Chapter 3
Thematic Mapping for Watershed Development

Abstract This chapter exclusive thematic maps are prepared for a semi-arid zone in the districts of Akola and Buldhana, while remote sensing and GIS technologies are used in earth surface mapping and watershed growth planning. In the study of land use and cover, soil density, soil erosion, and soil drainage maps, both satellite images and field data are used. Water precipitation is evaluated in the groundwater priority area in order to prepare a sustainable water supply in the watershed.

Keywords Thematic maps · Watershed · Remote sensing and GIS

3.1 Introduction

Thematic mapping relates to a specific subject matter. A thematic map shows a particular subject of interest, such as environmental and human characteristics like population density and health concerns, in contrast to an ordinary map, which reflects a range of geological and geographical events. It also shows spatial variants and minimal geographical diversity. Object maps are used for three specific purposes. First, to provide comprehensive information on various locations. Second, to present conventional data on spatial models. Third, to identify patterns on two or more maps. On thematic maps, features such as streams or roads are represented differently. They are reference points to enhance understanding of the desired characteristics of the sector (Khadri and Chaitanya 2015a, b, c).

Remote sensing and GIS are the most efficient methods for measuring more than a few earth sources. A large number of asset maps can be created by a completely remote satellite sensing method and a composite map with diverse information can also be analyzed with the aid of GIS software. Appropriate management policies and planning must be developed and implemented in line with field requirements (Patel and Dhiraj 2019).

In this chapter, an action plan for an effective water and soil conservation site is prepared that incorporates several thematic layer systems, including soil erosion, soil depth, land efficiency, slope, land use, and land drainage. The land resource action plan has been created using zoning maps and weighting for the different thematic

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layers. Forestry conservation and protection systems in the action plan include communal plantations with continuous trenches, forest protection and management, reforestation, canal management, agricultural dryland with ponds, horticulture planting, intensive agriculture, irrigation, and pasturing.

A water resource development action plan for the conservation of water and soil in the watershed uses different thematic layers, such as slope, land use and property, irrigation, soil textures, ground depth, soil erosion, soil and land capacities, and weightage. The use of a zoning system is proposed as a tool for sustainable management of watersheds for water conservation and to reduce soil erosion (Patode et al. 2017a,b). Suggested water conservation structures include control dam, percolation tank, earthen nala bund, form pond, graded bund, sunken pond, roof water harvesting, and loose bouldering.

3.2 Methodology

Environmental zoning is a natural system of sustainable watershed management designed to reduce soil erosion and environmental degradation of water and soil. A watershed is a region (or area) with a well-defined water outlet and topographical boundary. It is a natural area from which water concentrated in a certain location, such as a river or reservoir, is drained. The water bottom includes a complex of soils, landforms, vegetation, and land use within a topographical boundary or water divide. The terms water bath, tank, and tub are also used analogously.

Watersheds have long been known as ideal units for development planning and implementation. Their management requires the simultaneous consideration of hydrological, pedological, and biological resources, as well as the cumulative impacts of human activities and the ecological, economic, and esthetic integrity of the many strategies and drainage systems used to mitigate them. Watershed evaluation requires a methodology that can address challenging issues, but that is easily implemented, versatile yet consistent, can be implemented on various spatial levels, and can be converted into easily articulated management explanations and decisions. For resource planning, watershed strategies require timely and reliable spatial and statistical data and it is important that analytical methods and strategies that tackle spatial and temporal variation be properly utilized.

The use of satellite remote sensing has been significantly beneficial for water management with regard to both conservation and control. Remote sensory data also allow mapping of surface water resources and systems, enabling various hydrological processes and thus water equilibrium to be researched with a reasonable degree of accuracy. In this context, ARC GIS is extremely promising for handling spatial and temporal information, and can serve as an integrative management planning tool. GIS can construct and store spatial mapping and is capable of performing multiple scenario analyses/evaluations such as simulations of physical, chemical, and biological processes supporting watershed applications. Remote space-borne multispectral sensors (e.g. LISS in IRS, and others) supply spatial and temporal data at

24-day intervals at different defined and spatial resolutions (23.5 m for MSS data, and 5.8 m for panchromatic data). This helps understand the shifts in the dynamics linked to land and water supplies. Gross is an open-source GRASS-based system (geographic resources analysis support system) which works on a Linux platform. Gross can perform spatial raster and vector analyses as well as helping to interpret and model decisions. A user-friendly user Gross interface with all the GIS and image-processing capabilities has been developed that helps decision makers and planners collect, store, process, and display spatial and temporal information, imagine spatial and temporal decisions, and coordinate and prioritize them. Gross was used to classify possible sites for growth by contrasting the real watershed management websites with digital elevation models (DEMs). DEMs reflect the continuous variation in relief across the region and have widespread application in hydrological modeling, contributing to determining steep slope, slope length, the direction of flow, watershed boundaries, and outlets.

In Anantapur district, Andhra Pradesh, integral remote sensing technology provides micro-level preparation at the village level for long-term, remote sensing techniques to tackle drought. Various drought management measures related to plant water collection systems, fodder, timber, and permanent tree cover growth were recommended, as well as soil restoration and moisture conservation measures. In hot, arid regions in Karnataka the population has been swelling, but comprehensive planning approaches have been absent. A study of urbanization in river wetlands in Bangalore city shows that a range of dams, parks, playgrounds, coach stands and solid waste dumping grounds in and around the city have been converted to residential and commercial use. The study found that urbanization of 60% of the water area has more than doubled in thirteen years at the expense of farmland/open/scrub.

Various technologies have been used to construct databases designed for developing sustainable watershed management in the semi-arid zone. In the ARC Map 10.1 system, a drainage chart is produced from satellite data with SOI Toposheet. ERDAS Imagine software creates land-use/land maps with supervised classification techniques. ARC Map 10.1 software uses the available reference facts (Fig. 3.1 and Table 3.1) to create other thematic layers such as ground, geomorphology, and slopes.

3.2.1 Land-Use and Land-Cover Mapping

Land use and land cover are critical aspects of the value of the world's land, both currently and historically, and of how its use can be safely changed. Land cover is a fundamental parameter that assesses the surface material of the earth as a significant component affecting the ecosystem's situation and function. The study of land cover helps understand the interplay between biodiversity and ecosystems. Evaluation currently plays a significant role in the field of ecological science and assists land-use management. Remote sensing information has been shown to be very useful in mapping changing land-use trends for environmental protection purposes. These

