RESOURCE BASED LAND USE PLANNING IN SAWANGI WATERSHED OF YAVATMAL DISTRICT, MAHARASTRA

Ph. D. Thesis

by

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DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE
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INDIRA GANDHI KRISHI VISHWAVIDYALAYA
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Thesis

Submitted to the

Indira Gandhi Krishi Vishwavidyalaya, Raipur

by

SOMAN SINGH DHRUW

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in

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(Soil Science and Agricultural Chemistry)

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JULY, 2022

CERTIFICATE – I

This is to certify that the thesis entitled **"Resource based land use planning in Sawangi watershed of Yavatmal district, Maharashtra"** submitted in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Agriculture (Soil Science and Agricultural Chemistry)** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Soman Singh Dhruw** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma or certificate course. All the assistance and help received during the course of the investigation have been duly acknowledged.

Co-Chairman **Chairman**

Date:

THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE

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Member	(Dr. R. K. Naitam)	
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Member	(Dr. A. Verma)	
Head of Department	(Dr. K. Tedia)	

CERTIFICATE – II

This is to certify that the thesis entitled **"Resource based land use planning in Sawangi watershed of Yavatmal District, Maharashtra."** submitted by **Soman Singh Dhruw** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Agriculture** in the **Department of Soil Science and Agricultural Chemistry** has been approved by the external examiner and Student's Advisory Committee after oral examination.

Signature External Examiner

(Name Rajesh Sharma)

Date: 08-12-2022

Major Advisor ____________________

Head of the Department ____________________

Faculty Dean ____________________

Approved/Not approved

Director of Instructions ____________________

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LIST OF ABBREVIATIONS

Abbreviations	Description
AAS	Atomic Absorption Spectrophotometer
AIS&LUS	All India Soil and Land Use Survey
AWC	Available Water Content
B.D.	Bulk Density
B.S.	Base Saturation
C.F.	Coarse Fragments
CEC	Cation Exchange Capacity
cmol (p^+) kg^{-1}	Centimole protons per kilogram
dS m^{-1}	Deci Siemens per meter
DTPA	Diethyline Triamine Penta Acetic Acid
TM	Thematic Mapper
PAWC	Plant Available Water Capacity
EMP	Exchangeable Magnesium Percentage
EC	Electrical Conductivity
et al.	Et alia (and others)
FAO	Food and Agriculture Organization
FCC	False colour composite
GIS	Geographical Information System
Ha	Hectare
IRS	Indian Remote Sensing Satellite
kPa	Kilo pascal
LE	Linear Extensibility
LISS	Linear Imaging Self Scanner
Mg m^{-3}	Mega gram per cubic meter
MSL	Mean Sea Level
PET	Potential Evapotranspiration
Pf	Pressure faces
Ppm	Parts per million
SOI	Survey of India
Ss	Slickensides
TGA	Total Geographical Area
USDA	United State Department of Agriculture

THESIS ABSTRACT

a)	Title of Thesis	:	Resource based land use planning in Sawangi watershed of Yavatmal district, Maharashtra
b)	Full Name of Student	:	Soman Singh Dhruw
c)	Major Subject	:	Soil Science & Agricultural Chemistry
d)	Name and Address of major Advisor	:	Dr. Anurag Professor, Department of Soil Science & Agricultural Chemistry, CoA, IGKV, Raipur (C.G.), 492012
e)	Degree to be Awarded	:	Ph. D. (Agriculture)

Signature of the student

Signature of Major Advisor

Signature of Head of the Department

Date:

ABSTRACT

The present investigation entitled "Resource based land use planning in Sawangi watershed of Yavatmal district, Maharashtra" was carried out comprising study area about (11777.6 ha) during 2018-2021 and data analyzed for mapping and evaluated natural resources for their proper management and land use planning using remote sensing and Geographic Information System. The remote sensing data and Google Earth portal were used to derive spatial information about land use land cover changes, conduct an open well census, estimate irrigated area and groundwater potential zone demarcation, and finally, a land use plan was suggested for optimum utilization of the available

resources. The soil data were collected at a 1:10000 scale. The LANDSAT satellite data were interpreted in conjunction with Google Erath Image and Digital Elevation Model (DEM) data to derive spatial information about land use/land cover change, slope, drainage morphometry, physiography, and groundwater potential. Temporal data for the years 2008, 2012, and 2017 were analyzed for land use land cover changes (LULC) and further evaluate irrigation well and irrigated area mapping enumeration. Socio-economic data were collected through a census report (secondary data).

LULC studies showed a significant change. During the period between 2008 and 2017, the "habitation" increased by 8.7 ha at the watershed level. The "industrial" area increased by 27.7 ha and the wasteland increased by 275.0 ha. While the area under "forest" decreased by 10.4 ha and "shrubland" significantly declined by 326.6 ha at the watershed level. it was converted to agricultural land use mainly due to encroachment by the farmers or by habitation and industrial area development. Further, at the watershed level, agricultural land decline by 1489.9 ha from 2008 to 2017.

The slope map of the study area was delineated by ASTER-DEM (30 m resolution) which enabled the classification of the study area into five slope classes *viz*., very gently sloping (1-3%), gently sloping (3-8%), moderately sloping (8-15%), moderately steeply sloping (15-30%) and steeply sloping (>30%) covering an area of 7563.0 ha, 3482.4 ha, 492.1 ha, 239.8 ha, 0.09 ha respectively. The study area was divided into 10 major landform units *viz*., mound, plateau, denuded plateau, escarpment, upper pediment, lower pediment, alluvial plain, peneplain, upper valley, and lower valley occurring in an area of 238.7 ha, 540.5 ha, 3849.1 ha, 876.2 ha, 435.1 ha, 1854.5 ha, 619.4 ha, 1463.9 ha, 322.3 ha, and 1254.0 ha respectively.

Groundwater potential (GWP) assessment of the Sawangi watershed was delineated by using seven parameters *viz*., geomorphology, slope, LULC, soil texture, lineament density, drainage density, and rainfall. "High" GWP zone (501.87 ha) is located around the drainage channels and water bodies. The "Poor" GWP zone (1216.08 ha) is located mostly in the hilly region. More than 80% (10056.66 ha) of the watershed area was observed to have a " Moderate" potential zone. From (2008 to 2017) the mean irrigated area per well was in the order of 2.21 ha in high (H) > 2.12 ha in moderate (M) > 0.36 ha in poor (P) GWP zone. The well enumeration data indicated that in the Sawangi watershed total number of wells was 728, of which 332 functional wells irrigated 696.0 ha area and 396 wells became defunct in 2017 and the average area irrigated per well was highest at 1.45 ha. While the average area irrigated per well was the lowest at 1.13 ha in 2008.

Based on the physiography-soil relationship, ten soil series have been identified with fourteen soil phases from the twelve landform units. The representative of each soil series with each horizon was analyzed for different soil parameters. The major part of the areas belongs to *Entisols* (series 2, 3, 4, 5, and 10), *Inseptisols* (series 1, 6, 7, and 8), and *Vertisols* (series 9). These soils are very shallow to moderately deep, very gently sloping to steeply sloping escarpment, well-drained with moderate to severe erosion, and dark reddish-brown to very dark grayish brown. Whereas hue is in the range of 2.5 YR, 5 YR, and 10 YR, with the value of 3 to 5, and chroma in the range of 1 to 4. The structure of the surface horizons is medium sub-angular blocky and in the sub-surface, it is medium sub-angular blocky to angular blocky, with sandy clay loam to clay in texture. The sand, silt, and clay content varied from 1.7 to 76.2 %, 5.9 to 47.8 %, and 17.8 to 77.2 % respectively. The bulk density of the soils varied from 1.39 to 1.81 Mg m^{-3}. The available water content of the soils varied from 8.3 to 31.2 %. The pH values of the soil range from 6.55 to 8.94 and EC varied from 0.39 to 4.40 dSm^{-1}. The soil organic carbon content ranged from 0.29 to 1.83 %, which gradually decreased with soil depth. The $CaCO_3$ content of these soils ranged from 0.00 to 14.68 %, and it increases with depth. The cation exchange capacity of soils ranged from 31.39 to 70.43 cmol (p+) kg^{-1}. High CEC indicates the dominance of clay with high exchange properties as organic carbon is relatively low. Base saturation of soils ranged from 776.9 to 113.3 % and exchangeable sodium percentage ranged from 0.90 to 21.50 %. The available macro and micronutrient (N, P, S, and Zn) status of soils ranges from very low to medium, while K, Fe, Mn, and Cu are high range. Generally, the decreasing pattern of these macro and micronutrient content down the profile was exhibited in all the soils.

The soils of the Sawangi watershed (14 soil mapping units) were evaluated for land capability, irrigability, productivity, and suitability classes for the crops grown in the area. The land capability sub-classes grouped *viz*., IIes, IIIes, IVes, VIes and VItes and 2st, 3s, 3st, 3t, 4s and 5t land irrigability sub-classes respectively. The soil-site suitability evaluation for different major crops grown in the area was categorized as moderately suitable, marginally suitable, and not-suitable, indicating that 2183.2 ha (18.54%) are moderately suitable for cotton, pigeon pea, soybean, wheat, chickpea, marginally suitable (37.55 %) for wheat, chickpea, and soybean crop, and 36.57 % areas are suitable for cotton and pigeon pea, 32.09 % for sorghum. A total of 4585.2 ha (38.93%) areas are in the not-suitable category due to the severe limitations of soil depth, slope, AWC, and stoniness. The land productivity index for different crops is identified under the excellent, good, average, and poor productivity class. These are classified as poor due to the limitation of soil depth and moisture. A comparison of land evaluation methods (Sys and Riquier method) indicated that the Riquier method was better than the Sys soil-site suitability method.

शोध सारांश

अ) शोध का शीर्षक	:	महाराष्ट्र के यवतमाल जिले, के सवांगी वाटरशेड के लिए संसाधन आधारित भूमि उपयोग योजना
ब) छात्र का पूरा नाम	:	सोमन सिंह ध्रुव
स) प्रमुख विषय	:	मृदा विज्ञान एंव कृषि रसायन
द) प्रमुख सलाहकार का नाम एवं पता	:	डॉ. अनुराग प्राध्यापक कृषि महाविद्यालय,रायपुर (छ.ग.)
इ) सम्मानित किये जाने वाली उपाधि	:	पी. एच. डी. (कृषि) (मृदा विज्ञान एवं कृषि रसायन)

छात्र के हस्ताक्षर

प्रमुख सलाहकार के हस्ताक्षर

विभागाध्यक्ष के हस्ताक्षर

दिनॉकः

शोध सारांश

वर्तमान जांच ''यवतमाल जिले, महाराष्ट्र के स्वांगी वाटरशेड में संसाधन आधारित भूमि उपयोग योजना'' वर्ष 2018–2021 के दौरान अध्ययन क्षेत्र (11777.6 हेक्टेयर) में उनके उचित प्रबंधन और भूमि उपयोग के लिए प्राकृतिक संसाधनों का विश्लेषण, नक्शा और मूल्यांकन करने के लिए की गई थी। रिमोट सेंसिंग डेटा और गूगल अर्थ पोर्टल का उपयोग भूमि उपयोग भूमि कवर परिवर्तनों के बारे में स्थानिक जानकारी प्राप्त करने, एक खुले कुएं की जनगणना करने, सिंचित क्षेत्र और भूजल संभावित क्षेत्र के सीमांकन का

अनुमान लगाने के लिए किया गया था, और अंत में भूमि उपयोग योजना के इष्टतम उपयोग के लिए एक भूमि उपयोग योजना का सुझाव दिया गया था। उपलब्ध संसाधन मिट्टी के आंकड़े 1:10000 के पैमाने पर एकत्र किए गए थे। भूमि उपयोग–भूमि कवर परिवर्तन, ढलान, जल निकासी, आकृति विज्ञान, भौतिक विज्ञान और भूजल क्षमता के बारे में स्थानिक जानकारी प्राप्त करने के लिए लैंड सैट उपग्रह डेटा की व्याख्या गुगल अर्थ छवि और डिजिटल ऊंचाई मॉडल (डी ई एम) डेटा के साथ की गई थी। वर्ष 2008, 2012 और 2017 के लिए अस्थायी डेटा का विश्लेषण भूमि उपयोग भूमि कवर परिर्वन (एल यू एल सी) के लिए किया गया था और आगे सिंचाई के कुएं और सिंचित क्षेत्र मानचित्र गणना का मूल्यांकन किया गया था। जनगणना रिपोर्ट (द्वितीयक डेटा) के माध्यम से सामाजिक आर्थिक डेटा एकत्र किया गया था।

एल यू एल सी अध्ययनों ने एक महत्वपूर्ण परिवर्तन दिखाया। 2008 और 2017 के बीच की अवधि के दौरान वाटरशेड स्तर पर "आवास" में 8.7 हेक्टेयर की वृद्धि हुई। "औद्योगिक" क्षेत्र में 27.7 हेक्टेयर और बंजर भूमि में 275.6 हेक्टेयर की वृद्धि हुई। जबकि "जंगल" के तहत क्षेत्र में 10.4 हेक्टेयर और "झाड़ी भूमि" में वाटरशेड स्तर पर 328.6 हेक्टेयर की कमी आई है। इसे मुख्य रूप से किसानों द्वारा अतिक्रमण या आवास और औद्योगिक क्षेत्र के विकास के कारण कृषि भूमि उपयोग में परिवर्तित किया गया था। इसके अलावा, वाटरशेड स्तर पर कृषि भूमि में 2008 से 2017 तक 1489.9 हेक्टेयर क्षेत्र की कमी देखी गई।

अध्ययन क्षेत्र का ढलान नक्शा **अस्टर-डेम** (30 **मी.** रेजोल्यूशन) द्वारा चित्रित किया गया था, जिसने अध्ययन क्षेत्र को पांच ढलान वर्गों में वर्गीकृत करने में सक्षम बनाया। मध्यम ढलान (8 - 15%), मध्यम रूप से खड़ी ढलान (15-30%) और खड़ी ढलान (> 30%) क्रमशः 7563.0 हेक्टेयर, 3482.4 हेक्टेयर, 492.1 हेक्टेयर, 239.8 हेक्टेयर, 0.09 हेक्टेयर के क्षेत्र को कवर करता है। अध्ययन क्षेत्र को 238.7 हेक्टेयर, 540.5 के क्षेत्र में होने वाली 10 प्रमुख भू.आकृति इकाइयों में विभाजित किया गया था। हेक्टेयर, 3849.1 हेक्टेयर, 876.2 हेक्टेयर, 435.1 हेक्टेयर, 1854.5 हेक्टेयर, 619.4 हेक्टेयर, 1463.9 हेक्टेयर, 322.3 हेक्टेयर और 1254.0 हेक्टेयर.

सवांगी वाटर शेड के भूजल क्षमता (जी डब्ल्यू पी) के आकलन को सात मापदंडों जैसे भू-आकृति विज्ञान, ढलान, एल यू एल सी, मिट्टी की बनावट, लाइनमेंट घनत्व, जल निकासी घनत्व

और वर्षा का उपयोग करके चित्रित किया गया था। "उच्च" जीडब्ल्यूपी क्षेत्र (501.87 हेक्टेयर) जल निकासी चैनलों और जल निकायों के आसपास स्थित है। "**निम्न**" जीडब्ल्यूपी क्षेत्र (1216.08 हेक्टेयर) ज्यादातर पहाड़ी क्षेत्र में स्थित है। 80% से अधिक (10056.66 हेक्टेयर) वाटरशेड क्षेत्र में "मध्यम" संभावित क्षेत्र पाया गया। (2008 से 2017 तक) औसत सिंचित क्षेत्र प्रति कुआं 2.21 हेक्टेयर उच्च (एच) > 2.12 हेक्टेयर मध्यम (एम) > 0.36 हेक्टेयर **निम्न** (पी) जीडब्ल्यूपी क्षेत्र में था। कुओं की गणना के आंकड़ों से संकेत मिलता है कि सवांगी वाटरशेड में कुओं की कुल संख्या 728 थी, जिनमें से 332 कार्यात्मक कुओं से 696.0 हेक्टेयर क्षेत्र में सिंचाई की गई और 396 कुएं 2017 में निष्क्रिय हो गए और प्रति कुएं सिंचित औसत क्षेत्र 1.45 हेक्टेयर में सबसे अधिक था। जबकि प्रति कुएं सिंचित औसत क्षेत्र 2008 में सबसे कम 1.13 हेक्टेयर था।

भू-आकृति – मृदा संबंध के आधार पर बारह भू.आकृति इकाइयों से मिट्टी के चौदह चरणों के साथ दस मृदा श्रृंखलाओं की पहचान की गई है। प्रत्येक क्षितिज के साथ प्रत्येक मृदा श्रृंखला के प्रतिनिधि का विश्लेषण विभिन्न मृदा मापदंडों के लिए किया गया था। क्षेत्रों का प्रमुख हिस्सा एंटिसोल (श्रृंखला 2, 3, 4, 5, और 10), इंसेप्टिसोल (श्रृंखला 1, 6, 7, और 8), और वर्टिसोल (श्रृंखला 9) से संबंधित है। ये मिट्टी बहुत उथली से मध्यम गहरी होती है, बहुत धीरे-धीरे ढलान से **कम** ढलान वाली तक, मध्यम से गंभीर कटाव के साथ अच्छी तरह से सूखा, और गहरे लाल. भूरे से बहुत गहरे भूरे रंग के होते हैं। जब कि ह्यू 2.5 YR, 5 YR, और 10 YR की रेंज में है, 3 से 5 मान के साथ, और क्रोमा 1 से 4 की रेंज में है। सतह क्षितिज की संरचना मध्यम उप.कोणीय ब्लॉकी और है, उप. सतह, यह मध्यम उप.कोणीय ब्लॉकी से कोणीय ब्लॉकी है, बनावट में रेतीली मिट्टी दोमट से मिट्टी के साथ। रेत, गाद और मिट्टी की मात्रा क्रमशः 1.7 से 76.2%, 5.9 से 47.8% और 17.8 से 77.2% तक भिन्न होती है। मिट्टी का थोक घनत्व 1.39 से 1.81 मिली ग्राम प्रति मीटर क्यूब तक भिन्न होता है। मिट्टी की उपलब्ध जल सामग्री 8.3 से 31.2% तक भिन्न होती है। मिट्टी का **मिट्टी की अभिकिया** (pH) मान 6.55 से 8.94 और मिट्टी **की नमक सांद्रता (**EC) 0.39 से 4.40 dSm^{-1} के बीच होता है। मृदा कार्बनिक कार्बन सामग्री 0.29 से 1.83% तक थी, जो मिट्टी की गहराई के साथ धीरे.धीरे कम हो गई। इन मिट्टी में $CaCO_3$ की मात्रा 0.00 से 14.68% के बीच होती है और यह गहराई के साथ बढ़ती जाती है। मिट्टी की धनायन विनिमय क्षमता 31.39 से 70.43 cmol (p+) kg^{-1} के बीच

थी। उच्च सीईसी उच्च विनिमय गुणों के साथ मिट्टी के प्रभुत्व को इंगित करता है क्योंकि कार्बनिक कार्बन अपेक्षाकृत कम है। मिट्टी की आधार संतृप्ति 776.9 से 113.3% और विनिमेय सोडियम प्रतिशत 0.90 से 21.50% तक थी। मिट्टी की उपलब्ध मुख्य और सूक्ष्म पोषक तत्व (N, P, S और Zn) की स्थिति बहुत कम से मध्यम तक होती है, जबकि K, Fe, Mn और Cu उच्च श्रेणी की होती है। आमतौर पर, प्रोफाइल के नीचे इन मुख्य और सूक्ष्म पोषक तत्वों के घटते पैटर्न को सभी मिट्टी में प्रदर्शित किया गया था।

सवांगी वाटरशेड (14 मृदा मान चित्रण इकाइयों) की मिट्टी का मूल्यांकन क्षेत्र में उगाई जाने वाली फसलों के लिए भूमि क्षमता, सिंचाई ,उत्पादकता और उपयुक्तता वर्गों के लिए किया गया था। भूमि क्षमता उप. वर्गों को समूहित किया गया है, जैसे कि IIes, IIIes, IVes, Vies और VItes और 2st, 3s, 3st, 3t, 4s और 5t भूमि सिंचाई उप. वर्ग। क्षेत्र में उगाई जाने वाली विभिन्न प्रमुख फसलों के लिए मिट्टी.स्थल उपयुक्तता मूल्यांकन को मध्यम रूप से उपयुक्त, मामूली रूप से उपयुक्त और अनुपयुक्त के रूप में वर्गीकृत किया गया था, जो दर्शाता है कि 2183.2 हेक्टेयर (18.54%) कपास, अरहर, सोयाबीन, गेहूं, और चना के लिए मध्यम रूप से उपयुक्त हैं। गेहूँ, चना और सोयाबीन की फसल के लिए मामूली रूप से उपयुक्त (37.55%), और कपास और अरहर की फसल के लिए 36.57 प्रतिशत, ज्वार के लिए 32.09% क्षेत्र उपयुक्त हैं। कुल 4585.2 हेक्टेयर (38.93%) क्षेत्र मिट्टी की गहराई, ढलान, **उपलब्ध जल की मात्रा** और पथरी**ली** की गंभीर सीमाओं के कारण अनुपयुक्त श्रेणी में हैं। विभिन्न फसलों के लिए भूमि उत्पादकता सूचकांक की पहचान उत्कृष्ट, अच्छी,औसत और खराब उत्पादकता वर्ग के तहत की जाती है। मिट्टी की गहराई और नमी की सीमा के कारण इन्हें खराब के रूप में वर्गीकृत किया गया है। भूमि मूल्यांकन विधियों (Sys and Riquier method) की तुलना से संकेत मिलता है कि Riquier विधि Sys मिट्टी.साइट उपयुक्तता विधि से बेहतर थी।

CHAPTER - I

INTRODUCTION

Soil is a finite resource; its loss and degradation are not recoverable inside a human lifespan. As a core component of land resources, agricultural development, and ecological conservation, it is the basis for food, feed, fuel, and fiber production, and for many critical ecosystem services (FAO, 2015). It is hence an important natural resource, yet, often overlooked. the natural area of productive soils is restricted – it is under increasing pressure of intensification and competing uses for cropping, forestry, pasture/rangeland, and urbanization, and to satisfy the demands of the growing population for food and energy production. soils need to be recognized and valued for their productive capacities along with their contribution to food security.

In a country like India, where an increase in population inside a limited geographical area is a fast-growing problem, crop intensification accelerates the decline in production. this in turn, creates myriad problems with respect to food availability in order to meet the increasing demand for food, the farming community has to produce more and more. However, under the present situation, where land has become a limiting factor, it is impossible to bring more area under cultivation to satisfy the growing demand (Fischer *et al.* 2002). The only probability to address such issues is to raise the production in a vertical direction for which study and understanding of soil properties and their distribution over an area has become necessary since the development of proper soil management plan and agrotechnology transfer (Buol *et al.* 2003).

Land use planning is one of the tools of soil management that supports sustainable use of soil and other natural resources within the management unit. It pursues basic steps *viz*. land resource evaluations, interpretation of socio-economic factors, integration of land resource database with socio-economic assessments, simulation of various crop models to extract absolute best cropping options with the economic viability and finally, a decision support system since the planners are able to take suitable decisions in relation to the ground scenarios. the necessity of developing comprehensive land use plans at different levels has been progressively felt and emphasized in different five years plans.

Modern agriculture concerns precise information on biophysical and climatic resources for sustainable land use planning. the unique features of soil are the basic characters that directly influence the soil response to any specified use. a significant natural resource depends on the life-supporting system of a country and the socio-economic development of its people. all the more so before, modern attention is being given to soils due to the suddenly go down land area for agriculture, go down soil fertility and extending soil degradation, incorrectly land-use policies, and irrational and imbalance use of input (Kanwar, 2004).

In this background of land use planning, geospatial techniques and models have been researched and developed for their influential use in the sustainable development of natural resources through the unification of various GIS layers, which ahead exhibit those geospatial techniques help in the generate of a reliable spatial and non-spatial information database (Khuswaha *et al.* 2010). Geospatial modeling techniques used for establishes different levels of biological richness have also been envisaged to be helpful in the planning of land uses and planning for sustainable use of natural resources (Chandrashekhar *et al.* 2003).

The NITI Aayog, Govt. of India has identified 150 most disadvantaged districts of the country based on prevalence of poverty indicated by population of oppressed castes/tribes (listed in the schedule by the Government), agricultural productivity per worker and agricultural wage rate. These districts are covered under the National Food for Work programme (Patil *et al.* 2016). Yavatmal, located in Maharashtra state, one of these 150 districts, is often considered epicenter of farmer suicides that have gripped the cotton growing states of India. The problem is widely viewed as a consequence of agrarianism distress. The literature is replete with many investigations blaming the indebtedness or lack of credit infrastructure for supporting the farmers (Deshpande and Prabhu, 2005; Suri, 2006; Sainath, 2007; Kale *et al*. 2011 and Murthy, 2013). Few reports blame the absence of sufficient social support infrastructure (Behere and Behere, 2008) at the level of the village and district.

TISS (2005) argues that repeated crop failures, inability to meet the increased cost of cultivation and indebtedness evolve a situation that forces farmers to commit suicide. The UN report propounds another reason, the subsidy provided by the developed countries like the USA to cotton-growing farmers drives international prices down leading to poor returns for Indian farmers. (Anon, 2016). A 2008 study report by the International Food Policy Research Institute (Gruere and Yan sun, 2012) found indebtedness of Indian farmers can be linked to many causes, including a lack of credible credit, proper modification in government policies, cropping patterns, plant and insect resistance to pesticides, and alterations in the crops planted on the farm also.

Remote sensing (RS) and photogrammetric techniques provide spatially explicit, digital data representations of the earth's surface that can be combined with digitized paper maps in Geographic Information System (GIS) to allow efficient characterization and analysis of vast amounts of data. Satellite remote sensing, in conjunction with GIS, has proved to be an extremely useful tool for natural resource management. Karla *et al*. (2010) stated that integration of remote sensing within a GIS database can decrease the cost, reduce the time and increase the detailed information gathered for soil survey.

Remote sensing (RS) data provide multi-spectral, multi-temporal and multi sensor information of the earth's surface and offers greater accuracy, economy and is more efficient in data collection and mapping of land resource than the conventional method (Venkatratnam, 1981; Kasturirangan *et al.* 1996). The development of remote sensing and GIS techniques has opened up new dimensions in mapping and monitoring of natural resources (Karale *et al.* 1986). Saxena 2003 has demonstrated the utility of high special resolution data in large-scale soil mapping, at watershed and village level.

GIS has been defined as a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes (Burrough, 1986). GIS enables effective and efficient manipulation of spatial and non-spatial characterization and mapping of soils for the benefit of local people (Star *et al*. 1997). In recent years, the application of GIS has increased many folds in various fields. The introductions of GIS promoted inter disciplinary studies, both within the natural, environmental, social and economic sciences. Its applications have expanded rapidly in parallel with advances in remote sensing and provides infrastructure for the examination of complex spatial problems in new and exciting ways (Asadi *et al*. 2012).

Remote sensing (RS) technologies and Geographic Information Systems (GIS) have been widely deployed for assessing irrigated crop area and asses groundwater potential (Prasad *et al*. 2008; Yeh *et al*. 2009; Machiwal *et al*. 2011; Patil *et al*. 2018) and in fact now widely used for governance. However, till date there is no research report that used RS and GIS for well census. To fill this information gap, we propose a simple, accurate and reliable RS and GIS approach to enumerate dug out/open wells with estimate of associated irrigated area that are georeferenced and built into the information ecosystem over a timeline to assist the groundwater managers as a decision support system/well information system. Anthropogenic activity is thus intense causing LULC changes, depleting groundwater resources. Sustainable management of available land and water 8 resources is thus a major challenge faced by the state.

Keeping this in view, the present investigation has been planned to do **"Resource based land use planning in Sawangi watershed of Yavatmal District, Maharashtra"**.

The study is undertaken with the following objectives:

- To build database of biophysical resources, social and economical information of Sawangi watershed of Yavatmal.
- To study the land use land cover dynamics of the watershed over the last decade.
- To suggest sustainable land use plan for the watershed in accordance with the available resources and socio-economic factors.

CHAPTER - II

REVIEW OF LITERATURE

The present investigation was carried out in Sawangi watershed of Yavatmal district, Maharashtra, to characterize and assess the land resources of the watershed for agricultural land use planning.

The extensive literature about has been made on the lines of objectives of the investigation is reviewed and discussed in this chapter under the following headings.

2.1 Inventory of bio-physical and socio-economic resources

2.2 Geospatial techniques

2.2.1 Land use land cover

2.2.2 Landform analysis

2.2.3 Soil mapping

2.3 Watershed characterization and interpretation

2.3.1. Soil-site characteristics

2.3.2. Soil characteristics and classification

2.4 Land evaluation for land use planning

2.4.1 Classical concepts of land evaluation

2.4.2 Land evaluation systems:

2.4.2.1 Land capability classification

2.4.2.2 Land suitability classification

2.4.2.3 Land productivity classification

2.4.2.4 Land irrigability classification

2.5 Wells and irrigated area mapping

2.6 New trends of land suitability evaluation

2.7 Land use Planning

2.1 Bio-physical and socio-economic data

2.1.1. World socio-economic data

Reenberg *et al.* (1998) reported the study from the Sahelian zone in Northern Burking Faso the relationship of the dynamic between the human utilization of land and alteration in the bio-physical environments and socio-economic conditions. there was found the illustrates the dynamics of the cultivation patterns at the village level and the changing priorities given to different landscape units over time. Field measurement, aerial photographs and satellite images from seven successive years were used to study the changes in land use pattern from 1988-1995.

Dembele *et al*. (2018) reported that in different agro-ecological zones in Southern Mali, Kenya. to establish Smallholder farmers' dynamics of integrating crop and livestock production systems, as well as the classification and trajectory of the systems. 134 smallholder farming households from three villages were selected for the study. from the Malian Company of Textile Development (CMDT) from 1961 to 2014 and 1974 to 2014. The dynamics of smallholder farmers were discovered, and they were divided into various classes or groups. There were five different types of smallholders identified. Type 1 consisted of super large families, which represents 14% of all smallholder farmers. Type 2 consists of large families and constituted 28%. Type 3 consists of medium-sized families which represented 28%. Types 4 and 5, were small and young families which accounted for 19 and 11 percent of smallholder farmers, respectively.

2.1.2. India socio-economic data

Das (2013) reported the current studies in various Indian states to establish the vulnerability profile of agricultural systems to changing climate scenarios. Bio-Physical and Socio-Economic, for example, are two sub-indices. It is found that four states like, Bihar, Nagaland, Sikkim, and Meghalaya have very high levels, followed by Arunachal Pradesh, Orissa, Manipur, Mizoram, Rajasthan, Tamil Nadu, Uttar Pradesh, Maharashtra, Assam, and Madhya Pradesh, which have high levels around 40%. Then there are five states (20%) that fall into the medium vulnerability category: Karnataka, Gujarat, Andhra Pradesh, West Bengal, and Jammu and Kashmir. while Haryana, Punjab, Tripura, Kerala, and Himachal Pradesh are among the low-vulnerability states (20%). Though one state (4%) Goa has a very low vulnerability.

Bhat (2013) studied effect of land use-land cover on the socio-economic status of Gangavali River Basin, Dharwad, and Uttarakannada districts of Karnataka. There was found to investigate that where the agricultural area is more, the growth rate of settlement and population is also more. Where agriculture is a significant occupation, female literacy is less. where the settled economy is noticed. In the central part of the basin female literacy is high due to a definite source of income. Economically the central part of the basin is better developed.

