8	0.01	0.01	3.7
68-120	86.5	7.1	6.4	8.1	0.18	0.23	2.6	5.0	0.01	0.01	3.3
Avg. Mean	73.4	17.5	9.1	7.9	0.19	0.46	2.2	5.4	0.01	0.02	3.8
Profile 4											
0-20	47.9	39.3	12.8	7.6	0.33	0.44	1.6	8.2	0.25	0.05	7.2
20-40	45.8	38.2	16.0	7.8	0.20	0.39	2.2	8.0	0.04	0.05	8.0
40-65	83.2	10.0	6.8	8.0	0.12	0.23	Nil	6.4	0.01	0.01	6.0
65-120	83.9	6.3	9.8	8.0	0.14	0.28	Nil	5.0	0.04	0.02	6.1
120-150	54.0	38.6	7.4	8.1	0.16	0.23	Nil	4.6	0.03	0.01	4.3
Avg. Mean	63.0	26.5	10.5	7.9	0.19	0.31	0.8	6.4	0.07	0.03	6.3

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH (2:1)	EC (dS m ⁻¹)	OC (%)	CaCO ₃ (%)	Exchangeable cations			CEC (cmol kg ⁻¹)
								(cmol(+)kg ⁻¹)			
								Ca ²⁺ + Mg ²⁺	Na ⁺	K ⁺	
Profile 9											
0-21	35.7	37.3	27.0	8.1	0.17	0.90	Nil	7.6	0.03	0.02	9.7
21-47	28.3	43.9	27.8	7.8	0.17	0.41	Nil	8.4	0.02	0.02	12.0
47-82	25.4	47.2	27.4	7.9	0.17	0.54	Nil	7.2	0.01	0.01	15.1
82-115	23.1	50.7	26.2	8.6	0.16	0.52	Nil	4.4	0.02	0.02	10.7
115-150	32.5	41.1	26.4	7.9	0.19	0.34	Nil	3.0	0.01	0.02	11.7
Avg. Mean	29.0	44.0	27.0	8.1	0.17	0.54	Nil	6.1	0.02	0.02	11.8
Profile 16											
0-16	68.5	15.9	15.6	8.6	0.17	0.96	Nil	6.0	0.01	0.01	6.2
16-40	75.2	19.4	5.4	8.4	0.12	0.78	Nil	5.8	0.01	0.01	7.8
40-73	70.3	23.5	6.2	8.7	0.14	0.44	Nil	5.2	0.01	0.01	5.5
73-120	80.2	13.0	6.8	8.8	0.26	0.36	Nil	2.8	0.01	0.01	4.5
Avg. Mean	73.5	18.0	8.5	8.6	0.17	0.64	Nil	5.0	0.01	0.01	6.0

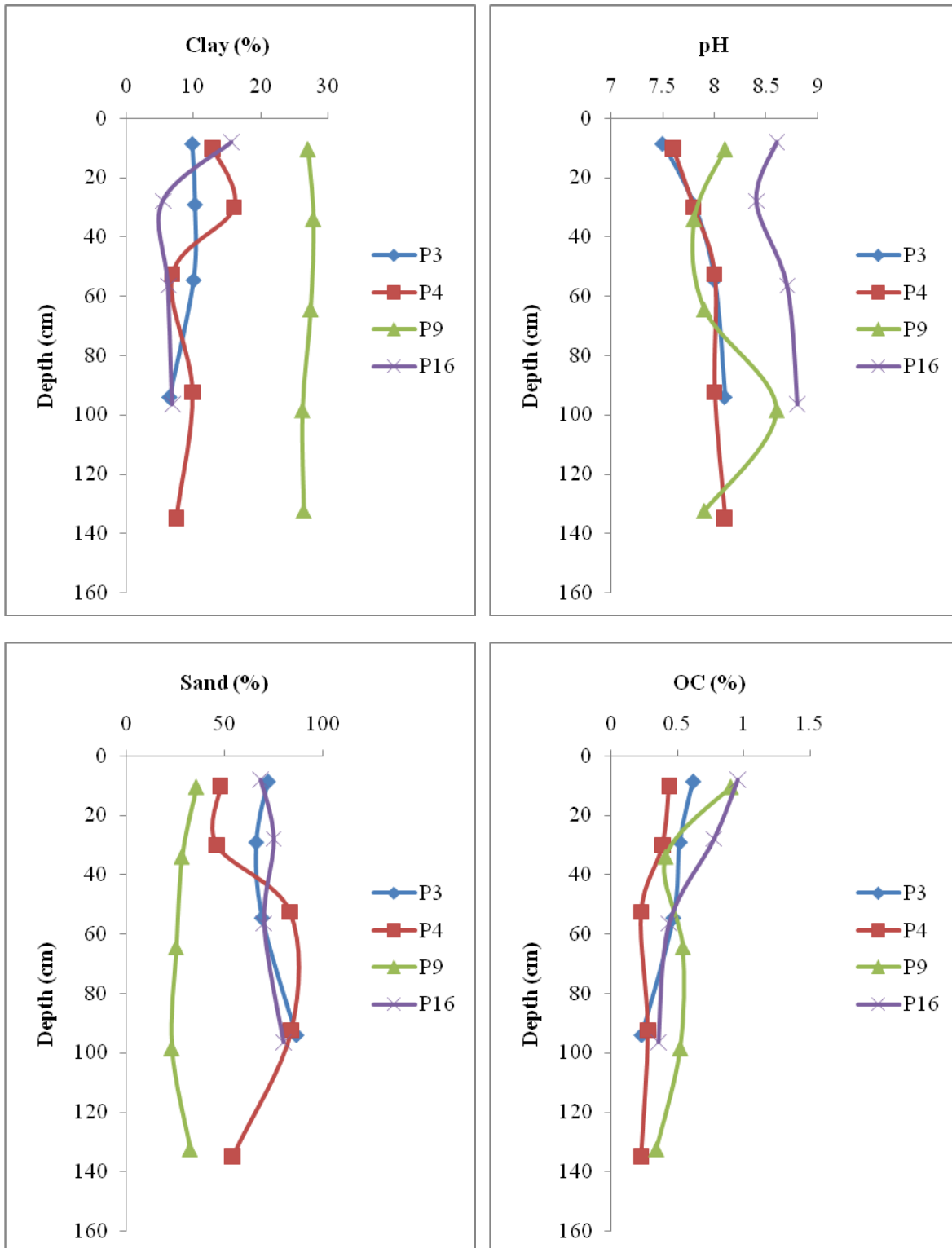


Fig. 4.6: Depth-wise distribution of Sand, Clay, pH and OC in soils of hill slopes

4.5.3 Physico-chemical characteristics of soils of hill terraces

The physico-chemical characteristics of the soils of hill terraces are presented in Table 4.12. The particle size distribution data indicated dominance of sand fraction in these soils (Table 4.12). The hill terraces soils varied in sand content from 54.5 to 72.8 per cent (AM= 64.3%), silt content from 19.4 to 35.5 per cent (AM= 25.8 %) and clay content 7.8 to 12.6 per cent (AM= 9.9%). The sand content was the lowest in P17 profile (AM= 60.1%) and the highest in P12 profile (AM = 68.5%). The clay content was the lowest in the P12 soil (AM= 8.7%) and the highest in P17 soil (AM= 11.1%). The irregular variation in sand, silt and clay contents with depth is due primarily to geologic causes responsible for parent material (Nayak *et al* 2002). The soils were alkaline in reaction with pH ranging from 8.1 to 9.2 (AM= 8.3). Raj-Kumar *et al* (1995) reported occurrence of alkali soils (having pH 8.8 to 9.7) and udic moisture regime from the steeply sloping Siwalik hills of Satluj-Yamuna divide in north-west India. The soil pH decreased with depth in P12 soil however irregularly increased slightly in P17 soil (Fig 4.7). Electrical conductivity varied from 0.06 to 0.98 dS m⁻¹ having the highest in P12 profile and the lowest in P17 profile. Electrical conductivity was increased to certain depths and then decrease in these profiles suggesting some degree of leaching during soil formation.

The hill terrace soils were low in organic carbon content which varied ranging from 0.16 to 0.28 per cent having the lowest organic carbon in P12 and the highest content in P17 profile. There is no much variation of organic carbon as these soils are not under natural vegetation but under limited cultivation. Organic carbon content was relatively higher in the surface horizon and lower in subsurface horizon (Fig 4.7). The depth distribution of organic carbon was regular in P17 soil but irregular in P12 soil. Calcium carbonate was, though, present in both the terrace soils but missing from upper two horizon of P17 profile. Calcium carbonate content varied from nil to 2.3 per cent in different horizons of these profiles. The presence of calcium carbonate in the terrace soils is not exception as is also reported by Sawhney *et al* (2000). No specific trend in distribution of calcium carbonate with depth was observed in these profiles. Cation exchange capacity varied from 4.3 to 7.0 cmol (+) kg⁻¹ having the lowest in P17 and highest in P12 profile. Relatively low CEC is the reflection of parent material and depletion of bases in the higher rainfall area. Further, it may be due to dominance of clay minerals with low CEC such illite and kaolinite (Visalakshi Devi and Naidu 2016). Cation exchange capacity was found to be significantly positive correlated ($r = 0.54$) with clay content (Table 4.10) as the exchange ions mainly located on clay particles and low content of organic matter (Sidhu and Sharma 1990). Calcium and magnesium cations (Ca²⁺ + Mg²⁺) were dominated on the exchange complex and their content varied from 5.0 to 6.8 cmol(+)kg⁻¹. The exchangeable Na⁺ and K⁺ varied from 0.01 to 0.23 and 0.01 to 0.03 cmol (+) kg⁻¹ respectively.

Table 4.12: Physico-chemical characteristics of soils of hill terraces

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH (2:1)	EC (dS m ⁻¹)	OC (%)	CaCO ₃ (%)	Exchangeable cations			CEC (cmol kg ⁻¹)
								(cmol(+)kg ⁻¹)			
								Ca ²⁺ + Mg ²⁺	Na ⁺	K ⁺	
Profile 12											
0-20	64.5	26.5	9.0	9.2	0.08	0.28	1.3	5.8	0.10	0.02	5.2
20-35	68.0	23.4	8.6	9.0	0.15	0.23	1.2	6.8	0.05	0.01	5.8
35-55	66.6	25.0	8.4	8.4	0.98	0.16	1.5	5.2	0.23	0.03	6.2
55-70	70.8	19.6	9.6	8.1	0.10	0.18	2.3	5.8	0.06	0.01	4.3
70-110	72.8	19.4	7.8	8.1	0.06	0.21	1.6	5.0	0.01	0.01	7.0
Avg. Mean	68.5	22.8	8.7	8.6	0.27	0.21	1.6	5.7	0.09	0.02	5.7
Profile 17											
0-18	54.5	35.5	10.0	8.3	0.12	0.27	Nil	5.1	0.10	0.02	5.2
18-31	61.4	29.0	9.6	8.3	0.14	0.22	Nil	5.6	0.15	0.02	5.6
31-56	63.3	25.3	11.4	8.4	0.18	0.18	2.0	5.3	0.20	0.03	5.8
56-83	58.8	28.6	12.6	8.4	0.19	0.16	1.7	5.0	0.15	0.02	4.5
83-119	62.4	25.8	11.8	8.5	0.16	0.16	1.6	5.0	0.10	0.02	6.0
Avg. Mean	60.1	28.8	11.1	8.4	0.16	0.20	1.1	5.2	0.14	0.02	5.4

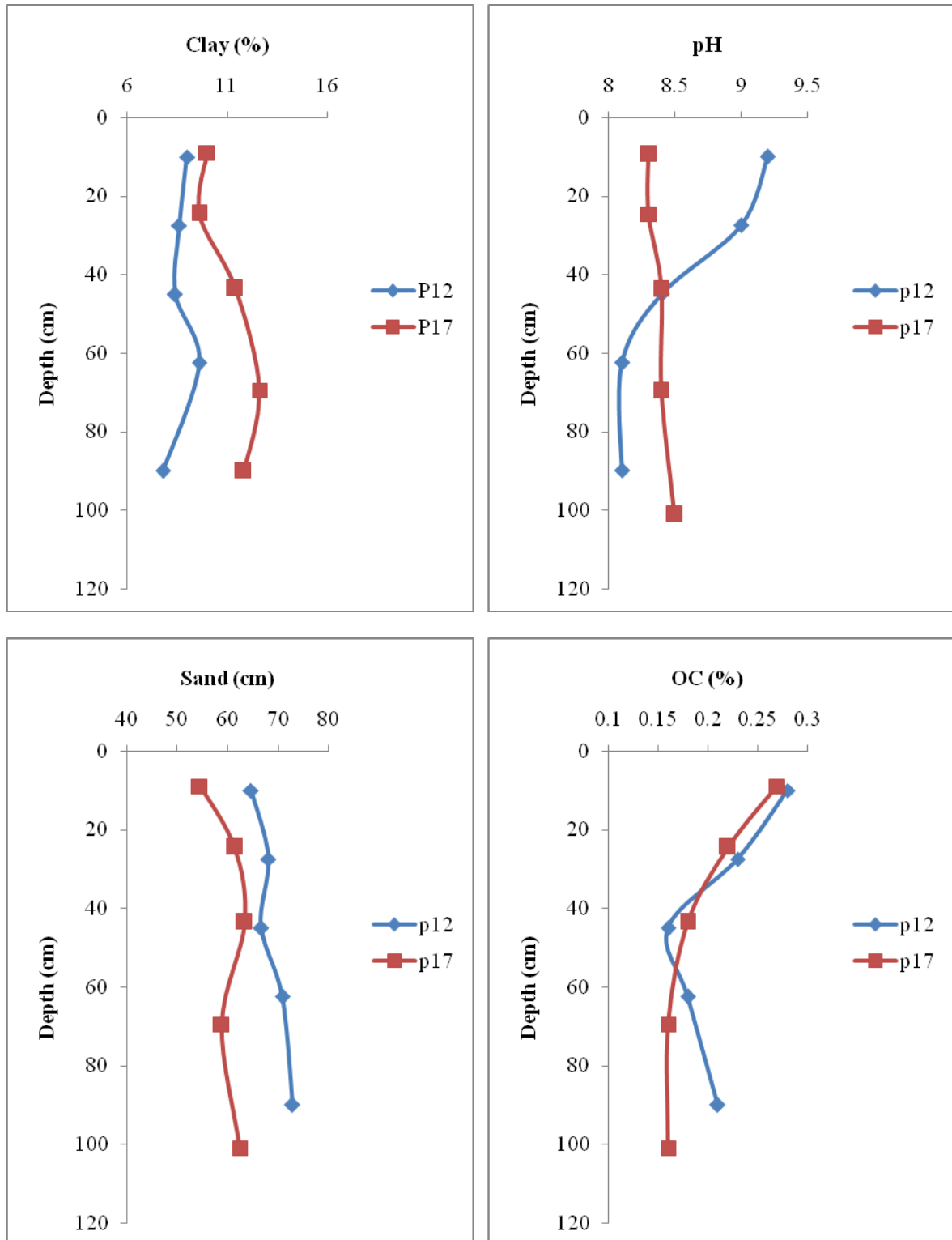


Fig. 4.7: Depth-wise distribution of Sand, Clay, pH and OC in soils of hill terraces