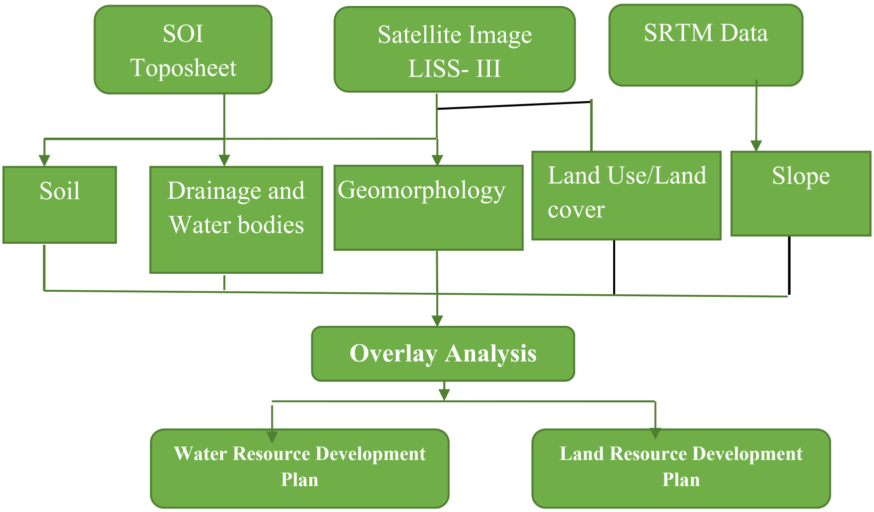

Fig. 3.1 Methodology flow chart

Table 3.1 GIS data collection and sources

S. N.	Satellite data product	Data sources
1	Satellite Data National Remote Sensing, LISS-III of IRS IC and IRS—P6 (Raw data) LISS IV Agency Government of India	Bhuvan Portal freely available satellite data in National Remote Sensing IRS ID-PAN, LISS-III of IRS1D Agency Government of India site
2	1:50,000 Toposheet, district resources map, geological formation map	Government of India, Survey of India at 1:25,000 scale
3	Maps showing existing information on the semi-arid area Akola and Buldhana district study area	M.H. State Remote Sensing Applications Centre M.H. GSDA Amravati Divisions M.H. Survey of India, Nagpur M.H. Irrigation Department, Nagpur GSDA, Amravati
4	Field data	Intensive fieldwork

changes can be identified using GIS methods even if exceptional scales/resolution are present in the resulting spatial datasets (Sarma et al. 2001).

Land is the most important natural resource in the entire ecosystem. Land use is the use of land resources by humans and associated fauna. Land cover consists of natural plants, bodies of water, rock/stone, and synthetic coverings. Changes in land cover are often the most significant environmental impacts of intense human activity. Land-use and land-cover mapping is important in the watershed landscape. Changes in land usage are not necessarily the only differences in land-use and land-cover charts, which also include in-depth and management adjustments (Pande et al.

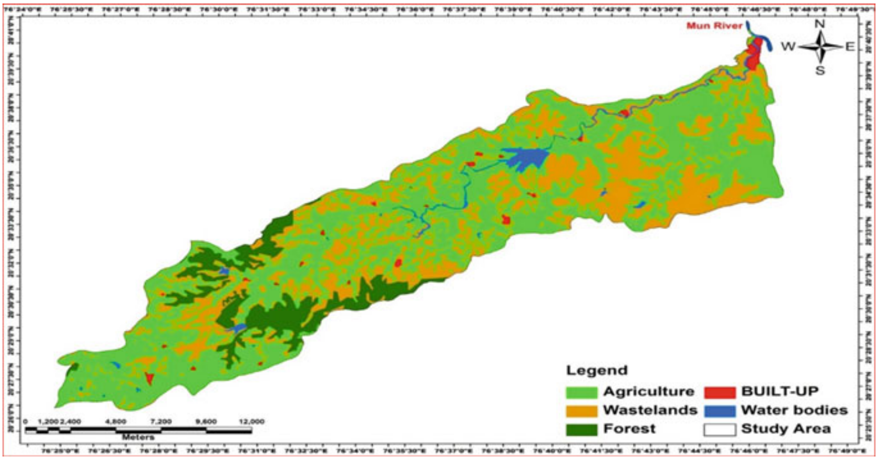

Fig. 3.2 Land-use map (Level 1)

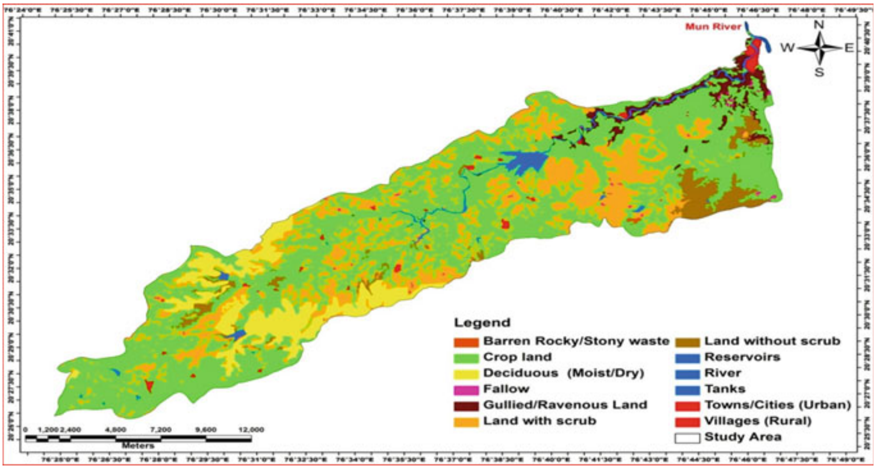

Fig. 3.3 Land-use map (Level 2)

2018; Reddy et al. 2017). They also reveal the biophysical state of the Earth and its immediate surface, including soil material, plants, and water in the watershed.

Changes to land use/cover also include modifications in the ordinary climate, either direct or indirect, which have an impact on the local ecosystem. Land utilization/alternative reporting has become a central element of contemporary strategies for natural resource management and environmental change monitoring. A land use/cover sample of a region provides data on natural and socioeconomic factors, and human subsistence and growth. Like other resources, land resources are limited by

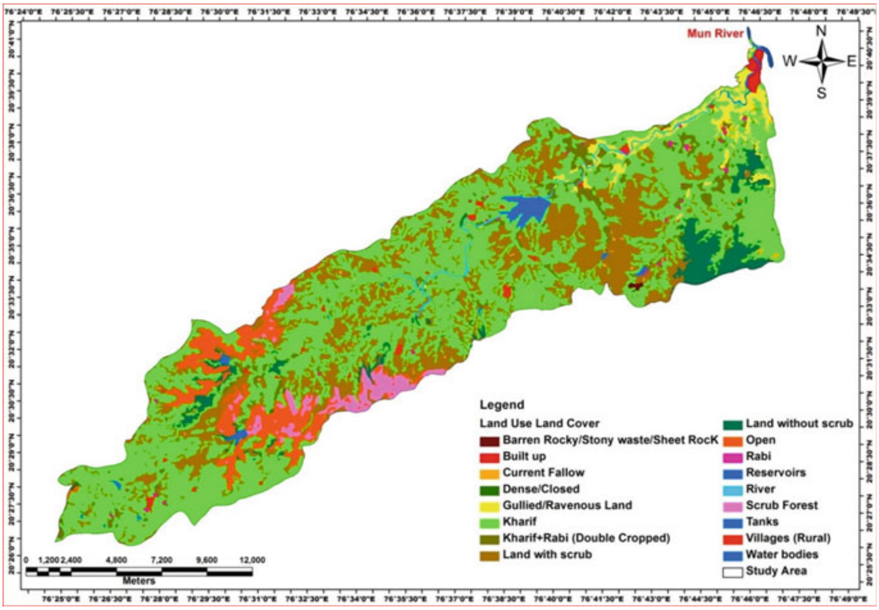

Fig. 3.4 Land-use map (Level 3)