Pathak (2013) reported that the biophysical, socio-economic, environmental, and ecological parameters impact this watershed program. In the village of Gokulpura-Goverdhanpura in bundi eastern Rajasthan, India. It is found that the groundwater availability has substantially increased, significant increases in irrigated area, cropping intensity along with diversification of crops. It has been also greatly improved people's socioeconomic status, raising their income and lowering their poverty levels by creating good work opportunities and also decreasing migration of both skilled and unskilled labor. It has also enhanced environmental quality and ecological status by increasing the vegetative index or greenery, reducing runoff, soil depletion, and land degradation, and increasing biodiversity in vulnerable habitats. Overall, in addition to soil and water conservation and other beneficial environmental effects, provided resilience and numerous sustainable outputs.

Mondal *et al*. (2014) studied watershed-livestock linkages in the Bundelkhand region of Madhya Pradesh and there investigated a larger holding size per household and unit land area in watersheds than control villages. Land holding size and off-farm income were the significant factors, which impact livestock ownership as well as holding. Livestock enterprises contributed a very low share of income at both watersheds as well as control villages. There is a need to unified livestock improvement activities explicitly in the planning and implementation of watershed programs in the country.

2.1.3. State level socio-economic data

Dewangan *et al*. (2011) studied socio-economic empowerment of tribal women through sericulture a study in Lailunga block of Raigarh district, of Chhattisgarh. there found to the source of additional income generation was discovered. Sericulture employs more than fifty percent of the respondents who migrate between enter-states. According to the MNREGA (Mahatma Gandhi National Rural Employment Guarantee Program), the population should get 100 days of employment per year, but sericulture provides 151-200 days or 64%. Before accepting sericulture, the majority of agriculture was doing rearing activities (possibly 80%), with an average annual income of Rs. 19,350/- from the old occupation. The average monthly income produced by sericulture occupation-related families amounts to 3840/- comes from all sources. The total monthly expense for the families comes to around 2380/- from all sources.

Singh (2014) studied socio-economic status of Chilli growers of Abhanpur block of Raipur district, Chhattisgarh. There was found investigate the majority of the respondents (30.62%) were illiterate and others a backward class (96.88%), had a medium-sized family (75%) of six to twelve members, and had no membership in any organization (61.25%), indicating weak participation. According to the survey, 43.75 percent of respondents had a small landholding (up to 1 hectare). The majority of the respondents (61.25 percent) worked in farming (chilli cultivation), with 35% earning an annual income between Rs. 35,001 and 60,000. In terms of credit availability, out of the total respondents who had obtained credit, 100 percent had done obtained so without any difficulty.

2.2 Geospatial techniques

The geospatial technology involves the integration of Geographic Information System (GIS) and Remote Sensing (RS) techniques so that multi-dimensional geo-referred to data can be entered, manipulated, checked, analyzed, and displayed as the data referred to the earth (Burrough, 1986). The utilization of the Geographic Positioning System (GPS) during the soil survey gives a wide cluster of uses and facilitates the preparation of accurate and detailed soil maps and thematic maps of different physical and chemical soil properties.

GIS is an ideal tool to introduce soil survey information. The strength of GIS in comparison with the conventional soil maps lies in the way that GIS has many layers of geo-coded information which can be combined into one to have an integrated impact of at least two layers. Any kind of information can be recovered and, all the more importantly, any combination of information might be synthesized. For example, if the soil map is showing Great Groups as the mapping unit, one can call upon any Great Groups and request all such crops grown on this soil as well as the yield of a given crop. GIS along these lines has become a powerful tool and is being progressively utilized in the land-use planning process (Sehgal, 1996).

GIS, along with RS data, has become an integral part of soil mapping in current times. several researchers have detailed the utilization of GIS in soil resource inventory, land capacity classification, soil suitability assessment, and productivity assessment (Dwivedi, 2001; Srivastava and Saxena, 2004).

Soil resource inventory gives insight into the capabilities and limitations of soil for its effective utilization. Satellite, RS, GPS, and GIS have been giving new dimensions to monitor and manage soil resources for their effective utilization. Particularly remote sensing techniques have greatly reduced our fieldwork to a significant extent and soil boundaries are more clearly delineated than in traditional techniques. Thus, it is a more proven technology that is effective for mapping and characterizing land resources (Thilagam and Sivasamy, 2013).

A soil survey constitutes a valuable resource inventory that is related to the sustainability of life on the earth. Remote sensing and Geographical Information Systems have a boon for such surveys thanks to technical advances. The role of remote sensing and Geographical Information System (GIS) technologies in mapping and characterizing soils at various scales is discussed in this paper. The spectral behavior of soil and its components, which is crucial for extracting information from remote sensing data, is also discussed with illustrations. Fore, the scope of present-day remote sensing data is also examined for various levels of knowledge generation.

2.2.1. Land use land cover

Land use and land cover (LULC) is a significant component in understanding the interactions of human activities with the environment. Proper planning, monitoring, and management of natural resources depend on the availability of precise land use information. Remotely sensed data particularly satellite data can be effectively used in mapping as well as monitoring of temporal changes in land use land cover (Tagore and Shah, 2013).

Changes in the LULC have been observed since time immemorial, and have been related to both natural phenomena and human interference. Land-use changes are normal in the tropical areas where the growth of population is high and government needs to increase income through trade (Jorge and Missing, 2005). The FAO’s Global Forest Resources Assessment 2000 (FAO, 2001) estimated that during the 1990s 15.2 million ha of forest were cleared each year in the tropics. Most a large portion of the cleared land was utilized for cultivation.

2.2.1.1. World LULC change detection studies

Fan *et al*. (2008) studied of LULC change in core corridor of Pearl River Delta China (1998-2003). Based on remote sensing data, Over the study period (1998-2003), the rate of urban expansion increased from 169,078.32 to 184,146.48 ha (8.91%), and the farmland deficit increased from 312,069.06 to 293,539.95 ha (5.94%), where a large portion of forest and grassland converted into farmland and farmland converted into urbanization or expansion area accordingly.

Liu *et al*. (2011) detected LULC change dynamic in the Hun-Taizi River watershed, Northeast China from 1988 - 2004, based on RS and GIS technology. where found that the main land-use categories were Forest land, dry farmland, paddy, and shrubland. There Paddy and dry farmland were converted to the urban area and rural expansion areas, although urban and rural expansion areas expanded rapidly from 1988 to 2004, urban planning and ecological protection will be prioritized over the next 20 years.

Gautam *et al*. (2011) detected LULC change in the western part of Kabhrepalanchok district in Nepal from 1976, 1989 and 2000 by using RS and GIS technology. There investigated between (1976-2000) and there were found a broadleaf forest, conifer forest, and lowland agricultural area increased while shrublands, upland agriculture, and grasslands declined. While during the study period (1989-2000), shrublands increased and lowland agriculture also declined.

Kawy *et al*. (2011) detected LULC change in the western Nile delta of Egypt landsat images found over periods (1984, 1999, 2005 and 2009), where found that the area was converted barren land to agricultural land gradually 28 percent, 14 percent, and 9 percent in the periods 1984-1999, 1999-2005, and 2005-2009, respectively, to study for a sustainable development program, a review of supervision classification of the final result.

Forkuo *et al.* (2012) detected LULC change that the smallest forest conservation areas in Ghana from 1986-2007 based on NDVI classification and post-classification techniques. Where found between the period of 1986-2002 and 2002-2007 decline of forest cover approximately 2136.6 ha and 1231.56 ha, while decreased forest cover about 3368.16 ha in 1986-2007, and also decrease in vegetation had been as a result of anthropogenic activities, Other LULC conversions grassland to croplands 23.67 ha and sparse forest to croplands 109.53 ha, while 191.07 ha wetlands converted to build-up land, croplands to sparse forest land 17.37 ha, and sparse forest land to croplands 109.53 ha respectively.

He-Bing Hu *et al*. (2012) investigated land-use change characteristics in the Jiuxiang river watershed images over the past six years from 2003-2009 based on remote sensing and GIS technology. There found that the decline of arable land from 3695.53 ha (34.86%) to 2069.57 ha (19.52%), while the rapid increase of construction land was founded from 1887.26 ha (17.80%) to 2735.10 ha (25.80%). and other areas of land increases were in unused land, which increasing from 366.05 ha (3.45%) to 822.28 ha (7.76%) from 2003 to 2009. In order to achieve the sustainable use of land resources.

Alqurashi *et al*. (2014) detected LULC change in the unstable of urban dissemination in Makkah city and Al-Taif Saudi Arabia from 1986 to 2013 based on Landsat images. The change detection was carried out using GIS and post-classification comparison. In Makkah, the urban area increased by 17574 ha (174%) and in Al-Taif, it increased by 7391 ha (113%). Both Makkah and Al-Taif saw steady increases in vegetation cover, with 3145 ha (291%) and 5017 ha (262%) respectively. remote sensing satellite data can be provided Information play an important role of the relationship between population growth and LULC changes, for future planning and potential environmental impacts of consequences of urbanization.

Kafi *et al.* (2014) detected LULC change dynamically in the Bauchi North Eastern part of Nigeria over the decade from (2003-2013) based on remote sensing and GIS technology, where investigation, it was found that all LULC areas, such as farmland and other land areas, had increased over time. the farmland decreases up to 178% between 2003 to 2013. While built-up area increased up to 138% over the decade.

Mengistu *et al.* (2014) carried out LULC change detection in parts of south-western Nigeria over a 16-year period of 1986 to 2002 based on Landsat images, RS, and GIS techniques and were found that observed major part of the area was degraded forest, high forest, and montane forest areas which covered about 49.6%, 30.6% and

3.4% in 1986 and 48.7%, 28.1% and 2.4% in 2001; the area was scrubland covered about 2.7%, in 1986 and 14.0% in 2001; bare land covered about 1.0%, in 1986 and 3.0% in 2001; derived savanna land covered about 12.6%, in 1986 and 3.5% in 2001; water body covered about 0.099%, in 1986 and 0.12% in 2001.

Hassan *et al*. (2016) studied LULC changes over the year 1992 to 2012 using RS and GIS in the northeast of Rawalpindi, Islamabad, Pakistan. Where it was observed that the built-up area, agricultural areas, and water bodies increased, while the forest and barren areas decreased significantly, indicating that the forest and barren land was rapidly transformed into urbanization, causing extensive environmental degradation in the study area.

2.2.1.2. India LULC Change detection studies

Mahajan (2005) studied LULC changes detection in Ashwini khad watershed mid hill Himachal Pradesh, India Over a period of 20 years during 1979-1999 using RS and GIS technology. Where investigated the agricultural region, which increased from 13.23 to 28.62 sq. km. Both the forest and wasteland areas decreased from 11.98-10.17 sq. km and 60.09-46.51 sq. km respectively. The agricultural area was converted to wasteland and wasteland to agriculture. Whereas forest area was encroached for agriculture use over a period of time (1979-1999).

Deka *et al.* (2014) studied LULC changes detection in Kamrup district of Assam from 1991 - 2011 on the basis of RS and GIS technology. There were observed built-up area increased by 45.82 percent, while the area under wetlands declined by 39.45 percent and over the same time span, area of scrublands increased by 30.70 percent, and also croplands increased by 4.16 percent.

Mondai *et al*. (2014) studied LULC change of Lower Gangetic Basin highly populated areas of India over a period of 20 years 1985-2005 based on Landsat and IRS images. There most important conversion has been to built-up land, with agricultural land (515 sq. km) and scrubland (53 sq. km), and other land converted were from agriculture to plantation (247 sq. km), fallow to scrubland (838 sq. km), and from water body to scrubland (407 sq. km) respectively.

Pandian *et al*. (2014) studied LULC changes detection in Coimbatore and Tiruppur, India during 2000-2009 based on RS and GIS technology, found over the year, the agricultural area decreased from 33.9 per cent to 26.3 per cent, while the fallow land area increased from 43.9 per cent to 54.5 per cent, and the built-up area increased from 0.1 per cent to 0.3 per cent.

Lakshmi *et al*. (2016) studied LULC changes in Papagni River, Andhra Pradesh, India during from 1973-2012 using RS images and GIS technology. Found that the area was increased gradually in mining, scrub, settlement, plantation, cropland from 0.02 to 0.07%, 0.82 to 4.1%, 0.10 to 0.42%, 1.46 to 3.64% and 35.12 to 60.27%, respectively. while water bodies, forests, and barren rocks were declined from 3.11 to 1.40%, 58.73 to 29.89, and 0.60 to 0.18% respectively. Minor changes were observed between 1973-1992, with mining activities and agricultural production area increasing, but significant changes occurred between 2001-2012.

Singh *et al*. (2016) carried out LULC change detection in Lower Assam, India during the year 1990-2014 by using RS images and GIS technology. and found investigated in the agricultural area increased from 78.53 per cent to 84.30 per cent, while the forest area decreased from 43.9 per cent to 54.5 per cent and the wetland area decreased from 3.75 percent to 0.79 percent. However, the area under water bodies decreased by 7.26 to 7.36 percent, between the year 1990-2014.

Vishwakarma *et al.* (2016) studied the LULC change in Sonbhadra district of Uttar Pradesh and Singaruli region of Madhya Pradesh over a period of 23 years from 1991 to 2014, there result found during 1991 to 2000 and 2000 to 2014, the forestland has by 1.74 per cent and 5.83 per cent, respectively, while the overall improvement in forest area was 7.57 per cent from 1991 to 2014. The area was increased of mining by 1.62 per cent. and also increased agriculture land, built up area and scrubland. while, barren land and forestland decrease from 1991 to 2014.

Ashwathi *et al.* (2017) studied LULC change detected in western Ghats of South India for three time periods 1990, 2002 and 2008 based on using RS images and GIS technology. which found that the forest area was decreased from 220.014 sq km to 184.53 sq km during 1990 to 2008 over the period. Agricultural land increased from 26.03 to 40.32 sq km, while built-up land increased from 14.50 to 41.71 sq km, and also plantation crops increased from 106.27 sq km to 138.20 sq km during this period.

Kaliraj *et al*. (2017) studied LULC change and transformation of Kanyakumari coastal, India, from 2000-2011 based on using RS images and GIS technology. There findings show that the area of beach face land cover, plantation, cultivable land, fallow land, and barren land was converted into built-up land and increased by more than twice in the last decade. The beach face land cover area of 1.24 sq. km is encroached for built up and 0.63 sq. km for placer mining in the period of 10 year. Whereas, the area of 0.21 sq. km is converted into wetland and salt water bodies.

Kumar *et al*. (2017) studies LULC change detected in Kamrup district of Assam, India in year from 1977-2010 based on using RS and GIS technology. where that agriculture land and dense forest declined by 32.23%, 24.13%, and 21.68% respectively, and fallowed by 29.08%, 23.83%, and 22.34%. Whereas Open Forest and urban settlement land acreage, on the other hand, increased by 14.75%, 19.42%, and 2.06% and fallowed by 12.18%,21.48%, 24.57%. over the 34-year period 1977, 1987, and 2010.

Thakur *et al*. (2018) investigated the LULC change on hydrologic characteristics over the year from 1989-2011 by using RS, GIS and Arc SWAT observed that increased was evapo-transpiration by 2.21%. whereas, total water yield was decreased by 6.90 %, and also approximately decreased were yearly wise surface runoff and total aquifer recharge by 1.62 % and 8.13% over the time.

Duraisamy (2018) studied LULC changes detection in semi-arid region of Maharashtra during the year from 1991-2016 based on Landsat and IRS images. where found identified some part of fallow and uncultivable lands was converted into agricultural land. The overall increase in agriculture area was 98%. and, also the built-up area increased by 195% respectively. The cultivated area inside the Rabi season increased by 60% and also increased area under plantations by 16.01% respectively.

2.2.1.3. State level LULC detection studies

Joshi *et al*. (2007) studied LULC change in Raigarh district, northern Chhattisgarh, India in the year from 1972 to 2004 based on RS images and GIS technology. The area covered by forests and agriculture decreased from 563.67 (31.84%) and 1206.88 (68.16%) sq. km to 242.07 (13.33%) and 1175.52 sq. km, (64.07%) respectively. Areas of forest and Agriculture have been converted into industrial, barren, and wasteland areas.

Singh *et al.* (2014) studied LULC change detection over the period from 2006-2012 for Durg block, situated in Durg district of Chhattisgarh. where observed major part of the area was agricultural land decreased from 395 sq. km to 388 sq. km and also with decreased wasteland area from 97 sq. km to 93 sq. km. While built-up area increased from 123 sq. km to 134 sq. km respectively during this period.

Khan *et al.* (2016) studied LULC change detection in the Raipur municipal corporation, Raipur, Chhattisgarh during the year from 1999-2016 using remote sensing and GIS and found tremendous change in LULC in 2016.The area settlement, industry, open land and the area of roads were increased followed by 27.5 per cent to 43.1 per cent, 2.1 per cent to 5.2 per cent, 3.7 per cent to 6.1 per cent and 2.8 per cent to 3.7 per cent. While area under cultivation, Vegetation, Drainage and Lake declined respectively followed by 56.8% to 37.9%, 2.9% to 2.5%, from 2.3% to 1.5% and 2.2% to 1.4%.

2.2.2 Landform analysis

Landforms are formed by geologic and geomorphologic processes that occur on the surface of the earth. The term landform was used by geoscientific modelers to describe a portion of the earth that unites the qualities of homogeneous and continuous relief due to the action of common geological and geomorphological processes

(Crevenna *et al.* 2005) described and quantified landforms into simple relief elements by parametrization of digital elevation model (DEM).

Information on terrain characteristics is critical for explaining geographical constraints and mapping of natural resource variability in order to maintaining sustainable land management and support decision-making processes (Zawawi *et al.* 2014). Understanding the topography of the area and identifying the most suitable sites for different land uses requires combining landform analysis with additional information such as surface geology and soil data.

2.2.2.1 World landform studies

In the 1950s, the digital terrain model (DTM) was first used in the geosciences (Miller and Laflamme, 1958). Many studies have been carried out to map the variability of natural resources and landform classification to evaluate land capabilities.

Dikau (1989) studies had previously introduced an approach to identify plateau, convex scarps, valleys and crests. Gardner *et al*. (1990) developed methods to extract terrain features while Azanon *et al*. (2001); Bailey (1987) and Cheng *et al*. (2005), Using topographical parameters and cluster analysis, he suggested a method for dividing land into ecosystem units. Other significant studies include Dragut and Blaschke (2006), who used object-based image analysis to classify landforms, and Manap *et al*. (2010) who had extensively applied the capability of RS in identifying terrain features. Topographical variables and the Digital Terrain Model are highly accurate, making them ideal for land classification, especially for site assessment and land use planning (Fabian, 2004; Yanni, 1996). However, several of these classifications necessitate additional steps and the extraction of various primary terrain attributes as inputs to classification processes.

Zawawi *et al*. (2014) carried out landform classification for site evaluation and forest planning in Yambaru forest area in the northern most part of Okinawa Island, Japan. observed ten landform classes *viz*; high ridges, midslope ridges, upland drainage, upper slopes, open slopes, plains, valleys, local ridges, midslope drainage and streams.

The ‘topographical position index' module was used to construct groups, and selected terrain variables were combined with vegetation data for site evaluation.

2.2.2.2 India Landform studies

Singh (1998) investigated was carried out by the classification of landform in Lower Gangetic Plains of West Bengal, India based on the using RS and field survey studies. where identified the Three major landforms such as Uplands, Old Fluvial Deltaic Plains and Young Fluvial Plains.

Khan and Singh (2000) apparent investigated the physiographic Characterization and Mapping of Soil Resources for Watershed Planning in Arid Western Jodhpur, Rajasthan, India using IRS LISS-II (1995) FCC (1:50,000) of spectral bands 2, 3 and 4. Identified seven major physiographic landform units such as hills, pediment-flat to undulating, buried pediments, older alluvial plains, younger alluvial plains, and dune complexes.

Potdar *et al.* (2003) studied physiography map of Nanda-Khairi watershed, Nagpur district, Maharashtra using FCC of IRS-IC (LISS-III) data. Based on the physiography-soil relationship groups were identified and delineated six physiographic classes such as plateau/summits, escarpment, upper foot slope, lower foot slope, upper alluvial plain, and lower alluvial plain.

Srivastava and Saxena (2004) studied was carried out in Junewani village of Hingna, Nagpur district, Maharashtra Based on using IRS-1C PAN data and SOI, toposheet (1:50000 scale), to describe a physiography land use (PLU) map based on various approaches, such as landforms, slope, and land use characteristics of a given parcel of land, and also the PLU–soil relationship also helps to clarify the variation in soil phases. In addition, five landform classes were identified such as plateau top, escarpment, pediments, upper and lower alluvial plains.

Maji *et al*. (2005) investigated the classification of landform and soil characteristics of Ringnabodi watershed of Nagpur, in sub humid tropical of central

India Based on using IRS-1C LISS-III and GIS data, and were identified the dominant landforms units such as summit crest, escarpment, foot slopes, denuded plateau, isolated mounds, upper piedmont, lower piedmont, and narrow valley floor.

Solanke *et al.* (2005) delineated the physiography classes map of Ganeshpur micro-watershed near Nagpur district, Maharashtra using IRS-1 PAN merged LISS-III data with SOI toposheet. Based on the physiography-soil relationship, identified there were four major soil physiographic units like, plateau top, escarpment, pediment, and valley, which were further subdivided into different sub-classes based on slope and image characteristics.

Velmurugan *et al*. (2009) studied the physiographic analysis and soil resource mapping of Solani watershed Haridwar district, Uttarakhand using Landsat, RS images and GIS technology. Where different physiographic units were identified like that Alluvia plain, Piedmont, Siwalik hill, Residual hill, and River. The relationship between physiography and soil development was well-defined in this research.

Martin *et al.* (2010) studied physiography classes map the Garhwal hills of Himalayan region Uttarakhand, India using GIS and 1:50000 scale was generated for physiographic map. and identified were four major landforms units such as, hilltops, hillside slopes, valley, and pediments. Which were further divided into 14 physiographic land classes based on drainage, aspect, slope gradient, land use, and terrain feature.

Wadodkar and Ravisankar (2011) delineated the physiography map on the basis RS -1 LISS-IV + Cartosat-1 data in Mohammadabad village, Nalgonda district, Andhra Pradesh. and there identified were four major physiographic units such as hills, undulating plain, gently sloping plain and valley.

Pachpor *et al.* (2012) interpreted the physiographic characterization and mapping of soils in Savli micro-watershed Nagpur, Maharashtra, India based on the using IRS-P6 LISS-IV data, FCC (1:50,000) along with SOI toposheet. They identified were five major physiographic landform classes such as, plateau, escarpment, pediments, alluvial plain, and narrow valley, and also suggested suitable soil and water conservation measures for land resources management.

Nasre *et al.* (2013) studied the soil physiographic characterization and soil map of Karanji watershed, Yavatmal district, Maharashtra by using IRS- P6, LISS-III, (1:50000 scale) and GIS technology. They identified seven different landform units such as plateau top, escarpment, isolated hillock, foot slopes, undulating land, alluvial plain, and valley.

Sahu *et al.* (2014) interpreted the physiography map of Miniwada panchayat, Nagpur district, India on the basis of using IRS-P6 LISS-IV and Cartosat-1 DEM data of two seasons. They identified were seven different major landforms units such as, plateau top, scarp slopes, plateau spurs, pediment, undulating plains, valley, and floodplain.

Gangopadhyay *et al*. (2015) interpreted the landform characterization and classification of Subarnarekha catchment, Chhotanagpur plateau Medinipur district, West Bengal based on using FCC, (1:50,000 scale) of IRS-ID LISS-III. Which was found five landforms unit such as, moderately steeply sloping upland, moderately sloping undulating upland, moderately sloping terraced land, gently sloping low land, and narrow valley bottom.

Nagaraju *et al.* (2015) interpreted by the physiographic characterization and evaluation of land resource management in Saraswati watershed, Buldhana, Maharashtra, India using IRS- P6, LISS-III, and GIS technology. They identified four physiographic units such as plateau, pediments, broad and narrow valleys.

Sahu *et al.* (2016) studied was carried out the Soil Resource Mapping Using IRS-P6 LISS-IV and Cartosat-1 DEM in Miniwada Panchayat comprising three villages in a basaltic terrain of Central India. and they identified eight major physiography units such as plateau top, scarp slopes, plateau spurs, pediment, undulating plain, broad valley, narrow valleys, and floodplain.

Potdar *et al*. (2017) studied the carried out Physiographic Characterization and management of land recourse on the basis of using IRS-LISS- III, IV, and GIS technology in Shegaon watershed of Chandrapur district, Maharashtra. They identified and mapped six major landform units such as isolated mound, subdued plateau, upper pediment, lower pediment, upper plane, and lower plane.

Sarkar *et al*. (2017) studied the Physiographic Characterization and soil mapping for sustainable development of Chorgali village in hora block, Puruliya District, West Bengal using RS and GIS technology. they identified different landform units such as upper Pedi plain, lower Pedi plain, toe slope, foot hill slope, and depression. and also, the thirteen-soil series with twenty-six mapping units were identified.

Borse *et al*. (2018) studied the physiographic characterization, classifying, and estimated the land resources by using IRS-LISS-IV and GIS in Barela village of Seoni district, Madhya Pradesh. They identified five major landforms units such as plateau top, escarpment, isolated mound, pediment, and alluvial plain.

Meenakshi *et al*. (2018) studied the classification of landforms and soil mapping of Pannur North-3 micro watershed Manvi Taluk, Raichur, Karnataka using cadastral map (1:50000 scale) with RS-1 PAN, LISS IV, and GIS. the landforms and other surface features were discovered in three distinct landform units such as upland, midland, and stream slope.

Patangray *et al*. (2018) studied the Physiography Characterization, classification, and landform map of Kupti watershed of Yavatmal district, Maharashtra, India using SOI toposheet (1:50000 scale), with RS and GIS technology. Where identified various major landform units such as Plateau top, Pediment, Upper Alluvial plain, Lower Alluvial plain, Escarpment, Isolated Hillock, and Drainage

Chandrakala *et al.* (2019) studied the generated soil mapping have been taken of different landform classes by using RS and GIS technology in Elamdesam tahsil, Idukki, Kerala. Where identified the different landform units such as foot hills, high hills and midlands, and low land region of rubber growing soils of Kerala qualify as Ultisols or Inceptisols (Endosaturation).

Ingle *et al*. (2019) studied the landform catheterization, classification, and evaluation in Bareli watershed, Seoni district, Madhya Pradesh Based on the IRS - LISS - III image, cartosat -1 DEM, and GIS technology. where identified five major landform units such as plateau, escarpment, isolated mound, hills/ridges, and pediment.

2.2.3 Soil mapping

Understanding soils in terms of their extent, distribution, characteristics, potentials, and constraints is critical for land use planning. Past research and development efforts have developed remote sensing as a highly accurate, efficient, and cost-effective tool for soil resource appraisal. Soil mapping is the process of identification, description, and delineation of various types of soils based on field morphological observations and laboratory investigations (Challa *et al*. 1995).

National Bureau of Soil Survey and Land Use Planning, Nagpur has produced soil resource maps on a 1:250,000 scale for various Indian states using a three-tier method. *viz*. landform analysis using Landsat MSS data, field surveys and laboratory investigations and cartography and printing. A field manual on soil resource mapping for different states in India was prepared to ensure uniformity in the method (Sehgal *et al.* 1987).

2.2.3.1 Soil Mapping studies in abroad and India

Challa *et al.* (1995) prepared the soil map of Maharashtra on a 1:250,000 scale using three-tier approaches viz. landform analysis using Landsat MSS data, field surveys and laboratory investigations, cartography, and printing. The soils were mapped as soil family associations. In total, 356 mapping units with 5 orders were discovered in the state (Entisols, Inceptisols, Alfisols, Vertisols, and Mollisols), 8 sub-orders, 9 Great Groups, and 19 sub-groups.

Khadse (1999) prepared the soil map of Dham catchment area of Wardha district, Maharashtra on 1:50,000 scale using visual interpretation of satellite data (IRS-1C LISS-III). following that would be ground truth verification, and laboratory analysis. they identified 22 soil series in the area and mapped them as soil series associations.

Khan and Singh (2000) studied IRS LISS-II FCC (1:50,000) of January 1995 of spectral bands 2, 3, and 4 for mapping of soils of the arid watershed in Jodhpur district, Rajasthan. on the basis of physiographic variation and soil-site characteristics such as texture, depth, slope, erosion, and underneath the substrate 41 soil mapping units were defined and mapped on a 1:50,000 scale.

Bodhankar *et al*. (2002) prepared soil map of Dewadkasha watershed in Nagpur district, Maharashtra using geo-coded false colour composite (FCC) of IRS-1C. Based on physiography-soil relationships, the twelve-soil series were tentatively identified in the area and delineated as an association of soil series.

Potdar *et al.* (2003) prepared physiography map of Nanda – Khairi watershed of Nagpur district, Maharashtra using geocoded false colour composite of IRS-1C. Based on the physiography soil relationship were identified seven soil series and mapped as the association of soil series.

Kashiwar *et al.* (2009) prepared physiography map using FCC of IRS-1D LISS-III and PAN sharpened LISS-III in conjunction with SOI toposheet in Salai watershed of Nagpur district, Maharashtra. where 8 soil series were identified and mapped.

Nasre *et al.* (2013) studied used IRS-P6 LISS-IV and LISS-III (1:50000 scale) satellite data from two seasons to build a soil map of the Karanji watershed of Yavatmal district, Maharashtra.

Nagaraju *et al.* (2014) used a high-resolution DEM with a posting of 10 m generated from a Cartosat-1 stereo pair to derive terrain attributes. where identified nine soil series and a detailed soil map was developed soil series information and augur observations based on physiographic land use – soil relationship.

2.3 Watershed characterization and interpretation

The drainage basin analysis is important in any hydrological investigation such as assessment of groundwater potential, groundwater conservation, pedology, and environmental assessment. Hydrologists and geomorphologists have recognized that some relationships exist between run-off characteristics and drainage basin system geographic and geomorphic characteristics (Rastogi and Sharma, 1976). Various important hydrologic phenomena can be correlated with the physiographic characteristics of drainage basins such as size, shape, the slope of drainage area, drainage density, size and length of the contributories, etc.

Identification of drainage networks inside basins or sub-basins can be achieved utilizing traditional methods, for example, field observations and topographic maps or alternatively with advanced methods using RS and GIS (Sreedevi *et al.* 2009). In traditional methods, it is difficult to examine all drainage networks from field observations due to their extent throughout rough terrain and/or vast areas. In India, some of the recent studies on morphometric analysis using remote sensing and GIS technique were carried out by Kumar *et al.* (2000), Srinivas *et al*. (2004), Chopra *et al.* (2005) and Vandana (2013).

2.3.1 Soil-site characteristics

The flow and distributions of natural fluxes of rain water, nutrients, eroded soil, microflora, fauna and energy occur within boundaries of naturally defined hydro-geological unit of a watershed (Samra, 2002). Watershed characterization is required to understand the potential and constraints of the existing natural resources and the integrated management of all the resources to harmonize their synergies for maximum economic and conservation benefits. The characterization of watershed involves studying its site characteristics and various morphological, physical and chemical properties of soils.

Biswas and Gawande (1962) studied catenary soils of Chhattisgarh basin of Madhya Pradesh and they reported that the soils of these regions differ widely in their characteristics along slope gradient. The position in the toposequence influences the morphological, physical, chemical, and mineralogical properties of soils. Biswas and Gawande (1962) studied catenary soils of Chhattisgarh basin of Madhya Pradesh and they reported that the soils of these regions differ widely in their characteristics along slope gradient. The position in the toposequence influences the morphological, physical, chemical, and mineralogical properties of soils.

Sehgal *et al*. (1991) studied the assessment of Soil-Site Suitability for Cotton crops of Swell-Shrink soils of Khapri watershed Nagpur, India. Various important hydrologic phenomena can be correlated with the physiographic characteristics of drainage basins such as size, shape, the slope of drainage area, drainage density, size and length of the contributories etc.