4.5.4 Physico-chemical characteristics of soils of choe beds

The physico-chemical characteristics of the soils of hill slopes are presented in Table 4.13. The particle size distribution data indicated the dominance of sand fraction in all the choe bed soils (Table 4.13). The sand content of the soils of choe beds (P2, P8 and P10) varied from 43.7 to 93.5 per cent (AM= 69.5%), silt from 1.3 to 43.4 per cent (AM= 18.5%) and clay from 3.0 to 20.8 per cent (AM= 12.0%). The sand content was the highest in P10 (AM= 87.3%) and lowest in P2 (AM= 56.6%). The clay content was the highest in P8 soil (AM= 17.6%) and lowest in P10 soil (AM= 8.2 %) respectively. The distribution of sand, silt and clay was irregular with depth in P2 and P10 profiles but shown regularity in P8 profile (Table 4.13). The particle size composition of the soils is very heterogeneous as it also contained appreciable amounts of gravels and pebbles. The textural composition of the soils is primarily the consequence of geologic processes rather than pedologic nature. The soils were alkaline in reaction with pH ranging from 7.5 to 9.1 (AM= 8.3). The soil pH was the highest in P10 (AM= 8.6) and the lowest in P8 (AM= 7.7). Relatively higher values of pH and almost absence of calcium carbonate in P10 soil suggested no relationships between the two in choe bed soils (Table 4.10). No definite trend of pH with depth was observed in these soils. The electrical conductivity ranged from 0.07 to 0.25 dS m⁻¹.

The profile P8 had the highest EC value (AM= 0.22 dSm⁻¹) whereas profile P10 had lowest EC value (AM= 0.8 dS m⁻¹). The electrical conductivity of profiles was very low which might be due to well to excessively drained condition that triggered off the removal of bases through percolating and drainage water particularly in soils. (Leelavathi *et al* (2009). The electrical conductivity was generally decreased with depth in P2 and P8 soils but was irregular in P10 profile. No specific trend of EC suggests little redistribution of salts due to absence of enough pedogenic activity in these soils.

Organic carbon content was low to high as it varied from 0.10 to 0.88 per cent in these soils (Table 4.13). Generally organic carbon content of the surface horizon was higher than that of the sub-surface horizon. Organic carbon content was the lowest in P10 profile (AM= 0.26%) and the highest in P8 profile (AM = 0.52%). There is definite decreasing trend of variation of organic carbon with depth in these soils (Fig 4.8). Calcium carbonate content varied from nil to 4.9 per cent in different horizons of these soils. Calcium carbonate was observed throughout the profile in P2 and P8 soils but almost absent except at 62 to 90 cm horizon in P10 profile. The finer texture soils showed relatively higher calcium carbonate than coarser texture soils (Young and Spycher 1979). No specific trend in distribution of calcium carbonate with depth in these soils was observed. So CaCO₃ content within and among the soils is result of geologic consequences. Cation exchange capacity varied from 3.0 to 11.2 cmol(+)kg⁻¹ and with the highest in the P8 (AM= 8.6 cmol(+)kg⁻¹) and the lowest in the P10 (AM= 4.2 cmol(+)kg⁻¹)

Table 4.13: Physico-chemical characteristics of soils of choe beds

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH (2:1)	EC (dS m ⁻¹)	OC (%)	CaCO ₃ (%)	Exchangeable cations			CEC (cmol kg ⁻¹)
								(cmol(+)kg ⁻¹)			
								Ca ²⁺ + Mg ²⁺	Na ⁺	K ⁺	
Profile 2											
0-22	81.0	10.8	8.2	8.0	0.17	0.88	2.9	5.2	0.12	0.03	5.3
22-43	50.8	41.3	7.9	7.7	0.18	0.28	3.4	7.4	0.11	0.01	8.3
43-75	44.6	43.4	12.0	7.6	0.21	0.23	4.9	6.4	0.14	0.03	5.8
75-110	43.7	42.1	14.2	7.9	0.23	0.21	1.1	5.8	0.14	0.03	5.4
110-140	62.9	29.3	7.8	7.9	0.23	0.10	3.2	5.0	0.07	0.01	5.3
Avg. Mean	56.6	33.4	10.0	7.8	0.20	0.34	3.1	6.0	0.12	0.02	6.0
Profile 8											
0-22	57.2	22.0	20.8	7.5	0.21	0.78	2.9	7.6	0.01	0.09	11.2
22-40	61.0	20.0	19.0	7.7	0.22	0.54	2.6	7.0	0.01	0.02	11.1
40-65	63.9	19.7	16.4	7.8	0.25	0.49	3.3	8.2	0.14	0.05	6.6
65-110	76.6	9.2	14.2	7.7	0.21	0.26	2.2	7.4	0.02	0.01	5.5
Avg. Mean	64.7	17.7	17.6	7.7	0.22	0.52	2.8	7.6	0.05	0.04	8.6
Profile 10											
0-20	87.5	1.3	11.2	8.6	0.08	0.65	Nil	3.6	0.06	0.03	5.7
20-38	90.0	1.8	8.2	8.2	0.07	0.23	Nil	4.4	0.04	0.02	3.0
38-62	74.5	12.8	12.7	8.2	0.08	0.18	Nil	5.4	0.01	0.01	5.9
62-90	91.1	3.1	5.8	8.9	0.07	0.16	1.5	2.4	0.03	0.01	3.2
90-140	93.5	3.5	3.0	9.1	0.09	0.10	Nil	3.4	0.15	0.02	3.0
Avg. Mean	87.3	4.5	8.2	8.6	0.08	0.26	0.3	3.8	0.06	0.02	4.2

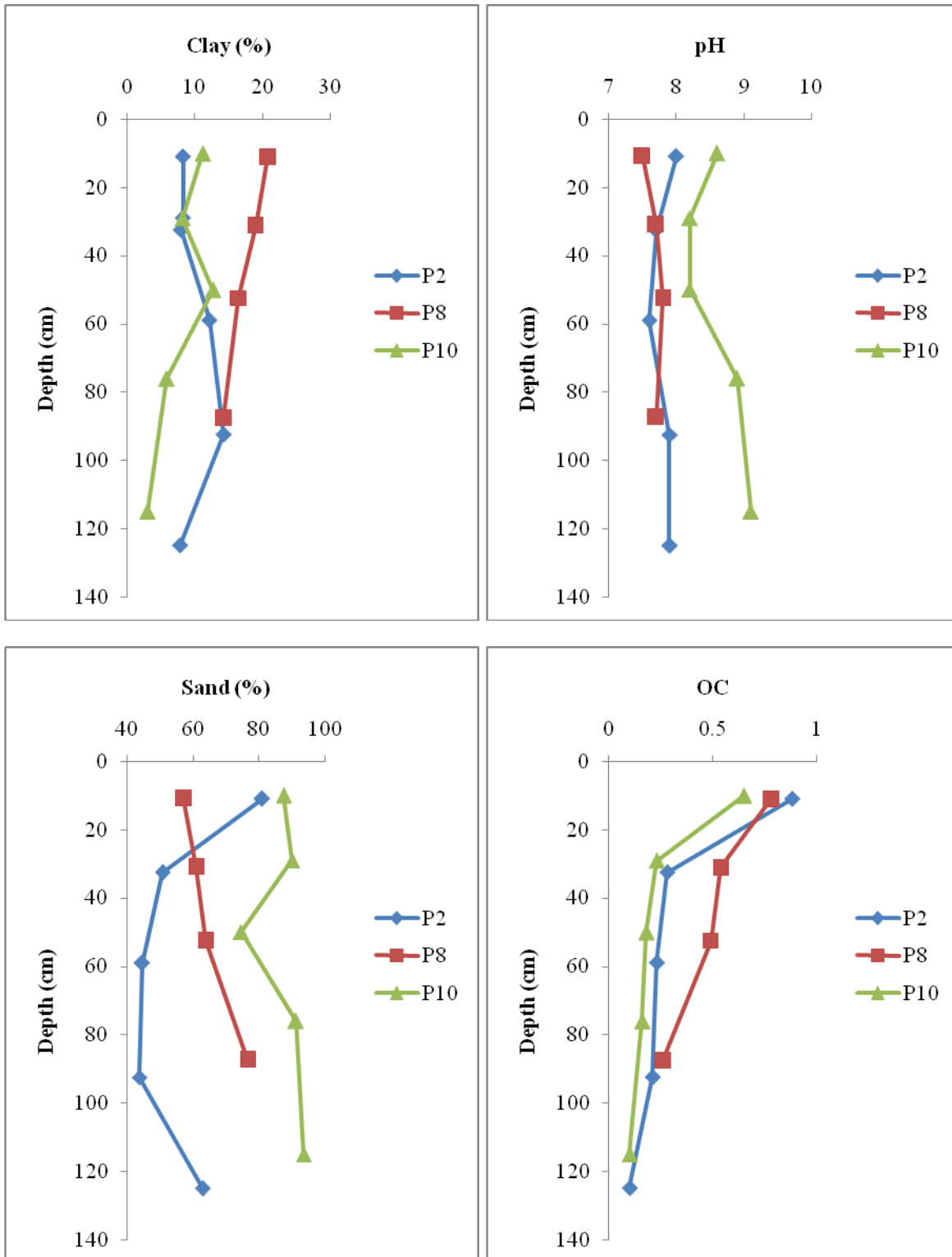


Fig. 4.8: Depth-wise distribution of Sand, Clay, pH and OC in soils of choe beds

profiles. The positive correlation of CEC with clay content (Table 4.10) was probably due to low organic matter content and location of exchange ions mainly on clay particles. Calcium and magnesium cations ($\text{Ca}^{2+} + \text{Mg}^{2+}$) were dominated on the exchange complex and their content varied from 2.4 to 8.2 $\text{cmol}(+)\text{kg}^{-1}$. The exchangeable Na^+ and K^+ varied from 0.01 to 0.15 and for 0.01 to 0.09 $\text{cmol}(+)\text{kg}^{-1}$ respectively.

4.5.5 Physico-chemical characteristics of soils of piedmont plains

The physico-chemical characteristics of the soils of piedmont plains are presented in Table 4.14. The particle size distribution data indicated the dominance of sand fraction in P5 profile and silt fraction in P6 and P7 soils. The sand content of soils of piedmont plain (P5 to P7) varied from 15.4 to 77.9 per cent (AM = 43.7%), silt from 18.3 to 62.3 per cent (AM= 41.3%) and clay from 3.8 to 25.8 per cent (AM = 15.0%). The sand content was the lowest in P7 profile (AM= 22.6%) and highest in P5 profile (AM= 66.2%). The clay content was the highest in P7 soil (AM= 23.4%) and lowest in P5 soil (AM= 9.6 %) respectively. The irregular variation in sand, silt and clay contents with depth is primarily due to geologic causes responsible for parent material (Nayak *et al* 2002).

The soils were slightly acidic to slightly alkaline in reaction with pH ranging from 6.5 to 8.2 (AM= 7.5). There is no definite trend of pH with depth in these soils (Fig 4.9). The profile P6 showed slightly acidic pH whereas profiles P5 and P7 showed slightly alkaline pH. Within profile, there was no much variation in soil pH. The electrical conductivity ranged from 0.08 to 0.33 dS m^{-1} . The electric conductivity was relatively higher in the surface horizon as compare to lower horizons in all the piedmont soils. Among the different soils, electric conductivity was the highest in P7 soil and the lowest in P6 soil. The soils having finer texture as in P7 profile had higher electrical conductivity as it accumulate more salts in soils.