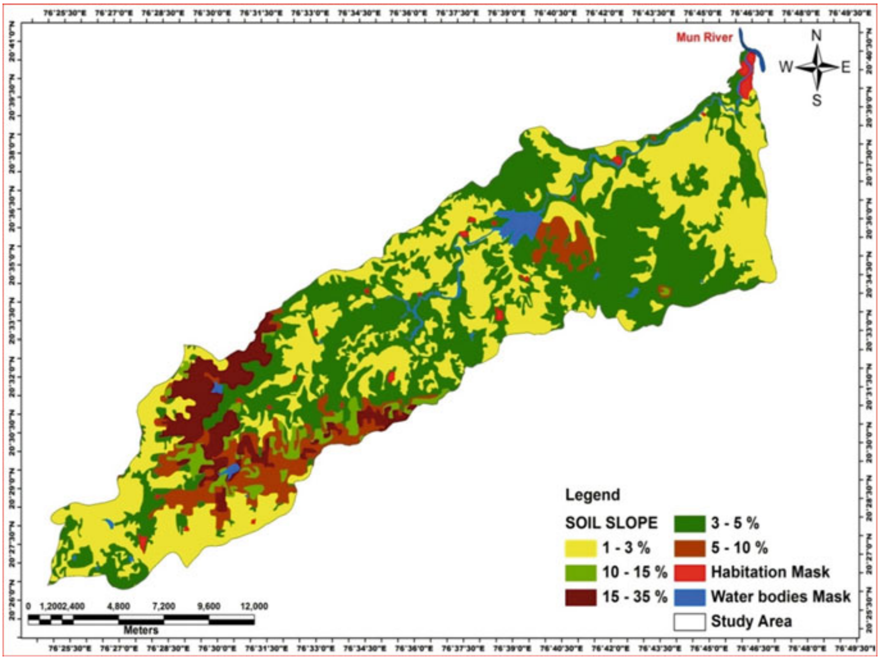

Fig. 3.5 Soil slope map

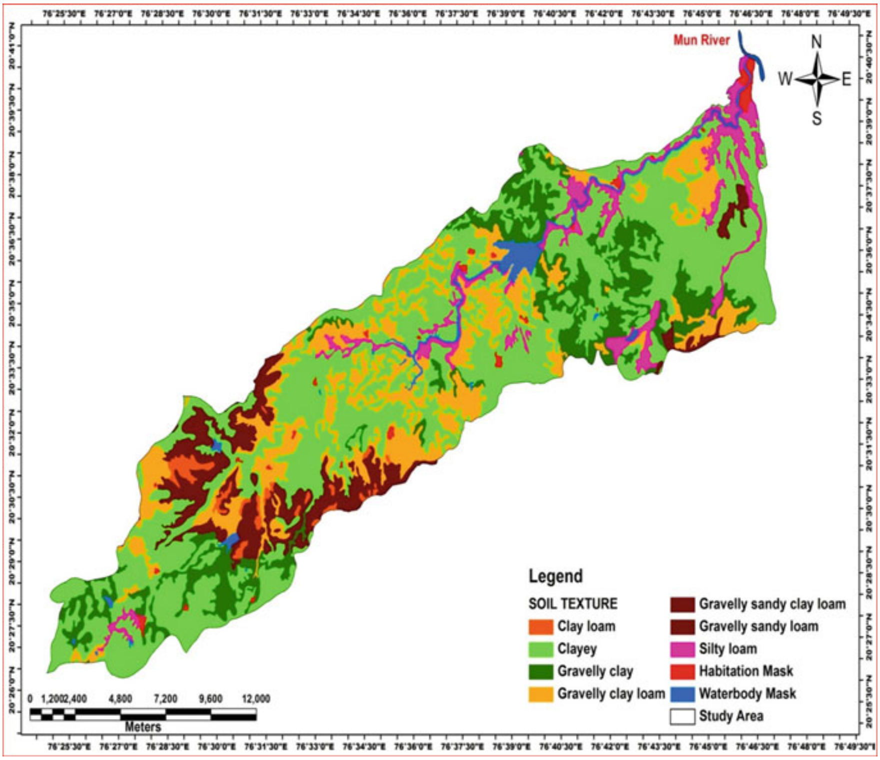

Fig. 3.6 Soil textures map

the high demand for agricultural products and the rising day-to-day stress of population. Land-use statistics and the possibilities of optimal use are therefore crucial to selecting and enforcing policy, and for planning to meet increased human needs and welfare (Moharir and Pande 2014a, b).

The study of full data on the spatial distribution of land-use groups is a prerequisite for the management and usage of semi-arid land sources. Any terrain's land-use pattern reflects the diverse physical solutions occurring on the earth's surface that influence the distribution of soils, vegetation and water prevalence in the atmosphere. In addition to environmental conditions, it is important to have timely and accurate geomorphological, geological and topographical records to develop and maintain watershed areas (Khadri et al. 2013; Kokate et al. 2014).

Satellite data has been used to establish land-use mapping in the study area (Pande and Moharir 2014; Pande and Kanak 2014). Most land is under cultivation, together with a preserved forest located in the eastern portion of the basin, and the wasteland in its south-western part. Land use and land cover captured by the satellite image are visually represented and translated into vector formats for polygon maps. Mapping groups may vary from sheet to sheet depending on the ground conditions. Analysis includes reference to relevant details, enabling compatibility with existing maps