Kharche *et al.* (1995) reported that the assessment of Soil-Site situation for the Suitability of Rubber crops in Kerala and Tamil Nadu district. The effects of moisture availability (LGP), followed by soil depth, PAWC, slope, winter temperature, and excess rains, were established as major constraints for rubber output yield when developing criteria for the crop's soil-site suitability.

Patil and Prasad (2004) characterization of soils in Dindori district of Madhya Pradesh It was observed that soil on flat-topped hills' foot slopes was very dark greyish brown, that on scarp slopes was dark brown to dark reddish brown, and that soil on flat-topped hills and hill slopes was dark brown on the surface and dark reddish brown to red in the sub-surface.

Maji *et al*. (2005) investigated the classification of landform and soil characteristics of Ringnabodi watershed of Nagpur, India. The location of the topographic changed as the soil depth changed, according to the study. Dark brown, dark brown to very dark grey and very dark greyish brown soil has improved at both high and low elevations.

Prasad *et al*. (2009) studied the Soil suitability for crops of Selsura research farm in Wardha district of Maharashtra. In calcareous and clayey soils, very dark grey to very dark greyish brown soils were identified and classified as *Entisols*, *Inceptisols*, and *Vertisols* in different depths. then identified nine soil series and thirteen mapping units.

Dash *et al*. (2019) studied the morphometric analysis purpose planning and management of soil and water conservation using RS and GIS techniques in Baruband watershed, Seoni district of Madhya Pradesh. Where observed indicated has low drainage density, permeable subsoil, and flatter peak runoff for a longer duration which can be easier to handle as compare to circular shape basin. Soil can be used to make site-specific decisions about soil and water conservation measures, as well as artificial groundwater recharge systems.

2.3.2 Soil characteristics and classification

Prasad *et al*. (1995) reported that the characterization and classification of soil for the development of soil from basalt on the spur of Western Ghat, Nasik district of Maharashtra, India. Based on morphological and Physico-chemical properties, and there found that the soils were classified under hot-humid climate were dark reddish brown colour with the argillic horizon and Typic Rhodustalfs. While under sub-humid climate were very deep, dark reddish brown, clayey and Typic Ustochrepts. The piedmont plain's very deep, relatively well-drained clayey and Chromic Haplusterts were also found in a semi-arid climate.

Khan and Singh (2000) studied the characterized and mapped for soil resources of Arid-watershed in Jodhpur district of Rajasthan based on the Physico-chemical characteristics of the soil. where identified and classified were dominant soils such as Para-Lithic Torriorthents, coarse-loamy, Lithic / Typic Haplosalids, and Typic Torrifluvents and Typic Torripsamments.

Satyavathi *et al*. (2004) studied the appraisal for soil-site suitability of major soil in telangana region of Andhara Pradesh. The soil order was identified as *Vertisols*, *Inceptisols*, *Alfisols,* and *Entisols*. The most significant constraints were drainage and texture in Vertic Haplustept, Typic Haplusteets and Chromic Haplusterts in all major crops. Whereas, in all soils, drainage, texture, coarse fragment, soil depth, pH, and organic corban are for crop growth. Reclamation measures of the soils can be changing the improved soil-site suitability classes.

Muthumanickam *et al*. (2010) reported the characterization and classification of soil Kangeyam tract, Erode district, Tamil Nadu. The soil was classified into *Entisols, Inceptisols* and *Alfisols* based on the Morphological, Physical, Chemical and Exchangeable properties for development of physiographic-soil relationship, and the soil was found to be shallow to deep, poorly to moderately well drained, and of varying colour and texture.

Sankar *et al*. (2010) studied the detailed soil survey (1:5000 scale) of Kutturavupatti village in Sivagangai district, Tamil Nadu. On the basis of morphological, physical, and chemical properties, these soils were classified into two orders such as *Alfisols* and *Inceptisols*. there identified were that the soils of the Sivagangai series had more than 70% gravel content, more than 10% free CaCO3, and a pH of 8.3.

Katariya and Bhakare (2013) studies was undertaken to characterize, and classify the soils of water management project in MPKV, Rahuri, Ahmednagar district of Maharashtra. the soils were studied clayey to silt clay loam in texture, and they range in colour from brown to dark yellowish brown, dark grey to very dark greyish brown, and dark yellowish brown to very dark greyish brown. The soil pH was moderately alkaline in nature, organic carbon was in the medium to high range, available N was low, available P was medium to high, and available K was high. Based on soil characteristics, the soils are classified as Vertic Haplustept, Typic Haplustept, Fluventic Haplustept, Typic Haplustert.

Nasre *et al*. (2013) reported that the soil Characterization and Classification of Karanji watershed, Yavatmal district, Maharastra. On the basis of the development of soil profile and diagnostic characteristics, they classified the soil classes as Lithic Ustorthen and Typic Ustorthens, Typic Haplustepts, Vertic Haplustepts, and Sodic Haplusterts. and also reported the soils developed on plateau tops, escarpments, isolated hillocks, and foot slopes were very shallow to shallow, loamy to clayey, well-drained, and moderately to severely eroded, whereas soils developed on undulating lands, alluvial plains, and valleys were deep to very deep, fine to very fine in texture, moderately well drained, and slightly eroded. The soil colour, in general, is 10YR in hue and at places (plateau top and foot slope) exhibited 5YR with chroma 1 to 3 and value 3 to 5.

Ram *et al*. (2014) studies the soil characterized and classified for sustainable land use planning in Markapur, Prakasam district, Andhra Pradesh. Observed that the soils of hillside slopes and undulating pediments formed over quartzite, sandstone, and shale complex were shallow to moderately deep, brown (7.5 YR 4/4) to dark brown (7.5 YR 3/4) in colour, whereas the soils were under forest, open scrub and rainfed farming in patches. The soils in the pediplains and stream bank ranged from yellowish red (5 YR 4/6) to dark reddish brown (5 YR 3/3), were deep to very deep low fertility, and were cultivated in the pediplains but waste land in the stream bank.

Pulakeshi *et al*. (2014) studied the soil resources to characterize, and classify based on morphological and physico-chemical properties of Mantagani village in northern transitional agro-climatic region of Karnataka. There identified had been a silty clay texture, an alkaline reaction, and a low salt content. in which the most abundant cations were calcium and magnesium, followed by sodium and potassium. The soils were identified in the following order *Vertisols, Alfisols, Inceptisols*, and *Entisols*.

Adhanom and Toshome (2016) studied the topography characterization and classification of the soil of Aba-Midan sub-watershed in Bambasi Wereda, West Ethiopia. The soil was classified as Mollic Nitisol based on the morphological, physical, and chemical properties of the pedons. The surface horizons of all the pedon mollic epipedon. While the middle and lower pedons had isolated clay increment in the B horizons, which was found all of the natic horizon, and the upper sub surface pedons with cambic horizons. Further the soil was also found to be dark reddish brown (10YR 4/2) to dark red (10YR 3/6) in colour and shallow to moderate in depth. The pH of the soils ranged from mildly acidic (pH: 5.2) to moderately acidic (pH: 5.5). (pH: 6.4) with bulk density ranging from (1.14 to 1.49 gm/cm3) and prismatic to sub angular blocky structure, Low total porosity found that the soils have poor physical conditions for plant growth.

Gurav *et al*. (2017) studied the swell-shrink characterization of *vertisols* of Agro-ecological zone of India. there found that the soil of the sub-humid zones was referred as Typic Haplustert, while the soil of the semi-arid zone was Typic/Sodic/Calcic Haplustert, and the soil of the Aride zone was Sodic/Calcic/Aridic Haplustert. And also recognized the characterized all *vertisols* were dark brown colour, clay texture in calcareous these soil have high bulk density and high water retention capacity, these soil were dominated by Ca^{2+} ion and there exchangeable complex around the depth, however, in the sub-humid environment dominant Mg^{2+} ion in the lower horizons, while the simi-arid dry soil were more Na+ ions in exchangeable complex around the depth, The soil was alkaline in nature, ranging from slightly alkaline to highly alkaline, with low organic matter. In the Panjari soil series, the CEC varies from 59.3 to 68.2 cmol (k+) kg^{-1}, followed by the Teligi series profile, where the calcium carbonate ($CaCO_3$) gradually increases with depth in all soil profiles.

Borse *et al*. (2018) studied the characterization, classifying and evaluation of land resources management in Barela village of Seoni district, Madhya Pradesh. The identified five soil series such as clayey soil texture, shallow to moderately deep depth, moderately to well drained, and moderate to extreme erosion. The soils are neutral to slightly alkaline in reaction and non-saline for Lithic Ustorthents/ Typic Haplustepts/ Typic Haplusterts at subgroup level.

Ghode *et al*. (2018) studied the Characterization, classification and evaluation of cotton growing soils of Nanded District, Maharashtra. The identified that the soil pH was slightly to moderately alkaline, the texture was loam to clay, the depth was shallow to deep, and the colour ranged from black (10 YR 2.5/1) to very pale brown (10 YR 7/4) in colour. Low too high in organic carbon, whereas low to very high in calcium carbonate, and high in cation exchange capacity and the Taxonomically classes were classified as Typic Ustorthents, Typic Haplustepts and Typic Haplusterts and Calcic Haplusterts.

Meenkshi *et al*. (2018) studied the characterization and classification of soil in Pannur North-3 micro watershed, Manvi block, Raichur district, Karnatka. They were identified soil depth ranged from moderately deep to very deep, colour several from dark brown to dark gray. Texture was seen almost to be clay, surface structure was moderate, medium, subangular blocky, while in subsurface structure ranged from moderate, medium, angular blocky to strong, coarse, angular blocky. Consistency several ranged from slightly hard to hard, very hard, friable to firm, slightly sticky to very sticky and slightly plastic to very plastic under dry, moist and wet condition, and also found the soil was ranged from moderately alkaline to alkaline, EC and organic matter ranged from low to medium, (CEC), ESP and base saturation ranged from 45.1 to 62.4 (cmol (P+) kg1), 7.88 to 8.93 percent, and 91.86 to 94.69 percent, respectively in all the mapping units.

Patangray *et al*. (2018) studied the soil characterization and classification in Kupti Watershed of Yavatmal district, Maharashtra. There identified were ten different soil series then showed that the soil is shallow, shallow to slightly deep, and very shallow to moderately deep followed by escarpments, pediments, and plateau, the soil was grouped under Lithic Ustorthent/ Vertic Haplustepts of the watershed.

Narsaiah *et al*. (2018) studied the characterization and classification of soil in Jangon district, Telangana based on morphological, physical and physico-chemical properties. There identified the soil colour as relatively deep to very deep, reddish brown to dark reddish brown, as well as the soil structure as granular and sub-angular blocky and the soil texture gravelley sand to clay. While rising clay content along with depth in all pedons and also, were the classified of soils as Typic Rhodustalfs, Typic Haplustalfs, Typic Haplustepts, Calcic Haplustepts, Vertic Haplustepts and Typic Haplusterts.

Ingle *et al*. (2019) studied the Characterization, classification and evaluation of land resource mapped in Bareli watershed of Seoni district, Madhya Pradesh. There at higher elevations, the soils are shallow, clayey well-draining, and heavily eroded, while at lower elevations, the soils are moderately deep, clayey moderately well-draining, and mildly eroded. Sustainable development for better management of land resources in the watershed has included appropriate land use indentation and soil and water conservation measures.

2.4 Land evaluation for land use planning

Assessment of site and soil characteristics for their suitability with respect to different types of agricultural land use has been carried out for many decades. Many concepts and methods have been developed over a period of century to evaluate land suitability for various agricultural uses. The classical and modern methods for land suitability evaluation are reviewed in this section.

Land evaluation is a process of predicting land performance over time according to the specific types of use (Martin and Saha, 2009). Agriculture land suitability assessment is defined as the process of assessment of land performance when used for alternative kinds of agriculture. The principal purpose of agriculture land suitability evaluation is to predict the potential and limitation of the land for crop production.

Land evaluation is concerned about the assessment of land performance for determining land uses purposes. Such evaluation is necessary during the process of land use planning because since it might direct choices on land usage in such a way that the resources of the environment are ideally utilized and supported sustained land management is accomplished. In another word, land assessment is the evaluation of the reasonableness of land for man's utilization in agriculture, forestry, engineering, hydrology, regional planning, recreation, so on. (FAO,1976) Land suitability assessment is a methodology in a land assessment that concerned the evaluation and grouping of specific areas of land in terms of their suitability for defined uses.

Eswaran and Gathrie (1982) the value of soil resource inventory for rise food production and protecting natural resources has been getting significant information for soil resource database produced as well as its quality.

2.4.1 Classical concepts of land evaluation

According to FAO (1976), land evaluation (LE) is the appraisal of land execution when utilized for a specific reason, including the execution and interpretation of surveys and investigations of land forms, soils, vegetation, environment and different viewpoints to identify and make a correlation of promising types of land use in terms applicable to the objectives of the evaluation. Land suitability evaluation can likewise be characterized as the appraisal or forecast of land quality for exclusive use. This procedure incorporates identification, selection, and explanation of land use types applicable to the area under consideration; mapping and explanation of the various kinds of land that happen nearby and the appraisal of the suitability of the various kinds of land for the chose land use types.

Land suitability evaluation is the prerequisite for sustainable agricultural production. It includes assessment of the standards going from the soil, terrain to socio-economic, market, and framework (Prakash, 2003). Land assessment for ecological regions and territories targets making another best production power along with stability and sustainability (Jamal, 2003). Land suitability evaluation requires experts of various subjects like soil scientists, agro-ecologists, socio-economists, and planners. The evaluation of the environmental and socio-economic status of the area comprises consideration of inputs and projected outputs of the production process.

Land suitability evaluation can as well be defined as the characterized as the evaluation or forecast of land quality for a particular use, as far as its productivity, degradation hazards, and management requirements (Astin and Basinsky, 1978). Abiotic, biotic, and socioeconomic factors decide the success of a crop. Thus, the appraisal in regards to crop value should include the abiotic, biotic, and socio-economic components that decide the profitability (Prakash, 2003). The level of material data sources is characterized in the assessment as land enhancements, for example, soil conservation or drainage, and their overall effect is considered in foreseeing crop yields or output. Suggested land utilizes should not cause soil erosion yet should monitor the land for long term production; improve the efficiency of land use systems which may include the introduction of new crops, changes in land management, or another innovation in the current farming system (FAO, 1986).

2.4.2 Land evaluation systems:

The suitability of a given part of the land is its inherent capacity to support a special purpose. Suitability can be scored dependent on factor rating or degree of the limit of land use necessities when coordinated with the land characteristics. in another word, land suitability evaluation is a correlation and coordinating of land use type's necessities with land units' attributes.

2.5.2.1 Land capability classification

According to Klingebiel and Montogomery (1961) land capability classification is one of the conservation-oriented interpretative gatherings made for agricultural purposes. Individual land units are the structure block of the system. Land capability classification is essentially founded on three land qualities for example natural soil attributes, outer land characteristics, and environmental factors that limit the utilization of land (AIS&LUS, 1971). According to Sys (1985) the land capability classes permit individual areas to be better managed Olsen (1981) advocated the principles of land classification which can be applied similarly well to both urban and village. He further expressed that the principal inconvenience of the capacity classification is that it is characterized overall terms and a high level of technology of innovation is verifiably assumed.

Vliet *et al.* (1979) expressed that land capability classes can give suitable forecasting of potential yield. Gabhane *et al*. (2006) evaluated the land for land use planning of micro-watershed in Vidarbha region of Maharashtra. The area was classified into land capability classes II, III, IV and VI. Tripathi *et al*. (2006) worked in Kiar-Nagali micro-watershed in North-West Himalaya and grouped the soils into VIIIe, VIIes, IIIes and IIe land capability sub-classes.

Panhalkar and Sachin (2011) evaluated the soils of Dudhganga basin of Southern Maharashtra and grouped the soils in to class II, III, IV and VI using RS and GIS tools. The class II suitable for agriculture accounts for 16.30 per cent. Class IV is a dominating class as far as the areal extent is concerned (34.05 per cent). The class VI is most susceptible to land degradation which accounts for 28.61 per cent.

Ardak *et al*. (2010) studied the assessment of land resources in Khapri village of Nagpur district, Maharashtra. They classified land capability sub-classes under viz, IIs, IIIs, IVs, IVes and VIes. The soil were good cultivated lands with minor limitation by fine texture of soil comes under class IIs. While the soil were moderately good cultivable lands with moderate limitation by depth of soil under sub-class IIIs, whereas the soil under sub-class IVs and Ives were fairly good cultivated lands with fair limitations by soil depth and slope, erosion and soil depth and also indicated the soil was non-arable lands (VIes) with moderately limitation due to strong slopes, erosion and soil depth.

Ram *et al.* (2014) evaluated the rapid reconnaissance soil survey of Markapur mandal of Prakasam district of Andhra Pradesh. where found that the soils of undulating pediments and hill side slope were grouped under land capability class IV and VII, whereas soils of pediplains and stream bank were placed under land capability class II and III respectively.

Bhandari *et al.* (2014) studied the classified under land capability based on RS and GIS technology in watershed of Tons River Dehradun, Uttarakhand. There found the land capability classes such as II, III, IV and VI. The very steep slopes were come under IV and VI, while the gentle slopes and piedmont plains in a class II and III.

whereas covered mainly forests in Class VI and also class III covered mainly agricultural land while flood plains came under class IV.

Raju *et al*. (2015) evaluated the Land Capability based on RS and GIS technology in Vizianagaram district of Andhra Pradesh. They identified four land capability sub-classes such as II, III, IV and VII. The soil was identified in three mandals out of 34 mandals under class II to good cultivated land. While under moderately good cultivated land in class III were found in four mandals of 34 mandals and class VII land capability class were identified in five mandals out of 34 mandals. They have used area were grazing land and forest cover.

Nagdev *et al.* (2017) assessment the land capability classification and management for sustainable land use planning in Aravalli fringes of Southern Haryana. There found six soil classes (Shikolhpur A to F) and mapped into six mapping soil series on the basis possibility and limitation for sustainable crops production. The soil in Shikolhpur A to C under (62.4 %) area was laid down as class III and they were required organic manure and sufficient amount of fertilizers for batter crops production. While soil (19.9 %) area were in Shikolhpur B to D under as class IV and required INM, RDF, and sufficient irrigation and also indicated soil (19.9 %) area were in Shikolhpur E to F under class ranged from V to VI soil on hills slopes of Aravalli's which was mainly non-agriculture lands.

Borse *et al*. (2018) studied the assessment and classified of land capability for land resources management in Barela village of Seoni district, Madhya Pradesh. They identified four land capability sub-classes such as II, III, IV and VI. The soil high smectitic clay posing drainage problem of the soil Barela-5 come under good cultivable lands (IIs). The moderate limitations due to soil depth, slope and erosion under moderately good cultivable lands (IIIes). The soils of Barela-1, and Barel-3 with varied limitations were fairly good cultivable lands (IVst) and the soils of Barela-2 was (VIst) non-arable lands come under degraded forest with strong and steeply slope lands with varied limitation of soil depth, slope and erosion.

Gashaw *et al*. (2018) studied the land capability classification for land use planning in Geleda watershed of Blie-nile basin Ethiopia. They identified six land capability classes (I-VI) and the land capability classes categories from I to IV (95.5%) were suitable for agriculture whereas class ranged from V to VI (8.5%) were none arable lands.

Rajesh *et al*. (2018) studied the land resources inventory for assessment of land capability based on RS and GIS technology of Amarapura-2 micro watershed. They were classified land capability sub-classes ranged from IIIes and IVes was 63 ha and 195 ha, respectively with several limitations of soil erosion, texture, soil drainage, soil fertility and topography. Amongst all the eight series, Bhogapur series, Chatra series and Vaykarnala series comes under class III were moderately suitable crops like that, green gram, sorghum, pearl millet and guava. Whereas stream bank series were severe limitation of erosion under class IV.

Supriya *et al*. (2018) studied the classified of Land capability classes using RS and GIS technology in Mahanandi mandal of Kurnool district, Andhra Pradesh. They classified land capability sub-classes on the basis suitable land use plan was indicate as Pedons 1, 4, 9 and 10 were come under good cultivable land in sub-class IIs and Pedon 2 was capability sub-class IIes and also were comes under capability sub-class IIe of Pedons 7 and 8. Whereas Pedons 3 and 5 were capability sub-class IIIe and Pedon 6 was come under the capability sub-class IIIs. those soils were good to moderately cultivable lands.

2.5.2.2 Land suitability classification

According to the FAO general framework for land suitability evaluation (1976), the land suitability classification consists of assessing and grouping the land types in orders and classes according to their capacity. Land evaluation portray the suitability of the land for agriculture and other uses, wherein land is classified considering a number of soil characteristics, associated land features and environmental factors such as climate. Suitability categorization with very highly suitable (S1), moderately suitable

(S2), marginally suitable (S3) and not suitable (N) only are being used by many researchers for different crops.

Tripathi *et al*. (2006) studied the soil suitability for major crops of Kair-Nagali Micro-watershed in North-west Himalayas. There identified after investigation the soil of Kundla and Nagali-II were highly suitable for commercial vegetable crops as like pea and tomato and also marginal suitable for wheat and maize crops.

Jafarzadeh *et al*. (2009) evaluated the soil suitability classes of major crops in Souma area (Iran). the classified under agriculture lands of land capability class as highly suitable area (S2) for wheat, maize and alfalfa, but results in 822 ha for maize and in 126 ha for alfalfa refers to an excellent suitable (S1) and moderately suitable (S3).

Savalia and Gandhi (2009) reported the assessment of soil-site suitability for groundnut in southern saurashtra region of Gujrat. There found that the soil which upper piedmont, lower piedmont, piedmont plain and coastal piedmont were moderately suitable (S2), while upper piedmont, and coastal plain were moderately suitable (S3) for groundnut forming. However, the soil which were upper piedmont plain and coastal plain were currently not suitable (N1) while all the soil which was hill slope were not suitable for groundnut cultivation.

Asheaf (2010) analyzed the land suitability classification for wheat crop based on multicriteria evaluation and GIS technology in Damghan plain of Iran. Where identified that 21.94% area was marginal suitable (N3) and 9.40% not suitable (N1) and also several limitations and unchangeable (N2) 68.66 % area for wheat crop.

Agarkar *et al*. (2012) the characterized some cotton growing soils of Wardha district of Vidarbha region. They concluded that Leptic Haplusterts and Typic Haplusterts belonging to order *Vertisols* were the overall better soils for cotton growing.

Malode and Patil (2013) studies on characterization of some *Vertisols* of drought prone areas of Marathwada region (India) and reported that Typic Haplusterts belonging to the order *Vertisols* was the best suited than others soil for cotton growing.

Gandhi and Savalia (2014) evaluated the soil-site suitability for mustard of Girnar toposequence in Southern Saurashtra, Gujarat. They were found the soil which Typic Haplustert were highly suitable for mustard, while the soils Lithic Ustorthents, Lithic Haplustepts, Typic Haplustepts and Typic Ustifluvents were currently not suitable for mustard cultivation.

Majaliwa *et al*. (2015) studied and assessed the suitability for major agricultural land uses around Kibale National Park. There found that the western part of Kabarole district was highly suitable for tea, while the highly suitable for maize of the southern part and also to be highly suitable for banana the northern part. Whereas the central part was highly suitable for both banana and maize.

Nagaraju *et al*. (2015) analyzed the soils of Saraswati watershed in Buldhana district of Maharashtra. They found that the soils of Kinhi, Wadgaon and Dhad are moderately suitable, soils of Lonar are marginally suitable and soils of Saraswati and Khurumpur are not suitable for cotton, pigeon pea and sorghum.

Devi and Naidu (2016) studied the land suitability for land use planning of sugarcane growing soils in chittoor district, Andhra Pradesh. These soils were identified moderately suitable (S2) and moderately to marginally suitable (S2-S3) respectively for sugarcane growing soils.

Gandhi and Savalia (2016) the soil-site suitability evaluated for wheat in calcareous basaltic soils of Girnar toposequence in Southern Saurashtra region of Gujarat. Where observed that the Typic Haplustert were suitable for wheat, while the Typic Haplustepts and Typic Ustifluvents were currently not suitable for wheat. The soils of Lithic Ustorthents and Lithic Haplustepts were not suitable for wheat cultivation.

Borse *et al*. (2018) studied the soil-site suitability evaluated of land resources in Barela village of Seoni district, Madhya Pradesh. The soils of Barela-4 were moderately suitable for gram, soybean, maize and pigeon pea cultivation. While the soils of Barela-5 are highly suitable for pigeon pea and moderately suitable for gram, soybean and maize cultivation. Whereas the Soils of Barela-1, Barela-2 and Barela-3 were not suitable for gram, soybean, maize and pigeon pea cultivation respectively.

Chadar *et al*. (2018) evaluated the soil site suitability of farm College of Agriculture, Latur, Maharashtra. The soil suitability class were classified as Typic Ustorthents, Calcic Haplustepts, Vertic Haplustepts and Calcic Haplusterts, respectively. The Typic Ustorthents soils are not suitable (N1) for soybean and pigeon pea due to limitation of soil depth, calcium carbonate, PAWC and soil pH. Where as in Calcic Haplustepts soils are not suitable (N1) to moderately suitable (S2) due to severe limitation of calcium carbonate, soil depth and soil pH. Vertic Haplustepts soils were marginal (S3) to moderately suitable (S2) and Calcic Haplusterts soils were highly (S1) to moderately suitable (S2) for soybean and pigeon pea due to limitation of calcium carbonate, soil depth, drainage and soil pH.

Kumar *et al.* (2018) studied carried out the soil suitability for cotton cultivation in semi-arid region of Hinganghat tehsil, Wardha district, Maharashtra, The Hewan soil was found to be best for the cultivation of cotton. The latter two series were moderately fit for cotton. The Chanakpur soil series was found to be of last rank (4.4%) and are least suitable for cotton cultivation in the study area.

Ghode *et al*. (2018) evaluated the soil-site suitability cotton growing soils of Nanded District, Maharashtra. They were found that the soil was marginally suitable of Typic Ustorthents. while the Typic Haplustepts were moderately suitable and the soil were highly suitable of Typic Haplusterts for cotton crop.

Orimoloye *et al*. (2019) studied the suitability evaluation of some peri-urban soils for rainfed arable crop production in Lagos State, Southwestern Nigeria. Found that the each pedons were laid down as marginally suitable (S3) for maize excluded

Idesan and Owode Series that made up 2.53% and 34.74% of the total area respectively, while were laid down as moderately suitable (S2). Whereas every pedons were laid down marginally suitable (S3) for cassava and leafy vegetables beside the Atan series acquire19.71 % of the total area, that was laid down non-suitable (N1).

2.4.2.3 Land productivity classification

Land evaluation is the process of assessing the capability of land for effective kinds of utilizes. Vink (1975) stated that land evaluation is an importance tool in land use planning. The utilizes can be productive such kinds arable farming, fodder/forage production (livestock production), forestry or other uses as catchment protection, recreation, tourism, wildlife conservation. It includes interpretation of survey, climate, soils, vegetation and different parts of land use and land qualities.

Unplanned and unpredictable utilization of land is a reason for concern as land and soils are limited resources and must be used on scientific lines without causing imbalance to the natural ecosystem. he needs to put the land under sustainable management accepts even more important with regards to the always expanding pressure ashore due to the burgeoning population. Sustainable land management attempts to balance the often-conflicting ideals of economic growth and environmental quality and viability.

Requier *et al*. (1970) have evolved a system of soil examination condition actual and possible productivity. Productivity or actual productivity (P) is the initial soil capability to produce a specific measure of crop per hectare per annum and expressed as a percentage of optimum yield per hectare of a similar crop developed on the best soil. Potentiality or potential productivity (P') is the productivity of soil when all possible measures for improvement have been made. Nine factors such as moisture, drainage, depth, texture, base saturation, soluble salts, organic matter, CEC and mineral reserves are rated on a scale 0-100 and the percentages cumulatively multiplied to obtain productivity index (P). In a similar manner the potentiality index (P’) is calculated after indicting the extent to which productivity can be improved. Co-efficient of improvement is the ratio between P' and P. Soil with rating index 65-100 are excellent, 35-64 good, 20-34 average, 8-19 poor and below 8 extremely poor. This system of land evaluation has the limitation in that one finite factor decreases the index of productivity. as well, assigning value to factors ought to be selected according to the limits influencing crop development inside particular areas to get a more practical productivity rating.

The productivity classification for salt influenced soils of Purna valley, Vidharba locale, Maharashtra was done by Padole and Deshmukh (1998). The soils of Walagon and Hara were grouped under best productivity class. The soil of Khartalegaon, Keliveli, Papura Adsul, and Kinkhed fell under poor productivity class.

Kumar and Mura (1999) evaluated the made productivity rating for the soils of denuded hills, weathered pediments and valley fills. These were evaluated as extremely poor to poor in productivity while covered pediment soils had average to great productivity.

Chaudhary and Singh (2007) studies the productivity capability of soils created on differing physiographic positions of Solan district of Himachal Pradesh and reported that soils developed on very steep hill slopes (Loamy-skeletal Typic Udifluvents) are extremely poor to nil, Fine-loamy Typic Eutrudepts are poor, Fine Dystric Eutrudepts are average and Fine-loamy Typic Eutrudepts soils are best in actual productivity potential.

Shukla *et al*. (2009) studies the productivity possibilities of the Dhamni micro watershed of Chandrapur district of Maharashtra and reported that soils of Dhamni-3, Dhamni-5, Bijoni-1, and Bijoni-3 were good in the productivity with moderate limits of soil moisture, organic matter, soil texture, structure, and mineral reserve and soils of Dhamni-1, Dhamni-2, Dhamni-4, Dhamni-6, and Bijoni-2 were average in productivity due to severe limitations of soil moisture, texture, structure and soluble salts.

Kashiwar *et al*. (2009) studies the soil productivity of Salai watershed of Nagpur district, Maharashtra, and reported that the soils of Khursapar-5 were good in soil productivity; soils of Khursapar-4 are average whereas, soils of Khursapar-1, Khursapar-2, Khursapar-3¸ Junapani-1, Junapani-2, and Salai were extremely poor to poor in soil productivity.

Ardak *et al.* (2010) evaluated the productivity potentials of Khapri village of Nagpur district of Maharashtra and reported that soils of Khapri-7 and khapri-8 were good in productivity, Khapri-2, Khapri-3, Khapri-4 Khapri-5, and Khapri-6 were poor in productivity, and soils of Khapri-1 are extremely poor in productivity.

2.4.2.4 Land irrigability classification

The main objective of land irrigability classification is to forecast the soil behavior under the gently adjusted water system brought out by the presentation of the irrigation system. It is also important to anticipate the benefits of irrigation to the farmer and whether the land can be irrigated on a sustained based on without harm to the environment. Thusly, all significant land attributes including soil, climate, topography, water resource, vegetation, socio-economic conditions, and infrastructure need to be considered (FAO, 1985).

AIS&LUS (1971) mentioned detailed process for classifying land as per land irrigability classification. Contingent upon the degree of limitation, six classes (class 1 to class 6) have been characterized. The most limiting characteristic decided the class.

Mishra and Nanda (1984) have developed a system for land irrigability classification for the humid and sub-humid regions in India. Three main points for example soil topography and drainage have been a consideration.

Palaskar and Varade (1987) proposed six land irrigability classes which are perceived based on soil structure, infiltration rate, permeability, salinity, sodicity, gravels, landscape and water position.

Solanke (2003) studies the soils of Ganeshpur micro watershed of Nagpur district, Maharashtra, and also recognition five land irrigability classes viz, 2s, 2sd, 3sd, 4ts, and 6t in the village.

Tripathi *et al*. (2006) studies in Kiar-Nagali micro-watershed in North-West Himalaya and assembled the soils into 2t, 3t, and 6t land irrigability sub-classes.