Organic carbon varied from 0.03 to 0.98 per cent suggesting low to high content in these soils (Table 4.14). Generally organic carbon content of the surface horizon was higher than that of the subsurface horizon. There is definite decreasing trend of variation of organic carbon with depth in these soils (Fig 4.9). The P7 soil had relatively higher organic carbon content (AM= 0.52%) than P5 and P6 soils (AM= 0.43%). Except for some horizons of P5 profile, all the soils were free of calcium carbonate. The absence of calcium carbonate in the piedmont soils suggests influence of some degree of pedogenesis that possibly leached down the carbonate from these relatively stable surfaces. Cation exchange capacity varied from 2.9 to 11.4 $\text{cmol}(+)\text{kg}^{-1}$ having the highest in P7 profile and the lowest in P5 profile. The soils with relatively higher clay content had higher cation exchange capacity as in P7 soil. Calcium and magnesium cations ($\text{Ca}^{2+} + \text{Mg}^{2+}$) were dominated on the exchange complex and their content varied from 2.8 to 8.2 $\text{cmol}(+)\text{kg}^{-1}$. The exchangeable Na^+ and K^+ varied from 0.01 to 0.18 and for 0.01 to 0.06 $\text{cmol}(+)\text{kg}^{-1}$ respectively.

Table 4.14: Physico-chemical characteristics of soils of piedmont plains

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH (2:1)	EC (dS m ⁻¹)	OC (%)	CaCO ₃ (%)	Exchangeable cations			CEC (cmol kg ⁻¹)
								(cmol(+)kg ⁻¹)			
								Ca ²⁺ + Mg ²⁺	Na ⁺	K ⁺	
Profile 5											
0-18	67.8	23.1	9.1	7.6	0.33	0.47	Nil	7.0	0.17	0.10	4.9
18-34	64.3	24.3	11.4	7.4	0.21	0.36	Nil	4.0	0.18	0.05	5.7
34-65	67.0	22.8	10.2	7.8	0.16	0.31	1.1	4.8	0.04	0.02	4.9
65-105	77.9	18.3	3.8	8.0	0.14	0.26	Nil	4.0	0.05	0.03	2.9
105-140	54.0	32.6	13.4	7.9	0.13	0.21	1.2	4.6	0.04	0.01	6.5
Avg. Mean	66.2	24.2	9.6	7.7	0.19	0.32	0.5	4.9	0.10	0.04	5.0
Profile 6											
0-20	47.5	39.4	13.1	6.5	0.16	0.75	Nil	3.8	0.09	0.05	3.4
20-40	40.3	42.7	17.0	6.5	0.15	0.52	Nil	3.4	0.11	0.03	2.9
40-78	29.9	62.3	7.8	6.6	0.12	0.44	Nil	3.6	0.10	0.01	3.0
78-120	51.7	39.2	9.1	6.5	0.08	0.44	Nil	2.8	0.04	0.02	5.1
Avg. Mean	42.4	45.9	11.7	6.5	0.13	0.54	Nil	3.4	0.08	0.03	3.6
Profile 7											
0-20	25.7	52.5	21.8	8.1	0.22	0.98	Nil	8.2	0.05	0.02	12.4
20-48	15.5	58.7	25.8	8.1	0.22	0.75	Nil	7.0	0.05	0.06	10.2
48-80	21.3	54.9	23.8	8.2	0.19	0.67	Nil	4.6	0.03	0.04	11.4
80-120	22.6	54.8	22.6	8.0	0.16	0.36	Nil	4.2	0.01	0.02	10.9
120-150	27.9	48.9	23.2	8.0	0.20	0.03	Nil	3.6	0.02	0.01	11.2
Avg. Mean	22.6	54.0	23.4	8.1	0.20	0.56	Nil	5.5	0.03	0.03	11.2

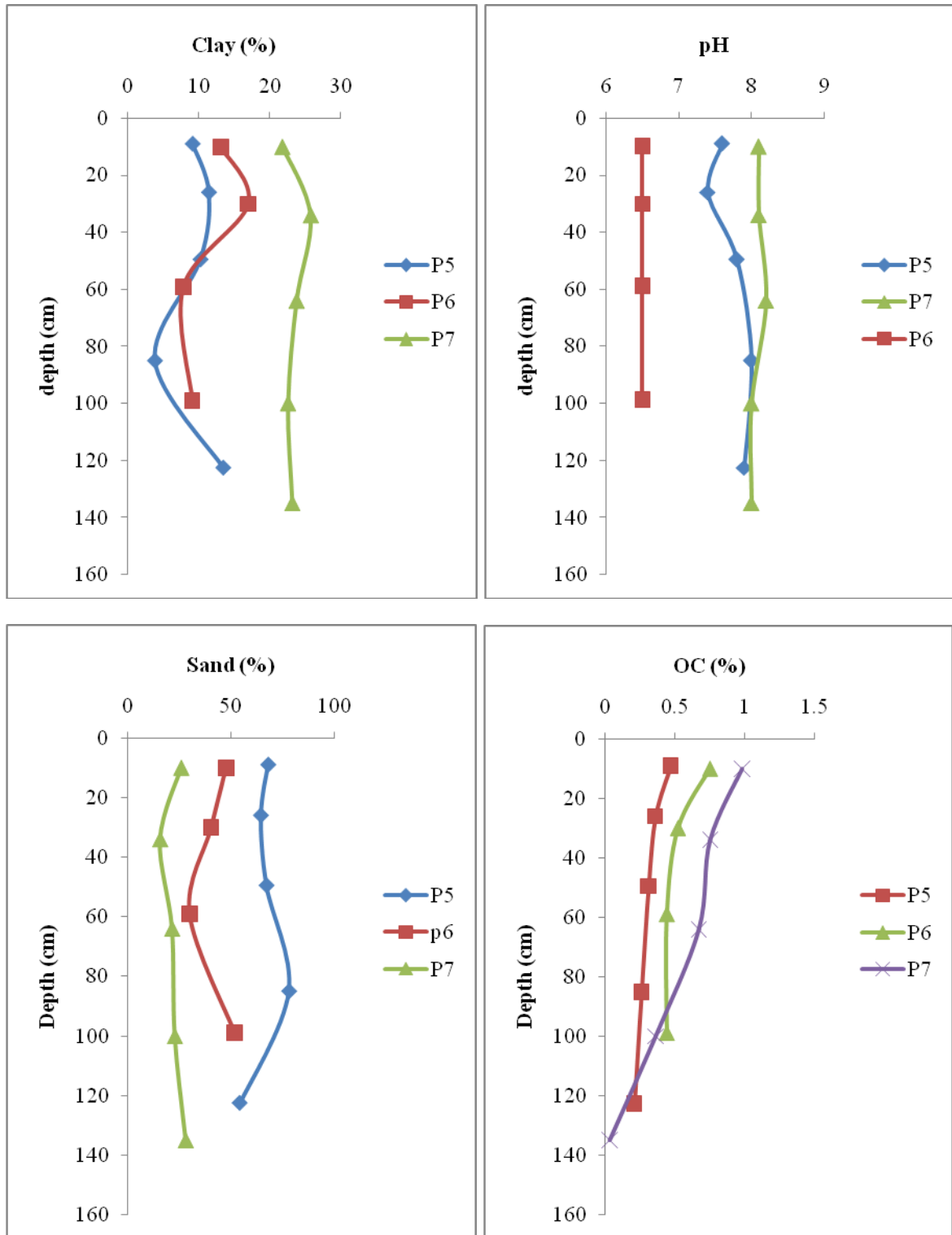


Fig. 4.9: Depth-wise distribution of Sand, Clay, pH and OC in soils of piedmont plains

4.6 Taxonomic classification of soils

The soils of Maili watershed were classified following the criteria of Soil Taxonomy (Soil Survey Staff, 1999). Based on field survey and supplementary laboratory data the soils of Maili watershed were classified. The taxonomic classification of the Maili watershed soils is discussed in the following heads:

4.6.1 Agro-ecological sub-regions

The components of natural physical environments, such as climate, soils and physiography act as sources of energy and physical support for agricultural ecosystem. The farm output depends largely on the potentiality of these components. Hence, a detailed knowledge of these components in environment helps in proper understanding of soil-plant-climate relationship. The significance of homogeneous agricultural environments, called as agro-ecological regions, is therefore of great importance. An agro-climatic zone is a land unit uniform in respect of climate and length of growing period (LGP) which is climatically suitable for a certain range of crops and cultivars. Out of the six agro-ecological sub-regions, Maili watershed covers the two namely (i) moist subhumid, Siwaliks and (ii) dry - moist subhumid, Siwaliks. The moist subhumid, Siwaliks mainly occupying the Siwaliks in northern parts of Maili watershed with annual rainfall varying from 1000 to 1300 mm and length of the growing period extends from 170 to 210 days. The dry - moist subhumid, Siwaliks covers the undulating piedmont part close to the south of Siwaliks in the watershed area. The annual rainfall here varies from 850 to 1200 mm and the length of growing period extends from 150 to 170 days.

4.6.2 Soil moisture regime

The moisture availability period start with the onset of monsoon in June and continues until the end of November. The July, August and September are the prominent humid months as they receive maximum rain with water surplus from 150 to 250 mm. The mean annual rainfall ranges from 850 to 1200 mm. This region also receives low intensity winter rain during January and February that helps moisture availability during rabi crops. The rainfall covers about 75 per cent of the evapotranspiration (PE) The period between September and November is the dry period. The soil moisture control section (SMCS) remains partly or fully dry during the period from second half of February to first half of June. So soils remain dry for 8 to 9 months and moist for three consecutive months in a year. Further, the soils are not remained dry with the moisture control section for 90 or more cumulative days and are moist for 180 cumulative days in a year. Hence, the soils qualified for ustic moisture regime. The northern part of Maili watershed covering the Siwalik hill however experience little higher rainfall and thus suggest udic moisture regime. However, this udic moisture regime closely borders the relatively warm and less moist ustic soil moisture

which prevails over the southern undulating plains and beyond. So Maili watershed represent udic moisture regime in the Siwalik hills and ustic moisture regime in piedmont plains.

4.6.3 Soil temperature regime

The climate of the area is moist to dry sub-humid with warm summer and cold winter. On an average, the mean maximum temperature ranges between 25⁰C and 36⁰C and mean minimum temperature ranges between 8⁰C and 22⁰C in summer and winter seasons, respectively. The mean annual soil temperature (MAST) at 50 cm depth is greater than 22⁰C. The difference between mean summer soil temperature (MSST) and mean winter soil temperature (MWST) being greater than 6⁰C, the area qualifies for the hyperthermic soil temperature regime.

4.6.4 Classification of soils of geomorphic units

The soils different geomorphic units of Maili watershed were places under different categories of the Soil Taxonomy namely orders, suborder, great group, subgroups and family levels (Table 4.15).

4.6.4.1 Classification of soils of hill tops

The soils developed on hill tops of Siwalik hills showed two stages of profile development, first as immature profile represented and second as weakly developed profile. The hill top soils having immature profile are represented by P1 and P11 profiles whereas weakly developed profile are represented by P13, P14 and P15 profiles. The immature soils of hill tops showed A-C horizon sequence. The immature soils did not show development of any diagnostic subsurface horizon. The surface horizon did not have rock structure, but light colour with value and chroma 4 or more when moist, and organic matter content less than 1 percent. The surface horizon of immature soils qualified for ochric epipedon. The P1 and P11 soils exhibited finer texture than the loamy fine sand in all the horizons in the control section. The profile P1 had shallow depth whereas P11 has moderately deep depth. The shallow to moderately deep, well drained, calcareous, coarse loamy soils (P1 and P11) of hill tops were classified as Typic Ustorthents. The weakly developed soils of hill tops showed A-Bw-C horizon sequence. The profiles P14 and P15 had moderately deep depth whereas P13 had deep depth. These weakly developed soils generally had sand loam texture in the control section thus identified as coarse loamy for family identifier. The A- horizon has relatively darker colour than the subsurface B horizon. The weakly developed soils exhibited presence of structural or altered B- horizon in subsurface. Free calcium carbonate occurs throughout the profile except in surface in P13 but absent in P14 and P15 soils. The deep, well drained, calcareous, coarse loamy P13 soil of hill tops was classified as Typic Haplustepts and deep, well drained, non-calcareous, coarse loamy P14 and P15 soils were classified as Udic Haplustepts.