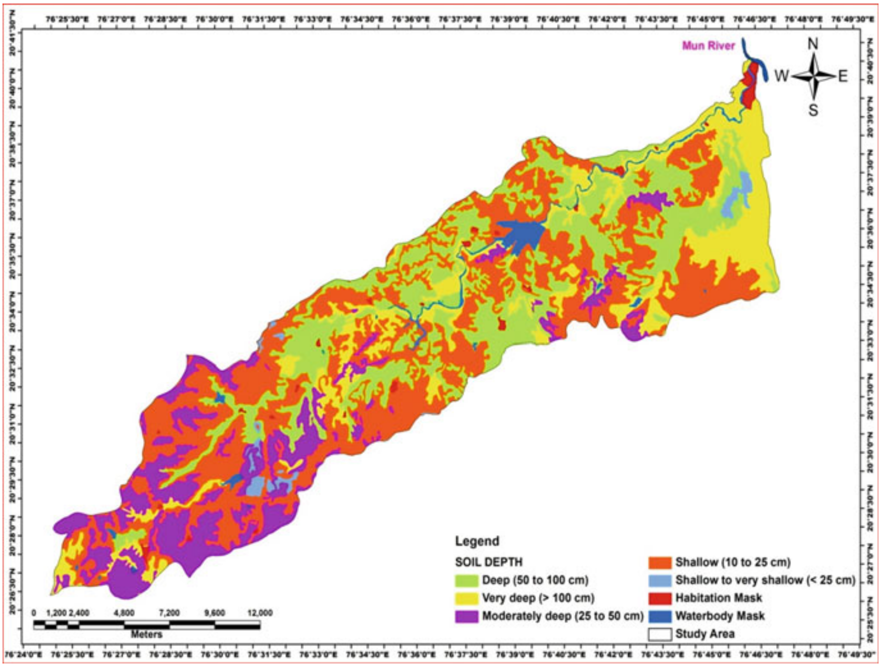

Fig. 3.7 Soil depth map

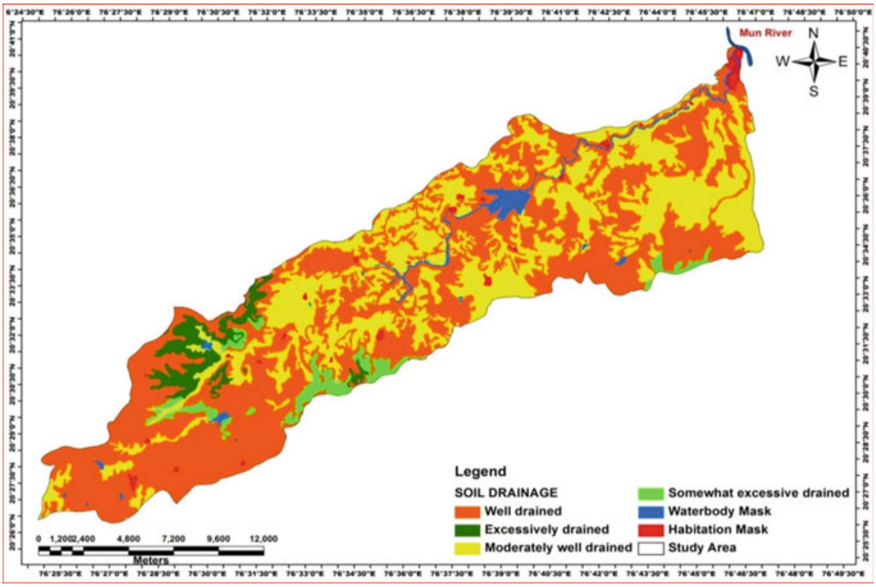

Fig. 3.8 Soil drainage map

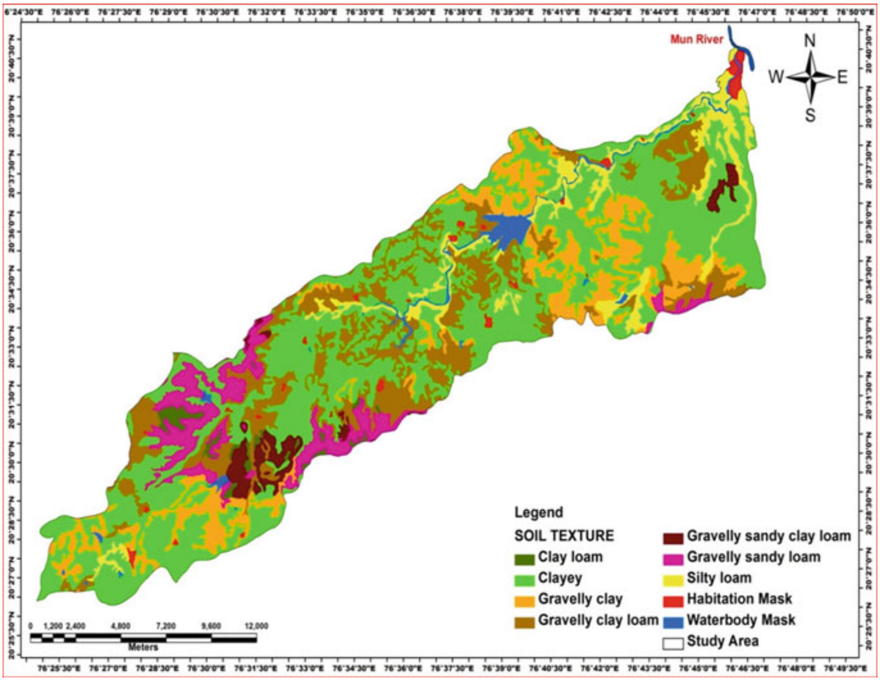

Fig. 3.9 Soil map

and knowledge of points on the Survey of India (SOI) maps, for example forest boundaries.

Three land-use and land-cover maps based on distance-sensing data are described in this analysis. The field details and classifications used are shown in Table 3.2. The level 2 and 3 maps cover kharif and rabi. All surface bodies of water (reservoirs, lakes, and tanks) are represented on an SOI toposheet survey and new constructions are identified by the current satellite data which depicts water depth. Field visits have enabled collection and interpretation of data on the ground, as well as estimates of classification accuracy. Interpretation continues until it meets the data accuracy requirements. To remove digitization errors (Pande et al. 2018b), the ARC GIS 10.1 version shapefile has been developed and updated to polyconic projection and metered co-ordinate units. The transformation was geo-referenced based on the input type file and corresponding toposheets using ground control points (GCPs) (Plate 3.3).

The use of groundwater in most watersheds is constrained by the pace of natural regeneration. Many environmental issues will emerge from unmanaged use. Soil particles are dislodged and transported by winter, water, and soil erosion, affected by factors that include climate, topography, soil use and characteristics, and vegetative cover. In many areas natural floodwater is used to counteract soil erosion and sedimentation. Wind erosion is a significant cause for concern in arid and coastal areas

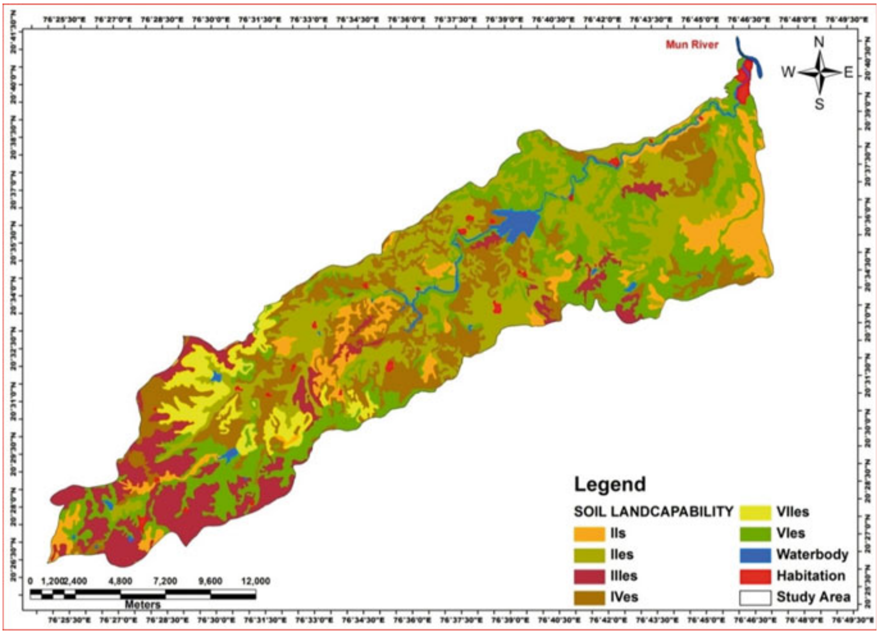

Fig. 3.10 Soil capability map

Plate 3.1 Cement nala bund at Atali village

Plate 3.2 Loose boulder structure at Undri village

Table 3.2 Classification scheme for land-use and land-cover mapping

S. N.	Level 1	Level 2	Level 3
1	Built-up	Built-up (urban) Built-up (rural)	Core urban, peri-urban Village, mixed settlement
		Mining/industrial	Hamlets and dispersed households, mining/industrial
2	Agricultural land	Transportation, cropland, agriculture plantation	Transportation, cropland, agriculture plantation
3	Forest	Forest, forest plantation	Forest, Forest plantation
4	Wasteland	Waterlogged, scrub land	Waterlogged, dense scrubland
			Open scrubland
		Sandy areas, barren rocky	Sandy areas, barren rocky
5	Water bodies	River, stream, drain	River, stream, drain
		Canal, lake, pond	Canal, lake, pond
		Reservoir, tank	Reservoir, tank

Plate 3.3 Farm Pond at Lokhanda village in Buldhana District

worldwide (especially in the tropics). Annual erosion through forestry operations and road building amounts to xxxxxx and xxxx, respectively.