2.5 Wells and irrigated area mapping

2.5.1 Open/dug well enumeration and estimation of groundwater usage

Minor irrigation census (including well enumeration) is operated periodically in India. The recent (2017) report describes that there are all out of 8.78 million dug wells in 661 districts of the country irrigating 16.8 million ha of land. Probably due to these reasons, not a single report on well enumeration with its location coordinates or detailed information like its time of opening, irrigated/command areas, and so on. could be found in the literature. The fifth Minor Irrigation Scheme report (2017) estimates that there are 27 million wells and bore wells in India. Nearly half of these are open/dug out wells. Ground water survey and Development agency, Maharashtra (2012) states plainly that the area irrigated by each well isn't available.

The Central Ground Water Board (2017) and many other reports (Sayre, 2019; GSDA, 2017; Rajan and Verma, 2017; India Water Tool, 2017; Rodel *et al.* 2009; Bassi *et al.* 2008) caution that over misuse of groundwater resources is causing progressive decrease in water table in India particularly the arid and semi-arid areas of India. Well failure was a genuine result of groundwater abuse and significant obstacle to the farmers‟ income in India, particularly in hard rock regions of the country like Karnataka state, Tamil Nadu, Maharashtra and Andhra Pradesh *etc*. (Nagaraj *et al.* 1994; Nagaraj and Chandrakanth, 1997; Ballukraya and Sakthivadivel, 2002). The explanation is either over misuse of water from existing wells or failure in identifying the specific water bearing zones or aquifers. Palanisami *et al.* (2008) estimated that the average rate of well failure in Tamil Nadu territory of India was 47% for open wells and 9 percent for tube wells.

Throughout the long term, the total number of irrigation wells enhanced while there was a synchronous enhanced in excluded or failed wells (Palanisami *et al.* 2008). In certain states, an enhancement in various wells didn't add to a comparing enhancement in groundwater irrigated area. In Tamil Nadu state number of wells enhanced yet the region under groundwater irrigation diminished constantly after 1980 (Janakarajan and Moench, 2006). Similarly, in 5 districts of Madhya Pradesh namely Balghat, Chhindwara, Shahdol, Jhabua and Betul, the average command area of activated wells was getting to declined approximately incessant in the range of 1974 and 2000 (Kumar, 2007).

Changming *et al.* (2001) investigated the groundwater misuse and its effect on the environment in the North China Plain (NCP). The investigators find out that, persevering groundwater overexploitation in the northern parts of the NCP has brought about water-level decreases in shallow aquifers. In 600 shallow groundwater observation wells in the Hebei Plain, the average depth to water increased from 7.23 m in 1983 to 11.52 m in 1993, indicating a average water table decline of 0.42 m/year.

Perrone and Jasechko (2017) studied groundwater wells data in the western US between 1950 to 2015 and found that the percentage of dry wells enhanced 2013–2015 over the years. These dry wells were identified in rural areas with high agricultural productivity, like that the parts of the California Central Valley and the High Plains. The results support anecdotal evidence that wells used for domestic purposes were more susceptible to drying than wells used for agricultural purposes throughout California‟s Central Valley. The findings suggest that decreasing groundwater the levels are threatening drinking water reliability, agricultural productivity and therefore have key ramifications for both domestic and agricultural water security.

Janakarajan and Moench, (2006) studied decline in groundwater irrigation in Tamil Nadu. They overviewed 51 villages of the Palar basin and found that there exists a close relationship between well density in the command area of tanks and springs and the decrease of these traditional sources. 44 In the surveyed villages, well density ranged from a low of 0.30 to a high of 0.79 per hectare, density in wet lands traditionally irrigated from surface sources were typically higher (0.33 to 0.79 wells per hectare) than those in dry land (0.30 wells per hectare).

Kumar *et al.* (2016) studied groundwater extraction in Karnataka and detailed that half of the states cultivated area goes under basic to over-exploitation class. The density of groundwater structures in state was 10.63 units per 100 ha (0.9/ha) which was three times more than what was in eighteen Century. The number of open wells failures in the state increased due to drying existing wells.

Patil *et al.* (2018) studied groundwater recharge potential zone with well analysis in Darwha block in Yavatmal district. The observators investigated a more well density of 0.22 per ha in irrigated crop area while is 27 percent in the high potential zone against well density of 0.02 per ha with 6 percent irrigated area in the weak potential zone.

2.5.1 Irrigation area mapping

Throughout the most recent few decades, remote sensing has arisen as a powerful instrument to monitor irrigated lands over an assortment of climatic conditions and areas as of late various new techniques were suggested to identify and there mapping the irrigated areas, either by time series analysis of SPOT vegetation and spectral data analysis with Normalized Difference Vegetation Index (NDVI) (Kamthonkiat *et al.* 2005; Biggs *et al.* 2006) or by integrating decision tree based supervised classification (Ozdogan and Gutman, 2008). The use of satellite derived vegetation indices for crop monitoring and assessment is established (Meyer and Ling, 1992; Benedetti and Rossini, 1993; Moulin *et al.* 1998). Vegetation indices got from satellite imagery give a formal estimate of the health and vigor of agricultural crops. Vegetation indices are quantitative measures dependent on mathematical combinations of spectral reflectance data to evaluate such things as vegetation biomass and vigor. Most vegetation indices depend on the inherent characteristics of effectively photosynthesizing vegetation. Chlorophyll in healthy plants absorbs red and blue energy for photosynthesis. Vegetation reflects highest in the near infrared due to the internal cell structure of plants (mesophyll cells). In healthy plants, mesophyll cells reflect 40 to 50 per cent of the infrared radiation incident upon the leaf (Lillesand and Kiefer, 1994).

Perhaps the most generally utilized vegetation indices is the NDVI created by Rouse *et al*. (1974). NDVI gives information at every area to indicate the kinds of crop or land cover and irrigated or not irrigated field (Meyer and Ling, 1992; Benedetti and Rossini, 1993). The benefit of band rationing is that it passes on the spectral or color characteristics of image features regardless of variations caused by topographic slope and aspect, shadows, or seasonal changes in illumination conditions. Greater the amount of photosynthesizing 46 vegetation present, larger the digital number value for each pixel. Vegetation cover shows high NDVI values, water body shows negative values, and bare soils show near zero values (Ozdogan and Gutman, 2008).

The NDVI proved to be indispensable for identifying irrigated areas in local-scale studies, partially due to differential spectral reaction between irrigated and non-irrigated fields (Ozdogan and Gutman, 2008). Temporal NDVI profiles of both irrigated and non-irrigated crops in these areas may display an identical pattern. While irrigated fields frequently display more prominent greenness because of the consistent availability of moisture, the NDVI contrast between irrigated and non-irrigated fields was simple for distinction (Gordon *et al.* 2005). Thresholds are set to distinguish productive fields from nonproductive and non-irrigated area, and also multi-temporal NDVI features such as the range and maximum NDVI (Xiao *et al.* 2005; Ozdogan and Woodcock, 2006). At the point when different NDVI observations were available from similar growing seasons for a very long time, it is also possible to recognize crop types just as the progressions in irrigated regions. To find the NDVI threshold, it is important to find the best value that chooses the most irrigated field pixels while not choosing pixels from non-irrigated fields (Ozdogan and Woodcock, 2006).

The resolution of imagery has a major impact on the recognizable accuracy of irrigated areas (Ozdogan and Woodcock, 2006; Xiao *et al.* 2006). Ozdogan and Gutman, (2008) reported that irrigated area enhanced as the satellite imagery resolution became better on the better resolutions to show the fragmented areas, for example, those from groundwater, small reservoirs, and tank irrigation, and thus can be represented more precisely. The review of local-scale studies recommends that NDVI on the basis of classification of image data works well in identifying the irrigated area and its precision was more than 85% (Ozdogan *et al.* 2006; Thenkabail *et al.* 2009).

2.6 New trends of land suitability evaluation

Land evaluation is either qualitative or quantitative in nature. Quantitative evaluation is most importance for economic surveys. The majority of the land evaluations are qualitative in nature reliant upon the specialist decision of soil surveyors and agronomists who explain their field data information to make comprehendible to planners, engineers, extension officers and farmers.

More recently in-depth studies of specific soil related constraints (in particular soil fertility, available water, available oxygen, soil workability and degradation hazards such as soil erosion and soil salinization) recently in-depth investigations of specific soil-related limitations have all facilitated with quantitative simulation of specific land use measures and opened the way for yield prediction. The reform of information technology innovation during the last two decades has engaged experts to gain speedy progress in the examination of interactions between land resources and land use in quantitative land evaluation based on quantitative land use systems investigation.

2.6.1 Qualitative to quantitative land evaluation

Quantitative economic assessments, be that as it may, require appraisals of crop yields and rates of plant growth, or another measures execution. Quantitative models have been created for a few significant yields however this demand credible information. Such choices need possibly qualitatively land assessment in any event when forecasts depend on carefully controlled test, they might be stunned practically by alteration in management. Thus, it attempts to computation a category of implementation under the probable standards of the management **(**Beek *et al.* 2000). The structure for land evaluation (FAO, 1976) is implied especially for use in the area with restricted availability of essential information and can work at various grads of detail. yet many applications are qualitative, matching levels of restriction of the land with the corresponding prerequisites of explicit kinds of land use, and the general appropriateness class.

2.6.2 Multi-disciplinary land evaluation

Some different prerequisites include both the bio-physical necessities and the socio-economic setting. A decision is offered between a two-stage land assessment system where the bio-physical examination is trailed by socio-economic investigation (which is preferred by most physical researchers) and an equal methodology that endeavors to integrate biophysical and socio-economic analyses (favoured by social scientists, especially at the farm level). Land suitability investigation and land use planning are significant are considered as a very complex question since it is typically addressed by multi-criteria and interdisciplinary approaches. By common, land suitability analysis shows the impacts of physical aspects while social-economic and framework information bases are utilized and delineated for maps control in land evaluation and land use planning (Chuong *et al.* 2006).

2.6.3 Land suitability assessment approaches

There are a few investigations around the globe carried out main objectives to connecting local and scientific knowledge (Kundiri *et al.* 1997 in Nigeria; Guillet *et al.* 1996 in Peru and Norton *et al.* 1998 in New Mexico). Little work has been done in Asia and North Africa. Briggs *et al.* (1998) studied the choice and management of cultivation sites in Upper Egypt. Recently Zurayk *et al.* (2001) completed a participatory land capacity classification for suitability and a land-use analysis in a semi-arid mountainous village in Lebanon. These endeavors were endeavored to build up connection between farmers discernment and specialist knowledge. A usevalized up land use planning approach was adjusted and integrated into a passable political and authoritative system. The intention of planning approaches has gotten essentially significant and analyzed under apparently centralized top-down planning and participatory bottom-up planning, impacted by the rising orientation to local requirements and individuals (Chambers, 1994).

- Top-down approach

At the point when land-use planning and land-use evaluation are conveyed with the choice from the state or specialist or policymaker and carried out at the below level for example at cultivating level, then, at that point it is named as a top-down approach. The classic or conventional model of top-down planning places the state as the executive of the environment, and the state makes on all judgment concerning resource usage. This makes land use planning an instrument of administrative guidance and control, firmly connected to national improvement plans. Improvement possibilities are evaluated for all regions and objectives set for every governmental level, while observing is simply an appraisal of objective achievement. This approach was especially boundless in Indonesia in the National Land Agency and Sri Lanka in the Land Use Planning Division (Betke, 1994).

- Bottom-up Approach

The contrary term is bottom-up planning initiated at the local level and involves the dynamic cooperation by the neighborhood local community. Main choice of the land use planning depends on the information and view from the level of the producers and later it is incorporated in the national scheme by policy creators or specialists. The main objectives of the local area at the rural or one level higher is the improvement of local planning and implementation abilities in natural resource management (Betke, 1994). The experience and information on land users and specialized staff are activated to choose improvement needs and detail execution plans. As far as artists at the local level and liable governments, there are a huge variety of institutions (FAO, 2007).

2.6.4 Land evaluation using GIS

The powerful question, examination, and integration component of GIS make it an optimal scientific device to investigate land use planning. The Management of agricultural resources dependent on their abilities and limitations is needed for the improvement of land and another resource on a sustainable basis. GIS innovation is being increasingly utilized by various users to make resource data sets and to show up at suitable ideas/strategies for the sustainable improvement of agricultural resources (Venkataratnam, 2002). GIS techniques are being influential used in the modern era as tools in carrying out the morphometric investigation, which helps appropriate assessment and the management of the land resources (Reddy *et al.* 2002). The land suitability classifications are determined by overlaying thematic maps and by analyzing attribute data with supporting of GIS which prompts the introduction of results quicker and all the more precisely.

Geographical Information System (GIS) was utilized to evolve a form-level activity plan keeping study survey boundaries as a unit of implementation for Vadakkalur village in Annur block, Avinashi taluk, Coimbatore district, Tamil Nadu covering an area of 1,158 hectares of land. MapInfo desktop mapper and Excel spreadsheet were utilized for digitizing village map and for extraction and integration of thematic maps. The activity planning indicated alternate land-use choices with the intention of ideal usage of soils and groundwater resources (Sivasamy *et al*. 1998). Martin and Saha (1999) made an endeavor to evaluate the soils of par of the Dehradun district for suggesting reasonable cropping patterns using remote sensing and GIS.

A geographic information system was utilized to recommend elective land-use planning on the basis of land capacity for the Panchal area of Gujarat state (Dasai and Subramanian, 1999). Jaishankar (1999) evolved Decision Support System (DSS) for village level planning for Naranapuram village of Coimbatore district. Data inputs incorporated the land use map, geomorphology map, slope map, soil map, socio-economic data, detailed soil survey report of the village, rainfall data, and so on. A grouping of the analytical act was performed using these inputs as the base whereupon a decision support system was created to help the organizers to aid village-level planning.

Kumar *et al*. (1999) utilized GIS to evaluate the soil productivity of West Bengal. The soil of denuded hills, weathered pediments and valley fills were appraised as extremely poor to poor in productivity while buried pediment soils had good productivity. The investigations featured the spatial modeling and cartographic capabilities of GIS software in the generation of productivity maps.

Kumar *et al*. (2002) utilized GIS and false colour composites (FCCs) to assess the soil and land resource in the Tillari irrigation project for the land capability and irrigation reasonableness for its sustained use under the irrigation system. A potential land use map was produced by the integration of land capability and land irrigability map. The investigation displays that 14.66 percent region had no limitation and can be brought to intensive agriculture by twofold cropping.

The land suitability analysis has been completed to identify reasonable regions within the University of Peradeniya, Srilanka for a production forest. Climate, slope, soil, topography, vegetation, accessibility was considered as significant factors in identifying the suitability. The spatial layers were digitized and incorporated into the GIS environment. Using GIS, a suitability map was ready with three suitability classifications to be specific, suitable, moderately suitable, and not suitable. According to the final suitability map, 5.35 ha of land under the highly suitable class and 0.65 ha of land under the respectably moderately suitable classification were identified (Ekanayake and Dayawansa, 2003).

Shekinah *et al*. (2004) utilized GIS technology for land capability assessment in a part of Sahaspur block of Dehradun district, Uttarakhand. The soil series had a place with four significant soil orders such as *Entisol, Inceptisol, Alfisol,* and *Mollisol,* and the major physiographic classes of the area are river terraces, hills, mountains, piedomts and uplifted terraces. The investigation region was characterized into six significant land capability classes (II, III, IV, VI, VII, and VIII). Almost about the 85 per cent of the area was found suitable for cultivation and the rest was non-arable. Erosion hazard was the significant limiting factor. The land use for physiographic soil units was likewise recommended for sustainable development, relating to the land capability units.

Dadhwal *et al.* (2006) utilized index-based technique for evaluated erosion hazards in Suarna rao watershed in Dehradun district of Uttarakhand. The normal precision of erosion hazards mapped by remote sensing data was 85.3 per cent inclusive of all the existing land utilizes in the watershed. so on, the index-based technique for evaluation erosion hazards was discovered to be satisfactory. It was also observed that problems in assessment with remote sensing data are mainly due to infrared reflectance of prevailing vegetation which masks the effect of other reflectance, while interpreting erosion hazards. It was also observed that problems in evaluation with remote sensing data are mainly because of infrared reflectance of prevailing vegetation which was create the impact of other reflectance, whereas interpreting erosion hazards.

Reddy *et al*. (2004) characterized the land resources in and around Mohgaon and Degma villages of Hingna tehsil, Nagpur district, Maharashtra using remote sensing and GIS softwere for cotton suitability. GIS based information produce and cotton suitability observation manifest that soil of Mohgaon-8 and Mohgaon-10 are highly suitable; Mohgaon-5 and Mohgaon-9 are moderately suitable and Mohgaon-1, Mohgaon-2, Mohgaon-6 and Mohgaon-7 are marginally suitable.

Bunruamkaew and Murayama (2011) appraisal soil site suitability of Surat Thani Province of Thailand using GIS and analytical hierarchical process (AHP) and found that 69.68% of area was marginally suitable (S3) located in the central part of the province, 29.02% of area was moderately suitable (S2) located in the Eastern and Western parts of the province and only a few percentages (0.89% and 0.41%) of the area were classified as not suitable (N) and highly suitable (S1), respectively.

GIS can play the capability to perform various utilizing both spatial and characteristic information stored in it. It can the ability to integrate diversify of geographic technologies such as GPS, Remote sensing *etc*. Krishna and Regil (2014), brought out the spatial dispersion of agricultural land suitability regions got from remote sensing data with an assessment of different factors like soil, landform, geology, land-use, and topographic information in GIS reference in the Kannur district of Kerala state. The land suitability concentrates in Turkey for rice cultivation dependent on GIS and statistical analysis considered factor rating of land quality parameters, including nutrient availability index and soil quality index (Dengiz, 2012); Khan and Khan (2014) utilized different soil series and their soil properties, land use Landsat TM data, and optional data for evaluating numerous cropland suitability in Bulandshahr district, UP, India.

2.6.5 Land evaluation using Analytical Hierarchy Process (AHP)

AHP can be utilized as a consensus building apparatus in circumstances involving a committee or cluster decision making (Saaty, 1980). AHP is a method that tries to think about the setting of the spatial planning decision, identifying and arranging the rules into various groups (Vogel, 2008). AHP is on the basis of three principles: decomposition, comparative judgment, and synthesis of priorities (Eldrandaly *et al.* 2007).

Assessing the overall significance of components to analyzed the suitability of land for agriculture in Golestan province, Iran using the AHP technique indicated that soil ability, slope and precipitation were second and third significant components (Kamkar *et al.* 2014) of evaluation of land suitability and the chance and performance of soybean. The weighting of parameters for AHP suitability can be assessed using the geometric mean technique (Prakash, 2003).

2.6.6 Land evaluation using fuzzy logic technique:

Zadeh (1965) proposed a hypothesis called 'Fuzzy sets' which is a collection of ideas and a method that gives a type of numerical exactness to human points of view that are imprecise and obscure in menu ways. A fuzzy set is a class of components or with no definite limits. The fuzzy logic is helpful to define this present reality objects, which are characterized by dubiousness and uncertainty (Prakash, 2003).

Kurtener *et al.* (2008) utilized this method of individual fuzzy indicators (IFI) and combined fuzzy indicators (CFI) of various soil characteristic information (texture, organic C, inorganic C, total C, total N, total P, extractable P, $NO^{-}{}_{3}$ and $NH^{+}{}_{4}$) located in Bell County, TX on the Elm Creek watershed provides an integrated estimation of agricultural land suitability.

Reshmidevi *et al*. (2009) assessed land suitability by fuzzy hypothesis approach for paddy in West Bengal and observed that 23 per cent of the existing paddy fields have been found less suitable/not suitable for paddy because of the weak surface water potential or unsuitable terrain situation of the area. By using same theory Mokarram *et al.* (2010) assessed land suitability for wheat in Shavur region, Khuzestan Province and result showed that 31 per cent of the area as highly suitable for wheat 29 per cent as moderately suitable, 19 per cent as marginally suitable and 21 per cent as unsatisfactory. Dependent on the outcomes, it has been reasoned that fuzzy technique permits obtaining results that appear to favorable with the present situation in this region. Fei Deng *et al*. (2014) evaluated land suitability for alfalfa cultivation of Northern China and uncovered that highly suitable areas covered 10,799.84 sq. km, accounting for 5.3 per cent of the complete region, and unsuitable areas covered 99,235.87 sq. km, accounting for 48.9 per cent of the total area.

2.6.7 Automated Land Evaluation System (ALES)

More as of lately, land assessment procedures have moved from expansive based to explicit appraisal, with the increasing utilization of evaluation different models have been created. Automated Land Evaluation System (ALES) is a system that permits land evaluators to construct specialist systems for land assessment according to the technique introduced in the FAO structure for land assessment. Elsheikh *et al.* (2013) assessed land suitability for mango by using ALSE in Terengganu, Pensular Malaysia, and inferred that 31 per cent of the area was recognized as generally suitable for mango, 55 per cent of the area as moderately suitable area, 9 per cent percent as marginally suitable and the remaining part (5 per cent) was unsuitable for mango.

ALES offers the design for a wide scope of specialist knowledge for a speedy appraisal, can be linked to socio-economic parameters, permits the evaluators to making their own specialist system, and has no fixed index for land attributes or land use requirements. Limits of this system is that it can't show maps, has no GIS works, and isn’t easy to understand for users (Rossiter and Wambeke, 1997).

2.6.8 Multi-criteria decision-making (MCDM) with GIS Multi-criteria decision-making:

Spatial multi-criteria decision-making (MCDM) is a cycle where geographical information is joined and changed into a decision. Multi-criteria decision-making includes input data, the decision creator's priorities, and manipulated of both data utilizing elaborated decision rules. In spatial multi-criteria decision-making, the information is geographical information. Spatial multi-criteria decision-making is more perplexing and harder as opposed to regular multi-criteria decision-making, as huge quantities of components should needed be recognized and believe of, with high correlated relationships among the elements (Drobne and Lisec, 2009).

Multi-Criteria Evaluation (MCE) approaches and GIS is helpful in therefore of the fact that different production factors can be assessed and each weighted by their overall significance on the best growth situation for crops (Perveen *et al.* 2008). The joining of GIS and MCDM technique gives energetic spatial investigation capacities. In the MCDM approach, GIS is most suited for dealing with a wide scope of criteria information at multi-spatial, multi-temporal and multi-scale from various sources for a period efficient and cost-effective investigation. In this way, there is increase interest in including to GIS ability with MCDM measures.

Joshua *et al*. (2013) utilized the GIS and multi-criteria decision analysis procedure for agricultural land suitability in Nasarawu, Nigeria. GIS overlay in spatial evaluation activity was likewise used to consolidate the diverse map layers of soil, geology, slope, topography and drainage to decide the most suitable lands for agricultural improvement. The assessment criteria are considered to address the land suitability decision making dependent on i) land use; ii) soil type, pH, texture, depth, fertility, capability and drainage; iii) lithology type; iv) ground water; v) topography; vi) climate.

Baniya (2008) found that the MCE with GIS is a importance device for unification of socio-economic and environmental data (Khoi and Murayama, 2010).

Utilizing various soil parameters and chemical parameters, Das and Sudhakar (2014) received thematic layer from GIS by the unification MCDM method and GEO spatial methodology for land suitability evolution for pineapple in East Hills, Meghalaya, India.

For the land-use suitability, the combined of GIS capacities with MCDM methods furnishes the decision-maker with support in all stages of decision making, that is, in the talented plan and choice periods of the decision-making measure (Chakhar and Mousseau, 2008). Jayasinghe and Machida (2008) developed an interactive web-based GIS consulting portal with crop-land suitability analysis, which gives information on tomato and cabbage cultivation in Sri Lanka. Soil pH, topography, average annual temperature, and average annual precipitation were viewed as significant criteria to determine crop-land suitability.

2.6.9 Multi-Criteria Evaluation (MCE) with GIS, RS, AHP and Fuzzy AHP:

This group of apparatuses is an all the more energetic unification method for the agricultural land suitability analysis. AHP, optimal vector approach and fuzzy AHP for farming area appropriateness investigation were utilized in Dehradun district, Uttaranchal, India, in light of the assessment criteria-soil, climate, irrigation, market, and infrastructure, socio-economic population (Prakash, 2003).

AHP was unified with MCE in GIS to depict the delineate the suitable regions for rice crop utilizing the compatible factors of soil and topographic information and delivered from RS image and unification bio-physical and socio-economic information for land-use suitability assessment of irrigated wheat cultivation in connection with its suitability level in Haripur, Bangladesh (Perveen *et al.*, 2008). Bio-physical, socio-economical, and environmental elements were utilized in Iran for rice cultivation alongside this technique (Moddahi *et al.* 2014), and in Kenya, Jafari and Zaredar (2010) utilized this methodology for suitability assessment of rice-cultivation areas. MCDM with GIS, AHP, weighted linear combination techniques were utilized to unified fuzzy suitability criteria maps of land suitability for pineapple. The information was multidisciplinary and included climatic (annual mean rainfall), topographic (slope), pedological (soil texture), hydrological (rivers and streams), demographic (population), transportation (roads) and land cover data in Eastern Region of Ghana (Attua *et al.* 2010).

Land suitability assessment for different agricultural crops has been completed at various research centers in India (Raju, 2015; Prakash, 2003). Remote sensing can give us the data like land use and land cover, drainage density, topography *etc*. (Das, 2000). A multi-criteria decision-making approach utilizing remote sensing and GIS technique (RS) was used for multiple crops land suitability evaluation in Agra district, UP, India *Kharif* and *rabi* season cropping patterns maps were developed by unification crop suitability maps for the winter and summer seasons separately. Results indicated that about 55 % is highly suitable (S1) for sugarcane and 60%, 54% and 48 % of the area are moderately suitable (S2) for cultivation pearl millet, mustard and rice respectively (Mustafa *et al*. 2011).

Das and Sudhakar (2014) followed the land assessment method given by FAO for soil site suitability under rainfed agriculture to evaluate the land suitability for Khasi mandarin orange and pineapple in the East Khasi Hills District of Meghalaya. The observation is apparent that highly suitable areas for orange are found in the Cherapunjee and Mawsynram region that covers 34.5 sq km regions. Moderately suitable (37% of TGA) and marginally suitable (24% of TGA) areas are found only because of slope constraint (8%-30% slope). The hills with deep gorges and ravines on the southern portion of the district is found not suitable for orange plantation because of steep slopes (>30%) and stoniness.

2.7 Land Use Planning

Worldwide driving in land use planning is either need for improvement, resource utilizes efficient management, or requests for a revised land-use pattern, directed by changing environmental or socio-economic circumstances. In 1996, FAO characterized land-use planning (LUP) as the efficient appraisal of land and water potential, land use alternatives, and socio-economic situation to receive the best land-use options. The definition featured the ecological, socio-economic and environmental facts that should be considered in the planning procedure. therefore, land assessment has internally been viewed as the core importance of LUP (FAO, 1996; Roetter *et al*. 2005; Baja *et al*. 2007).

In 2007, the FAO land assessment system ideas and methodological viewpoints have been reconsidered and extended, taking considerably more distinctly the various capacities and services offered via land and soil, risk for sustainable land uses, and limits detection its origin in social and economic situation (FAO, 2007).

The significance of land as a resource can't be overemphasized and one of the major worldwide concerns is the problem of decreasing land resources that are being intimidate by the quickly human population growth. There is an enhanced want to utilize resources in a sustained way to build enhance the production, simultaneously securing the environment, biodiversity and global climate systems. This requires cautious land-use planning and decision-making.

LUP implies various things to various people. Most professionals would put it as the appraisal of land and water potential, alternative for land use, and social and economic situation in order to elect and adopt the best land-use options (FAO, 1993). Dent and Deshpande (1993) mentioned it as an activity of foresight in making suitable, convenient decisions with respect to the utilization of land. The purpose land use planning is to bestow data and foresight to bestow decision-making. It ought to likewise resolve irreconcilable situations between the dissimilar groups of people who have a stake in the utilization of land and the interest of generations that will acquire it. Land use planning is along these lines an essential planning activity to survey the further capability of the agricultural area and compilation quick development through suitable management of land and water resources.

LUP can be applied at three wide levels, in particular, national, district and local. These are not really consecutive however relate to the levels of government at which decisions about land use are taken.

Land-use judgement are made at the farm level, impacted by policy judgement at the national level, and to a lesser extent at the regional and sub-territorial levels (Schipper, 1996). investigation the impacts of explicit policies on the agricultural area or a region consistently depends certainly or expressly on decision making at the farm family level (Kruseman, 2000). It may be prospecting those various farmers respond differentially to explicit policy instrument(s), due to contrasts in their biophysical resources and socio-economic condition. For instance, giving low-interest credits to change irrigation system frameworks from surface to compressed frameworks to rise water productivity in agriculture can be an impetus for farmers with medium and big farm sizes, while it's anything but for smallholders, on account of the great establishment costs per ha of this kind of irrigation system framework that enhanced with decline farm size. Various types of decisions are taken at each level where the techniques for planning and types of plans additionally vary. Nonetheless, at each level, there is a requirement for a land-use methodology or policies that tackle these needs and operational planning to complete the work.

LUP is required by either a need to use available resources ideally directed by changing climate/environmental conservancy or socio-economic conditions. The modern concept of LUP relies on biophysical, ecological and socio-economic aspects. The research work in LUP in India and abroad has developed basically in three distinct stages

1) LUP based on biophysical factors using mostly small-scale maps

2) Specific, well defined objective LUP

3) Multi-criteria / multi-objective LUP

Research in India started during the mid-eighties. The soils of the nation were identified through and resource mapping work. This stage went on for almost 20 years as a soil survey of the country was described at 1: 50000 scale. Climatic related data of the country were utilized for unification with soil mapping and consequently the main Agro-ecological (AE) map of the country was created. This mapping contained 20 AE areas, which are here after refined, and 60 sub-regions were delineated in 2000 as more climate data and soil survey data were obtained (Mandal *et al*. 2014).

Delineation of AER prompted another innovation of research works that attention on the assessment of land/soils for existing use and suggestions dependent on the available information. The ideas were for the most part conventional, for example, a crop-based system with respect to. Soil suitability criteria (Naidu *et al*. 2006) were created and refined for the Indian situation. These criteria were explained by considering agronomic information, specialist, and local experience. The crop-specific necessities such as rooting depth, length of the growing period, temperature, pH, and drainage required were communicated through records like Stories, (1933); Sys, (1985) and Riquier, (1970).

With the presentation of RS and GIS apparatuses, better instruments were utilized for assessment. recently, devices like MCA, MCE, AHP are utilized for land assessment. whereas these studies were going on contemporary field research target evaluating the soils for existing and recently presented crops pointed toward validating the soils suitability criteria showed empowering results (Hajare *et al.* 1993; Challa *et al*. 1995 and Chary *et al*. 1995).

Very same studies have been focused on the integration of biophysical and socio-economic information related to agricultural activity by connecting with the decision tools (Kalra *et al*. 2004: Kalra *et al*. 2005 and Singh *et al*. 2008).

CHAPTER - III

MATERIALS AND METHODS

Details of the study area, methods used for analysis and data collection are presented in this chapter.

3.1 Brief description of the study area

3.2 Remote sensing and collateral data

3.3 Remote sensing data interpretation

3.4 Ground truth collection

3.6 Soil characterization and method of soil analysis

3.7 Application of GIS

3.7 Land evaluation

3.8 Location mapping of dug/open wells

3.9 Ground water potential

3.10 Runoff estimation

3.1 Brief description of study area

3.1.1 Study area and its location

The Sawangi watershed area is located between 20^o 15’ 47” to 20^o 20’ 42” N latitude and 77^o 35’ 27” to 77^o 42’ 54” E longitude, The elevation ranges from 161 to 356 m (WGS 84 datum) above mean sea level (MSL). which occupies an area of 11777.62 ha in Sawangi Watershed of Yavatmal district, Maharashtra. Agro-climatically, the study area falls under North Deccan Plateau (M.H.) placed under hot moist to semi-arid eco-sub-region (Fig. 3.1).

3.1.2 Geology

Geologically, the area is mainly occupied by the Deccan trap formation known as basalt flows, which belongs to Sahyadri group of Ajanta and Chikhli formations.