Table 4.15: Taxonomic classification of soils of Maili watershed

Profile	Order	Suborder	Great Group	Subgroup	Family
Soils of hill tops					
P1 and P11	Entisols	Orthents	Ustorthents	Typic Ustorthents	Coarse loamy, Calcareous, Mixed, Hyperthermic
P13	Inceptisols	Ustepts	Haplustepts	Typic Haplustepts	Coarse loamy, Calcareous, Mixed, Hyperthermic
P14 and P15	Inceptisols	Ustepts	Haplustepts	Udic Haplustepts	Coarse loamy, Mixed, Hyperthermic
Soils of hill slopes					
P3, P4 and P16	Entisols	Orthents	Ustorthents	Typic Ustorthents	Coarse loamy, Calcareous/ non-calcareous, Mixed, Hyperthermic
P9	Inceptisols	Ustepts	Haplustepts	Udic Haplustepts	Fine loamy, Mixed, Hyperthermic
Soils of hill terraces					
P12 and P17	Inceptisols	Ustepts	Haplustepts	Typic Haplustepts	Coarse loamy, Calcareous, Mixed, Hyperthermic
Soils of choe beds					
P2 and P8	Entisols	Orthents	Ustorthents	Typic Ustorthents	Coarse loamy, Calcareous, Mixed, Hyperthermic
P10	Entisols	Psamments	Ustipsamments	Typic Ustipsamments	Mixed, Hyperthermic
Soils of piedmont plains					
P5 and P6	Inceptisols	Ustepts	Haplustepts	Typic Haplustepts	Coarse loamy, Calcareous/ non-calcareous, Mixed, Hyperthermic
P7	Inceptisols	Ustepts	Haplustepts	Typic Haplustepts	Fine loamy, Mixed, Hyperthermic

4.6.4.2 Classification of soils of hill slopes

The soils developed on hill slopes of the Siwaliks showed immature as weak profile development. The immature hill slope soils were represented by P3, P4 and P16 profiles whereas weakly developed profile were represented by P9 profile. The immature soils did not show development of any diagnostic subsurface horizon. The immature soils of hill slopes had A-C horizon sequence. The surface horizon did not have rock structure, but light colour with value and chroma 4 or more when moist, and organic matter content less than 1 percent. The surface horizon of immature soils qualified for ochric surface horizon. The P3, P4 and P16 soils exhibited finer texture than the loamy fine sand in all the horizons in the control section. The immature, shallow to very deep, well drained, calcareous/ non-calcareous, coarse loamy soils of hill slopes were classified as Typic Ustorthents. Sidhu and Surya (2014) have also classified these soils as Typic Ustorthents. The weakly developed hill slope soil (P9) showed presence of structural or altered B subsurface diagnostic horizon. The hill top soil had A-Bw-C horizon sequence. The profile P9 had very deep depth and was free of calcium carbonate. The weakly developed soil showed clay loam to loam texture in the profile thus classify for fine loamy for family identifier. The A- horizon has relatively darker colour than the subsurface B horizon. The profile P9 is on moderate hill slopes compared to other hill slope soils. The very deep, well drained, non-calcareous, fine loamy P9 soil of hill slopes has been classified as Udic Haplustepts.

4.6.4.3 Classification of soils of hill terraces

The hill terraces in the Siwalik hills cover small areas in patches that have relatively gentle or level surfaces over short distances. These terraces provide stable surfaces in hills for better development of the soils. During the field survey, the soils of the terraces were found to be of weakly developed stages. The hill terrace soils having weakly developed profile were represented by P12 and P17 profiles. The weakly developed soils of hill terraces showed A-Bw-C horizon sequence. The A- horizon has relatively darker colour than the underlying B horizon. The subsurface horizon showed structure or colour development suggesting presence of cambic diagnostic (Bw) horizon in the soils. These soils (P12 and P17) have deep to very deep profile with more than 110 cm depth. The weakly developed soils have sandy loam texture in the control section thus can be differentiated as coarse loamy class at family level. Calcium carbonate occurs throughout the profile in both the soils except in the upper two horizons of P17 profile. The deep to very deep, well drained, calcareous, coarse loamy soils of hill terraces were classified as Typic Haplustepts (Table 4.15).

4.6.4.4 Classification of soils of choe beds

The soils developed on choe beds have exhibited immature profile development. The choe bed soils having immature profile are represented by P2, P8 and P10 profiles. The profiles P2 and P8 occur in the hilly belt of Siwaliks whereas P10 in the piedmont plains. The immature soils of hill tops were characterized by A-C horizon sequence. Consequently these soils have been classified in order Entisols. The immature soils did not show development of any diagnostic subsurface horizon except the ochric surface horizon. The surface horizon A did not have rock structure, but light colour with value and chroma 4 or more when moist, and organic matter content less than 1 percent. The soils are deep to very deep and well drained. The profiles P2 and P8 contained appreciable amounts of rock fragments and were calcareous whereas P10 had occasional rock fragments and was non-calcareous. The loamy and sandy loam soils (P2 and P8) exhibited enough rock fragments at the lower depth in the profile. The deep to very deep, well drained, calcareous, coarse loamy soils (P2 and P8) over rock fragments of choe beds were classified as Typic Ustorthents. The profile P10 which was generally free of rock fragments and have texture of loamy fine sand or coarser in all the horizons in control section were classified as Typic Ustipsamments.

4.6.4.5 Classification of soils of piedmont plains

The piedmont plains cover southern part of the Maili watershed having undulating topography. The areas have alluvial parent material deposited by rivulets and choes during different periods in the past. The soils are generally medium texture and free of rock fragment. These plains provide the relatively stable surfaces for better development of the soils. The soils developed on plains (P5, P6 and P7) were found to be of weakly developed stages. The weakly developed soils of piedmont plains showed A-Bw-C horizon sequence. The A- horizon has relatively darker colour than the underlying B horizon. The soils had structure or colour B horizon in subsurface suggesting presence of cambic diagnostic (Bw) horizon. The profiles P5 and P6 have sandy loam and loam texture respectively in the profile and thus can be differentiated as coarse loamy class at the family level. The profile P7 had silty clay loam texture in the control section and thus can be differentiated as fine loamy class at the family level. The profile P5 representing the piedmont plains contained calcium carbonate in some horizons whereas P6 and P7 profiles were completely free of calcium carbonate. The soils of piedmont plains have deep to very deep profile with more than 150 cm depth. The deep to very deep, well drained, calcareous or non calcareous, coarse loamy or fine loamy soils (P5 P6 and P7) of the piedmont plains were classified as Typic Haplustepts (Table 4.15).

4.7 Fertility status of soils

The soils from five different physiographic units of Maili watershed, Hoshiarpur district were studied for the available forms of nutrients to assess their fertility status. The fertility evaluation and status of the Maili watershed is presented as under:

4.7.1 Soil sampling and evaluation

A total of seventeen profiles were exposed for such fertility evaluation. The surface as well as subsurface soil samples collected from the different profiles from different physiographic units were analyzed for the different available macro- and micro-nutrients. The available nitrogen, available phosphorus and potassium determined by standard procedures available for these macronutrients. The available form of micronutrients such as Zn, Cu, Mn and Fe was determined by DTPA extraction method. In all 79 soil samples surface and subsurface were analyzed for fertility evaluation in the laboratory.

4.7.2 Macronutrient and micronutrient contents

The content of available nitrogen varied from 250.9 kg ha⁻¹ to 652.3 kg ha⁻¹, relatively higher in the surface horizon and lower in subsurface horizons in the soils (Table 4.16). The highest content of nitrogen was found in P13 profile with an average mean value 454.1 kg ha⁻¹ and the lowest in P10 profile with an average mean value 338.7 kg ha⁻¹. On an overall basis in different physiographic units, the highest content of available nitrogen was found in the piedmont plain soils (AM= 469.1 kg ha⁻¹) and the lowest content in hill top soils (AM= 383.0 kg ha⁻¹).

The available phosphorus content varied from 0.5 to 6.0 kg ha⁻¹ having relatively higher in the surface horizon than in the subsurface horizons. The profile P16 showed the lowest content (AM= 1.1 kg ha⁻¹) of available phosphorus whereas that of profile P4 the highest content (AM= 4.8 kg ha⁻¹). Among the different physiographic units, the highest content of available phosphorus was found in the piedmont plain soils (AM= 3.8 kg ha⁻¹) and the lowest content in hill top soils (AM= 2.7 kg ha⁻¹).

The content of available potassium varied from 39.2 kg ha⁻¹ to 336.0 kg ha⁻¹, generally higher in the surface horizon and lower in subsurface horizons in the soils (Table 4.16). The lowest content of potassium was found in P14 soil (AM= 86.8 kg ha⁻¹) and highest in P5 soil (AM= 217.3 kg ha⁻¹). The different physiographic units showed the highest content of available potassium in piedmont plain soils (AM= 190.2 kg ha⁻¹) and lowest content in hill terrace soils (AM= 131.9 kg ha⁻¹). The depth distribution of available potassium was not regular with depth. Akbari *et al* (2014) indicated that the total nitrogen, phosphorus and total

nitrogen in surface layer (0-30 cm) and iron in both surface (0-30 cm) and subsurface (30-60 cm) varied significantly on different slope positions.

The DTPA extractable micronutrients showed relatively higher content of available manganese followed by iron, zinc and copper. The available copper content ranged from 0.10 to 0.52 mg kg⁻¹ in different horizons of the profiles. The content of copper was not higher in surface horizon of many soils of Maili watershed. The lowest content of copper was found in P15 soil (AM= 0.15 mg kg⁻¹) and highest in P7 soil (AM= 0.38 mg kg⁻¹). The different physiographic units showed the highest content of available copper in piedmont plain soils (AM= 0.33 mg kg⁻¹) and lowest content in hill terrace soils (AM= 0.18 mg kg⁻¹). The content of available zinc ranged from 0.03 to 1.25 mg kg⁻¹ having the lowest content in P3 soil (AM= 0.09 mg kg⁻¹) and the highest in P5 soil (AM= 0.42 mg kg⁻¹). On geomorphic unit basis, the highest content of available zinc was found in the piedmont plain soils (AM= 0.29 mg kg⁻¹) and the lowest content in hill terrace soils (AM= 0.14 mg kg⁻¹). The available zinc in all the soils from different physiographic units was deficient whereas available Cu was sufficient for normal plant growth. Similar observations were also made by several workers for the soils of Prakasam, Chittoor and Nellore districts of Andhra Pradesh (Venkatesu *et al* 2002, Thangasamy *et al* 2005 and Singh 2008).

The DTPA extractable iron and manganese ranged from 0.40 to 8.11 mg kg⁻¹ and 0.13 to 19.42 mg kg⁻¹ in different soils, respectively. The available iron content was the lowest in P17 profile and highest in P6 profile having average mean 0.58 mg kg⁻¹ and 7.29 mg kg⁻¹, respectively. The profiles P6 and P9 had high content of Mn with the average mean values of 17.83 mg kg⁻¹ and 11.18 mg kg⁻¹ respectively. The available Mn content was the lowest in P15 profile with the mean of 0.29 mg kg⁻¹. Similarly, except in P6 and P9 soils available content of Fe was also low in all the soils of the watershed as it was below 4.5 mg kg⁻¹. The micronutrient data showed that the soils are low in available Zn, Fe and Mn but sufficient in Cu. Taking the geomorphology as basis of differentiation, the highest content of the available iron was found in the piedmont plain soils (AM= 3.53 mg kg⁻¹) and lowest content in hill terrace soils (AM= 0.74 mg kg⁻¹) whereas available manganese in the piedmont plain soils (AM= 7.25 mg kg⁻¹) and lowest content in hill terrace soils (AM= 0.54 mg kg⁻¹).

Table 4.16: The available nutrient content of soils of Maili watershed

Profile	Depth (cm)	Available nutrients						
		N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)	Cu (mg kg ⁻¹)	Zn (mg kg ⁻¹)	Fe (mg kg ⁻¹)	Mn (mg kg ⁻¹)
Soils of hill tops								
P1	0-26	338.7	4.1	257.6	0.31	0.84	1.47	1.26
	26-50	338.7	3.2	173.6	0.23	0.16	1.12	0.10
	50-65	326.1	2.3	201.6	0.32	0.15	1.13	2.00
	65-110	301.1	2.3	196.0	0.27	0.10	1.38	1.91
	110-150	313.6	3.0	179.2	0.18	0.10	0.90	0.92
	AM	323.6	3.0	201.6	0.25	0.27	1.20	1.41
P11	0-15	614.7	4.6	235.2	0.13	0.05	2.09	0.51
	15-35	464.1	3.7	128.8	0.20	1.10	2.26	1.23
	35-60	401.4	3.2	123.2	0.14	0.11	1.74	0.71
	60-85	376.3	0.9	117.6	0.30	0.18	1.41	1.24
	85+	238.3	1.4	61.6	0.15	0.17	0.87	0.30
	AM	419.0	2.8	133.3	0.18	0.32	1.68	0.80
P13	0-18	652.3	3.6	240.8	0.29	0.31	1.89	3.41
	18-40	401.4	3.6	201.6	0.32	0.27	1.88	1.15
	40-80	414.0	3.3	190.4	0.27	0.26	1.59	1.39
	80-110	426.5	2.8	156.8	0.27	0.18	1.42	2.51
	110-130	376.3	1.9	106.4	0.24	0.17	1.23	1.65
	AM	454.1	3.0	179.2	0.28	0.24	1.60	2.02
P14	0-12	401.4	4.9	128.8	0.21	0.22	4.20	3.20
	12-36	401.4	3.3	95.2	0.20	0.08	3.05	2.60
	36-70	351.2	3.5	78.4	0.21	0.11	2.04	1.91
	70-125	326.1	1.7	44.8	0.15	0.06	1.18	1.54
	AM	370.0	3.4	86.8	0.19	0.12	2.62	2.31
P15	0-15	426.5	2.4	168	0.15	0.10	0.84	0.51
	15-38	363.8	1.1	117.6	0.16	0.27	0.74	0.32
	38-65	326.1	1.0	56	0.13	0.07	0.48	0.13
	65-125	276.0	1.8	95.2	0.15	0.06	0.66	0.20
	AM	348.1	1.6	109.2	0.15	0.13	0.68	0.29