Soil loss is a topographical factor for rainfall erosivity in a particular area. It is calculated using a combination of the angle and length of the slope, and is expressed in tons. l is compared with a 72.6 ft long slope, while c is compared with a slope of 9%) The crop management factor is expressed as a ratio of soil loss in the area of interest to soil loss from continuously tilled fallow under erosion control (a ratio of soil loss using erosion control practices to soil loss with farming up and down the slope). Rill and soil erosion measurements for agricultural watersheds in upland areas taken upstream of rivers or reservoirs do not include erosion from the banks of waterways and eroded sediments accumulated at the base of the slope and at other reduced flow sites. Distance formation in points and lines helps test the efficiency of hard rock wells obtain demand filters into a route chart or flow direction chart). Digitized contour interpolation and groundwater surface filtering are used to construct 2D flow network from remotely sensed data (Pande et al. 2019b).

Simple GIS models are used to measure peak runoff for environmental impact assessments. The adequacy of the drainage systems proposed by highway developers must be measured for a large number of catchments.

3.3 Precipitation and Interception

The amount, timing, and spatial distribution of water added to a watershed from atmospheric precipitation are largely beyond human control. The type, extent, and condition of vegetative land cover influence the deposition of water and the amount reaching the soil surface through interception. Dense coniferous forests and multi-storied tropical forest canopies intercept and store significant quantities of precipitation and a substantial quantity (around 30%) is returned to the atmosphere as evaporation. Moisture evaporation from soil, plant surfaces, and water bodies together with water transpired through plant leaves is called evapotranspiration. Larger-canopied plants transpire larger amounts than bare soil or smaller plants. Rainfall infiltration entering the soil through the surface, filling depressions in the soil or through rivers and streams makes up as much as 80% of the tropical watershed each year. The physical condition of the soil (porosity and hydraulic conductivity) affect the moisture content. Vegetation encourages higher infiltration than bare soils. Canopy cover reduces rainfall impact. The time and quantity of stream flow generated in a watershed is determined by characteristics such as, shape, size, channel and slope of the watershed, topography, and drainage density. The presence of wetlands and reservoirs affects infiltration and runoff. Water yield from a catchment usually increases, particularly when forests are cleared or thinned, and also when vegetation changes from deep-rooted species with high interception capacities to shallow-rooted plant species with low interception capacities.

Groundwater is the water that is accumulated beneath the soil surface. In saturated zones groundwater is very important to maintain wetness of the watershed but it is seldom found where it is most needed. Groundwater is often used as a source of fresh water and is important to sustain or revive vegetation. Groundwater that seeps into streams provides their base flow. However, in addition to the effects of fecal pollution by animals and humans, contamination with nitrates or chlorides has been reported in groundwater management studies, where pools have been dug to demonstrate the effects of nutrient contamination from agriculture.

3.4 Agriculture

Cultivation in the basin is widespread but the greatest value is concentrated in the lowlands where there are suitable water sources and other edaphic conditions. The key crops in this group are kharif, rabi, two crops, more than two cultivars, and Zaid crops. Crops were found on moderately sloping sites in the plateau areas or flat uplands (Fig. 3.2 and Table 3.3).

Table 3.3 Land-use/land-cover mapping area

Land-use classes	Area (km^2)	Percentage
Agriculture	181.90	55.41
Wasteland	109.24	33.26
Forest	30.53	9.30
Built-up land	3.0	0.91
Water bodies	6.68	1.30
Total area	328.25	100

3.4.1 Agricultural Land (Kharif Season)

The main kharif crops corresponding with the district's monsoon season (June to September) are soya, cotton, nachni, sunflower, safflower, *tur*, mung and *udid* (Fig. 3.2). The October 2014 satellite data shows an area of 166.02 km^2 under cultivation with this group.

3.4.2 Agricultural Land (Rabi Season)

Areas with reliable irrigation (surface and groundwater) are in this category, which covers an area of 1.05 km^2. The main rabi crops are wheat, gram, rabi, jowar, oilseed, and turmeric (Fig. 3.3).

3.4.3 Agricultural Land (Double Crop)

The area for the cultivation of double crops is very small, and measures approximately 13.72 km^2 (Fig. 3.4).

3.4.4 Agricultural Land (Currently Fallow)

Satellite data and field surveys find some fallow farmland, in particular in the dry mountains and plateau areas in both kharif and rabi seasons. The absence of cultivation is largely due to lack of irrigation or insufficient soil moisture. A total area of 1.09 km^2 is included as fallow in the current research (Fig. 3.4).

3.4.5 Agricultural Land (Plantations, Horticulture)

Citrus and other orchard production has a total surface area of 51.68 km^2 (Fig. 3.4).

3.4.6 Forest

Hills, upland valleys and sheltered spurs are identified in the satellite images as forest land. In Akola and Buldhana districts, only arid feeding forests are visualized due to the destructive soil conditions, hard rocky terrain, and climate factors (Fig. 3.2).

3.5 Soil Mapping

The surface layer of the earth is the product of the continuous interaction of parent matter, the surrounding atmosphere, plant and animal species, and soil elevation. It is a vital part of our ecosystem, acting as a plant anchorage and a nutrient supply. Soil is, therefore, the critical raw material for the production and planning of relevant watersheds. The study area has three types of soil. The black cotton soil lies primarily in the basin's rivers and along the riverbanks. The disintegrated volcanic basaltic lava is usually rich in clay and impregnable. It is heavy and has poor permeability. It is very dense in the lowlands and thin in the highlands. The red soil formed by the region's abundant iron compounds surrounds the black soil. In general, red soil is less fertile but is suitable for rice, millet, and fruit. In high altitudes, laterite soils are mainly found with precipitation along the ridgeline. Laterite soil is a key feature of the pebble crust.

3.5.1 Satellite and Ancillary Data

Satellite information obtained in the summer season when there is minimum crop or vegetation cover is ideal for identifying soil patterns in a semi-arid area. However, information obtained in the monsoon season combined with summer records provides better soil information under certain terrain conditions.

Additional data needed for the soil map are topographical maps, small-scale soil maps, geological maps, and climate statistics (rainfall, temperature, etc.). Ground data collection is required for the preparation of basic topographical maps (Pande et al. 2018a).

Table 3.4 Slope classes

Slope class	Slope (%)
Level to nearly level	0–1
Very gently sloping	1–3
Gently sloping	3–8
Moderately sloping	8–15
Moderately steeply sloping	15–30
Steeply sloping	30–50
Very steeply sloping	>50

3.5.2 Watershed Soil Characteristics

Soils from the soil map were used to digitize the details of the area in the semi-arid region being studied for sustainable watershed development planning. In general, satellite data identifies seven kinds of soil: asphalt, clay, stone, gravel, sand, sandy clay, and gravely clay.

The erosion of the topsoil diminishes soil fertility and causes crops to fail. As soil spectral reflectance with excessive repeatability can be quickly and easily collected, many samples can be studied to establish hydrological trends within the region. The spectrally defined indicators were adjusted to represent the pixels obtained from satellite data to spatially extrapolate the soil-physical situation in the watershed. Once established, a conditional addiction model was used to eliminate errors caused by connections between factors in the calibration model. A soil fitness index with reflective values from band 3, band 5, and band 7 was used (mean level 5%).