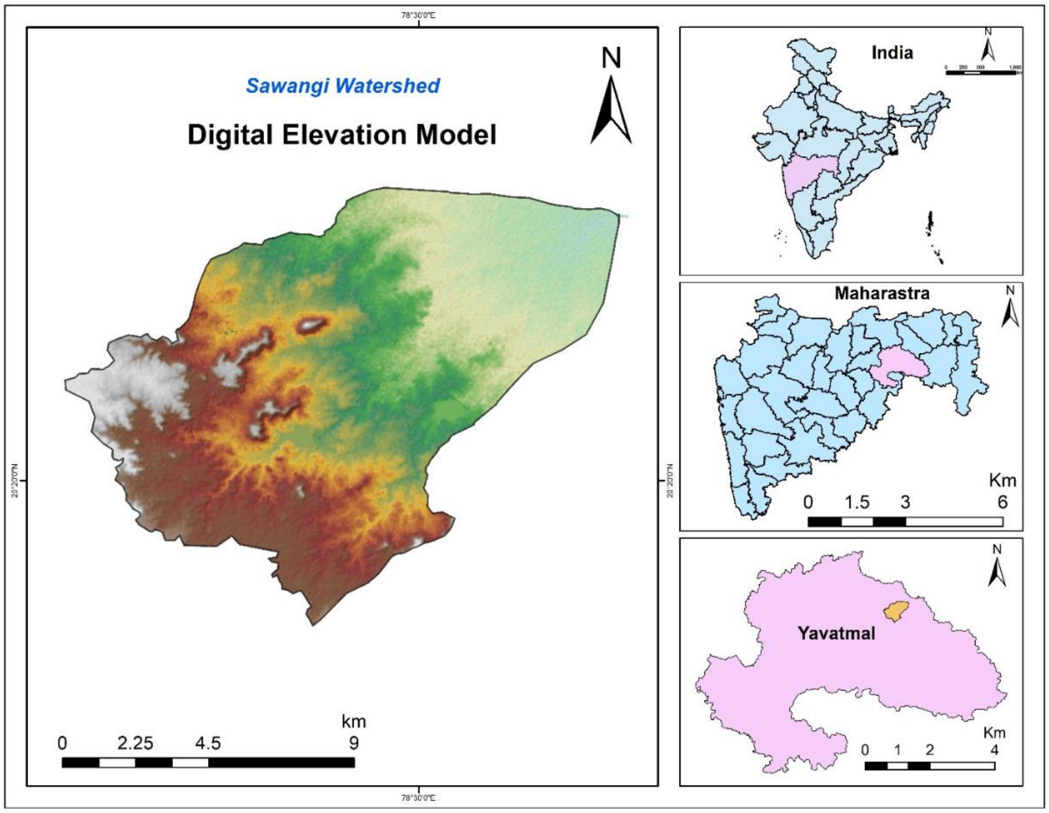


Fig. 3.1 Location map of Sawangi watershed

The basalt flows are generally dark grey, massive, fine to medium grained and non to moderately porphyritic with few flows of highly porphyritic nature (District Resource Map, Yavatmal District, Maharashtra of Geological survey of India, 2001). The recent alluvium occurs in the river valley. The basalt of the area is mainly of two types *viz*., massive and vesicular basalt. The vesicular basalts are filled up with secondary minerals like silica, zeolite and calcite.

3.1.3 Population and literacy

As per 2011 census, the total population of the watershed was 19,994 which is 17.82 per cent of tehsil's total population (1,12,203) and 0.72 per cent of district population (27,72,348). Population density of watershed is 178 per sq. km. whereas, it is 194 per sq. km. in tehsil and 204 per sq. km. of district. The total literacy of watershed is 70.67 per cent whereas in tehsil it is 73.14 per cent and in district it is 82.82 per cent.

There is a large tribal population accounting for 38.85 per cent *i.e.* 7767 in watershed, 29 per cent *i.e.* 32485 in tehsil and 18.54 per cent *i.e.* 514057 in district.

3.1.4 Climate

3.1.4.1 Seasons

The climate of the study area is characterized by a hot summer and general dryness with moderately cold winter except during the south-west monsoon with four seasons given in Table 3.1.

The hot season from March to about the middle of June is followed by cold season, December to February. The southwest monsoon season from the middle of June to September. October and November form the post monsoon or transition period.

Table 3.1 Climatological data of Sawangi Watershed of Yavatmal District

Month	Temperature °C			Rainfall	PET	½ PET	RH	LGP
	Max.	Min.	Mean	(mm)	(mm)	(mm)	(%)	(Days)
January	29.7	15.5	22.6	18.53	112	56	33	
February	33.1	17.9	25.5	0	133	66.5	28	
March	37.2	21.6	29.4	3.59	182	91	20	
April	40.3	25.5	32.9	0.5	206	103	15	
May	42.8	28.8	35.8	0	252	126	14	
June	37.8	26.4	32.1	147.12	199	99.5	38	30
July	31.2	23.8	27.5	315.75	126	63	72	31
August	30.3	23.3	26.8	214.6	117	58.5	84	31
Sept.	31.2	23	27.1	171.06	118	59	87	30
October	31.9	20.8	26.35	40.07	125	62.5	78	31
November	30	16.5	23.25	6.14	106	53	61	30
December	29.9	14.7	22.3	0	99	49	53	
Annual mean	**33.8**	**21.5**	**27.6**	**917.36**			**48.6**	**183 days**

3.1.4.2 Rainfall

The average annual rainfall of the study area for last 10 years (2008-2017) is 917.36 mm, out of which maximum rainfall (85.95 per cent) is received during rainy season (late June to October) and 3.14 per cent during winter (December to February). The variation in the rainfall from year to year is large. The highest annual rainfall received was 1472 mm during 2010 and the lowest was 369.6 mm during 2014.

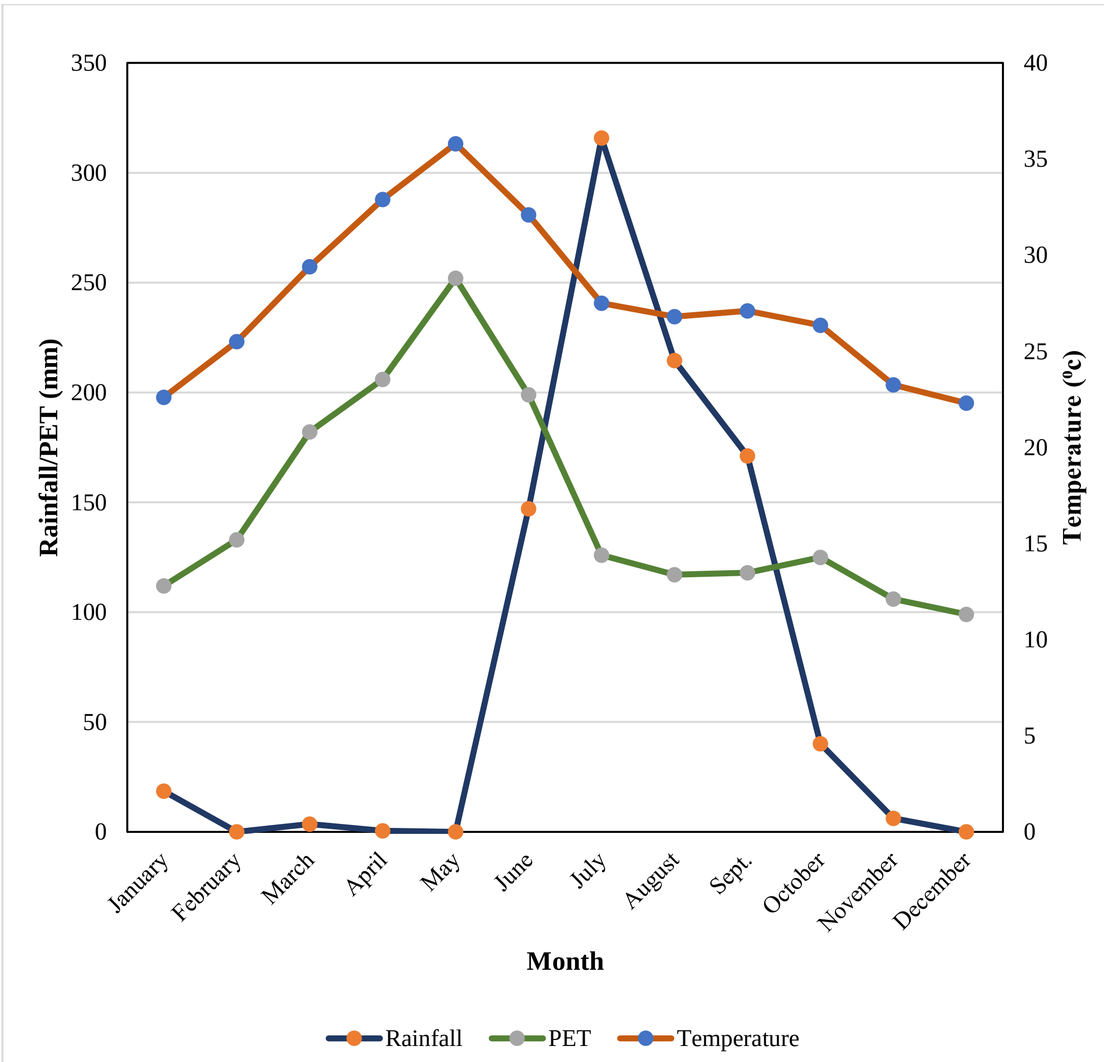


Fig. 3.2 Soil water balance diagram

3.1.4.3 Temperature

The normal maximum temperature in summer varies between 29.7 to 42.8 °C and mean daily temperature is 27.8ºC. whereas, the minimum temperature often falls below 14.7˚C during winter season and varies between 14.7 to 28.8 °C. The hottest and coolest months are May and December, respectively. (NBSS & LUP, 2015). The soil moisture regime of the district is characterized by *ustic* whereas the soil temperature regime is *hyperthermic* (Soil Survey Staff 2014).

3.1.4.4 Humidity

The relative humidity (Table 3.1) ranges from 44.3 per cent to 54.6 per cent. Except during the south-west monsoon season when the humidities are high, the air is generally dry.

3.1.4.5 Winds

Winds are generally light to moderate with some strengthening during the period from May to August. In the post-monsoon and cold seasons, the winds generally blow from the east or north-east. By March south-westerlies and westerlies start blowing, and in the rest of the summer and the south-west monsoon seasons winds are mostly from directions between south-west and north-west.

3.1.5 Agricultural land use

The main crops grown within the *kharif* season are soybean *(Glycine max),* sorghum *(sorghum bicolor),* pigeon pea *(Cajanus cajan),* groundnut *(Arachis hypogea),* maize *(Zea maize),* green gram *(Vigna sinesis),* liitle millet known as kutki (*Panicum sumatrense*) and seasame. While the major *rabi* season crops of the area are wheat *(Triticum aestivum)* and gram *(Cicer aritium)* grown under irrigation or stored moisture. In summer season where irrigation water is available, the crops like green gram and groundnut are grown.

3.1.6 Physiography, relief and drainage

Geologically, the area is very complicated with various formations. The rocks include cherty limestone, clay, sandstone and conglomerate of cretaceous period.

The watershed area was classified into seven most important physiographic units (i) Mound (ii) Denuded Plateau (iii) Escarpment (iv) Plateau (v) Pediment (vi) Pediplain (vii) Waterbody.

The physiographic units are in addition, sub-divided on the basis of slope length and land use/land cover. The important land use/land cover classes identified are-Forest land, Wasteland, Waterbody, Habitation, Single crop land and Double crop land.

The average elevation ranges from 203 m to 432 m above mean sea level (MSL). This area is has very gently sloping (1-3%), gently sloping (3 - 8%), moderately sloping (8 - 15%) and moderately steeply sloping (15 - 30%) classes.

3.2 Remote sensing and collateral data

The remote sensing data used in the present study were - Sentinel-2A (10m), ALOS PALSAR DEM (Digital Elevation Model) (12.5m), Landsat-5 TM (Thematic Mapper) and Landsat-8 OLI (Operational Land Imager). The satellite image was used as base map for location of sample areas, ground truth sites and planning to traverse in the field and other details.

The spectral resolution and bands of the satellite image data used in this study are shown in Table 3.2. Two Landsat satellite images, Landsat-5 TM in 2008, 2012 and Landsat-8 OLI in 2017, were analyzed.

- Open/dug wells and associated irrigated area, water bodies were delineated from high resolution satellite data of Google Earth at 5.8 m resolution.
- Cadastral map, village boundary map, geomorphology map was collected from Maharashtra Remote Sensing Applications Centre (MRSAC), Nagpur.

Table 3.2 Details of remote sensing data used in the present study

S. NO.	Satellite Sensors	Resolution (m)	Month of acquisition	Image Type
1.	LANDSAT- 5 (TM)	30m	March 2008	Level-1 GeoTIFF
2.	LANDSAT-5 (TM)	30m	February 2012	Level-1 GeoTIFF
3.	LANDSAT-8 (OLI)	30m	February 2017	Level-1 GeoTIFF

Note: In the 2nd column TM refers to thematic mapper, and also OLI refers to operation land imager. Source: USGS Earth Explorer Landsat archive.

- The basic soil depth, soil texture and hydrological soil group map were collected from National Bureau of Soil Survey and Land Use Planning (NBSS &LUP), Nagpur.
- The rainfall data of last 20 years was collected from, Department of Agriculture, Maharashtra (www.maharain.gov.in.)
- The information about crops was collected from District Superintending Agriculture office, Yavatmal.

Table 3.3 Data source used for the study

Data	Source
• Digital Elevation Model (30 m resolution)	United States Geological Survey
• Satellite Sentinel – 2 (10 m resolution)	European Space Agency
• Soil data on 1:50 K	National Bureau Soil Survey and Land Use Planning
• Geomorphology on 1:50 K	Maharashtra Remote Sensing Application Centre
• Satellite image	Google Earth

The standard false colour composite (FCC) was generated by bands 2,3 and 4 using Geomatica software. Satellite images of the area are shown in fig. 3.3, fig. 3.4, & Fig. 3.5. The details of the imagery used in investigation are given in the Table 3.2.

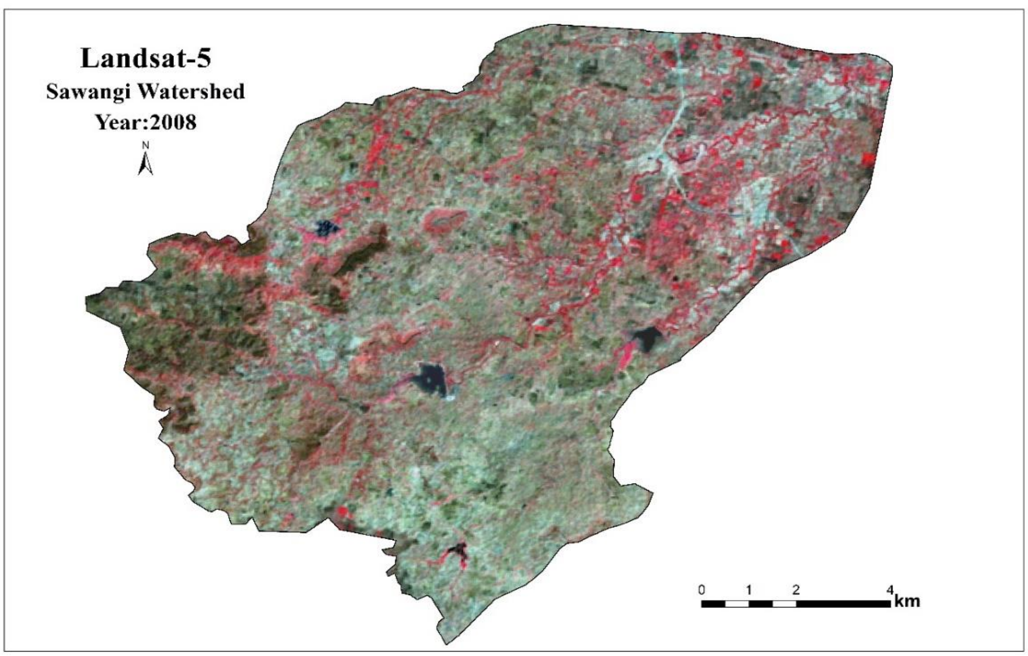


Fig. 3.3 Satellite data of Sawangi watershed (2008)

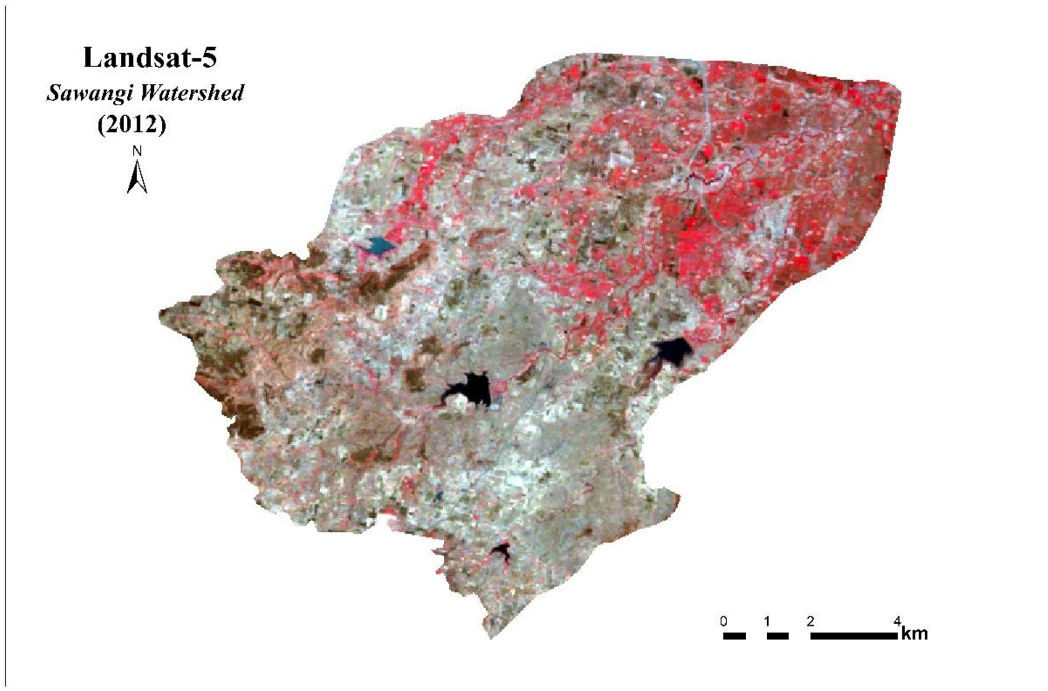


Fig. 3.4 Satellite data of Sawangi watershed (2012)

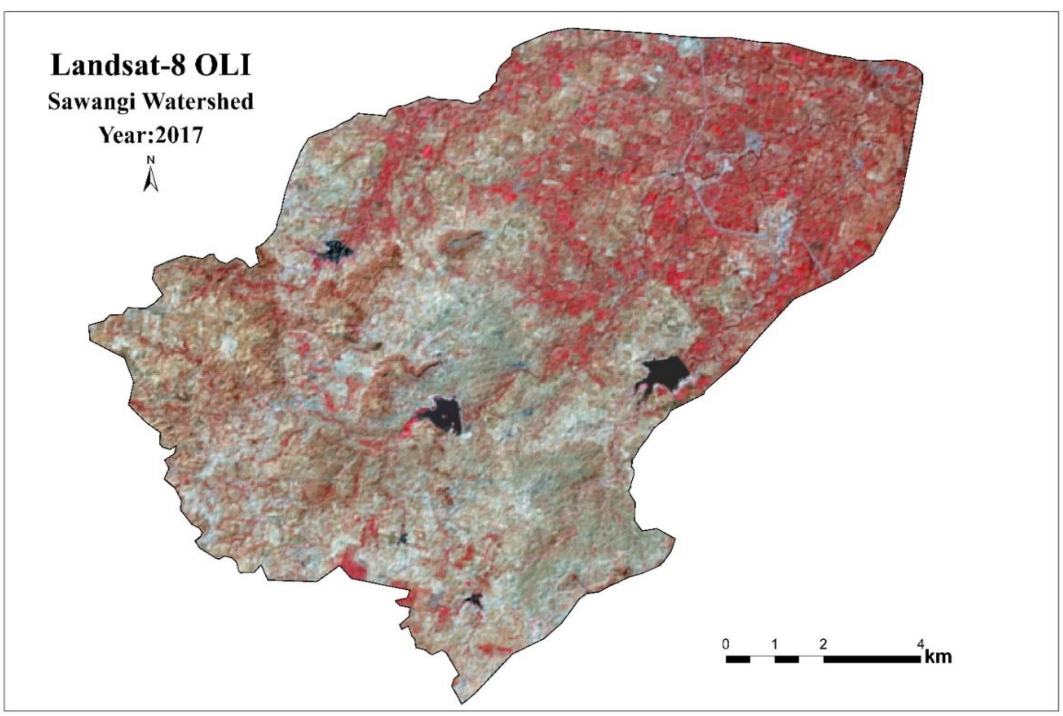


Fig. 3.5 Satellite data of Sawangi watershed (2017)

3.3 Remote sensing data interpretation

The drainage network of the watershed was delineated using the Spatial analyst toolbox in the ArcMap software (ver.10.4.1). The false colour composite (FCCs) were visually interpreted based on the interpretation keys developed from image elements namely tone, texture, size, shape and mottle through onscreen digitizing using ArcMap software by keeping the base map as the working layer likewise, different image interpretation units (IIUs) for the study area were developed. The pre-field map was prepared with the legend showing interpretation units and the corresponding image interpretation keys. In this process toposheets, geology and geomorphology were frequently consulted before finalizing these IIUs. The essential field verifications were carried out to finalize the originated base map of the study area.

Interpretation methodology broadly comprised of following steps.

- The orientation of satellite imageries with regards to the SOI topographical maps.
- Delineated the boundary of the watershed based on the drainage divide from the SOI topographical map.
- A systematic explanation of FCC using the image characteristics *viz*. tone/colour, texture, shape, pattern, and size to identify the different landforms, land use/land cover, and recognition of the object to generate pre-field image interpreted base map.
- To the physiographic delineation, the contours has been transferred from SOI toposheet based on picture interpretation sheet and based on spacing and shape of the contour data, varied physiographic series such as plateau top, escarpment, isolated hillocks, valley *etc*. were delineated.
- To understand the land use/land cover pattern of the watershed an unsupervised image classification has been done and identified six classes namely- agricultural land, forest land, fallow land, habitation, wasteland and waterbody with the help of both LANDSAT-8 OLI and LANDSAT-5 TM datasets.

- The ground truth points were collected based on the Pedon, land use/land cover, slope and erosion of the watershed.
- Correction of image interpretation units with the help of ground truth and translation of image interpretation for the generation of landform, soil and land use/land cover map.
- Finalization of soil map and land use map with necessary changes and modification subsequent to the field verification.
- The final output of land use/land cover, slope, and physiography map has been prepared with the help of ArcMap software.

3.3.1 Drainage Mapping

Drainage delineation was done manually using high resolution satellite data from Google Earth and Digital Elevation Model (DEM). In this method, reference drainage was extracted from toposheet on 1:50 K, and overlaid on Google Earth image. Google Earth gives latest information on the present course of the streams as well as some of the very minor 1St order streams.

3.3.2 Watershed Delineation

Watershed delineation was done manually using DEM, drainage lines, toposheet and contours as input. First a point is chosen as the watershed outlet, it is a pore point for all the water draining out of the watershed. Watershed boundary is delineated by drawing lines perpendicular to the elevation contours for the land that drains to the point of interest. The reference watershed was first delineated from the drainage and terrain information. Further the watershed boundaries were updated using high resolution images of Google Earth.

3.3.3 Slope analysis

The word slope has mainly two geographic applications. In the standard sense, “slope” refers to any geometric element of the earth’s surface. In a constrained experience, "slope" also refers back to the attitude which any part of the earth floor creates with the horizontal datum. The inclination of the region is the result of numerous factors namely relief, drainage, climate and geology working of this zone. The slope map for the study area was prepared using Digital Elevation Model (DEM) in the ArcMap module of ArcMap software and data collected during the field survey. The DEM was built using Aster (30 m resolution) data. The slope analysis function in the GIS was used to assess the variation of slope in the study block. The slope gradient has direct influence on infiltration of surface water. Different slope classes were differentiated as in Table 3.3.1.

Table 3.4 Slope classification

Sl. No.	Slope class	Descriptions
1	0–3 %	Very gently sloping
2	3–8 %	Gently sloping
3	8–15 %	Moderately sloping
4	15–30 %	Moderately steep sloping
5	> 30 %	Steeply sloping

3.3.4 Land use/Land cover mapping

Land use/land cover provides information about the current land use and forms the baseline information for sustainable land use planning and rural development. (Krishna *et al*. 1999). Remote sensing and GIS are more effective tools for mapping the land use land cover and vegetation. (Skidmore *et al*. 1991). The cloud free satellite imagery was used to analyze the land use land cover (LULC) of different years. Temporal satellite images (2008, 2012 and 2017) as detailed in Table 3.3.2 were acquired for analysis in Geographic Information System (GIS) platform. The following steps have been put for the preparation of the land use/land cover map.

- Orientation of satellite imagery with the context to Landsat satellite images.
- Land use/land cover details on the Landsat-5 and Landsat-8 satellite images.
- Interpretation of geocoded FCC using the image interpretation characteristics.
- Demarcation of notified forest area with the help of Landsat satellite images.

- Demarcation of water bodies.
- Development of legend key on the basis of the spectral behavior of land cover.
- Demarcation of land-use boundaries using Level-I.
- Collection of ground truth data for developing a correlation among the land use/land cover units and image characteristics.
- Validation and finalization of maps.
- Estimation of the area covered by varied classes.

Table 3.5 Data source

Primary data		
Watershed and Yavatmal district	Satellite data	United States Geological Survey, year 2008, 2012 and 2017 (Landsat V and Landsat VIII data, 30 m resolution) (https://earthexplorer.usgs.gov) European Space Agency, year 2017 (Sentinel II data, 10 m resolution) (https://scihub.copernicus.eu/dhus/home)
Maharashtra and Yavatmal district	Satellite data	Resourcesat-1 and 2 data from LISS-III sensor at 24 m resolution 1:50,000 scale data, year 2008 and 2012 (https://bhuvan.nrsc.gov.in/thematic/thematic/index.php)
Secondary Data		
	• Directorate economic and statistics reports (DES) year 2008, 2012, 2017 (https://mahades.maharashtra.gov.in/publications.do) • District census handbook of Yavatmal for village level information (http://censusindia.gov.in/2011census/dchb/2707_PART_B_DCHB_%20 YAVATMAL.pdf) • India stat, Socio economic statistical information about India (https://www.indiastat.com)	

Table 3.6 Land use land cover classes description

Sr. No.	Class name	Description
1	Agriculture	Crop fields and fallow lands
2	Forest cover	Mixed forest lands
3	Wasteland Land	Land areas of exposed soil and barren area due to anthropogenic influence
4	Habitation	Residential, commercial, industrial
5	Water body	River, open water, lakes, ponds and reservoirs

3.3.5 Physiography interpretation

Using the visual interpretation of ALOS-DEM, Sentinel-2A data and ground trothing, soil-landform relationship was stablished by studying different soils from different landforms.

- Preparation of base map from ALOS-DEM and Sentinel-2A data indicating cultural and physical features.
- Orientation of satellite imagery with reference to ALOS-DEM and Sentinel-2A data.
- Systematic visual interpretation using image characteristics, recognition of the object to generate pre-field image interpretation.
- Transfer of contours from ALOS-DEM and Sentinel-2A data to image interpretation sheet and the data interpreted for various landform units.
- Incorporating slope and land use information in physiographic map to subdivide the landform units into sub-landform units.
- Ground truth collection for developing correlation between landform and image interpretation units.
- Finalization of landform map with necessary changes and modification subsequent to field verification.

3.3.6 Resource map generation

Image interpretation of FCC imageries with the help of topographical information from ALOS-DEM was taken and the procedure comprises of the following steps

- Georeferencing of ALOS-DEM and Satellite imagery.
- Delineation of watershed area.
- Demarcating land use/land cover and landform units.
- Demarcation of other information like habitation, water bodies, drainage, roads, *etc*.
- Marking observation points along with identification of traverse routes for random field checking
- Pre-field studies.
- Soil sampling and ground truth collection.
- Soil characterization.
- Linking attribute database with base map.
- Spatial database generation.

3.3.7 Pre-field studie

The interpretation of satellite data and SOI toposheet map before fieldwork helped in the location of observation sites and deciding traverse routes in conjunction with pre-field preparatory studies.

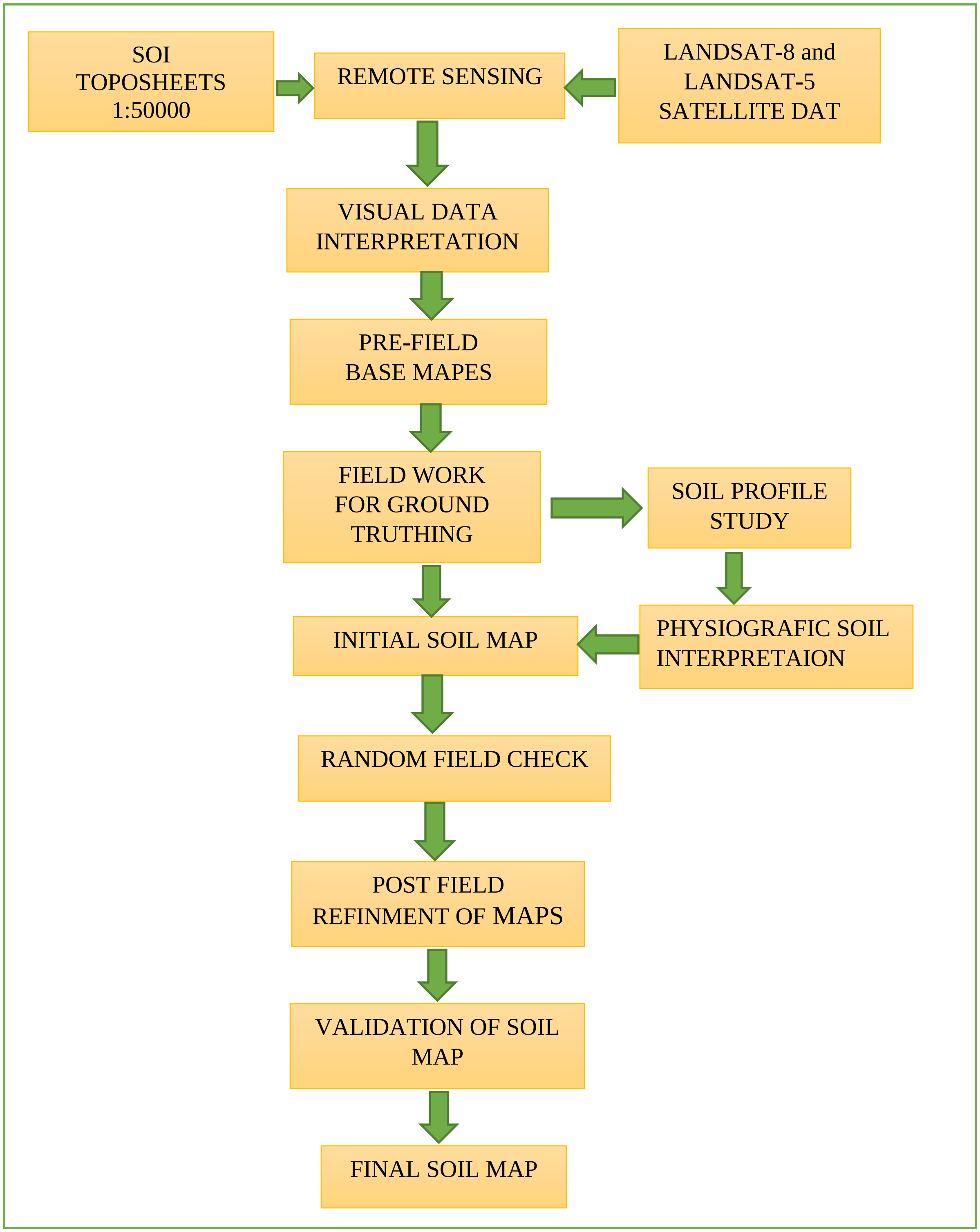


Fig. 3.6 Methodology for generation of soil map using remote sensing data

3.4 Ground truth collection

3.4.1 Pre-field work

The study area was traversed to recognize and validate landform classes to comprehend the soil heterogeneity and also the current land use/land cover units. Depending on the change in surface texture, slope, erosion and stoniness, representative area on landform units inside the location were selected for detailed soil profile studies. The soil profile-1.5m long, 1.0 m wide and 1.5m deep or till weathered layer was dug for examination of various morphological features on the basis of the remote sensing data interpretation and soil variability as suggested in the USDA Soil Survey Manual (Soil Survey Staff, 1998). Special observations regarding the depth and width of cracking and also the extent of slickensides was also recorded.