Profile	Depth (cm)	Available nutrients						
		N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)	Cu (mg kg ⁻¹)	Zn (mg kg ⁻¹)	Fe (mg kg ⁻¹)	Mn (mg kg ⁻¹)
Soils of hill slopes								
P3	0-17	526.8	5.0	173.6	0.20	0.09	2.02	0.79
	17-41	439.0	4.2	173.6	0.24	0.07	1.47	1.04
	41-68	426.5	5.0	140.0	0.22	0.07	1.36	0.61
	68-120	376.3	5.1	134.4	0.17	0.14	1.07	0.62
	AM	442.2	4.8	155.4	0.21	0.09	1.48	0.77
P4	0-20	539.4	6.0	123.3	0.22	0.84	1.84	1.32
	20-40	401.4	6.0	168.0	0.15	0.10	0.85	0.76
	40-65	414.0	5.3	140.0	0.15	0.20	0.71	0.50
	65-120	401.4	3.7	123.2	0.14	0.04	0.65	0.51
	120-150	401.4	2.8	44.8	0.19	0.05	0.68	0.93
	AM	431.5	4.8	119.9	0.17	0.25	0.95	0.81
P9	0-21	602.1	3.5	196.0	0.32	0.24	4.11	3.53
	21-47	564.5	0.9	190.4	0.29	0.06	5.79	13.84
	47-82	501.8	0.7	173.6	0.32	0.10	5.85	15.78
	82-115	476.7	0.9	168	0.36	0.11	6.90	18.88
	115-150	338.7	0.5	67.2	0.24	0.03	2.72	3.89
	AM	496.8	1.3	159.04	0.31	0.11	5.07	11.18
P16	0-16	439.0	1.9	224.0	0.18	0.24	1.61	0.68
	16-40	376.3	1.1	207.2	0.17	0.11	1.05	0.60
	40-73	363.8	0.6	173.6	0.18	0.15	0.98	0.66
	73-120	313.6	0.7	123.2	0.13	0.13	0.86	0.22
	AM	373.2	1.1	182	0.17	0.16	1.12	0.54
Soils of hill terraces								
P12	0-20	514.3	4.7	252	0.28	0.22	1.50	0.10
	20-35	439.0	4.1	128.8	0.20	0.10	0.77	0.65
	35-55	401.4	4.0	112.0	0.19	0.17	0.80	0.33
	55-70	388.9	0.6	100.8	0.15	0.06	0.71	0.42
	70-110	401.4	0.5	84.0	0.13	0.12	0.73	0.30
	AM	429.0	2.8	135.52	0.19	0.13	0.90	0.54

Profile	Depth (cm)	Available nutrients						
		N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)	Cu (mg kg ⁻¹)	Zn (mg kg ⁻¹)	Fe (mg kg ⁻¹)	Mn (mg kg ⁻¹)
P17	0-18	502.1	5.0	225.0	0.25	0.22	0.40	0.88
	18-31	349.0	4.3	121.2	0.17	0.17	0.68	0.77
	31-56	412.5	3.6	110.0	0.14	0.17	0.68	0.38
	56-83	428.3	1.4	98.8	0.17	0.11	0.61	0.39
	83-119	376.3	0.6	86.5	0.14	0.10	0.54	0.29
	AM	413.7	3.0	128.3	0.17	0.15	0.58	0.54
Soils of choe beds								
P2	0-22	627.2	4.8	179.2	0.10	0.08	1.08	0.68
	22-43	526.8	4.4	184.8	0.32	0.23	4.47	0.97
	43-75	514.3	4.3	151.2	0.32	0.14	3.48	0.74
	75-110	439.0	4.0	140.0	0.25	0.11	2.16	0.60
	110-140	363.8	2.8	72.8	0.23	0.12	0.88	0.60
	AM	494.2	4.1	145.6	0.24	0.14	2.41	0.72
P8	0-22	589.6	3.7	252	0.19	0.45	0.99	0.68
	22-40	526.8	3.6	184.8	0.23	0.16	1.66	1.55
	40-65	451.8	3.2	156.8	0.22	0.11	2.04	2.83
	65-110	288.5	1.7	156.8	0.22	0.05	1.60	2.48
	AM	464.1	3.1	187.6	0.22	0.19	1.57	1.89
P10	0-20	401.4	4.4	218.4	0.14	0.34	1.88	0.66
	20-38	376.3	4.3	151.2	0.14	0.06	1.24	0.57
	38-62	351.2	3.7	128.8	0.20	0.05	1.22	0.73
	62-90	313.6	3.7	50.4	0.17	0.08	1.40	0.58
	90-140	250.9	3.4	39.2	0.12	0.04	2.71	0.52
	AM	338.7	3.9	117.6	0.15	0.11	1.69	0.61
Soils of piedmont plains								
P5	0-18	551.9	4.7	336.0	0.23	1.25	2.09	3.83
	18-34	539.4	2.4	246.6	0.30	0.14	1.10	1.90
	34-65	426.5	2.1	218.4	0.29	0.08	1.02	1.82
	65-105	338.7	3.8	156.8	0.21	0.53	0.90	1.42
	105-140	276.0	2.8	128.8	0.29	0.09	1.09	1.99
	AM	426.5	3.2	217.3	0.26	0.42	1.24	2.19

Profile	Depth (cm)	Available nutrients						
		N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)	Cu (mg kg ⁻¹)	Zn (mg kg ⁻¹)	Fe (mg kg ⁻¹)	Mn (mg kg ⁻¹)
P6	0-20	589.3	5.7	162.4	0.33	0.46	8.11	19.42
	20-40	514.3	4.8	123.2	0.27	0.16	7.23	16.44
	40-78	439.0	4.5	145.6	0.31	0.15	5.97	17.68
	78-120	363.8	2.6	140.0	0.44	0.11	7.84	17.79
	AM	476.6	4.4	142.8	0.34	0.22	7.29	17.83
P7	0-20	639.7	4.5	151.2	0.28	0.59	1.30	1.13
	20-48	602.1	4.4	291.2	0.52	0.22	2.31	1.62
	48-80	514.3	3.9	257.6	0.41	0.09	2.28	2.31
	80-120	439.0	3.3	179.2	0.35	0.07	2.39	1.97
	120-150	326.1	2.9	173.6	0.34	0.10	2.08	1.60
	AM	504.2	3.8	210.6	0.38	0.22	2.07	1.73

AM= Average mean

4.7.3 Correlation coefficient between soil properties and available nutrients of all soils

The correlation coefficient data between soil properties and available nutrients (Table 4.17) revealed that the clay fraction had significantly positive correlation with nitrogen and potassium whereas sand fraction had significantly negatively correlated with these macronutrients. The silt fraction showed significant positive correlation with available potassium. Except zinc, all the micronutrients (Cu, Fe and Mn) showed significant positive correlation with clay and silt fractions and significant negative correlation with the sand fraction. Invariably, soil pH had negative correlation with all the nutrients but significant with N, P, Cu, Fe and Mn. Similarly the soil organic carbon had, invariably, positive correlation with all the nutrients but significant with N, P, K, Zn and Fe. Cation exchange capacity showed similar relationship as exhibited by clay fraction having positive correlation with N, K Cu and Fe.

Table 4.17: Correlation coefficient between soil properties and available nutrients

	Sand	Silt	Clay	pH	EC	OC	CaCO ₃	CEC
N	-0.27	0.20	0.32	-0.34	0.06	0.37	0.12	0.42
P	0.01	0.03	-0.14	-0.34	0.11	0.22	0.16	-0.15
K	-0.31	0.27	0.25	-0.12	0.10	0.30	-0.09	0.28
Cu	-0.65	0.65	0.30	-0.35	0.04	0.12	-0.12	0.41
Zn	-0.02	0.04	-0.02	-0.12	0.15	0.21	0.00	0.08
Fe	-0.40	0.36	0.34	-0.55	-0.10	0.28	-0.17	0.22
Mn	-0.42	0.37	0.37	-0.54	-0.08	0.16	-0.27	0.18

For df 78 the significance value of r at 5% = 0.21

The correlation coefficient data among available nutrients revealed that nitrogen had significant and positive influence on all other macro and micronutrients (Table 4.18) which could be related due to their association with organic matter content. The available P showed significant positive correlation with K and DTPA-Zn whereas available K showed significant positive correlation with DTPA-Cu along with P and Zn. Between micronutrients, DTPA-Cu had significant positive correlation with DTPA-Fe and DTPA-Mn whereas DTPA-Fe with DTPA-Mn.

Table 4.18: Correlation coefficient among available nutrients

	N	P	K	Cu	Zn	Fe
P	0.41					
K	0.55	0.29				
Cu	0.33	0.10	0.46			
Zn	0.30	0.32	0.36	0.11		
Fe	0.32	0.09	0.08	0.54	0.04	
Mn	0.25	-0.03	0.07	0.49	0.01	0.90

For df 78 the significance value of r at 5% = 0.21

4.7.4 Rating Limits of Nutrients

The rating limit for available macro and micronutrients, as followed in different laboratories in Punjab is given in Table 4.19. The soils having less than 271 kg ha⁻¹ available nitrogen is considered as deficient. The soils are deficient in available phosphorus and potassium when their contents are less than 12 kg ha⁻¹ and less than 113 kg ha⁻¹ respectively. The critical limits for available Fe, Mn, Zn and Cu are 4.5, 3.5, 0.60 and 0.20 mg kg⁻¹ respectively.

Table 4.19: Rating limits of nutrients for fertility evaluation

Rating	Nitrogen (kg ha⁻¹)	Phosphorus (kg ha⁻¹)	Potassium (kg ha⁻¹)	Iron (mg kg⁻¹)	Manganese (mg kg⁻¹)	Zinc (mg kg⁻¹)	Copper (mg kg⁻¹)
Low (L)	< 271	< 12	< 113	-	-	-	-
Medium (M)	271 - 543	12 – 22	113 – 280	-	-	-	-
High (H)	> 543	> 22	> 280	-	-	-	-
Deficient (D)	-	-	-	< 4.5	< 3.5	< 0.6	< 0.2
Marginal (Ma)	-	-	-	-	-	0.6 - 1.2	-
Sufficient (S)	-	-	-	> 4.5	> 3.5	> 1.2	> 0.2

4.7.5 Percentage of deficiency/ sufficiency of nutrients

The percentage distribution of soil samples falling in low, medium and high categories of available forms of N, P, K and micronutrients is given in Table 4.20. The areas under Maili watershed, being in relatively higher rainfall and forest cover may be expected to have relatively higher organic matter content and in turn the available nitrogen. Depending on the organic carbon content, the soil samples from the surface and subsurface horizon showed 84.8 per cent samples falling in medium category and 12.7 per cent in high category of available nitrogen status. So the soils are not generally deficient in nitrogen. Contrary to the available nitrogen, the availability of phosphorus is invariably low for all the samples. Very low availability of phosphorus may be due to continuous its mining by natural vegetation, erosion and no application of chemical phosphorus fertilizers in the area. The soils of the Maili watershed generally fall in low to medium available potassium having 22.8 and 74.7 per cent samples in these categories respectively. Though the soils have appreciable potassium bearing minerals but due to coarser texture the supply of potassium is low to medium.

Table 4.20: Fertility status of soil samples of Maili watershed, Hoshiarpur

Sr. No.	Nutrient	Category	No. of sample (Total sample= 79)	Percentage of sample (%)
1.	Nitrogen	Low	2	2.5
		Medium	67	84.8
		High	10	12.7
2.	Phosphorus	Low	79	100
		Medium	-	-
		High	-	-
3.	Potassium	Low	18	22.8
		Medium	59	74.7
		High	2	2.5
4.	Zinc	Deficient	76	96.2
		Marginal	2	2.5
		Sufficient	1	1.3
5.	Copper	Deficient	36	45.6
		Sufficient	43	54.4
6.	Iron	Deficient	72	91.1
		Sufficient	7	8.9
7.	Manganese	Deficient	69	87.3
		Sufficient	10	12.7

Among the DTPA extractable micronutrients, except for copper, the deficiency of Zinc, iron and manganese were nearly 90 per cent. The percentage of soil samples for copper in deficient and sufficient categories were 45.6 and 54.4 per cent respectively. The soils are generally sufficient in available Cu content being the value more than 0.2 mg kg⁻¹, especially in the surface horizons, except in P2, P8, P10, P11 and P15 soils. Among the micronutrients, zinc deficiency was more pronounced as compared to others.

4.8 Land evaluation and land capability classification

Land evaluation is the process of assessing the performance of land when used for a given purpose. Land evaluation may be operated either for a specific kind of use (maize, potatoes) or for a more general utilization (agriculture, grazing). Land evaluation assesses the performance of land based on a more or less systematic analysis of the physical land conditions and on the impact these have on present and alternative land use systems. Land evaluation in its simplest form selects the best land for a specific or general purpose. The evaluation process does not in itself determine the land use or land use changes, but provides data on the basis of which land use decisions and options can be taken.

4.8.1 Land evaluation methods

Land may be evaluated directly, by trial e.g. through growing crops, collection and processing of crop-yield data, and to see what happens. The most land evaluation systems are indirect based on soil and site properties that influence the success of a particular land use. A land may be assessed in different ways as land's suitability, capability and value. Suitability refers to a single, clearly defined, reasonably homogeneous purpose, practice or crop (with specific crop growth requirements), and has a sharp focus on sites possessing the positive conditions to apply the practice or grow crop beneficially. Capability stands for a much broader use such as agriculture, grazing or urban development, and it assessed in terms of negative limitations which prevent some or all of the activities concerned. The land value assessment focused on gains or losses involved in a proposed land use

4.8.2 Land capability classification

The land capability classification (LCC) system was developed by the Soil Conservation Service, USDA in 1930 as part of programme to control soil erosion. It is most widely used categoric system for land evaluation. The land capability classification is interpretative grouping of the soils based on (i) inherent soil characteristics (ii) external land features, and (iii) environmental factors that limit the use of land. However, the specific properties that may impose risk to yield and are used for assessment include (a) slope &

erosion hazards (b) soil depth, stoniness/rockiness (c) texture and structure (d) drainage / permeability (e) severity of climate (f) fertility/ nutrient availability, and (g) salinity / alkalinity / acidity / toxicity.