3.5.3 Soil Slope

Slope is an important aspect of land use. The total water runoff and soil erosion due to water flow have a marked influence on the field path. The pitch is normally expressed as a percentage. A 10% slope has a vertical fall of 10 m/100 m horizontal distance. On a 1–2% slope, soil management is increasingly required to avoid erosion problems. Slope classes are shown in Table 3.4 and mapped in Fig. 3.5 (NBSSLUP 1995).

3.5.4 Soil Texture Analysis

Soil is thick, clayey and sticky in the critical portion of the semi-arid region. The soil is a specific source of plant nutrients with higher cation levels. The earth has low hydraulic conductivity, a high degree of retrenchment, the swelling of the handling reaches 1–4 cm, with large cracks of up to 60 cm deep. The ground in the highlands is relatively saline and sodium free. In the absence of an appropriate descending gradient, the soils on the basin side are subject to soil and floor water salinization. Surface soils are sandy loam with a composition that is approximately 65% satisfactory in grain. At depths of 1 m up to 5.2 m the soil is silty clay. Soil thickness varies from place to place. In general, three types can be defined in the study area: slightly coarse in the higher levels in the south; medium in the dark black soil in the river valley; and maximum thickness in the northern part of Balapur. The deepest soil is located in the south-eastern part of the basin; in the middle and marginal or peripheral parts of the basin, shallow soil predominates (Fig. 3.6).

3.5.5 Methodology

The soil depth map was prepared using ARC GIS 10.1 and satellite data with ground reality for the extra-deep zones. Geographical software with remote sensing was used with reference to the toposheets of the SOI map as well as current geological, geomorphological, and land maps. Arc GIS version 10.1 has been developed and edited for digitalization errors. The functions are marked according to defined codes/symbols. The original file form was changed to WGS in 1984 and the coordinate device was metered. The process includes geometrical correction through the GCs found in the file and the corresponding SOI map.

Physiographical units in the form of sample strips were defined and further stratified by soil based on geological variants, landforms, parent material, elevations, slopes, aspect, vegetation, and so on. The true profiles depended on the terrain variability. Knowledge of mineralogical classifications is useful, as well as soil temperature, moisture regimes, and weather information. A specific local interpretation key is established through analysis of the physiographical unit/image and soil classes.

3.5.6 Soil Depth

The depth of the soil is of crucial importance for cultivation. It defines the root area and the volume of soil from which the plant can meet its requirements for water and nutrients. In some cases, depth varies across short distances (Fig. 3.7 and Table 3.5).

3.5.7 Soil Drainage

Soil drainage refers to the capacity of the soil to absorb excess water in its macropores through gravity. Soil drainage is analyzed by topography, texture, and tilt. Drainage is key to calculating crop yields in the semi-arid region and is an essential element

Table 3.5 Soil depth classes

Soil Depth (cm)m)	Series
<10	Extremely shallow
10–25	Very shallow
25–50	Shallow
50–75	Moderately shallow
75–100	Moderately deep
100–150	Deep
150+	Very deep

of the soil survey. Internal drainage, which occurs most naturally and frequently, is mainly related to texture and porosity, while external drainage relates to pooling on flat ground discovered in soils is drainage internals. The drainage conditions of a region are expressed in the soil color, low chrome mottling, and the extent of its effect in the soil. The natural drainage class refers to the extent and the moisture levels of conditions close to the soil. Soil water management through drainage or irrigation is not appropriate unless it substantially changes the morphology of the soil. The soil drainage classification (NBSSLUP 1995) is as follows (Khadri and Pande 2014).

3.5.7.1 Excessively Drained

Water is easily extracted. The soil is typically coarse-textured and highly conductive hydraulically or very shallow (Fig. 3.8).

3.5.7.2 Somewhat Excessively Drained

Water is easily extracted from the ground. The occurrence of freshwater is always very rare or very slight. In the wetlands, the soils are frequently ground textured and the hydraulic conductivity is overly saturated.

3.5.7.3 Well-Drained

Water is easily removed from the land, but not quickly. At some point, in most wetlands, water is accessible to plants in the growing season. The soils are typically free of wetness-related deep to redoximorphic aspects (Fig. 3.8).

3.5.7.4 Moderately Well-Drained

For part of the year water is removed gradually from the soil. In certain situations, hydraulic conductivity within the top 1 m layer is relatively low or lower, and occasionally rainfall is excessive or accessible (Fig. 3.8).

3.5.7.5 Imperfect

The soil is fed at a shallow depth during the growing season for long periods. Wetness greatly restricts the crop yield except for the use of artificial flux. Soils are usually one or more of the following: low or very low hydraulic conductance saturated, high water tables, additional water from drainage, or almost non-stop rainfall.

3.5.7.6 Poorly Drained

It is extracted so gradually that the soil is wet for long periods at low depths even during the growing season. The water is generally in or near the ground for long enough during the growing season to prevent growth of mesophytic plants. However, the soil is not continuously wet at plowing depth. Free water is usually located at a shallow depth.

3.5.7.7 Very Poorly Drained

Water stays close to the ground for most of the growing season. Many mesophytic crops cannot be cultivated without artificially drainage. Usually, the soils are stadium or depressed (Fig. 3.8).

3.5.8 Soil Erosion

The formation and transfer of particles of soil is called soil erosion. Soil erosion affects not only soil formation and its reputation for fertility but also land use. Agriculture and the environment are affected by soil erosion through water, wind, and tillage. Sometimes, soil erosion remains at roughly the same rate as when soil is formed. Accelerated soil erosion occurs when the rate of soil erosion is increasing and is caused by dangerous human activities, such as excessive cultivation. Soil can also be isolated or transported (including over long distances) during erosive rainfalls or windstorms.

It is not always easy to establish detailed facts about soil erosion. Research is carried out by geomorphologists, agricultural engineers, soil scientists, hydrologists, and others for the benefit of politicians, growers, environmentalists, and various individuals (NBSSLUP 1995). The following classification applies to soil erosion.

3.5.8.1 Slightly Eroded

Erosion has sufficiently altered the soil to require only minor management adjustments compared to soil without erosion; future usage and management are essentially the same. The majority of surveys do not differentiate slightly eroded areas from uneroded areas (Fig. 3.9).

3.5.8.2 Moderately Eroded

The cultivated layer typically consists of the surface layer and surrounding layers. Here erosion has so changed the soil that it needs to be managed very differently from the uneroded soil. Standard tillage implements reach the horizontal in most fairly eroded soils or fit conveniently below the single plowed layer (Fig. 3.9).

3.5.8.3 Severely Eroded

In severely eroded soil, the plowing layer generally consists of the underlying material but can also contain a combination of the surface and underlying layers. In some places, shallow or deep gullies are frequently found. Erosion has made a major difference to the soil such that: (1) eroded soil is only appropriate for applications that are significantly less intensive than uneroded soil because it is used on pastures rather than on crops; (2) the eroded soil requires immediate or sustained intensive management; (3) the eroded soil requires immediate or long-term intensive management to be suitable for the same uses as the uneroded soil; (4) productivity is drastically reduced; and (5) engineering operations are more limited than on unmodified soil (Fig. 3.9).

3.5.8.4 Very Severely Eroded

This soil type has an underlying network of slums and is typically of coarse texture and is medium to dark gray. The term ‘ravine’ generally refers not to an isolated gully but to a complex set of gullies that typically flows into a nearby river formed of deep alluvium. The key systems created by river ravines are wide gully systems (Fig. 3.9).

3.6 Soil Capability

The three factors affecting the evolution of watershed areas are internal soil characteristics, external land features, and environmental factors. Data on the first two aspects are shown on the soil maps created for this research.