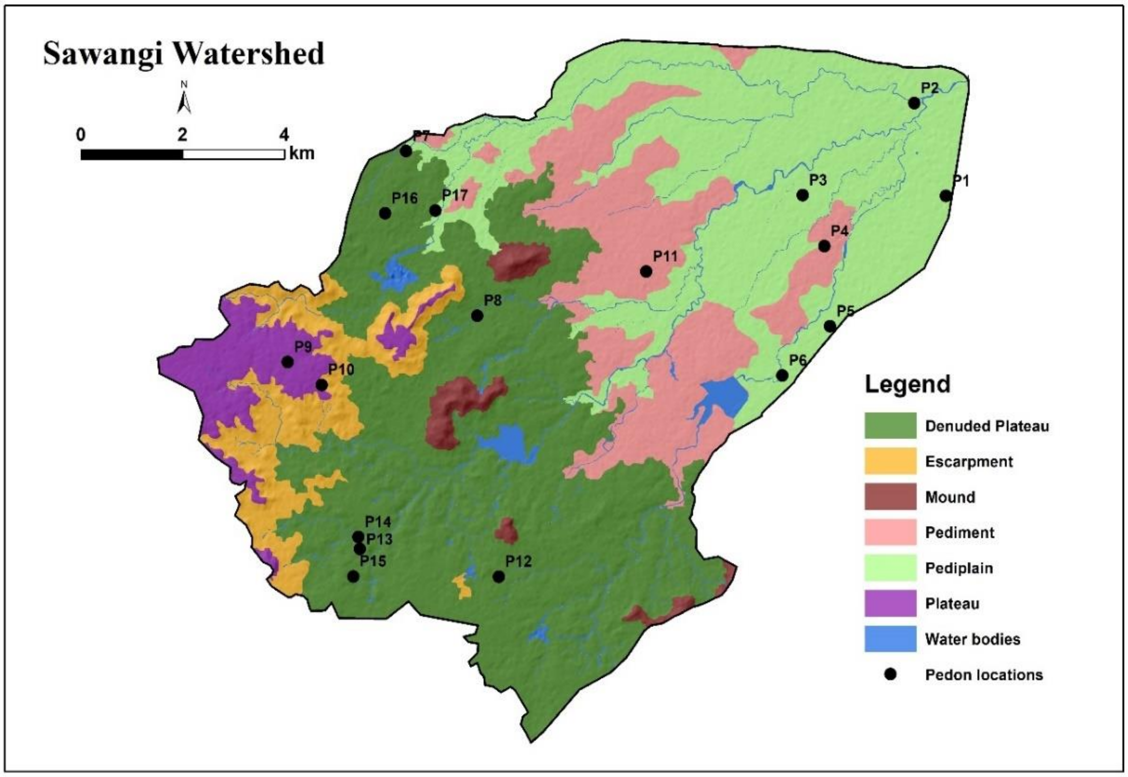


Fig. 3.7 Landform map with Pedon location

Table 3.7 Geo-referencing of soil pedons selected for study

Pedons No.	Village name	Landform	Soil taxonomy	Latitude/Longitude
1	Bhamb	Pediplain	Vertic Haplustepts	20° 23' 10.66"N 78° 33' 2.87"E
2	Sawangi	Pediplain	Typic Haplustepts	20° 24' 8.98"N 78° 32' 42.82"E
3	Raveri	Pediplain	Vertic Haplustepts	20° 23' 13.08"N 78° 31' 25.87"E
4	Pimpalkhuti	Pediment	Lithic Haplustepts	20° 22' 40.92"N 78° 31' 39.80"E
5	Pimpalkhuti	Pediplain	Vertic Haplustepts	20° 21' 48.72"N 78° 31' 45.18"E
6	Soyti	Pediplain	Typic Haplusterts	20° 20' 53.97"N 78° 31' 34.11"E
7	Krisnapur	Denuded Plateau	Lithic Ustorthents	20°23'45.92"N 78°26'57.71"E
8	Jalka	Denuded Plateau	Lithic Ustorthents	20° 22' 2.28"N 78° 27' 43.80"E
9	Potgawahan	Plateau	Lithic Haplustepts	20° 21' 35.84"N 78° 25' 34.70"E
10	Nimgavan-1	Escarpment	Lithic Ustorthents	20° 21' 21.13"N 78° 25' 57.40"E
11	Pimpari (Durg)	Pediment	Lithic Haplustepts	20° 22' 27.49"N 78° 29' 38.85"E
12	Dongarkhadda	Denuded Plateau	Lithic Ustorthents	20° 19' 19.07"N 78° 27' 54.70"E
13	Nimgavan-2	Denuded Plateau	Lithic Ustorthents	20° 19' 38.28"N 78° 26' 21.02"E
14	Dongarkhorda-1	Denuded Plateau	Lithic Ustorthents	20° 19' 45.69"N 78° 26' 20.19"E
15	Dongarkhorda-2	Denuded Plateau	Lithic Ustorthents	20° 19' 21.14"N 78° 26' 16.09"E
16	Warna	Denuded Plateau	Typic Haplustepts	20° 23' 7.39"N 78° 26' 42.77"E
17	Warna	Denuded Plateau	Lithic Ustorthents	20° 23' 8.53"N 78° 27' 16.82"E

Various location and soil characteristics such as slope, stoniness, erosion, colour, texture, structure *etc*. were observed in special format. Soils were classified according to 'Keys to Soil Taxonomy' (Soil Survey Division Staff, 2003).

Soil samples of nearly 1.5 kg weight were collected in a cloth bag from each horizon of all the representative pedons for laboratory analysis of soil physical and chemical properties. Soil clods were collected from the soil horizons for determination of soil bulk density. On the basis of detailed soil survey, seventeen soil series were identified in Sawangi watershed of Yavatmal district. The morphological characteristics these are presented in the Table 3.3.

The collected bulk soil samples were weighed after air drying. A wooden mortar and pestle were used to crush soil aggregates and then pass through a 2 mm sieve. Soil material passing through the sieve were placed in labeled boxes. A small portion of less than 2 mm sample to pass 0.2 mm (80 meshes) sieve (Jackson, 1973) was used for the determination of organic carbon and free calcium carbonate.

During the fieldwork, relationship between image interpretation units and soil classes were established. The relationship was later used to correct pre-field interpretation map and to produce a soil map.

3.4.2 Validation of soil map

The soil classes and soil unit boundaries were validated on the basis of field observations. The variability, wherever observed, was recorded for essential corrections in the relevant field, throughout the watershed area.

3.4.3 Post-field work

Following activities were accomplished after the field survey changed over.

- Refinement of landform and land use/land cover base map boundaries on the basis of information collected during the field survey.
- Correction of soil information with landform units by confirmation through further interpretation of satellite imagery, ALOS-DEM and Sentinel-2A data.

- Establishment of soil-landform relationship by considering various morphological and soil-site characteristics.

3.5 Soil characterization and methods of soil analysis

3.5.1 Soil morphological properties

The soil profiles have been examined inside the field for morphological features according to the procedure given in IARI Manual (1971) and USDA Soil Survey Manual (Soil Survey Staff, 1998). Morphological characteristics of every one of the horizons such as depth, colour, texture, the volume of gravel, structure, consistency, calcareousness, roots, pores, *etc*. were recorded. Additionally, data on pressure faces/slickensides, depth and width of cracks, coarse fragment content in soil expressed based on volume (%) *etc*. was noted.

3.5.2 Methods of Soil Analysis

A brief description of standard test procedures followed for various physical and chemical characteristics of soil samples are given below.

3.5.2.1 Physical parameters

a) Soil texture

Soil texture was determined by international pipette method, described by Piper (1950)

b) Bulk density

About 3 – 4 cm diameter size soil clods are collected; clod is firmly tied in one end of thread. The clod along with the thread is weighted. Dip the clod in the melted paraffin and allow the excess to drain. Weigh the clod and paraffin together. The wax coated clod is suspended from the hook of the balance, immersed into water without touching the bottom of the beaker and weighed. The clod is dried in an oven at 105˚C for about 24 hours to get a constant weight, cooled in room temperature and weighted again to obtain the oven dry weight.

$$\text{Bulk density (Mg m}^{-3}\text{)} = \frac{\text{Weight of oven dry soil (Mg)}}{\text{Volume of soil (m}^3\text{)}}$$

c) Water Retention Characteristics

Moisture retention was determined at -33 kPa and -1500 kPa using Pressure Plate Apparatus (Soil Moisture Equipment Co., Sant Barbara, California, USA) and available moisture content was determined from the moisture held at -33 kPa and -1500 kPa by difference (Klute, 1986).

Available water capacity

Available water capacity (AWC) was determined using the expression suggested by Gardner *et al*. (1984) and latter modified by Coughlan *et al*. (1986).

$$AWC = \frac{(Wmax - Wdry)}{DW} \times BD \times Depth\ (100cm)$$

Where,

Wmax = gravimetric water content (g g^{-1}) at the upper soil storage limit (33 kPa),

Wdry = gravimetric water content after the plant water extraction *i.e.* lower soil storage limit (1500 kPa),

BD = bulk density,

DW = density of water (approximately 1 Mgm^{-3})

d) Water holding capacity (WHC)

Water holding capacity of soil was measured by Keen Raczkowski Box Method as described by Black (1965)

3.5.2.2 Chemical properties

a) Soil Reaction (Soil pH)

pH in soil suspension (1:2 soil: water) was measured by a glass electrode pH meter after equilibrating the soil with water for 30 minutes with occasional stirring (Jackson, 1973).

b) Electrical conductivity (EC)

The clear supernatant extract obtained from the suspension used for pH (1:2 soil: water) was utilized for EC measurement by conductivity bridge (Jackson, 1973).

c) Organic carbon (OC)

Carbon is the chief element present in soil organic matter comprising about 48 to 58 per cent of the total weight. Therefore, organic carbon determinations are often used as the basis for estimating the organic matter by multiplying the organic carbon value by factor 1.724.

Organic carbon was determined by Wet-oxidation method (Walkley and Black, 1934). For this 100 mesh sieved soil samples were used.

d) Calcium carbonate ($CaCO_3$)

For the determination of calcium carbonate, the soils were first treated with a known volume of warm 0.5 N hydrochloric acid solutions to neutralize all carbonates and the excess hydrochloric acid was back titrated with standardized NaOH solution using phenolphthalein as an indicator (Piper, 1966).

e) Exchangeable sodium percentage

Exchangeable sodium percentage (ESP) was calculated by the formula given below.

$$ESP\ (\%) = \frac{\text{Exchangeable Na}}{\text{Cation exchange capacity}} \times 100$$

f) Base saturation

Base saturation was calculated (Jackson,1973)) as sum of cations (cmol (p^+) kg^{-1}) divided by CEC (cmol (p^+) kg^{-1}) and multiplied by 100. It is expressed as percentage.

g) Cation exchange capacity (CEC)

Weighed amounts of the fine soil samples were saturated with 1*N* sodium acetate solution (pH 8.2). After removal of excess sodium acetate by washing with alcohol, the adsorbed Na^+ was extracted by washing with 1*N* ammonium acetate (pH 7.0) and the leachate was made up to a known (100 ml) volume (Schollenberger and Simon, 1945). The Na^+ ions present in the leachate were determined by using an atomic absorption spectrophotometer.

3.5.2.3 Available macronutrient analysis

a) Available N

Available Nitrogen (N) in soil was determined by potassium permanganate method as described by Subbiah and Asija (1956)

b) Available P

Soil available Phosphorus (P) was determined by using 0.5 M $NaHCO_3$ (Olsen extractant) solution at 8.5 pH as described by Olsen *et al.* (1954)

c) Available K

Soil available Potassium (K) was extracted by shaking with neutral normal ammonium acetate for five minute (Hanway and Heidel 1952) and K in the extract was estimated by flame photometer by using K filter.

d) Available S

Soil available Sulphur (S) was extracted by 0.15 % $CaCl_2.2H_2O$ solution and the extract was determined by turbidimetric method (Tabatabai 1982)

e) Available micronutrients analysis

Available micronutrients *viz*., Fe, Mn, Cu, and Zn were determined by using DTPA extractant (Lindsay and Norvell 1978) and estimated by using atomic absorption spectrophotometer.

3.6 Application of geographic information system (GIS)

GIS is a systematic device helpful in the analysis of spatially referenced data on the basis of somewhat set of principles (Burrough, 1986). With the increasing requirements for mapping, assessment, monitoring and control of the precious natural sources, GIS has become an efficient and mandatory platform for current and future generation. The system contains four major functions *viz*. data acquisition, data storage and retrieval, manipulation and analysis and output generation.

3.6.1 Thematic mapping

Various soil features systematic in the characteristic database are connected to master soil horizon and then re-categorized to generate thematic maps. Thematic mapping is operationalized on the basis of logical evaluation of attributes. These maps assist us in understanding about the spatial distribution and nature of a selected particular theme character, which serves as diagnostics of land use planning parameters. The non-spatial (attribute) data are connected to soil layers to gain various thematic maps like soil drainage, soil depth, slope *etc*.

3.6.2 Spatial database generation

The spatial database was generated using the ArcMap module of ArcGIS software to generate several thematic maps. The diverse steps involved are shown in Fig.3.8.

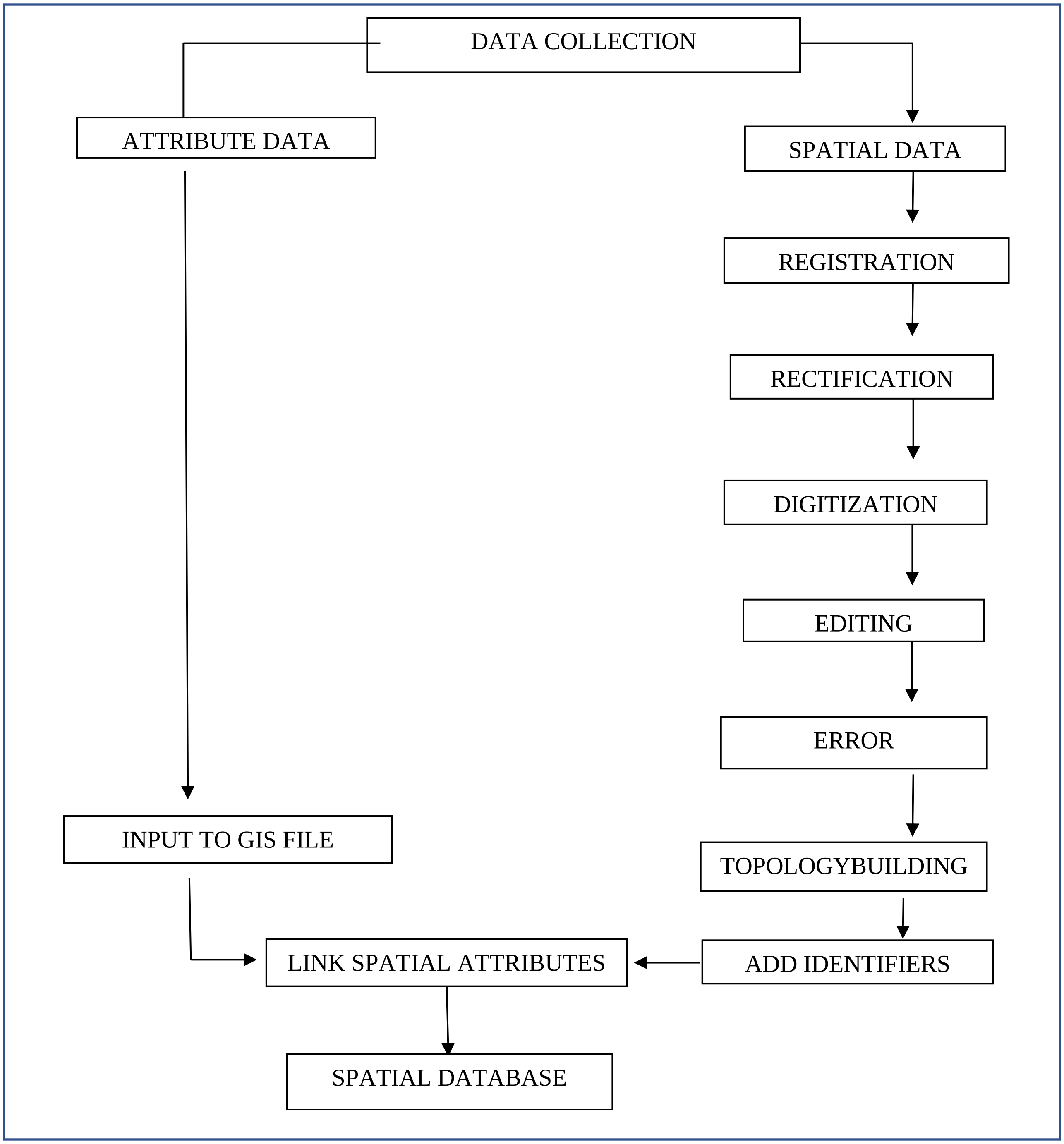


Fig. 3.8 Generation of the spatial database based on GIS

3.6.3 Soil mapping

The applicability of remote sensing in soil mapping relies over selection of appropriate record and its accurate interpretation, relating to the collateral information on physiography and vegetation, that have significant bearing to soil formation. Specific soils show characteristic spectral reaction in the visible and infrared range of the electromagnetic spectrum, that is a function of their physico-chemical properties. The reflectance pattern of radiant energy provides important clues to the soil classes. The variation in soil properties like colour, texture, moisture content, calcareousness and organic matter which are indicative of soil classes, are registered on the imagery. The presence or absence of vegetation and land use also indicate the type of soil depending upon the physiographic unit and influence of other image elements. Hence, a correlative approach involving image elements and physiographic system has been adopted in this study.

3.7 Land evaluation

Land evaluation is the procedure of accessing the capability of land for alternate uses. There are several techniques available for evaluating the land both for qualitative and quantitative assessment. A few of the numerous strategies- the land capability classification (Klingebiel and Montgomery, 1961), land irrigability classification (AIS & LUS, 1971), land productivity Riquier *et al*. (1970), Sys (1985) and land suitability classification (FAO, 1976) were used.

3.7.1 Land capability classification

The land capability classification is a qualitative system that was developed by United States Department of Agriculture (Klingebiel and Montgomery, 1961), later modified by AIS & LUS (1971) was adopted for grouping the soils in various land capability classes. The land capability classification is a wide grouping of land based totally on their boundaries and is designed to emphasize the hazards in specific types of land. Lands are grouped according to their capability and limitations for sustained production. Land functionality classifications provide three important categories of land grouping *viz*. Land capability class, Land capability sub-class and Land capability units. Land capability refers to the potential of land to keep maintain a number of pre-described lands uses build-in descending order of desirability, arable crops, pasture, wooded area, endeavor/wildlife and are labeled as magnificence I to class VIII. If the capability of land decreases, the land becomes desirable for fewer land uses. Land capability sub-classes are defined based on chief conservation issues *viz*. erosion (e), excess water (w), climatic limitation (c) and moisture limitation (s). Land capability is estimated by comparing the characteristics of the land mapping unit with crucial limits set for each capability class. Sub-class suggests variant limitations of capability unit and aggregate management requirements.

Within the present investigations, the interpretative grouping of the proposed area was made for land capability classification. The lands were evaluated in pursuance of the potentiality and limitations for the sustained production of crops.

3.7.3 Land productivity classification

Land productivity of soils was evaluated by using a parametric approach as per the manner mentioned by Riquier *et al*., (1970). This system suggests the calculation of productivity index considering nine elements to figure out the soil productivity *viz*. moisture (H), drainage (D), effective depth (P), texture / structure (T), base saturation (N), soluble salt concentration (S), organic matter content (O), mineral exchange capacity / nature of clay (A) and mineral reserve (M). Each factor is rated on a scale from 0 – 100, the actual percentages being multiplied by each other. The resultant index of productivity, also lying between 0 – 100, is set against a scale placing the soil in one of five productivity classes (excellent, good, average, poor and extremely poor to nil).

3.7.4 Soil–site suitability classification for major crops

Suitability is a measure of how properly the qualities of a land unit suit the necessities of a special form of land use. Suitability is appraised for each relevant use and each land unit identified in the study.

- Selection of the kinds of land use for which the evaluation has to be made.
- Definition of the specific land use requirements.
- Data collection from the area which is to be taken into consideration for the assessment, matching of the land attributes with the particular crop increase requirements and identity of the preliminary suitability classes.
- Validation of the preliminary classification and identification of the final suitability evaluation.

  Sub-class reflects the kinds of limitations or main kind of improvement measures required within a class. The sub-classes are

e	Climatic limitation
t	Topographic limitation
w	Wetness limitation
n	Salinity and alkalinity limitation
f	Fertility limitation
s	Physical soil limitations influencing soil water relationship and management.

In the current investigation, the soil-site suitability for major essential crops (cotton, pigeon pea, sorghum, soybean, wheat and chickpea) grown in the study area was worked out as per the methodology given in the FAO frame work on land evaluation (FAO,1976) and modified by (Sys *et al*.,1991). Land suitability refers to the fitness of a given type of land for a defined use. (Sys *et al.*, 1991), described suitability class levels *i.e.,* S1-highly suitable, S2-moderately suitable, S3-marginally suitable, and N-not suitable. The suitability units differ in management requirement. The soil-site suitability criteria as suggested by NBSS & LUP (1994) have been used for evaluating the suitability of soil for cotton, soybean, wheat, pigeon pea, chickpea, sorghum, green gram and black gram. The soil-site suitability criteria as suggested by (Naidu *et al.,* 2006), have been used for evaluating the suitability of soils for cotton, pigeon pea, soybean, sorghum, pearl millet, wheat and gram.

Table 3.7 Structure of land suitability classes and subclasses (FAO, 1976)

Order	Classes	Description
Suitable (S)	S1 (Highly suitable)	Land having no limitations to the given type of use
	S2 (Moderately suitable)	Land having minor limitations to the given type of use
	S3 (Marginally suitable)	Land having moderate limitations to the given type of use
Non-Suitable (N)	N1 (Currently not suitable)	Land having severe limitations that preclude the given type of use, but can be improved by specific management
	N2 (Permanently not suitable)	Land with severe limitations which are very difficult to overcome

3.8 Location Mapping of Dug/Open Wells

3.8.1 Data availability on Google Earth Pro

The Sawangi watershed is divided into 3 convenient grids. The available data for different years from 2008 to 2017. It could be noted that, the complete data of watershed are available for three different years viz. 2008, 2012 and 2017. Three years viz. 2007, 2013 and 2017 were selected for the analysis.

3.8.2 Well census and estimating well irrigated area mapping

Google Earth images (5.8 m resolution) during the last decade were accessed, visually interpreted and analyzed. We focused on three reference years -2008, 2012 and 2017.

Images earlier to 2007 were not available for the study area. For other two reference years (2008, 2013 and 2017) preceding and succeeding year images were interpreted to verify well enumeration, its classification (functional/defunct) and irrigated area estimates. For the year 2007, images for next two years were used. Seasonal images for each year were visualized to differentiate between crop grown to residual soil moisture and irrigated crop. A total of 20 images were thus studied. Visible round shape object located in agricultural field characterized by geometric shape was initially marked as candidate/probable dug out/open well. A typical open well on Google Earth image is shown in Fig. 3.9. In the next step, timeline image of the probable well was checked visually to know if it is existed during all the three reference years (2008, 2018 and 2017). Images during different months of the reference years were interpreted to rule out confusion with tree/tree shade or other objects. Normalized differential vegetation index (NDVI) of the study area was calculated to differentiate between crops grown on residual soil moisture and irrigated crops. Sentinel-2 data were used for this purpose. The study area does not have any surface irrigation project; however, there are farm ponds/percolation tanks to store rainwater. All such tanks/ponds were ruled out as possible source of irrigation and hence error in estimates of well irrigated area. After interaction with state officials and farmers, it was concluded that farm ponds/tanks mostly serve as source of life saving irrigation during kharif crop season and/or groundwater recharge structures. NDVI values and visible crop in a land parcel after 15th March were considered as proxy for irrigated land parcel to estimate irrigated area associated with each well. Other insignificant crops like irrigated chickpea and rare fodder crop were assumed to be wheat parcels for practical purpose if the farmer could not recollect historical information during ground truthing exercise. The dug out/open wells were classified into functional and defunct category based on timeline image interpretation. A well without associated irrigated area for 3 consecutive years was classified as defunct, while a well with associated irrigated area for 3 successive years was noted as functional. A well with interchanging behavior between two categories (functional and defunct) during the decade was marked separately. The georeferenced 71 locations were then mapped in Geographic Information System (GIS), overlaid on cadastral map to assign a unique Parcel Identification Number (PIN) commonly known as survey number, and Well Identification Number (WIN). This facilitated tracing of an owner of land/well through Mahabhumi (Maharashtra Bhumi Abhilekh)-a land record website of Maharashtra (https://bhulekh.mahabhumi.gov.in). The portal allows name based or PIN based query. The agriculture department provides contact details of its extension staff in public domain (https://agricoop.nic.in).

3.8.2.1 Normalized differential vegetation index

The normalized difference vegetation index (NDVI) is a simple graphical indicator used to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or 72 not. The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 μm) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7 to 1.1 μm). Healthy vegetation (chlorophyll) reflects more near-infrared (NIR) and green light compared to other wavelengths. But it absorbs more red and blue light. The NDVI is calculated from these individual measurements as follows

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

Where, Red and NIR stand for the spectral reflectance measurements acquired in the red (visible) and near-infrared regions, respectively.

3.9 Ground water potential

The thematic maps of LULC, soil, TWI, slope, drainage density and geomorphology were prepared and classified into defined raster classes. The weighted overlay analysis technique was deputed to develop groundwater potential map (Hand book of applied Hydrology,1972).

3.10 Runoff

The effect of LULC adjustments on runoff from the watershed was assessed by the usage of the Soil Conservation Service curve number technique assuming a normal rainfall of 927 mm within the watershed. The soil data 1:10000 scale collected through a detailed survey were used for hydrological grouping and overlaid with LULC layer to get curve number for estimating run-off from the delineated hydrologic response units. The computed total run-off was categorized into convenient classes for comparing the effect of LULC assuming another factor to be stable (Hand book of Hydrology,1972).

The overall steps carried out are as follows,

- Delineation of area from the SOI toposheet map.
- Conversion of raster data to vector format.
- Creation of the baseline data by digitizing the map and a digital database is prepared using ArcMap software.
- Preparation of thematic maps by visual interpretation.
- Preparation of thematic map from SOI toposheet and geomorphological and hydrological map overlays based on the visual interpretation of satellite image in conjunction with the existing maps/literature.
- Scanning and digitizing all these maps and creation of digital database.
- Field visits for checking the interpretation collecting the additional hydrogeological information.
- Incorporation of field observations in the thematic maps.
- Final output generation using GIS software

CHAPTER - IV

RESULTS AND DISCUSSION

The present investigation was carried out to assess the soil and land resources of Sawangi watershed in Yavatmal district of Maharashtra. On large scale as a model for future holistic planning and sustainable management of natural resources. It started with detection of socio-economic factors followed by crop dynamics, analysis of bio-physical factors, and also the soils have been evaluated for different crops suitability. The result of the field and laboratory investigation carried out and the interpretation made in the investigation have been presented and discussed in this chapter under the following heads.

This chapter presents the findings obtained from the present study and they have assessed the soil and land resources in Sawangi watershed of the Yavatmal district. It starts with the detection of socio-economic factors followed by crop dynamics, analysis of bio-physical factors, and also the soils have been evaluated for profile characteristics, such as morphological and physico-chemical properties. at the end decision support system for land use planning with different LUP scenarios. the result obtained during the investigation are presented and discussed under the following heads

4.1 Socio–economic analysis data

4.1.1 Population Dynamics

4.1.2 Cropping pattern

4.1.3 Crop dynamics

4.1.4 Cost of cultivation

4.1.5 Livestock Population

4.2 Land utilization and land use land cover change detection

4.2.1 Land utilization

4.2.2 Land use land cover change detection

4.3 Preparation of slope map

4.4 Landform classification and mapping

4.5 Watershed characterization and interpretation

4.5.1 Drainage morphometry

4.5.2 Stream ordering

4.5.3 Stream length

4.5.4 Bifurcation ratio

4.5.5 Drainage density

4.5.6 Drainage frequency and drainage intensity

4.6 Characterization and Classification of soils of Sawangi watershed

4.6.1 Site and Soil characterization of Sawangi watershed

4.6.2 Soil characterization

4.6.2.1 Morphological properties of soils

4.6.2.2 Physical properties of soils

4.6.2.3 Chemical properties of soils

4.6.2.5 Nutrient status of soil

4.7 Soil Mapping

4.7.1 Soil series description

4.7.2 Taxonomic classification of soils

4.8 Land Evaluation

4.8.1 Land capability classification

4.8.2 Land irrigability classification

4.8.3 Land productivity evaluation

4.8.4 Soil Suitability evaluation

4.1 Socio–economic analysis data

4.1.1 Population dynamics

As per 2011 census, the total geographical area of sawangi watershed is 118.2 sq. km and the total population of the watershed was 19,994 which is 17.82 per cent of tehsil's total population (1,12,203) and 0.72 per cent of district population (27,72,348). Population density of watershed is 169 per sq. km. whereas, it is 141 per sq. km. in tehsil and 204 per sq. km. of district. The total literacy in the watershed villages is relatively low 53.03 per cent compared to 74.4 per cent in the taluka and 73.0 per cent in the district. There is a large tribal population accounting for 38.85 per cent i.e. 7767 in watershed, 29 per cent i.e. 32485 in tehsil and 18.54 per cent i.e. 514057 in district. while schedule caste population only is 2.64 per cent in this watershed. The population, literacy, average family size, sex ratio and population density according to the census, (2011) of the sawangi watershed, Yavatmal district is presented in Table 4.1.

4.1.2 Cropping pattern

The Sawangi watershed is pre-dominantly a *kharif* crop growing area. where Cotton, soybean, pigeon pea and sorghum are the important crops of the *kharif* season, whereas the principal crops of the *rabi* season are wheat and chickpea. The *kharif* crop sowing usually starts after one or two monsoon showers in June and practically ends in the middle of July. The harvesting of *kharif* cotton crop is generally done between the October to December and pigeonpea between January and middle of February. The harvesting of soybean crop is between the mid of October to November and sorghum crop between third week of December and the first week of January. The *rabi* crops, like, wheat and chickpea are usually sown between the middle of October and the first week of November. The harvesting of wheat crop in March and gram between last week of February and the middle of March.