The land capability classification (LCC) is a grouping of land into defined classes depending on their capability based on limitations. According to that, the land capability is classified broadly into two groups based on the cultivability of the land. The first group consisting of all the lands which are suitable for cultivation is referred to as 'Group 1 Lands'. The remaining group consisting of all lands which are unsuitable for cultivation is referred to as 'Group 2 Lands'. Each of these two groups are further classified into four classes. Thus 'Group 1 Lands' comprise 'Land Classes I to IV' which are cultivable and 'Group 2 Lands' comprise 'Land Classes V to VIII' which are non-cultivable. The capability classes tell us the degree or extent of limitation of land to crop growth or land-use.

Class I- These lands are nearly level with slopes generally within 1%. The soils are deep, fertile, easily workable, and are not subjected to damaging overflows. There are hardly any restrictions or limitations for their use.

Class II- Have moderate limitations that reduce the choice of plants or that require moderate conservation practices. 2-5% slope is main difference

Class III- Have severe limitations that reduce the choice of plants or that require special conservation practices. 6-10% slope, shallow soil and water table.

Class IV- 12-18% slope. The land may have one or more of the following permanent features (Murthy and Jha 2011):

1. Heavy susceptibility for erosion due to wind, water with severe effects of past erosion;
2. Low moisture holding capacity;
3. Frequent overflows accompanied by severe crop damage;
4. Water logging, excessive wetness and severe salinity; and
5. Moderately adverse climate.

Class V- cannot be tilled or considered not suitable for cultivation. These soils are likely to erode, but have other limitations such as boulders, wetness impractical to correct that limit their use; therefore used for permanent grazing/pasture.

Class VI- Same as V. Slope 18-30%.

Class VII- It is suited for controlled grazing with careful management. Slope >30%.

Class VIII- It has severe limitations, and therefore used for recreation, wildlife, aesthetic uses only

The capability subclasses tell us about the kinds of dominant limitation. Lands in Classes II, III and IV are further categorized into sub-classes based on the following limitations:

1. Risk of erosion or past erosion damage is designated by the symbol 'e';
2. Wetness damage or overflow is designated by the symbol 'w';
3. Soil root zone limitations are denoted by 's'; and
4. Climatic limitations are designated by 'c'.

4.8.3 Land capability classes of Maili watershed

The land capability classification was performed based on degree of limitation and nature of limitation of the land for its uses. At first place land was differentiated in to two groups based on permanent limitation of the landforms. The Maili watershed falls in the semi-arid (submoist) less hot climate zone of Sehgal *et al* (1992). So water scarcity may be the one of the limitation for cultivation. Therefore, where no assured irrigation is available, climate may be the considered as a limiting factor. So the important factors considered for classification were topography, climate, slope, stoniness, soil depth, soil structure and soil texture/ water holding capacity.

Because of being complex topography of the terrain posing permanent limitation for cultivation of agricultural crops, the soils within hilly areas were mostly placed in classes V to VII. However the soils from hill terraces were placed class IV being on relatively stabilized slopes. The soils of piedmont plains being on gentle slopes and having least limitations were classed in III of land capability classification. The watershed area, thus, has been classified into capability classes III, IV, V, VI and VII based on topographic conditions and other various associated limitations. Each class has been further differentiated in to subclasses based on dominant limitation of the land. The land capability classes and subclasses identified in the study area are summarized in Table 4.21.

Table 4.21: Land capability classification of soils of Maili watershed

Profile	Limitation property of land				Capability class/ subclass
	Slope (%)	Stoniness (volume %)	Soil depth	Soil structure/ water holding capacity	
The soils of hill tops					
P1 and P11	15-20	15-20	Shallow to moderately deep	Poor	VIIces
P13	10-12	-	Deep	Moderate	Vce
P14 and P15	12-20	10-12	Moderately deep	Poor	VIIces
The soils of hill slopes					
P3 and P4	20-30	10-12	Shallow to moderately deep	Poor	VIIces
P9	15-20	5-8	Very deep	Moderate	Vce
P16	25-35	15-20	Deep to very deep	Poor	Vice
The soils of hill terraces					
P12 and P17	10-12	8-10	Deep to very deep	Poor to moderate	IVce
The soils of choe beds					
P2 and P8	10-12	20-25	Deep	Poor	Vcew
P10	3-6	2-3	Very deep	Poor	IVce
The soils of piedmont plains					
P5, P6 and P7	3-6	2-3	Very deep	Moderate	IIIce

CHAPTER V

SUMMARY

Soil is that precious, diverse, and fragile natural resource at the Earth's terrestrial surface that provides ample assistance for continuity of life. Soil is the base for every production system and knowledge on their properties, extent and spatial distribution at watershed level is extremely important for developing land use. Brief information on account of the type of soils along with their spatial distribution is a mandatory thing in the development of the watershed.

Soil characteristics related to the genesis are important factors for better land use management in a watershed. Many studies have illustrated the potential use of remotely sensed data and Geographical Information Systems (GIS) in study of watershed and evaluation of their linear, relief and areal morphometric parameters. The watershed morphometry influences the soil genesis and processes of landforms, and characteristics of soil parameters like texture, structure, drainage and land erosion conditions. Considering the importance of soil characteristics and morphometry of landforms in watershed management, an attempt has been made to study the soils of Maili watershed of Hoshiarpur district of Punjab for their morphological, physical-chemical and fertility aspects relation to geomorphology. The northern part of the Hoshiarpur district includes the kandi region and the submontane Siwalik hills of Punjab adjoining Himachal Pradesh. The Maili watershed, extending the Siwalik hills and kandi belt in Hoshiarpur district of Punjab was selected for this study. The watershed extends between the longitudes of $76^{\circ} 03' 46.8''$ and $76^{\circ} 09' 03.6''$ E and the latitudes of $31^{\circ} 25' 56.4''$ and $31^{\circ} 28' 44.4''$ N. The watershed covers an area of 36.07 sq km. The minimum altitude is 313 m and maximum 586 m respectively above the mean sea level. The mean annual rainfall of the area ranges from 850 mm to 1200 mm. The present study entitled "Characterization of soils as influenced by geomorphology in Maili watershed of Hoshiarpur district, Punjab" has been undertaken with the following specific objectives:

- i) To identify and study geomorphic units of Maili watershed
- ii) Morphological and physico-chemical characterization of soils
- iii) To evaluate soils for land capability classification

The geomorphic, morphometric and land use land cover analysis of the Maili watershed were carried using Survey of India Topo sheet no. H43E3 (open series updated in 2000-01) on 1:50,000 scales along with merged satellite data (LISS IV + CARTOSAT-1 PAN) with help of Arc GIS 10 software. Field survey was also performed for the verification of the ground truth of the watershed. The most characteristics physiographic features of the area are the Siwalik hills which marks a sharp physiographic boundary with the piedmont plains lying

to the south. The various geomorphic units identified in the watershed are the Siwalik hills, hill terraces, piedmont plains and choe beds.

The morphometric parameters of linear, areal and relief nature provided a quantitative description of the drainage system and the configuration of landforms of watershed. A total of 194 streams were identified belonging to 1st, 2nd, 3rd and 4th order. The variation in stream length ratio was observed due to change in slope and topography. The drainage density of Maili watershed is 3.033 km/km² indicating that the region has permeable subsoil, good vegetation cover and has moderate relief. The drainage texture is 5.639 indicated moderate drainage texture of Maili watershed. The drainage has adopted the dendritic/ sub-dendritic having the tributaries somewhat subparallel joining at acute angles. Although the Siwalik rocks showing marked bedding planes and steep dip, however due to their relatively soft nature these structures are not showed much influencing effect on drainage pattern.

Six common categories of land use land cover classes identified in the study area are cropland, plantation, forest, reservoir/lake, built-up area and scrubland. The most part of the watershed area comes under forest cover (74.6%) followed by cropland (17.6%) which will directly or indirectly impact the watershed development and management in future.

The physiographic map generated from remote sensing technique along with survey of India toposheet was used as base map for the study of soils during the field survey. The traverses and examination of soils at different random locations form the part of rapid reconnaissance survey. Based on rapid reconnaissance survey, seventeen locations from different parts of Maili watershed were selected for detailed observations and differentiation of the soils of the area. Out of these total seventeen representative soil profiles, five profiles are from the hill tops (P1, P11, P13, P14, P15), four from the hill slopes (P3, P4, P9, P16), two from the hill terraces (P12 and P17), three each from the choe beds (P2, P8, P10) and piedmont plains (P5, P6, P7). These profiles were exposed to different depths depending on thickness of soil solum and presence of bedrock. These profiles were exposed to a depth from 120 to 150cm and describe for their morphological properties in the field. The soil samples were collected from each of the morphologically differentiated horizon. The soils of the different physiographic units in watershed were characterized for morphological, physico-chemical and fertility aspects.

The soils of hill top had hue value 10YR throughout the profiles except P13 which showed 7.5YR hue. The value varied from 3 to 7 and chroma was in the range of 1 to 8. The slightly developed soils have more chroma than immature soils. The texture of the different horizons of these soils varied from silt loam through loam, sandy loam to loamy sand. The soils are generally coarser texture except P1 soil. They had weak fine granular structure in the

surface horizon and structurless or weak fine subangular blocky in the subsurface horizons. The hill top soils showed friable to loose consistence in moist condition. The soils of hill slopes showed invariably 10YR hue throughout the profiles suggesting no appreciable sign of alteration or weathering in the profiles. The value varied from 3 to 6 and chroma 1 to 8. The soils P3 and P16 have sandy loam texture in the upper horizons and loamy sand in the lowermost horizon and P9 soil is relatively finer texture throughout profile. The soils of hill terrace showed A-Bw-C horizon sequence. All the horizons of these profiles had 10YR hue whereas value varied from 4 to 6 and chroma from 2 to 4. The soil horizons generally had different shades of brown. The darker colour of the surface horizons was due to the accumulation of more organic carbon at the surface. These soils invariably had sandy loam texture. The soils indicate weak, fine granular structure in the surface horizon and weak, fine subangular blocky structure in the subsurface horizons. The soils had moist friable consistent. The terrace soils showed presence of calcium carbonate.

The soils of choe beds did not show any profile development. Textural composition is though variable in different parts of the three profiles but generally coarse-textured. All the horizons of these three profiles had 10YR hue whereas value varied from 3 to 6 and chroma from 2 to 6. No structural development was observed in the choe bed soils except in the surface horizon. The piedmont plain profiles have shown development of structural or altered subsurface diagnostic horizon distinguished as cambic horizon (Bw). These profiles of piedmont plain had 10YR hue throughout the profile. The value varied from 3 to 5 and chroma was in the range of 4 to 6. The subsurface horizons appeared relatively redder than other horizons suggesting some decomposition or weathering. The soils was weak, fine granular in surface horizon and weak, fine sub angular blocky in subsurface horizons. The soil consistence varied from moist friable to moist firm in the soils. The traces of calcium carbonate in some horizon of P5 profile may be expected as remains of parent material transported and deposited from the hills. The soils' successive horizons showed clear or gradual smooth boundaries.

The hill top soils varied in sand content from 19.2 to 83.8 per cent and clay content 3.2 to 24.2 per cent. The sand, silt and clay were irregular distribute with depth in soils of hill top. Electrical conductivity varied from 0.03 to 0.34 dS m⁻¹. The soils were alkaline in reaction with pH ranging from 7.3 to 9.4. No definite trend of pH with depth was observed in these soils. The hill top soils were low to high in organic carbon content which varied from 0.08 to 1.42 per cent. The hill slope soils varied in sand, silt and clay contents from 23.1 to 86.5 per cent, 6.3 to 50.7 per cent and 5.4 to 27.8 per cent respectively. The soils were alkaline in reaction with pH ranging from 7.5 to 8.8. The electrical conductivity ranged from 0.12 to 0.33 dS m⁻¹. The electrical conductivity was generally higher in surface horizon and then decrease to

certain depth. Cation exchange capacity varied from 3.3 to 15.1 $\text{cmol}(+)\text{kg}^{-1}$. The relatively finer textured soils had higher CEC than coarser texture soils suggested positive correlation with clay content ($r = 0.54$). Organic carbon content varied from 0.23 to 0.96 per cent suggesting its low to high content in hill slope soils. Organic carbon content was highest in the surface horizon and generally decreased with depth.