Among the essential inherent characteristics of the soil are: efficient soil density; soil texture; reaction; quality of natural matter; and salinity and/or sodium content. Natural surface drainage, slope, flooding, wetness, and gravity are important land features which have a direct effect on soil potential. These factors play a major role in assessing the workability of a specific piece of land for sustainable development in the local environment. A land capability classification is a guide to assessing the suitability of the land for arable, grazing, and forestry. The capability classification is divided into capability classes, capability subclasses, and capability gadgets (Fig. 3.10).

3.7 Planning and Management of Mini-watershed as a Village-Level Water Resource

3.7.1 Preparing a Mini-watershed Project

The study of water resources consists of three principal areas:

a. *Resources*
b. *Environment*
c. *Engineering.*

Each of these areas requires reconnaissance surveys, feasibility studies, planning, design supervision, project management, and training as listed below.

3.7.1.1 Resources

a. Hydrogeological and geological mapping from satellite imagery. Hydrometric network design and monitoring.
b. Assessment of regional surface and groundwater resources as a mini-watershed.
c. Sustainable surface water and groundwater development for irrigation, drinking water, and industrial use within the mini-watershed.
d. Aquifer protection and water conservation.
e. Harvested runoff towards recharging place.
f. Connected uses.
g. Economic evaluation.

3.7.1.2 Environment

a. Hydro environmental impact assessment and western land management.
b. Fallow land and contaminated land studies.
c. Aquifer protection and contaminant migration studies.
d. Hydro-chemical survey.
e. Industrial waste pollution.

3.7.1.3 Engineering

a. Aquifer dewatering; outflow and inflow runoff monitoring within mini-watershed.
b. Hydro-chemical and geotechnical effects on GIS software.
c. Hydrogeological impact on groundwater quality.

3.8 Water Resources Development Plan (WRDP)

An action plan was created for the conservation of water and soil in the watershed. A weighted overlay analysis was used to measure and plan water harvest using various management structures and a zoning map. Weighting and rank were calculated according to the significance of the thematic layer for zoning conservation systems. A control dam, cement bundles, barley package, percolation tank, farm pond, sunken pond, and a loosened boulder system using several thematic layers were suggested as part of the action plan for water and land protection structures (Dongardive et al. 2018).

3.8.1 Groundwater Conditions in the Study Area

Groundwater is generally acceptable for irrigation purposes, except for a few pockets of Risod with more conductivity. Deeper water from the alluvial field cannot be used for irrigation or is of questionable quality. Water analysis from wells in the Akola basaltic terrain shows the water is within the permissible limits for drinking water, excepting Murtizapur, where the saline in the Puma alluvium exceeds the allowable limits (Pande et al. 2014; Moharir et al. 2019).

The water quality is good for drinking and irrigation along the north bank and southern side of the river Puma. Most soils are salty and pH is high. The State Regulatory Authority should specify that the *Zilla Parishad*'s water-use rights are exclusively reserved for drinking water schemes for the villages located in the elementary watershed for the use of runoff for structures of less than 10 mem capability. The right to distribute wastewater rests solely with the district's Central Watershed Management Committee. The *taluka*-level committee determines priorities for the use of the surface runoff. In alluvial areas in Tapi and Puma, instances have been observed of rich farmers with more land and resources digging wells up to 40–50 m deep to obtain water at the expense of poor farmers (Moharir et al. 2020).

3.8.2 Drinking and Irrigation Water Problems

The drinking water problems are:

a. Uneven rainfall distribution across the study region.
b. 80.5% of the region is Deccan Trap rock, which is highly porous and permeable, and almost 48% of its geo-morphologic range has a slope of more than 22%.
c. Uneven surface water quality and amount in all regions. Over-exploitation through widespread creation of open wells in areas where resource issues were present.
d. Sustainability in the summer in several villages with deeper aquifers with a moderate and secure yield for drinking water.
e. Improper construction of tube supply wells for drinking water and lack of evaluation of resources to overcome shortfalls at the implementation stage.

3.8.3 Rooftop Storage

Collection from rooves in areas of settlements is a system for capturing and storing rainwater. The rainwater captured is used for drinking, to a limited extent for farming, or to recharge groundwater.

3.8.4 Storage Tanks

Aquifers usually become saturated in rocky regions during regular rainfall. Thus, unlike for alluvial aquifers, it is not generally necessary to recharge water during the monsoon. Underground storage tanks should therefore be planned according to the need for recharging the drill wells. Until now, much of Maharashtra's industrial area has been supplied from large or medium-sized dams or from continuously flowing rivers. This has continued to provide sufficient storage for growing industries. All industrial units have recently been required by the Indian government to capture and conserve the runoff from their premises' rooftops. The runoff can later be transported in the recharge framework using appropriate filter systems.

3.8.5 Sewage Treatment

Industrial wastewater is processed and re-utilized for agriculture by sewage plants in most developing countries. Some water is treated and reused as potable water in cities instead of being allowed to flow into rivers, thus controlling pollution. The main feature of recharge studies is the reuse of urban and industrial wastewater for recharging groundwater. Wastewater can be recovered by direct injection into wells, water spreading, or irrigation, according to local requirements, water quality, and viability. Wastewater may also be pumped into the water and removed by induced refueling from the wells. Soil aquifer treatment (SAT) is a method for purifying and recovering wastewater and other low-grade water from the soil and the aquifer using physical, chemical, and biological processes. Restored water is collected from wells at a suitable distance to eliminate impurities, unlike groundwater recharging schemes where surface water is applied without any controls. In the SAT system, recovered wastewater flows continuously to the untapped part of the aquifer. All firms in Maharashtra are implementing this type of wastewater treatment program to limit contamination of the groundwater from open wells and reuse the water for irrigation and even for drinking.

3.8.6 Check Dam

A barrier protection dam is a small rock, gravel-bag, sandbag, fiber-sheet, or reusability barrier positioned over a built-in drainage ditch in agricultural land. The check dam decreases the channel's slope, reducing the speed of the water flow, allowing sedimentation and reducing erosion. When a test dam is constructed, an area upstream of the dam is submerged to ensure that the worst places would continue to be overwhelmed. The appropriate location for the building of a check dam can be decided based on the land-use map. From a conservation point of view, the fourth-order stream connecting to the mainstream was chosen for a dam site.

A check dam may be appropriate in the following situations:

- To promote sedimentation.
- To prevent erosion in small seasonal canals or temporary swales by decreasing the channel flow speed.
- In a small open channel that drains 10 acres or less.
- In a steep channel where stormwater runoff velocities exceed 5 ft/s.
- When grass filling and drainage ditches or canals are to be created.
- In temporary ditches where erosion-resistant lining is not required for the a limited time.

The check dam is not to be used for extended flows in live streams or channels. Nor is it suitable for canals that drain over 10 acres, or in grass-lined channels, as planting will destroy vegetation unless erosion is expected. It encourages the capture of sediments that may be re-suspended or removed during subsequent storms.

3.8.7 Cement Nala Bund

This is a low weir without a drainage canal, but it provides lift irrigation and agriculture under the wells in the field. It also helps to restore water sources that are exhausted by wells. Tube wells are usually supported on little streams or nala with a continuous flow, especially during the rabi season. Terrestrial soil areas where soil depth is greater than 100 cm are proposed for the structural cement nala band (Plate 3.1).