4.1.3 Crop dynamics

The collection of Crop history data of Ralegaon taluka and Yavatmal district were collected from the sources of the census report 2011, annual report, and the District

Social Economics (DSE) review report of Yavatmal district (Secondary data from available online). Cotton, soybean, pigeon pea, chickpea and sorghum are the principal *kharif* crops in this area. The area was sowing to cotton crop shows an increase of 12996 ha in taluka and 36388 ha in the district from 2003-2015. It is obvious that the sorghum crop is at this point not a favored choice in the watershed. This is in contract with the findings prior (Patangray, 2016) that after the introduction of Bt cotton in the Vidarbha region of the Maharashtra State, sorghum is nearly left of cultivation. whereas declining returns from sorghum show some effect as soybean replaced sorghum it's owing to better economic returns, low input, low maintenance required, and availability of the marketing. Its region increased to 9019 ha in taluka and 169755 ha in the district.

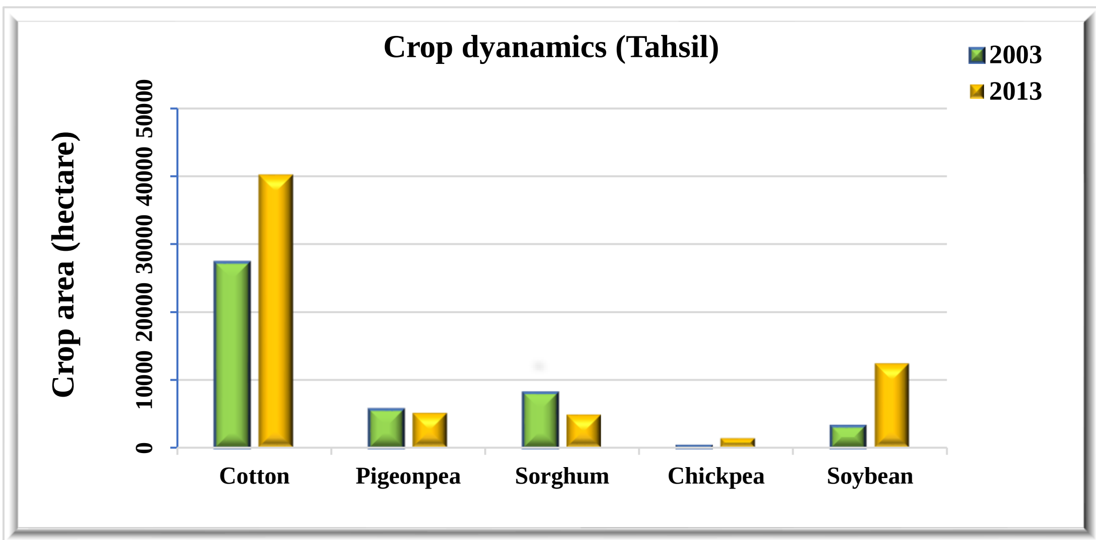
Table 4.1 Population dynamics of Sawangi watershed

Sl. No.	Population Characteristics	Watershed	Per cent	Ralegaon	Per cent	Yavatmal	Per cent
1	Area in sq. km	118.2		792.58	-	13552	-
2	No. of households	4438		28170	-	646886	-
3	Total population	19994		112203	-	2772348	-
4	Population of men	10262	51.3	57,384	51.1	1419965	51.2
5	Population of women	9732	48.7	54,819	48.9	1352383	48.8
6	Scheduled castes population	526	2.6	8869	7.9	328518	11.8
7	Scheduled tribes' population	7767	38.8	32485	29.0	514057	18.5
8	Literate population	11081	55.4	83464	74.4	2022574	73.0
9	Illiterate population	8913	44.6	28739	25.6	749774	27.0
10	Total cultivator	2929	14.6	16991	15.1	333504	12.0
10.1	Main cultivator	2824	14.1	15216	13.5	310818	11.2
10.2	Marginal cultivator	106	0.53	1775	1.6	22686	0.8
11	Total agricultural labour	6392	32	38784	34.5	739718	26.7
11.1	Main agricultural labour	5662	28.3	31304	27.9	633145	22.8
11.2	Marginal agricultural labour	1054	5.3	7380	6.6	106573	3.8
12	Average family size	4		4	-	5	-
13	Population density	169		141		204	
14	Sex Ratio	959		955		952	

(Source: Census of India, 2011)

Table 4.2 Crop dynamics of Ralegaon tahsil and Yavatmal district (Area in ha)

Year	Cotton		Pigeon pea		Sorghum		Chickpea		Soybean	
	Tahsil	District	Tahsil	District	Tahsil	District	Tahsil	District	Tahsil	District
2003	27225	453100	5676	58767	8106	128090	268	13966	3195	80722
2013	40221	386700	5100	96537	4855	57504	1375	65311	12414	228928
Sift in area	**12996**	**-66400**	**-576**	**37770**	**-3251**	**-70586**	**1107**	**51345**	**9019**	**148206**



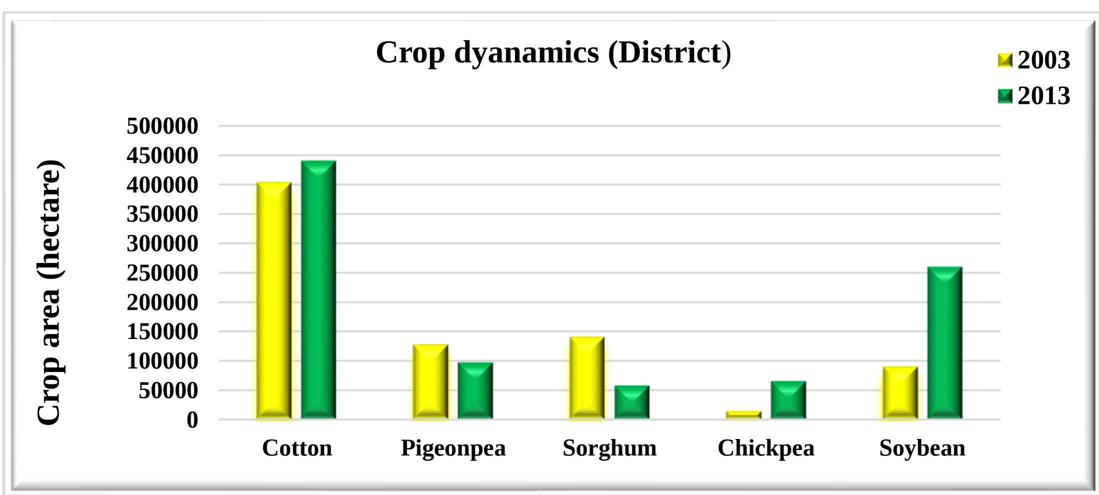


Fig. 4.1 Land utilization of Ralegaon tahsil and Yavatmal district.

Wheat (irrigated) and chickpea (unirrigated/somewhat irrigated, residual soil moisture crop) are the main *rabi* season crops. Subsequently, the watershed is arranged as a rainfed farming region. Pigeon pea was cultivated as an intercrop during the year 2017 - 18, the pulse prices arrived now all time high but farmers didn't select pigeon pea as the first option. In certainty, historic crop data (Table 4.4) shows that pigeon pea was a famous preference. The area cultivated to pigeon pea crop shows a decline of -576 ha in taluka and -30755 ha in the district from the last decade.

The crop dynamics of the Yavatmal district and Ralegaon taluka are shown in Fig. 4.1 and Table 4.2. Such data are not available for the study area (watershed) but an identical trend was ascertained during field visits. The area under different crops in the Sawangi watershed is shown in Table 4.5.

4.1.4 Cost of cultivation

The estimated average cost of cultivation per acre for cotton incurred by the farmers is Rs. 16975/- while per acre of average yield is restricted to 4.5 quintals which brings an average per acre income of Rs. 21150/-, resulting in a net per acre benefit of Rs. 4175/- while, the net average incomes per acre from soybeans, pigeonpea, sorghum, and chickpea results in the benefit of Rs. 3200/-, Rs. 3375/-, Rs. 3850/- and Rs. 5400/- respectively (Table 4.3). These findings are depending on the interaction with the farmers during field surveys in the watershed villages and the useful information from annual reports of the Yavatmal district. It is evident that as far as the B/C ratio, sorghum is the most profitable crop while cotton is the minimum profitable crop with high input cost.

It very could be seen from Table 4.4 that the farmers accorded priority to cotton because of better returns in the past and no vulnerability to crop depredation. Apart from ranking, the farmers also explained the rationale for choosing soybean as a second choice because it is essentially a low input, low care crop. Subsequent to investing in cotton, the thin resources cause them to select that is free from crop harvest and required low investment. The crop selection made by farmers among the year 2017-18 is

Table 4.3 Crop-wise per acre cost of cultivation and net returns

Item & Cost (per acre)	Major crops of study area				
	Cotton	Soybean	Pigeonpea intercrop	Sorghum	Chickpea
Ploughing	1200	600	600	600	600
Harrowing	1000	500	500	500	500
Seed	850	500	450	1000	500
Sowing	500	500	500	500	500
Weeding & intercultural operation	1000	500	300	0	300
Gap filling	300	0	0	0	0
Fertilizers	1850	1250	0	700	900
Pesticides	4500	3500	1000	0	3000
Spraying	400	400	200	0	400
Harvesting	1200	700	1400	1000	1000
Threshing	400	200	200	200	200
Interest amount on capital cost	375	450	175	250	200
Family labour	400	200	300	200	300
Wage labour	1000	1200	1200	800	1200
Compost	2000	700	700	300	300
Total cost	16975	11200	6525	6050	9900
Yield in (Q)	4.5	6	2.2	4.5	4.25
Revenue (Rs)	21150	14400	9900	9900	15300
Net returns in Rs (Revenue - Cost)	4175	3200	3375	3850	5400
BC Ratio	1.25	1.29	1.52	1.64	1.54

(Price in Rs. based on farmer’s interview and secondary data)

displayed in Table 4.5, it is obvious that cotton and soybean are cultivated in nearly equivalent proportion. Land parcels with low fertility status/shallow depth of soils, in commonly were cultivated to cotton whereas is a good soil for cultivated of soybean. pigeonpea was cultivated as an intercrop during the year 2017-18, the pulse prices arrived at every time high but then farmers did not select pigeonpea as a first priorities. Indeed, historic crop data (Table 4.2) shows that pigeonpea was a favairate for all people and 5676 ha in tehsil and 58767 ha in district the area were cultivated to this crop in 2003. These findings also indicate the shift in performance of cash crops in place of cereal crops. The shift in the performance is depicted in Fig. 4.1. Area grown to sorghum in Ralegaon tehsil and Yavatmal district shows steep decline. Similarly, area grown to pigeonpea declined by 5779 ha in tehsil and 30755 ha in district during the last decade. Such data were not available for the watershed villages but the trend was reportedly identical as confirmed during interaction.

Table 4.4 Ranking of crop choice given by farmers

Sl. No.	Crop	Ranking	Reasons for choosing crop
A)	Cotton	1	To avoid crop depredation
		2	Ready market availability
		3	Suitable to soil type
		4	Risk minimization
B)	Soybean	1	Less labour requirement
		2	Low input
		3	Ready market
		4	Risk minimization
C)	Pigeonpea	1	Family need
		2	Easy availability of inputs
		3	Ready market
		4	Suitable to soil type

Table 4.5 Area under different crop in Sawangi watershed (*Kharif* 2017-18)

Sl. No.	Area under crops	Area (ha)	% of total agriculture land
1.	Cotton	3285	41.63
2.	Soybean	2140	27.12
3.	Pigeonpea	710	9.00
4.	Sorghum	290	3.68
5.	Black gram	129	1.63
6.	Other crops	252	3.19
7.	Fallow land	1084	13.74
8.	**Total agriculture land**	**7890**	**100**

4.1.5 Livestock population dynamic

According to the 17th, 18th, and 19th livestock census of 2003, 2007, and 2012 directed by the commissioner of Animal husbandry (Pune), it was found investigated that the livestock population declined between 2003 to 2007, 2007 to 2012, and 2003 to 2012 of these periods in Yavatmal district by 1.2, 14.1 and 15.1 per cent while, in Maharashtra state by 3, 9.6 and 12.3 per cent declined respectively in this period. The livestock population of Ralegaon tehsil, and Yavatmal district could be corelated with an increased in the pasture land of Ralegaon tehsil by 37.45 per cent. while, decreased in the pasture land of Yavatmal district 40.80 per cent, respectively, and unavailability of about the fodder crop, for example sorghum, as the cultivation of sorghum crop area (Table 4.2) was declined by 40.13 per cent in Ralegaon tehsil and 55.11 per cent in Yavatmal district. The temporary livestock information of watershed villages areas are not accessible. The cooperation (PRA) with villagers, however, confirmed that the declining pattern was seen in watershed villages. The crop economics and declining livestock population in the watershed hence arose as main component affecting land use planning.

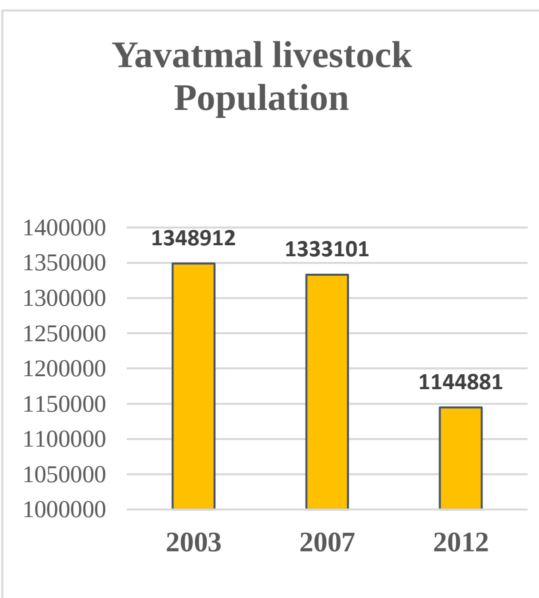


Fig. 4.2 (a)

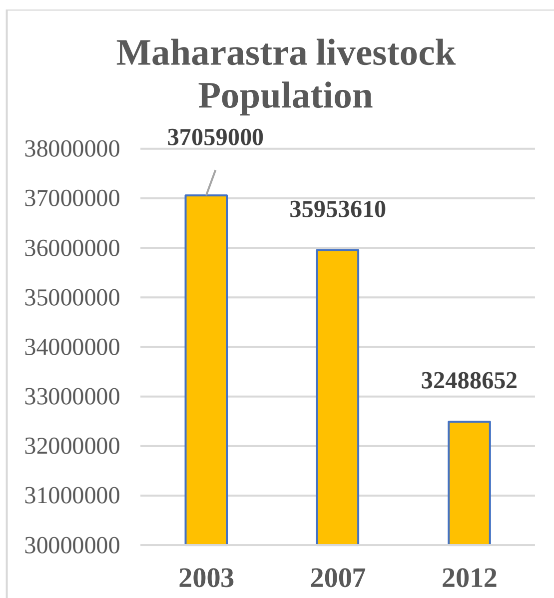


Fig. 4.2 (b)

4.2 Land utilization and land use land cover change detection (LULC)

4.2.1 Land utilization

As per the 2001 and 2011 census Land utilization statistics of Ralegaon tehsil and Yavatmal district, it was investigated that the forest area in Ralegaon tehsil and Yavatmal district increased by 8.46 per cent and 5.68 per cent respectively. Pasture land in Ralegaon tehsil decline by 59.87 per cent while, Yavatmal district enhanced by 40.80 per cent. Wastelands in Ralegaon tehsil declined by 35.24 per cent while, Yavatmal district increased by 8.12 per cent, respectively. The areas under Fallow lands in Ralegaon tehsil and Yavatmal district declined by 69.78 and 21.71 per cent respectively. while, cultivated land were increased by 1.43 and 8.81 per cent respectively in Ralegaon tehsil and Yavatmal district. So, that it implies that a huge part of wastelands and fallow land were converted into pasture land, forest land and few part cultivated land in Ralegaon tehsil.

Table 4.6 Land utilization of Ralegaon tehsil and Yavatmal district (area in ha)

Year	Forest land		Pasture land		Waste land		Fallow land		Agril. land	
	Tahsil	District	Tahsil	District	Tahsil	District	Tahsil	District	Tahsil	District
2001	5214	226787	4931.1	173553	5277.5	64185	10201	83614	57503	803787
2011	5655	239689	7883.2	102737	3417.6	69396	3083.2	65461	58322.6	874643
Sift in area	441	12902	2952.1	-70816	-1859.9	5211	-7117.8	-18153	819.6	70856

Table 4.7 LULC classes

Sl. No.	Class name	Description
1	Agriculture	Crop fields and current fallow lands
2	Forest cover	Mixed forest lands
3	Wasteland	Land areas of exposed soil and barren area due to anthropogenic influence
4	Shrub land	Land covered with the small plants
5	Habitation	Residential, commercial, industrial
6	Waterbody	River, open water, lakes, ponds and reservoirs

4.2.2 Land use land cover change detection

LULC classes were identified and delineated by visual interpretation, Landset-5 and Landset-8 satellite images. The delineated classes were agriculture, current fallow, habitation, forest cover, shrubland, wasteland, industrial area and waterbody. The area under different land use/land cover classes with image characteristics are presented in (Table 4.8). The Sawangi watershed is classified in which LULC maps were generated for different years 2008, 2012, and 2017 using satellite data at 1:50,000 scale and showed Fig. 4.3, 4.4, 4.5, 4.6, 4.7 & 4.8. The distribution of various LULC classes and their area statistics was calculated using maps which are showed Table 4.9.

The LULC of Sawangi watershed is dominated by agriculture, wasteland, and current fallows lands of the total geographical area of the watershed. The investigated results showed that wasteland, habitation and industrial area increased continuously between 2008 to 2017, while forest land and shrub land which is a forest degradation class has been decreased continuously between 2008 to 2017. The current fallows land has continuously increased between 2008 to 2017. The agriculture land has been decreased continuously between 2008 to 2017.

Table 4.8 Land use / land cover distribution (2008, 2012 & 2017)

LULC class	2008		2012		2017	
	Area (ha.)	Area (%)	Area (ha.)	Area (%)	Area (ha.)	Area (%)
Agriculture land	5926.46	50.32	5347.59	45.40	4436.5	37.67
Current fallows	1510.40	12.82	2144.88	18.21	2983.0	25.33
Wasteland	2292.12	19.46	2390.72	20.30	2567.1	20.80
Shrub land	1272.90	10.81	1002.01	8.51	946.3	8.03
Forest cover	329.45	2.80	320.11	2.72	319.0	2.71
Industrial Area	1.17	0.01	22.27	0.19	28.8	0.25
Habitation	73.37	0.62	75.69	0.64	82.1	0.70
Waterbody	371.75	3.16	474.36	4.03	414.7	3.52
TGA	11777.62	100	11777.62	100	11777.6	100

The land use and land cover change comparison of each class over different years was presented in Table 4.10. During the year of 2008 to 2017 area under agriculture, class decreased by 1489.93 ha (12.65%). The decline of agriculture class in the watershed area was due to construction mainly by an industrial area and habitation and the area around the water bodies in the watershed has shifted from a wasteland into an agricultural area. During the 2008 to 2017 area under fallow land class increased by 1472.63 ha (12.50%).

Table 4.9 LULC change detection

LULC class	2008-2012		2012-2017		2008-2017	
	Area (ha)	**(%) Change**	**Area (ha)**	**(%) Change**	**Area (ha)**	**(%) Change**
Agriculture	-578.88	-4.9	-911.06	-7.7	-1489.93	-12.7
Current fallows	634.48	5.4	838.15	7.1	1472.63	12.5
Wasteland	98.60	0.84	176.42	1.50	275.02	2.34
Shrub land	-270.89	-2.30	-55.70	-0.47	-326.58	-2.77
Forest	-9.34	-0.08	-1.08	-0.01	-10.42	-0.09
Industrial Area	21.10	0.18	6.56	0.06	27.66	0.23
Habitation	2.31	0.02	6.39	0.05	8.70	0.07
Waterbody	102.61	0.87	-59.68	-0.51	42.93	0.36

The decline of fallow land class in the watershed area was due to converted of fallow land into industrial areas and wasteland. It has also been seen in the study area that the industrial or habitation areas are mostly surrounded by agricultural areas, especially in the catchment area. it means that the area near the residential area has been cleared for the production of crops in order to fulfill the necessities of life. During the field survey, it was observed by the investigation that wastelands around the villages have also been utilized under cultivation land.

It was observed by ground truthing from 2008 to 2017 that some of the forest and shrubland areas were decreased by 10.42 ha and 326.58 ha, which was shifted into cultivated lands due to encroachment by the farmers and habitation. while during 2008 to 2017 that some of the habitation and industrial areas increased by 8.70 ha and 27.66 ha. This was attributed to population growth and increased housing requirements by the people of the study area. The classification results revealed that the wasteland area increased by 275.02 ha from 2008 to 2017. The increase of wasteland in the watershed area was due to converted of fallow land and shrubland into the wasteland. Water bodies area 42.93 ha increased from 2008 to 2017 and decreasing by 59.68 ha from 2012 to 2017.

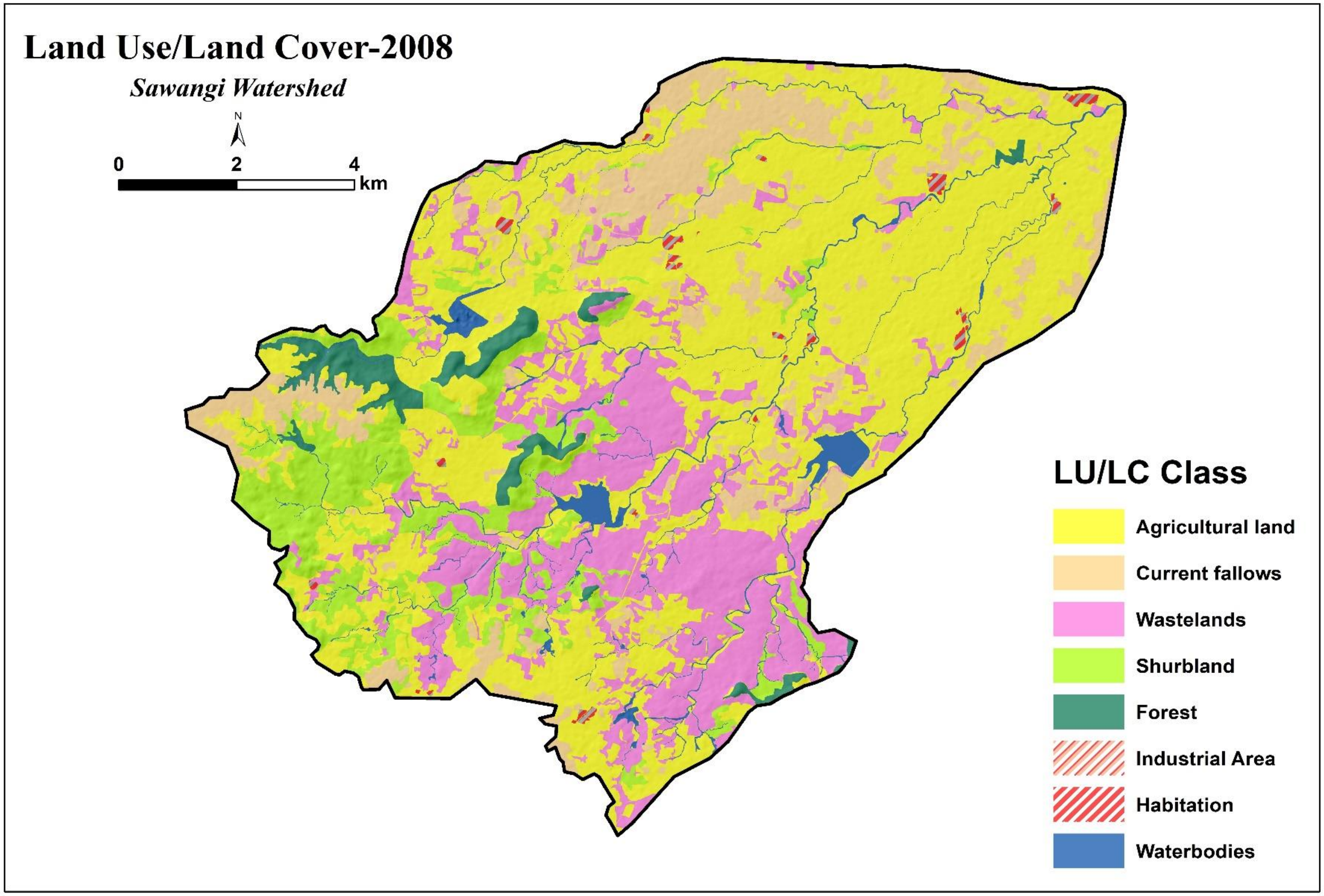


Fig 4.3 LULC of Sawangi watershed in year 2008

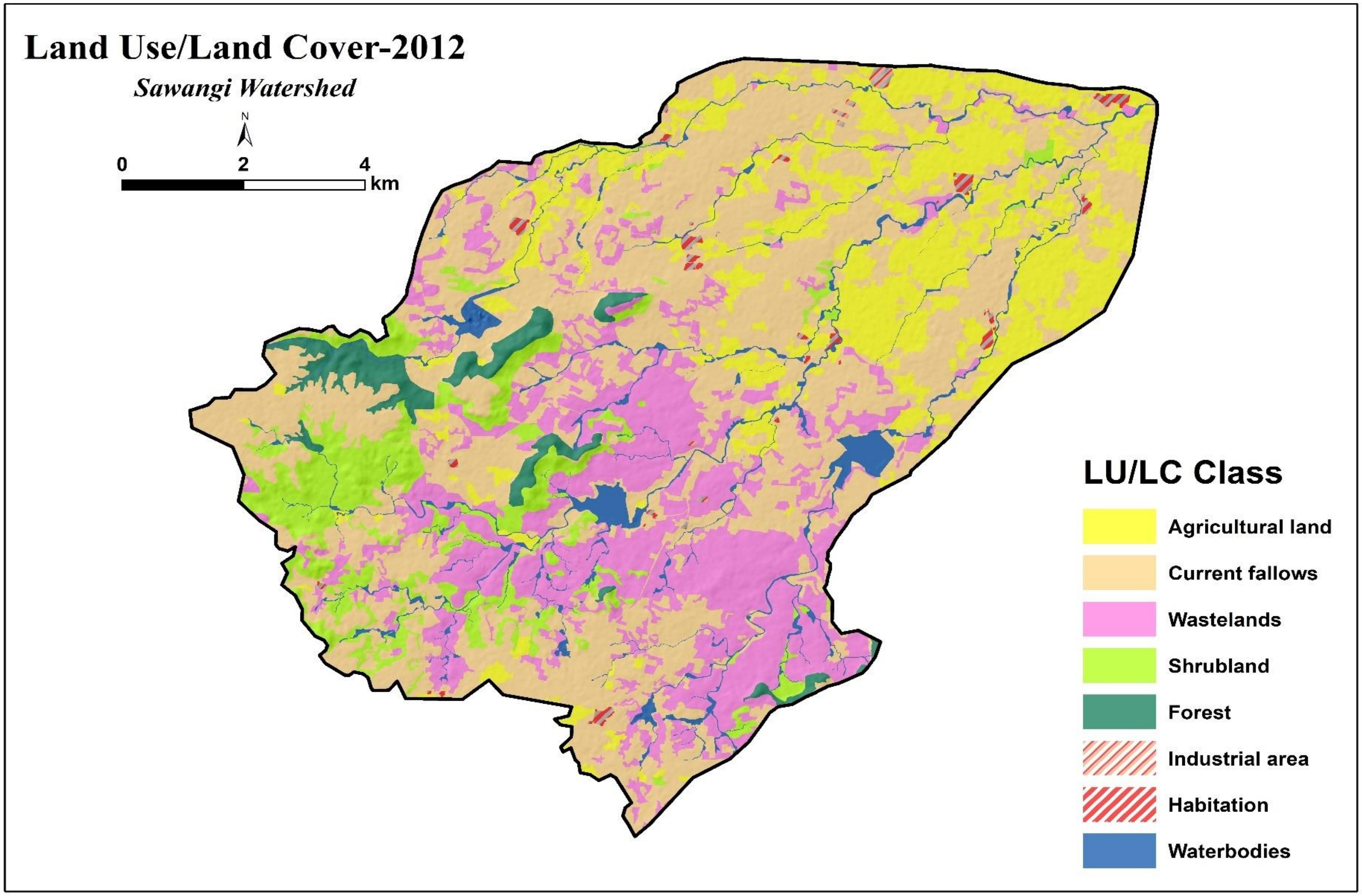


Fig 4.4 LULC of Sawangi watershed in year 2012

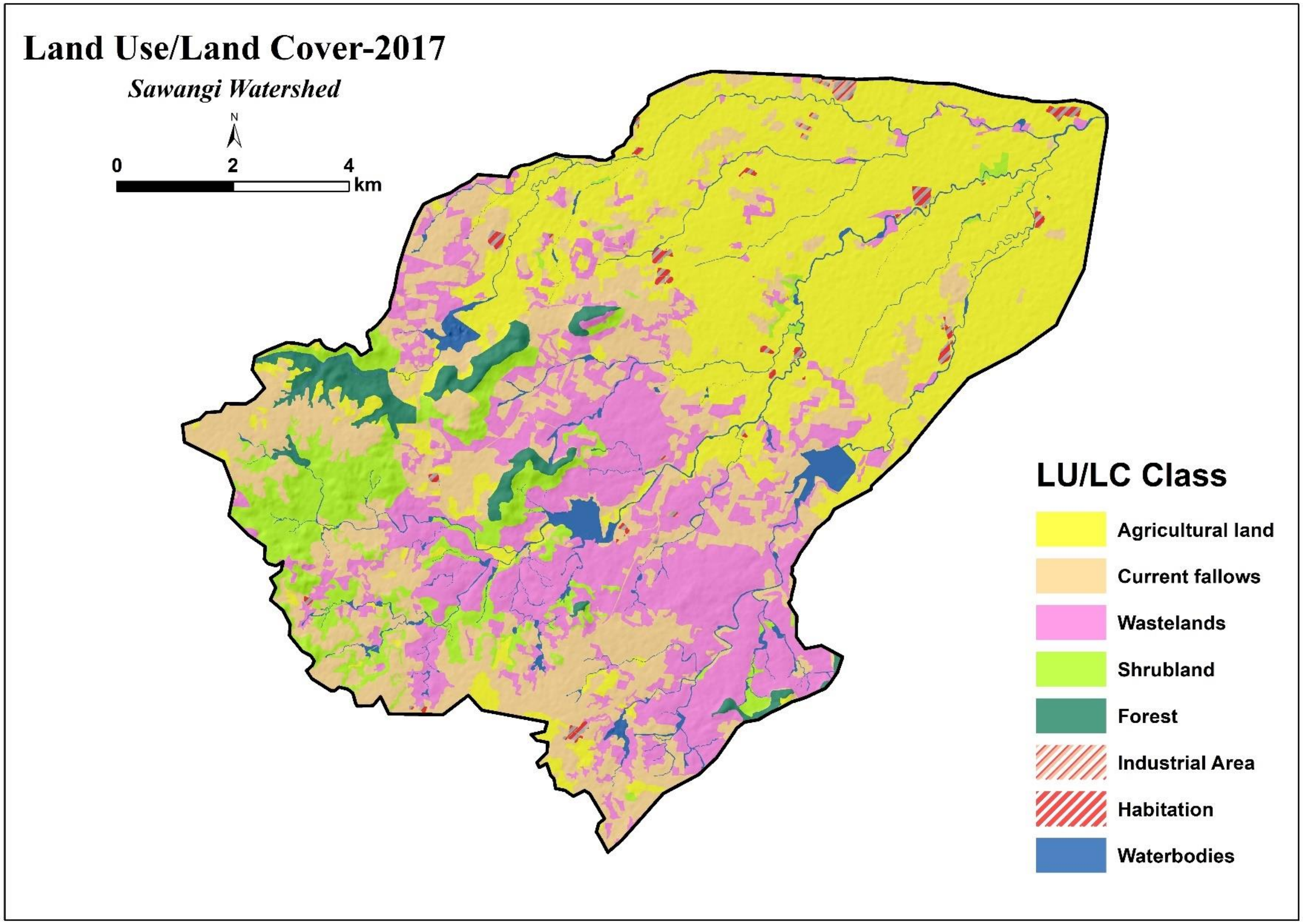


Fig 4.5 LULC of Sawangi watershed in year 2017

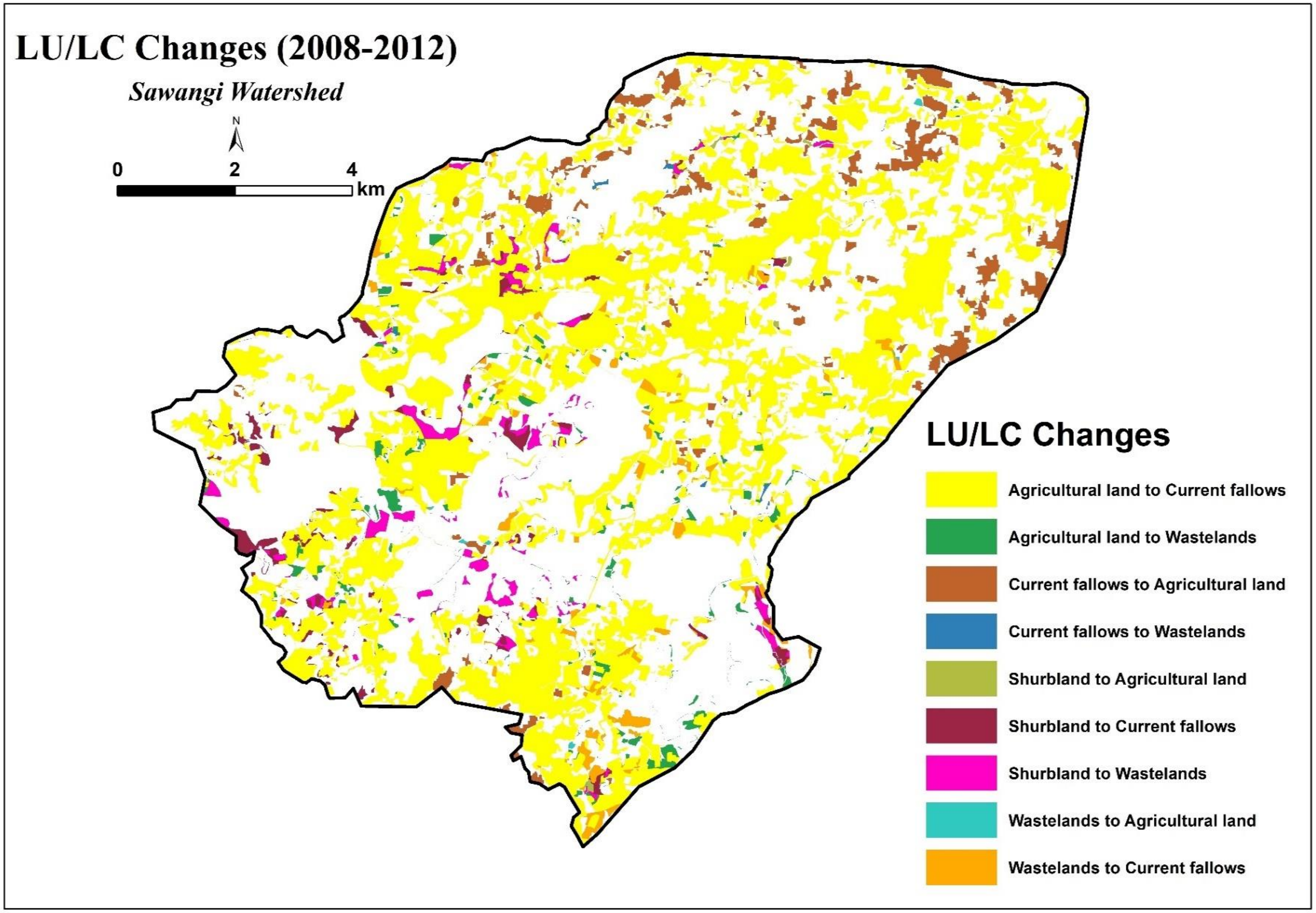


Fig. 4.6 LULC changes in Sawangi watershed (2008-12)