The hill terrace soils varied in sand content from 54.5 to 72.8 per cent and clay content 7.8 to 12.6 per cent (WM= 27.72%). The irregular variation in sand, silt and clay contents with depth is primarily due to geologic causes responsible for parent material. The soils were alkaline in reaction with pH ranging from 8.1 to 9.2. The hill terrace soils were low in organic carbon content which varied from 0.16 to 0.28 per cent. The depth distribution of organic carbon was regular in P17 soil but irregular in P12 soil. Cation exchange capacity varied from 4.3 to 7.0 $\text{cmol}(+)\text{kg}^{-1}$ and was found to be significantly positive correlated ($r = 0.54$) with clay content. In the soils of choe beds, sand content varied from 43.7 to 93.5 per cent, silt from 1.3 to 43.4 per cent and clay from 3.0 to 20.8 per cent. The soil pH ranged from 7.5 to 9.1. The electrical conductivity ranged from 0.07 to 0.25 dS m^{-1} . Organic carbon content was low to high as it varied from 0.10 to 0.88 per cent in the soils. Calcium carbonate content varied from nil to 4.9 per cent in different horizons of these soils. Cation exchange capacity varied from 3.0 to 11.2 $\text{cmol}(+)\text{kg}^{-1}$. Calcium and magnesium cations were dominated on the exchange complex and their content varied from 2.4 to 8.2 $\text{cmol}(+)\text{kg}^{-1}$. The sand content of the soils of piedmont plain varied from 15.4 to 77.9 per cent, silt from 18.3 to 62.3 per cent and clay from 3.8 to 25.8 per cent. The soils were slightly acidic to slightly alkaline in reaction with pH ranging from 6.5 to 8.2. Organic carbon varied from 0.03 to 0.98 per cent. Except for some horizons of P5 profile, all the soils were free of calcium carbonate. Cation exchange capacity varied from 2.9 to 11.4 $\text{cmol}(+)\text{kg}^{-1}$. Calcium and magnesium cations were dominated on the exchange complex and their content varied from 2.8 to 8.2 $\text{cmol}(+)\text{kg}^{-1}$.

The immature soils of hill tops represented by P1 and P11 profiles did not show development of any diagnostic subsurface horizon except the ochric surface horizon, and classified as Typic Ustorthents. The weakly developed soils of hill tops represented by P13, P14 and P15 profiles exhibited presence of structural or altered B- horizon in subsurface. The deep, well drained, calcareous, coarse loamy P13 soil of hill tops was classified as Typic Haplustepts and the deep, well drained, non-calcareous, coarse loamy P14 and P15 soils were classified as Udic Haplustepts. The immature hill slope soils were represented by P3, P4 and P16 profiles whereas weakly developed profile were represented by P9 profile. The immature, shallow to very deep, well drained, calcareous/ non-calcareous, coarse loamy soils of hill slopes were classified as Typic Ustorthents whereas the weakly developed hill slope soil (P9) having A-Bw-C horizon sequence classified as fine loamy as Udic Haplustepts.

The hill terraces in the Siwalik hills cover small areas in patches that have relatively gentle or level surfaces. The weakly developed soils of hill terraces represented by P12 and P17 profiles showed A-Bw-C horizon sequence. The weakly developed soils have sandy loam texture in the control section thus can be differentiated as coarse loamy class at family level. The deep to very deep, well drained, calcareous, coarse loamy soils of hill terraces were classified as Typic Haplustepts. The choe bed soils having immature profile are represented by P2, P8 and P10 profiles. The immature soils did not show development of any diagnostic subsurface horizon and hence characterized by A-C horizon sequence. The profiles P2 and P8 contained appreciable amounts of rock fragments and were calcareous whereas P10 had occasional rock fragment and was non-calcareous. The deep to very deep, well drained, calcareous, coarse loamy soils (P2 and P8) were classified as Typic Ustorthents whereas sandy/loamy sand soil (P10) was classified as Typic Ustipsamments.

The piedmont plain soils are generally medium in texture and free of rock fragment. These plains provide the relatively stable surfaces for better development and as such showed A-Bw-C horizon sequence. The A- horizon has relatively darker colour than the underlying B horizon. The soils had structure or colour B horizon in subsurface suggesting presence of cambic diagnostic (Bw) horizon. The profiles P5 and P6 belong to coarse loamy class whereas profile P7 to fine loamy family class. The profile P5 representing the piedmont plain soil contained calcium carbonate in some horizons whereas P6 and P7 profiles were completely free of calcium carbonate. The deep to very deep, well drained, calcareous/ non calcareous, coarse loamy/ fine loamy soils (P5 P6 and P7) of the piedmont plains were classified as Typic Haplustepts.

The available nitrogen content varied from 250.9 kg ha⁻¹ to 652.3 kg ha⁻¹ having the highest content in the piedmont plain soils (AM= 469.1 kg ha⁻¹) and lowest content in hill top soils (AM= 383.0 kg ha⁻¹). The available phosphorus content varied from 0.5 to 6.0 kg ha⁻¹ having the highest content in the piedmont plain soils (AM= 3.8 kg ha⁻¹) and the lowest content in hill top soils (AM= 2.7 kg ha⁻¹). The content of available potassium varied from 39.2 kg ha⁻¹ to 336.0 kg ha⁻¹ showing the highest content in piedmont plain soils (AM= 190.2 kg ha⁻¹) and the lowest content in hill terrace soils (AM= 131.9 kg ha⁻¹). Depending on the rating limit for available macronutrients, 84.8 per cent samples falling in medium category of available nitrogen, 100 per cent samples are low in available phosphorus and 22.8 and 74.7 per cent samples in low and medium available potassium, respectively.

The DTPA extractable copper content ranged from 0.10 to 0.52 mg kg⁻¹ having the lowest content in P15 soil (AM= 0.15 mg kg⁻¹) and highest in P7 soil (AM= 0.38 mg kg⁻¹). The content of available zinc ranged from 0.03 to 1.25 mg kg⁻¹ having the lowest content in P3 soil (AM= 0.09 mg kg⁻¹) and the highest in P5 soil (AM= 0.42 mg kg⁻¹). The DTPA

extractable iron and manganese ranged from 0.40 to 8.11 mg kg⁻¹ and 0.13 to 19.42 mg kg⁻¹ in different soils, respectively. The available iron content was the lowest in P17 profile (AM= 0.58 mg kg⁻¹) and highest in P6 profile (AM= 7.29 mg kg⁻¹). The profiles P6 had the highest content of Mn (AM= 17.83 mg kg⁻¹) whereas profile P15 had lowest content (AM= 0.29 mg kg⁻¹). On geomorphic unit basis, the highest contents of copper, zinc, iron and manganese were found in piedmont plain soils (AM= 0.33, 0.29, 3.53 & 7.25 mg kg⁻¹, respectively) and lowest contents in hill terrace soils (AM= 0.18, 0.14, 0.74 & 0.54 mg kg⁻¹ respectively). Among the DTPA extractable micronutrients, except for copper, the deficiency of Zinc, iron and manganese were nearly 90 per cent.

The correlation coefficient data revealed significant positive correlation of clay fraction with nitrogen and potassium whereas sand fraction had significant negative correlation with these macronutrients. Except zinc, all the micronutrients (Cu, Fe and Mn) showed significant positive correlation with clay and silt fractions and significant negative correlation with the sand fraction. Invariably, the soil pH had negative correlation with all the nutrients but significant with N, P, Cu, Fe and Mn. Similarly the soil organic carbon positively correlated with all the nutrients but significant with N, P, K, Zn and Fe.

Land evaluation assesses the performance of land based on a more or less systematic analysis of the physical land conditions and on the impact these have on present and alternative land use systems. Land evaluation in its simplest form selects the best land for a specific or general purpose. Land may be evaluated directly, by trial e.g. through growing crops, collection and processing of crop-yield data, and to see what happens. The most land evaluation systems are indirect based on soil and site properties that influence the success of a particular land use.

The land capability classification (LCC) system was developed by the Soil Conservation Service, USDA in 1930 as part of programme to control soil erosion. The land capability classification (LCC) is a grouping of land into defined classes depending on their capability based on limitations. There are eight land capability classes belonging to two broad groups based on the cultivability of the land. The Group 1 comprises 'Land Classes I to IV' which are cultivable and 'Group 2 comprises 'Land Classes V to VIII' which are non-cultivable.

The lands were differentiated in to two groups based on permanent limitation of the landforms. The Maili watershed being in the semi-arid (sub moist) less hot climate zone therefore climate may be one of the limiting factors in the absence of irrigation. The other important factors considered for classification were topography, slope, stoniness, soil depth,

soil structure and soil texture/ water holding capacity. Because of being complex topography of the terrain posing permanent limitation of for cultivation of agricultural crops, the soils within hilly areas were mostly placed in classes V to VII. However the soils from hill terraces were placed in class IV being on relatively stabilized slopes. The soils of piedmont plains being on gentle slopes and having least limitations were classed in III of land capability classification. The watershed area, thus, has been classified into capability classes III, IV, V, VI and VII based on topographic conditions and other various associated limitations.

The soils of Maili watershed needs separate land use management and development because of being complex topography of the terrain. The immature to weakly developed Typic Ustorthents or Typic Ustipsamments and Udic Haplusteps or Typic Haplusteps in the hills poses major permanent limitations however the weakly developed Typic Haplusteps of piedmont plains could be used with advantage for cultivation because of least limitations associated with topography and soil characteristics.

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APPENDIX I

PROFILE 1

Location	31°28'07.6" N latitude and 76°07'37.1" E longitude
Physiographic unit	Hill tops
Elevation	451 M msl
Classification	Coarse loamy, Calcareous, Mixed, Hyperthermic, Typic Ustorthents

Horizon	Depth (cm)	Morphological description
A	0-26	Light yellowish brown (10YR 6/4, m), loam, presence of some pebbles, weak fine granular, friable, slight effervescence, pH 7.9, common fine roots, clear smooth boundary
C	26-50	Very pale brown (10YR 7/3, m), loam, presence of some pebbles, structureless massive, friable, slight effervescence, pH 8.4, few fine roots, clear smooth boundary
Cr1	50-85	Light gray (10YR 7/1, m), loam, structureless massive, friable, no effervescence, pH 8.8, clear smooth boundary
Cr2	85-110	Light gray (10YR 7/1), silt loam, structureless massive, friable, no effervescence, pH 8.8, gradual smooth boundary
Cr3	110-150	Light gray (10YR 7/2), silt loam, structureless massive, friable, no effervescence, pH 8.9

PROFILE 2

Location 31°27'48.4" N latitude and 76°07'26.6" E longitude

Physiographic unit Choe beds

Elevation 432 M msl

Classification Coarse loamy, Calcareous, Mixed, Hyperthermic, Typic Ustorthents

Horizon	Depth (cm)	Morphological description
A	0-22	Light brownish gray (10YR 6/2, m), loamy sand, weak fine granular, friable, slight effervescence, pH 8.0, common fine roots, clear smooth boundary
C1	22-43	Brown (10YR 5/3, m), loam, structureless massive, friable, slight effervescence, pH 7.7, few fine roots, gradual smooth boundary
C2	43-75	Yellowish brown (10YR 5/4, m), loam, fine pebbles, structureless massive, friable, slight effervescence, pH 7.6, few fine roots, gradual smooth boundary
C3	75-110	Pale brown (10YR 6/3, m), loam, fine to medium pebbles, structureless massive, friable, slight effervescence, pH 7.9, gradual smooth boundary
C4	110-140	Pale brown (10YR 6/3, m), sandy loam, enough pebbles and cobbles, structureless massive, friable, no effervescence, pH 7.9

PROFILE 3

Location	31°27'39.5" N latitude and 76°07'23.0" E longitude
Physiographic unit	Hill slopes
Elevation	427 M msl
Classification	Coarse loamy, Calcareous, Mixed, Hyperthermic, Typic Ustorthents

Horizon	Depth (cm)	Morphological description
A	0-17	Dark yellowish brown (10YR 4/4, m), sandy loam, some pebbles, weak fine granular, friable, slight effervescence, common fine roots, pH 7.5, clear smooth boundary
C1	17-41	Brown to dark brown (10YR 4/3, m), sandy loam, structureless massive, friable, slight effervescence, few fine roots, pH 7.8, gradual smooth boundary
C2	41-68	Yellowish brown (10YR 5/4, m), sandy loam, some pebbles, structureless massive, friable, slight effervescence, pH 8.0, gradual smooth boundary
Cr	68-120	Pale brown (10YR 6/3, m), loamy sand, presence of pebbles, structureless single grained, loose, slight effervescence, pH 8.1

PROFILE 4

Location	31°25'23.5" N latitude and 76°07'11.0" E longitude
Physiographic unit	Hill slopes
Elevation	427 M msl
Classification	Coarse loamy, Calcareous, Mixed, Hyperthermic, Typic Ustorthents

Horizon	Depth (cm)	Morphological description
A	0-20	Dark brown (10YR 3/3, m), loam, some pebbles, weak fine granular, friable, slight effervescence, pH 7.6, common fine roots, clear smooth boundary
AC	20-40	Brown to dark brown (10YR 4/3, m), loam, structureless massive, friable, slight effervescence, pH 7.8, few fine roots, clear smooth boundary
Cr1	40-65	Grayish brown (10YR 5/2, m), loamy sand, structureless single grained, loose, no effervescence, pH 8.0, few fine roots, gradual smooth boundary
Cr2	65-120	Gray (10YR 5/1, m), loamy sand, structureless single grained, loose, no effervescence, pH 8.0, gradual smooth boundary
Cr3	120-150	Light brownish gray (10YR 6/2, m), sandy loam, structureless massive, friable, no effervescence, pH 8.1

PROFILE 5

Location 31°25'52.6" N latitude and 76°05'32.1" E longitude

Physiographic unit Piedmont plains

Elevation 383 M msl

Classification Coarse loamy, Calcareous, Mixed, Hyperthermic, Typic Haplustepts

Horizon	Depth (cm)	Morphological description
Ap	0-18	Dark yellowish brown (10YR 3/4, m), sandy loam, weak fine granular, friable, no effervescence, many fine roots, pH 7.6, clear smooth boundary
Bw1	18-34	Dark yellowish brown (10YR 4/4, m), sandy loam, weak fine subangular blocky, friable, no effervescence, common fine roots, pH 7.4, gradual smooth boundary
Bw2	34-65	Yellowish brown (10YR 5/4, m), sandy loam, weak fine subangular blocky, friable, slight effervescence, few fine roots, pH 7.8, clear smooth boundary
BC	65-105	Yellowish brown (10YR 5/6, m), loamy sand, few pebbles, weak fine subangular blocky, friable, no effervescence, pH 8.0, clear smooth boundary
C	105-140	Yellowish brown (10YR 5/6, m), sandy loam, structureless massive, friable, slight effervescence, pH 7.9