The following conditions should be observed:

a. The stream should be straight both upstream and downstream.
b. The nala bed slope should not be more than 3%.
c. The nala width should be less than 30 m.
d. The nala should have a stable bank on either side.
e. The rock level below the bed level should not be more than half the height of the structure above the ground level.
f. The structure should not in any way lead to water spreading into nearby agricultural fields.

3.8.8 Continuous Contour Trench (CCT)

In steeply sloping or hilly areas with heavy precipitation, continuous contour trenches are built. Runoff and soil degradation can be minimized in steep pathways. The continuous contour trenches are suitable on slopes of 3–5% with very shallow to shallow soil (>10 cm). Soil and water management trenches are dug into the slopes and around the contour lines.

3.8.9 Loose Boulder Structure (LBS)

Loose boulder structures are appropriate on slopes of 5–10%, with gravel sandy clay and low ground depth (>10 cm) on agricultural cropland. They are suitable where there are multiple stones and gullies of small to medium-sized drainage areas in moderate pitfalls. Their flexibility and weight help to maintain contact with the ground. Flat stones are the best material to use (Plate 3.2).

3.8.10 Earthen Nala Bund (ENB)

An earthen nala bund is suggested on forested slopes of 1–3%, where the soil is very deep (>100 cm). The dam is built over a rivulet and holds the water for a period, allowing it to percolate and gradually raising the level of subsoil water surrounding it. The site requires a narrow valley for soil filling, with a slope of no more than 3%. The width of the nala should be more than 5 meters. The system will not contribute to water spreading in the surrounding farmland. The fundamental strata should be able to bear the structure's load.

3.8.11 Sunken Pond

These are constructed to create more storage by recharging the groundwater through percolation. They are constructed in suitable places across the nala. The site should be relatively flat, the slope not exceeding 2%. The catchment of the structure should be above 40 ha. An emergency spillway, preferably in hard rock, may be provided alongside a percolation tank bund.

3.8.12 Percolation Tank

Percolation tanks installed across the nala generate additional soil water storage and aquifer recharging by percolation. They also provide drinking water to cattle and in many cases also to the human population. Percolation tanks should be constructed preferably on second-to third-order streams, and located on highly fractured and weathered rocks with downstream lateral continuity.

Appropriate sites, ideally in hard rock, are relatively flat with a slope of 2%. The system catchment covers 40 ha. An emergency spillway can be provided to avoid binding of the percolation tank. In many cases the structure also provides drinking water for cattle and people.

3.8.13 Graded Bund

In addition to soil protection, safe disposal of excess moisture is of key importance in areas of higher rainfall. In this region, excess moisture should be funneled into graded sites after it has been allowed to soak into the soil to the necessary depth. Graded bunds conserve excess water in a natural vegetated waterway. They are designed to channel water at non-erosive speeds, flooding the ground up to root level. Graded bunds may also offer advantages in low rainfall areas as they eliminate the need for side bunds. Length, grade, and parts of the bund must, therefore, be carefully calibrated according to the nature and quantity of rainfall and soil type (Pande 2014b).

3.8.14 Canal Control

Between 1 and 3% of the farmland is covered by an irrigation network of canals. The soil type is clay and the depth ranges from shallow to very deep (>100 cm).

3.8.15 Pond

A reservoir pond is suggested for rainwater storage in a specific agricultural area and for irrigation purposes. This is suitable on slopes varying from 1% to 3% with clay soil and depth of small to very deep (>100 cm).

3.9 Water Resource Development

There is a variety of alluvial and Deccan Trap exposures in the study area. Water resources in the area can be divided into three distinct groups: (i) good, in which the electrical conductivity (EC) value is between 250 and 750; (ii) medium, with EC values of 750–2000; and (iii) doubtful, where the EC value is between 2000 and 3000. The alluvial zone, with EC values reducing towards the south, has doubtful water quality that is not suitable for drinking. Interestingly, none of the analyzed samples shows EC > 3000, which means that the salinity rate of the alluvial region of the study area is in the lower range and can be eliminated by effective drainage methods and also by rainfall pumping of salty water into the Man River (Khadri ans Chaitanya 2015a, b).

Variations in the water level are probably due to distinct changes in precipitation and the indiscriminate extraction of groundwater in the area. Extensive climate and weather data obtained over ten years from observation wells were used to understand the complexity of the groundwater system and identify suitable sites for groundwater production. Numerous measures are proposed to boost the capacity and volatility of groundwater levels in the area with a focus on environmental management (Prakasam 2010).

The region is distinguished by the presence of an alluvial field that shows saline flows in the south and basaltic lava flows in the north. Tapped with dug wells, small, unconfined aquifers are the biggest groundwater producers in the region (Pande et al. 2016). Groundwater salinity is largely regulated by lithology, with high carbonate- and evaporite-regulating salinity showing different chemical relations between soil and rock lithology. Water chemistry depends mainly on minor alteration of the host rock. In this watershed area there is good scope for hydrological investigation and environmental protection measures. Investigations provide useful clues for the assessment of groundwater potential in the region. They can also assist in the reconstruction of groundwater routes in a particular watershed, which are of use for optimal soil and water planning and management. In this area, groundwater replenishment is determined by topographical characteristics, including thickness of the weathered zone, and soil and soil strata permeability in the aeration region (Pande et al. 2017). Red boles reveal seven lava streams isolated from each other in the region. Every part of the flow forms a different unit depending on the porosity and permeability of the flow units. The water content of various lava flows depends on the form and composition of the eruption. Broad sections having low porosity are not beneficial to groundwater. In comparison, vesicular and amygdaloidal horizons in lava flows with interconnected and evenly distributed vesicles are extremely porous and permeable. Their contribution to the groundwater potential depends on varying weather conditions. Occasionally porosity can be formed by closely spaced interconnecting joints between massive horizons. On basaltic soil, the size and number of vesicles, degree of weathering and joint patterns are mainly responsible for water productivity and water supply potential. Heavily weathered vesicular and amygdaloidal basalt regions are therefore good producers of soil water (Moharir and Pande 2014a, b).

Thus, water chemistry is consistent across the area of the traps, while the alluvial region shows some changes in chemistry due to salinity. Variations in pH and total dissolved solids (TDS) are influenced by lithology and environment (Pande and Kanak 2018c). In downstream temperate areas, chemical weathering plays an important role in water chemistry regulation. Low water quality not suitable for drinking and irrigation is observed in the northern saline region (Khadri et al. 2013; Pande et al. 2019a). Decent to excellent groundwater quality is found, however, in the area of the traps. Within our study area, the maximum amount of water is found in the highly divided, weathered, and joined horizons of the Deccan Traps. There are also many aquifers that show both productive and unproductive zones due to the presence of laterally varying massive and vesicular units (Khadri and Chaitanya 2015c). Groundwater levels fluctuate between pre-monsoon and post-monsoon. Water depth studies indicate variations in groundwater table replenishment according to irrigation methods. Based on field characteristics, specific mineral levels, textural characteristics, and distribution of geochemical signatures, the existence of ten lavic flows belonging to the Atali, Lokhanda, and Amdapur formations has been established. A detailed geological map of the study area depicting the lava sequence has been prepared.

3.10 Conclusion and Recommendation

This chapter has shown the importance of thematic mapping for novel models of sustainable watershed development in the semi-arid region. Watersheds are biophysical systems with structures designed to create and maintain land and water resources on a sustainable basis. The significance of an IMM solution for addressing ground, water, and hydraulic extremes should be understood by the reader.

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