PROFILE 6

Location	31°25'10.1" N latitude and 76°05'7.6" E longitude
Physiographic unit	Piedmont plains
Elevation	341 M msl
Classification	Coarse loamy, Mixed, Hyperthermic, Typic Haplustepts

Horizon	Depth (cm)	Morphological description
Ap	0-20	Dark yellowish brown (10YR 4/4, m), loam, weak fine granular, friable, no effervescence, common fine roots, pH 6.5, clear smooth boundary
Bw1	20-40	Dark yellowish brown (10YR 4/4, m), loam, weak fine subangular blocky, friable, no effervescence, common fine roots, pH 6.5, clear smooth boundary
Bw2	40-78	Dark yellowish brown (10YR 3/4, m), silt loam, weak fine subangular blocky, firm, no effervescence, pH 6.6, clear smooth boundary
BC	78-120	Dark yellowish brown (10YR 3/6, m), loam, weak fine subangular blocky, friable, no effervescence, pH 6.5

PROFILE 7

Location	31°26'48.5" N latitude and 76°04'21.3" E longitude
Physiographic unit	Piedmont plains
Elevation	344 M msl
Classification	Fine loamy, Mixed, Hyperthermic, Typic Haplustepts

Horizon	Depth (cm)	Morphological description
Ap	0-20	Dark yellowish brown (10YR 3/6, m), silt loam, weak fine granular, friable, no effervescence, pH 8.1, common fine roots, clear smooth boundary
Bw1	20-48	Dark yellowish brown (10YR 4/6, m), silt loam, weak fine subangular blocky, firm, no effervescence, pH 8.1, few fine roots, gradual smooth boundary
Bw2	48-80	Yellowish brown (10YR 5/6, m), silt loam, weak fine subangular blocky, firm, no effervescence, pH 8.2, few fine roots, gradual smooth boundary
Bw3	80-120	Dark yellowish brown (10YR 4/4, m), silt loam, weak fine subangular blocky, firm, no effervescence, pH 8.0, few fine roots, clear smooth boundary
BC	120-150	Yellowish brown (10YR 5/6, m), loam, weak fine subangular blocky, friable, no effervescence, pH 8.0

PROFILE 8

Location	31°26'48.4" N latitude and 76°04'59.8" E longitude
Physiographic unit	Choe beds
Elevation	364 M msl
Classification	Coarse loamy, Calcareous, Mixed, Hyperthermic, Typic Ustorthents

Horizon	Depth (cm)	Morphological description
A	0-22	Dark yellowish brown (10YR 3/6, m), sandy clay loam, appreciable pebbles, weak fine sub granular, friable, strong effervescence, pH 7.5, common fine roots, clear smooth boundary
C1	22-40	Brown to dark brown (10YR 4/3, m), sandy loam, structureless massive, friable, strong effervescence, pH 7.7, few fine roots, gradual smooth boundary
C2	40-65	Dark yellowish brown (10YR 4/4, m), sandy loam, appreciable pebbles, structureless massive, friable, strong effervescence, pH 7.8, gradual smooth boundary
C3	65-110	Yellowish brown (10YR 5/4, m), sandy loam, appreciable pebbles structureless massive, friable, strong effervescence, pH 7.7

PROFILE 9

Location	31°26'57.7" N latitude and 76°05'6.7" E longitude
Physiographic unit	Hill slopes
Elevation	383 M msl
Classification	Fine loamy, Mixed, Hyperthermic, Udic Haplustepts

Horizon	Depth (cm)	Morphological description
A	0-21	Dark yellowish brown (10YR 3/6, m), clay loam, some amounts of pebbles, weak fine granular, firm, no effervescence, pH 8.1, many fine roots, clear smooth boundary
Bw1	21-47	Dark yellowish brown (10YR 4/6, m), clay loam, weak fine subangular blocky, firm, no effervescence, pH 7.8, common fine roots, gradual smooth boundary
Bw2	47-82	Dark yellowish brown (10YR 4/4, m), clay loam, weak fine subangular blocky, firm, no effervescence, pH 7.9, few fine roots, clear smooth boundary
BC	82-115	Yellowish brown (10YR 5/4, m), silt loam, weak fine subangular blocky, firm, no effervescence, pH 8.6, clear smooth boundary
C	115-150	Yellowish brown (10YR 5/6, m), loam, structureless massive, friable, no effervescence, pH 7.9

PROFILE 10

Location	31°25'42.2" N latitude and 76°05'22.1" E longitude
Physiographic unit	Choe beds
Elevation	343 M msl
Classification	Mixed, Hyperthermic, Typic Ustipsamments

Horizon	Depth (cm)	Morphological description
A	0-20	Dark yellowish brown (10YR 3/4, m), loamy sand, weak fine granular, friable, no effervescence, pH 8.6, common fine roots, clear smooth boundary
C1	20-38	Grayish brown (10YR 5/2, m), sand, structureless single grained, loose, no effervescence, pH 8.2, few fine roots, clear smooth boundary
C2	38-62	Yellowish brown (10YR 5/4, m), sandy loam, structureless massive, friable, no effervescence, pH 8.2, few fine roots, clear smooth boundary
C3	62-90	Light brownish gray (10YR 6/2, m), sand, few pebbles, structureless single grained, loose, slight effervescence, pH 8.9, gradual smooth boundary
C4	90-140	Dark grayish brown (10YR 4/2, m), sand, structureless single grained, loose, no effervescence, pH 9.1

PROFILE 11

Location 31°25'43.2" N latitude and 76°06'21.4" E longitude

Physiographic unit Hill tops

Elevation 377 M msl

Classification Coarse loamy, Calcareous, Mixed, Hyperthermic, Typic Ustorthents

Horizon	Depth (cm)	Morphological description
A	0-15	Dark yellowish brown (10YR 3/4, m), loam sand, weak fine granular, friable, no effervescence, pH 8.8, common fine roots, clear smooth boundary
C1	15-35	Yellowish brown (10YR 5/4, m), sandy loam, appreciable amount of pebbles, structureless massive, strong effervescence, pH 8.6, few fine roots, gradual smooth boundary
C2	35-60	Yellowish brown (10YR 5/4, m), sandy loam, appreciable amount of pebbles, structureless massive, strong effervescence, pH 8.8, clear smooth boundary
C3	60-85	Light yellowish brown (10YR 6/4, m), loam sand, appreciable amount of pebbles/ cobbles, structureless single grained, loose, strong effervescence, pH 9.4, gradual smooth boundary
Cr	85+	Light brownish gray (10YR 6/2, m), loam sandy, structureless single grained, loose, strong effervescence, pH 8.7

PROFILE 12

Location 31°25'34.4" N latitude and 76°06'43.9" E longitude

Physiographic unit Hill terraces

Elevation 384 M msl

Classification Coarse loamy, Calcareous, Mixed, Hyperthermic, Typic Haplustepts

Horizon	Depth (cm)	Morphological description
Ap	0-20	Dark yellowish brown (10YR 4/4, m), sandy loam, weak fine granular, friable, slight effervescence, pH 9.2, many fine roots, clear smooth boundary
Bw1	20-35	Yellowish brown (10YR 5/4, m), sandy loam, weak fine subangular blocky, friable, slight effervescence, pH 9.0, common fine roots, gradual smooth boundary
Bw2	35-55	Brown (10YR 5/3, m), sandy loam, weak fine subangular blocky, friable, strong effervescence, pH 8.4, few fine roots, gradual smooth boundary
Bw3	55-70	Light brownish gray (10YR 6/2, m), sandy loam, some pebbles, weak fine subangular blocky, friable, strong effervescence, pH 8.1, gradual smooth boundary
C	70-110	Light brownish gray (10YR 6/2, m), sandy loam, some pebbles structureless massive, friable, strong effervescence, pH 8.1

PROFILE 13

Location	31°25'27.0" N latitude and 76°05'56.8" E longitude
Physiographic unit	Hill tops
Elevation	389 M msl
Classification	Coarse loamy, Calcareous, Mixed, Hyperthermic, Typic Haplustepts

Horizon	Depth (cm)	Morphological description
A	0-18	Dark yellowish brown (10YR 4/6, m), sandy loam, weak fine granular, friable, no effervescence, pH 7.8, many fine roots, clear smooth boundary
Bw1	18-40	Strong brown (7.5YR 5/8, m), sandy loam, weak fine sub angular blocky, friable, slight effervescence, pH 7.8, common fine roots, gradual smooth boundary
Bw2	40-80	Strong brown (7.5YR 5/8, m), sandy loam, weak fine sub angular blocky, friable, slight effervescence, pH 8.2, few fine roots, clear smooth boundary
C	80-110	Reddish yellow (7.5YR 6/6, m), sandy loam, structureless massive, friable, slight effervescence, pH 8.7, clear smooth boundary
Cr	110-130	Strong brown (7.5YR 5/6, m), loamy sand, structureless single grained, loose, slight effervescence, pH 8.7

PROFILE 14

Location	31°25'40.6" N latitude and 76°08'3.7" E longitude
Physiographic unit	Hill tops
Elevation	453 M msl
Classification	Coarse loamy, Mixed, Hyperthermic, Udic Haplustepts

Horizon	Depth (cm)	Morphological description
A	0-12	Yellowish brown (10YR 5/8, m), sandy loam, some pebbles, weak fine granular, friable, no effervescence, pH 7.3, common fine roots, clear smooth boundary
Bw1	12-36	Yellowish brown (10YR 5/8, m), sandy loam, weak fine subangular blocky, friable, no effervescence, pH 8.1, common fine roots, gradual smooth boundary
Bw2	36-70	Yellowish brown (10YR 5/6, m), sandy loam, weak fine subangular blocky, friable, no effervescence, pH 7.7, few fine roots, clear smooth boundary
Cr	70-125	Yellowish brown (10YR 5/4, m), loamy sand, structureless single grained, loose, no effervescence, pH 7.9

PROFILE 15

Location	31°25'0.6" N latitude and 76°08'9.9" E longitude
Physiographic unit	Hill tops
Elevation	443 M msl
Classification	Coarse loamy, Mixed, Hyperthermic, Udic Haplustepts

Horizon	Depth (cm)	Morphological description
A	0-15	Yellowish brown (10YR 5/6, m), loam, weak fine granular, friable, no effervescence, pH 7.9, many fine roots, clear smooth boundary
Bw1	15-38	Dark yellowish brown (10YR 4/6, m), sandy loam, appreciable amounts of pebbles, weak fine subangular blocky, friable, no effervescence, pH 8.4, common fine roots, gradual smooth boundary
Bw2	38-65	Yellowish brown (10YR 5/6, m), sandy loam, appreciable amounts of pebbles, weak fine subangular blocky, friable, no effervescence, pH 7.8, few fine roots, clear smooth boundary
Cr	65-125	Yellowish brown (10YR 5/4, m), loamy sand, structureless single grained, loose, no effervescence, pH 8.1

PROFILE 16

Location 31°25'6.4" N latitude and 76°08'7.4" E longitude

Physiographic unit Hill slopes

Elevation 429 M msl

Classification Coarse loamy, Mixed, Hyperthermic, Typic Ustorthents

Horizon	Depth (cm)	Morphological description
A	0-16	Dark yellowish brown (10YR 4/4, m), sandy loam, some pebbles, weak fine granular, friable, no effervescence, pH 8.6, common fine roots, clear smooth boundary
AC	16-40	Dark yellowish brown (10YR 4/6, m), sandy loam, appreciable pebbles, structureless massive, friable, no effervescence, pH 8.4, few fine roots, gradual smooth boundary
C1	40-73	Yellowish brown (10YR 5/8, m), sandy loam, appreciable pebbles, structureless massive, friable, no effervescence, pH 8.7, clear smooth boundary
C2	73-120	Yellowish brown (10YR 5/8, m), loamy sand, structureless single grained, loose, no effervescence, pH 8.8

PROFILE 17

Location	31°25'35.7" N latitude and 76°07'38.05" E longitude
Physiographic unit	Hill terraces
Elevation	389 M msl
Classification	Coarse loamy, Calcareous, Mixed, Hyperthermic, Typic Haplustepts

Horizon	Depth (cm)	Morphological description
Ap	0-18	Brown (10YR 5/3, m), sandy loam, some pebbles, weak fine granular, friable, no effervescence, pH 8.3, many fine roots, clear smooth boundary
Bw1	18-31	Light yellowish brown (10YR 6/4, m), sandy loam, weak fine subangular blocky, friable, no effervescence, pH 8.3, common fine roots, gradual smooth boundary
Bw2	31-56	Pale brown (10YR 6/3, m), sandy loam, weak fine subangular blocky, friable, slight effervescence, pH 8.4, few fine roots, gradual smooth boundary
Bw3	56-83	Yellowish brown (10YR 5/4, m), sandy loam, weak fine subangular blocky, friable, slight effervescence, pH 8.4, very few fine roots, gradual smooth boundary
C	83-119	Pale brown (10YR 6/3, m), sandy loam, some pebbles, structureless massive, friable, slight effervescence, pH 8.5

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