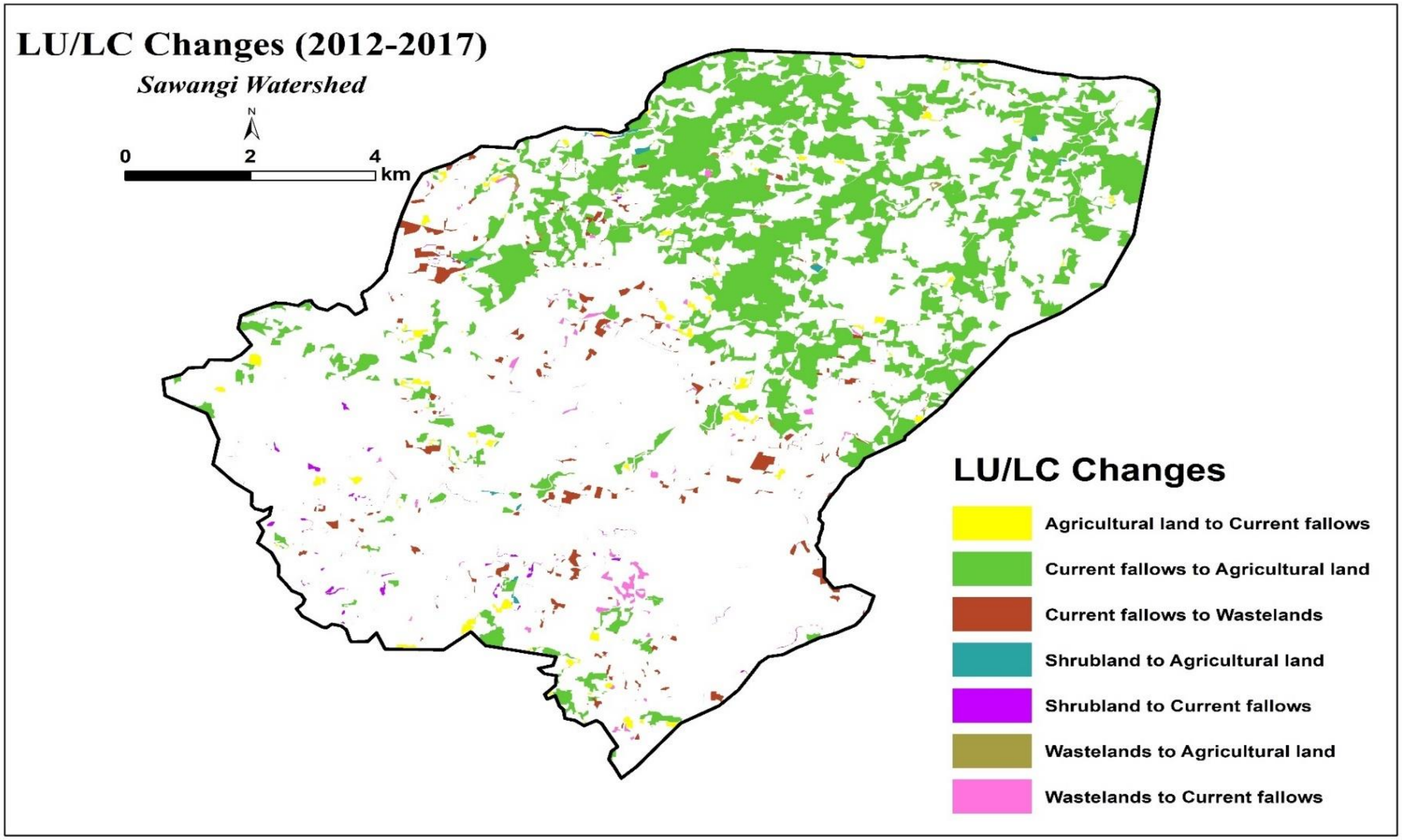


Fig. 4.7 LULC changes in the Sawangi watershed (2012-17)

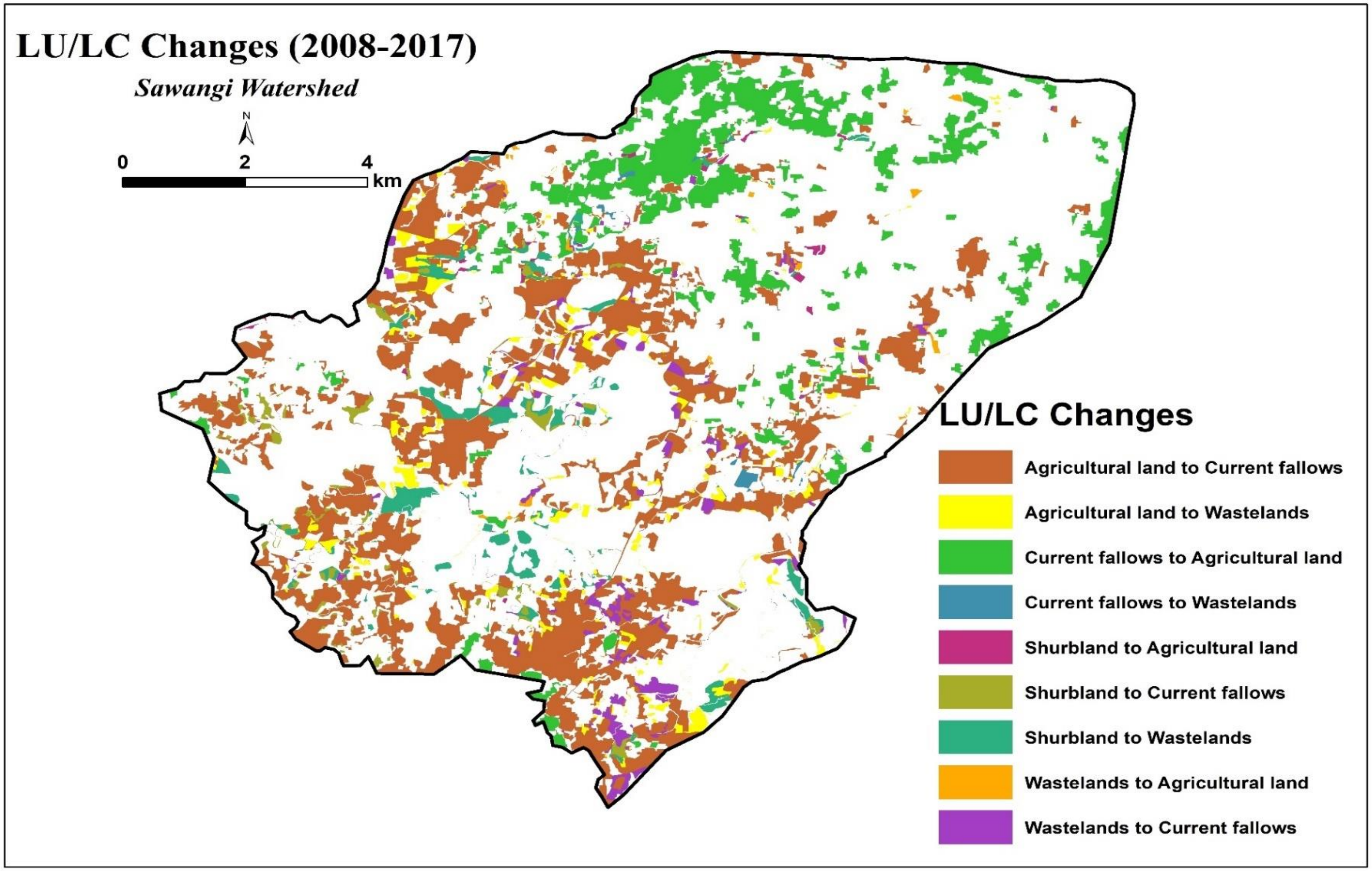


Fig. 4.8 LULC changes in the Sawangi watershed (2008-17)

4.3 Preparation of slope map

The slope is an important soil forming factors that controls the soil erosion and surface run-off. Slope are very important from the land capability, irrigability and land utilization perspective. The Digital Elevation Model (DEM) utilized for determining the slope map of the watershed is displayed in Fig. 4.10 and area under various slope classes are presented in Table 4.10. The slope is defined as the ratio of the altitude change to the horizontal distance between any two points on the line.

The land slope were classified under five major classes viz. very gently sloping (1-3%), gently sloping (3-8%), moderately sloping (8-15%), moderately steeply sloping (15-30%) and steeply sloping (>30%) were identified according to Field Manual (NBSS&LUP, 1987).

Table 4.10 Extent and distribution of slope classes

Sl. No.	Slope class	Area (ha)	% of TGA
1	1–3 % Very gently sloping	7563.04	64.22
2	3–8 % Gently sloping	3482.42	29.57
3	8–15 % Moderately sloping	492.19	4.18
4	15–30 % Moderately steep sloping	239.88	2.04
5	> 30 % Steeply sloping	0.09	0.00
	Total Geographical Area (TGA)	**11777.62**	**100**

Very gently sloping classes (1-3% slope) have dominant class in the study area covering an area of 7563.04 ha (64.22 % of TGA) and mainly occurs on plateau top, lower alluvial plain, and upper alluvial plain. These areas constitute prime parcels of land where maximum activities are concentrated. The gently sloping (3-8 % slope) class covers around 3482.42 ha (29.57 % of TGA) of land and mostly found on pediments, which is the second largest covering of the watershed area. The moderately gently sloping (8-15% slope) covering an area of 492.19 ha (4.18 % of TGA), are for the most part situated on Denuded plateau and escarpment. Moderately steep sloping land (15-

30% slope) and steeply sloping land (>30% slope) land involve an area about 239.88 ha (2.04 % of TGA) and 0.09 ha (14 % of TGA), respectively. The slope plays an important role in groundwater infiltration as well as its prospects. Generally, flat and gently sloping areas promote infiltration and groundwater recharge and steeply sloping ground encourage run-off and little or no infiltration. Groundwater potential is expected to be better in flat and gently sloping area (Rao, 2006; Waikar and Nilawar, 2014; Patil *et al.* 2018).

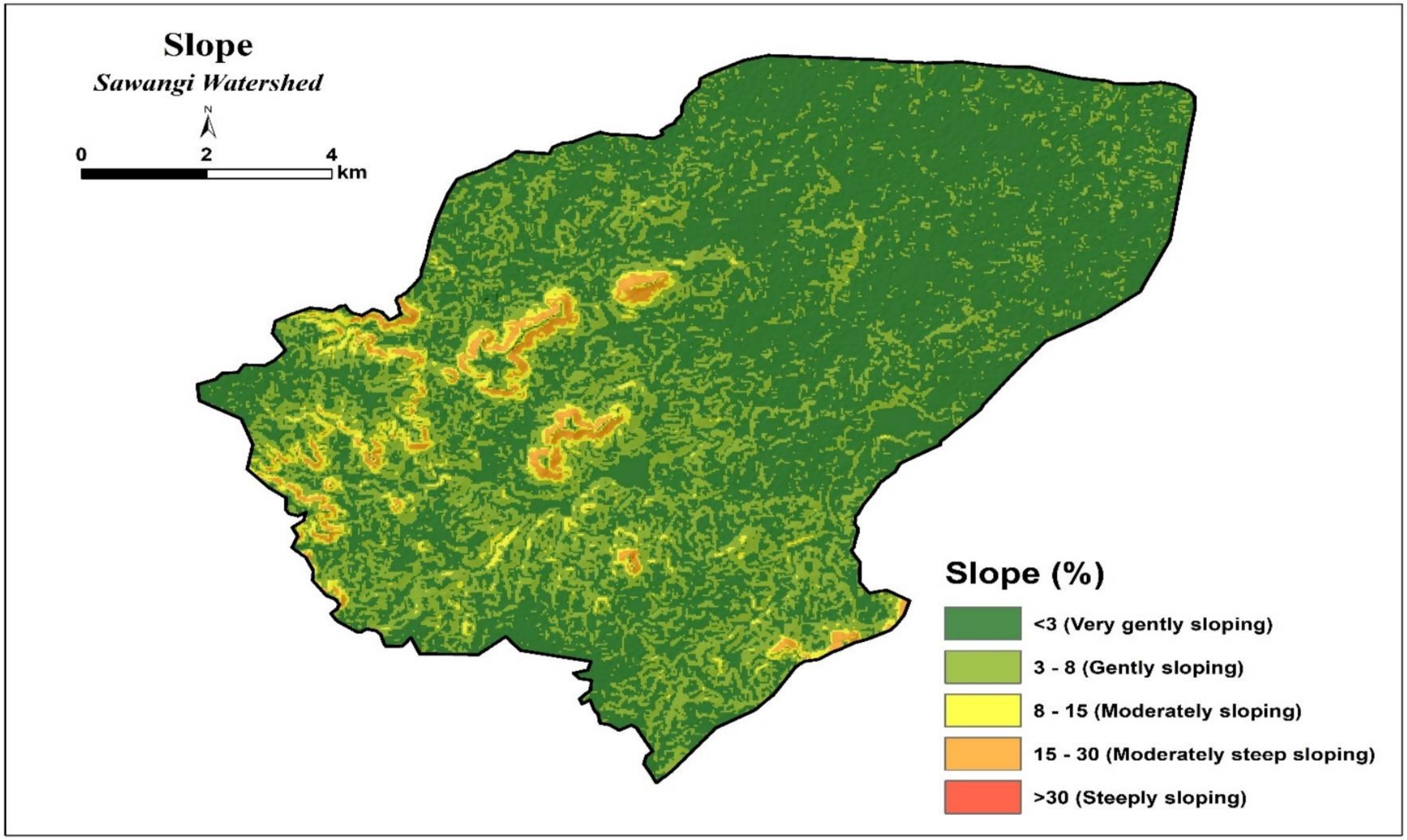


Fig. 4.9 Slope map of Sawangi watershed

4.4 Landform classification and mapping

The watershed represents typical basaltic terrain, which shows topography expressed by the various heights of the plateau related to the diverse basaltic streams. These steps are indicative of successive geological horizons of the various lava flows one over the other intervening intertrappean beds shaping the terrace levels because of their lesser resistance capacity (Anon, 1995). The resulting diastrophic movement and subaerial procedures have given rise to appreciable regional and local changes in landscape evolution.

Based on visual interpretation of ALOS-DEM, sentinel 2A data and subsequent ground truth verification, a landform map has been prepared and the different landforms identified were as follows *viz.*, mound, plateau, denuded plateau, escarpment, upper pediment, lower pediment, alluvial plain, pediplain, upper valley, lower valley and waterbody.

Table 4.11 Extend and distribution of different landform units of Sawangi watershed

Sl. No.	Landform units	Area (ha)	% TGA
1	Mound	238.73	2.03
2	Plateau	540.58	4.59
3	Denuded Plateau	3849.19	32.68
4	Escarpment	876.25	7.44
5	Upper Pediment	435.13	3.69
6	Lower Pediment	1854.51	15.75
7	Alluvial Plain	619.44	5.25
8	Pediplain	1463.94	12.43
9	Upper Valley	322.32	2.74
10	Lower Valley	1254.04	10.65
11	Habitation	80.51	0.68
12	Waterbody	170.27	1.44
	Total Geographic Area (TGA)	**11777.62**	**100**

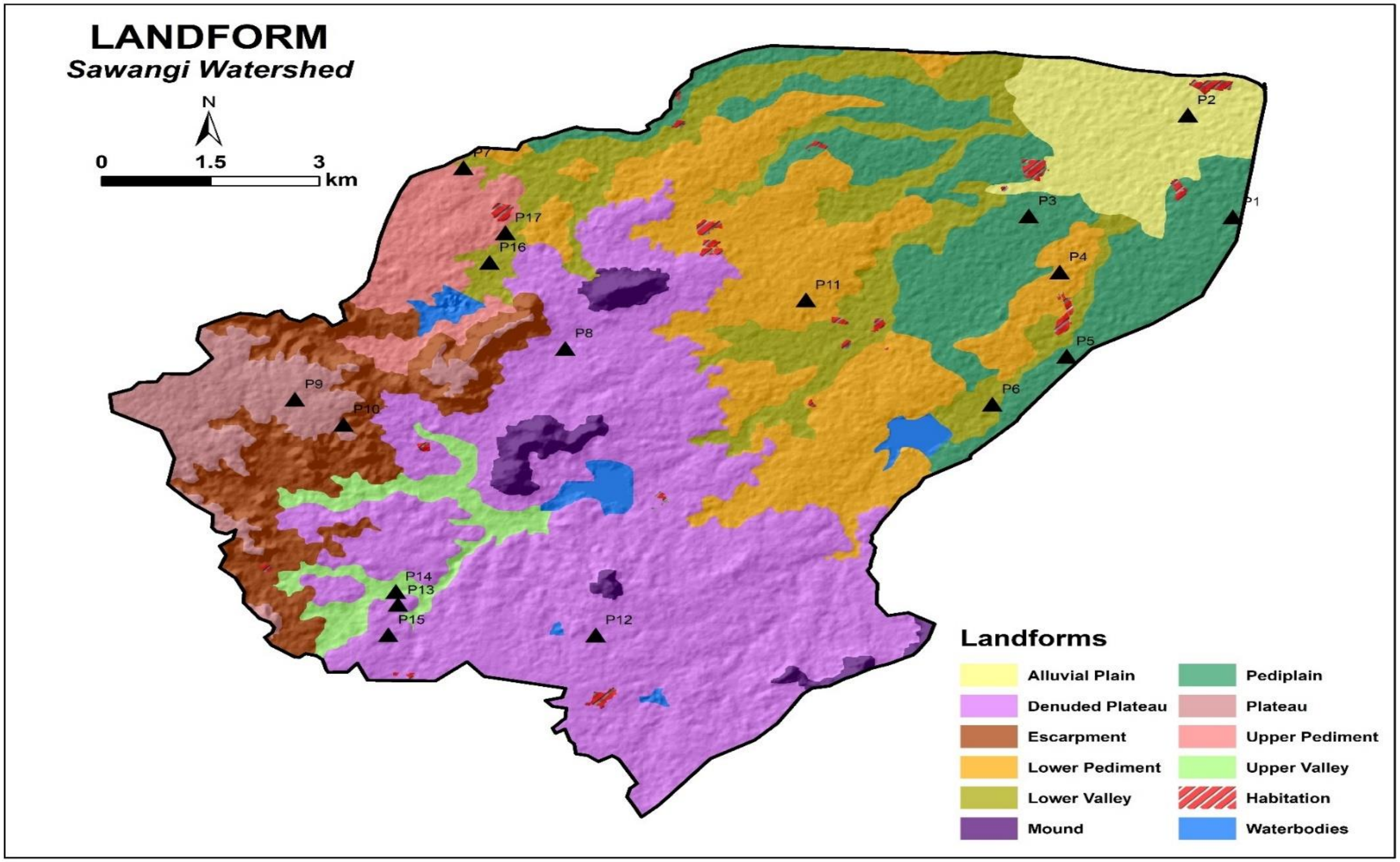


Fig. 4.10 Landform map of Sawangi watershed

A review of data shows that the denuded plateau is the major landform portion of the watershed involving an area of 3849.19 ha representing about 32.68 per cent of the total geographic area (TGA) of the watershed, followed by lower pediment 1854.51 ha (15.75 % of TGA). The upper valley and lower valley cover an area of 322.32 ha (2.74 % of TGA) and 1254.04 ha (10.65 % of TGA) respectively. Escarpment occupies 876.25 ha (7.44 % of TGA) and pediplain involving 1463.94 ha (12.43 % of TGA). Upper pediment and alluvial plain cover an area of 435.13 ha (3.69 % of TGA) and 619.44 ha (5.25 % of TGA) respectively. The mound and plateau cover area of 238.73 ha (2.03 % of TGA) and 540.58 ha (4.59 % of TGA). Waterbody occupies an area of 170.27 ha (1.44 % of TGA) and habitation 80.51 ha (0.68 % of TGA.

4.5 Watershed characterization and interpretation

4.5.1 Drainage morphometry

The analysis of morphometric parameter is a reflection of ruggedness of surface as well as soil erosion condition. Morphometric analysis of the area has been completed in which trust is given on the parameters such as stream ordering, measurement of the catchment area, length, and perimeter of drainage channels, bifurcation ratio, stream length, drainage density, drainage frequency, drainage intensity etc. (Reddy *et al.* 2004). The analysis of morphometric parameters of landscape helps to assess and evaluate erosion risk, soil and water conservation strategies, groundwater potential, watershed characterization and other environmental parameters. The quantitative drainage morphometric analysis helps us to understand the relationships between the various aspects of drainage parameters and land resources distribution. The review area has for mostly flat topography represented by the dendritic type of drainage pattern with a good network of small and medium drains throughout the area (Fig. 4.12). The relationship between various morphometric patterns have been investigated and show in the Table 4.12.

4.5.2 Stream ordering

The initial phase in the morphometric analysis is the assignment of stream orders. The stream order is a measure of the position of a stream in the hierarchy of the tributaries (Horton, 1945).

Table 4.12 Different parameters for morphometric analysis of Sawangi watershed

Area (km^2)	Perimeter (km)	Order (u)	Number (Nu)	Total stream length (km)	Average stream length (Lu) (km)	Bifurcation Ratio (Rb)	Drainage density (D) ($km\ km^{-2}$)	Drainage frequency (km^{-1})	Drainage intensity
117.58	52.73	1	53	89.45	1.69	4.16	1.29	0.88	3.06
		2	19	21.48	1.13	0.55			
		3	28	39.06	1.40	18.08			
		4	3	2.16	0.72				
	Total		**103**	**152.15**	**1.23**				

The first-order streams are those which have no tributaries. The second-order streams are those which have just first-order streams as tributaries. Also, the third-order streams get the first and second-order streams as tributaries. The data showed in Table 4.12 reveal that 103 streams drain the watershed and highest number of streams (53) belong to first order and number of streams decreases in general with increase in order. In general, it is observed that (Table 4.12) higher number of streams belong to lower order and continue decreasing with higher order. The highest order observed in the watershed is 3rd and the first-order streams occur mostly in the upper reaches of the watershed where the terrain is hilly and higher-order streams are situated in the central and lower portion of watershed where the topography is plain for example higher number of streams observed in upper reaches of watershed and continue decreasing towards lower reaches. It is also seen that, more the number of streams in an area more the soil erosion and poor soil development as well as opposite in upper reaches as compared to lower reaches.

4.5.3 Stream length

The average length of the stream indicated the size of the component of a drainage network and the basin area contribution. Generally, the cumulative length of stream of a particular order is measured and the mean length (Lu) of that order (u) is obtained by dividing cumulative stream length by a number of segments of that order (Nu). The mean stream length (Lu) of a stream-channel segment of order (u) is a dimensional property. It is presented from Table 4.12 that the total length of the channel in the watershed is 152.15 km and highest in first order decreases with increasing stream orders. It is because of a decrease in the number of streams with increasing orders, thus representing ideal situation of watershed. The overall average stream length (computed) in area is 1.23 and 2.16 kilometers from first order stream to fourth order stream respectively.

4.5.4 Bifurcation ratio

The term bifurcation ratio (Rb) is utilized to express the ratio of the number of streams of any given order (Nu) to the number of streams in the next higher order (Nu+1). The lower bifurcation ratio values are characteristic of the watershed, which have suffered less structural disturbances (Strahler, 1964), and the drainage pattern has not been distorted because of the structural disturbances.

The average bifurcation ratios determined for watershed are listed in table 4.12 and these values are well below 2 implying no structural disturbance (Krishnamurthy *et al.* 1996). The variation in Rb values are attributed to differences in their stages of geomorphic developments and topographic variations.

4.5.5 Drainage density

The drainage density (D) is one of the important indicators of the linear scale of landform elements in stream-eroded topography; which was defined by horton as the ratio of total channel segment lengths (cumulated for all orders) within a basin to the basin area. The drainage density (D) is characterized as the closeness of spacing

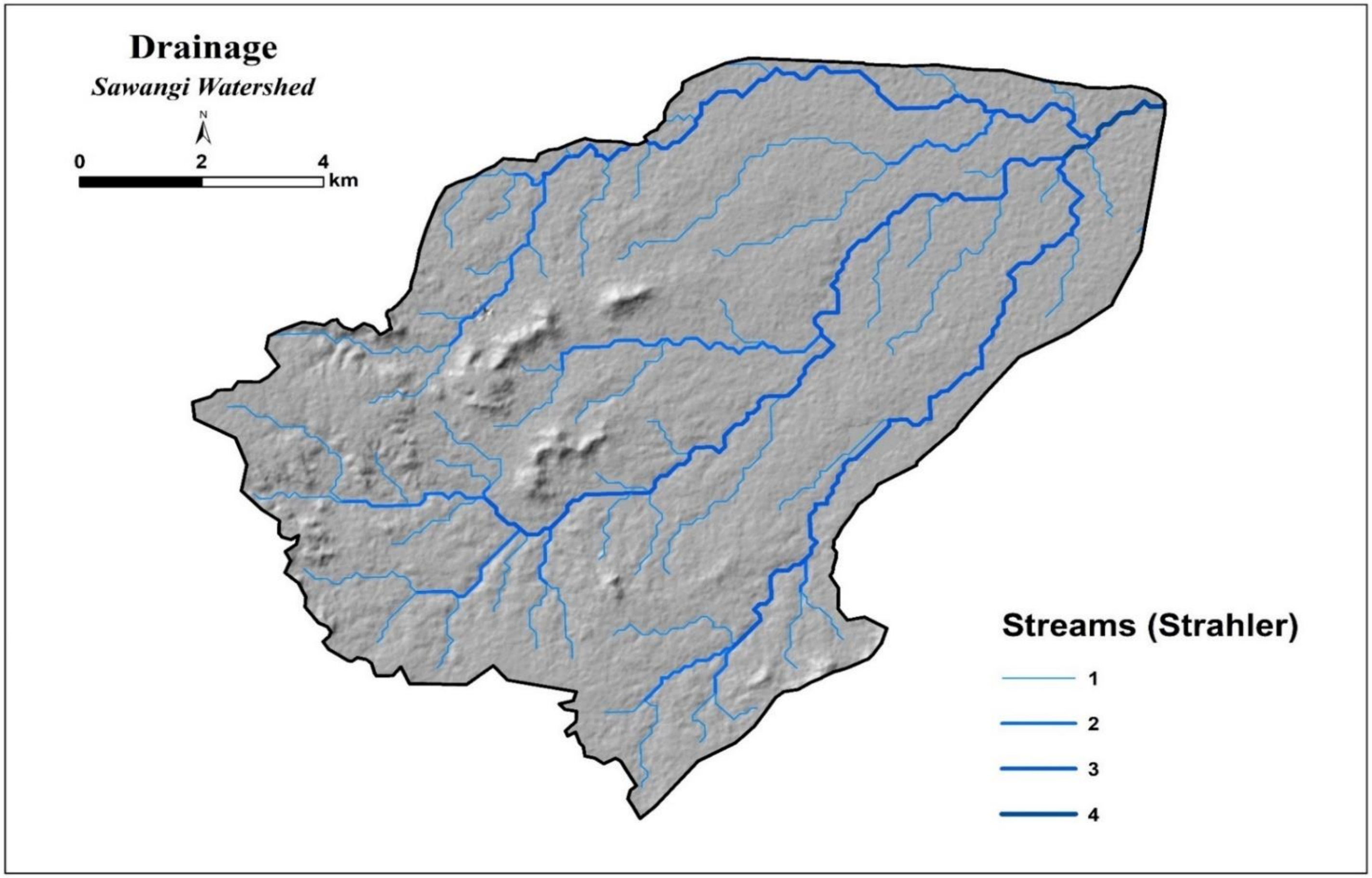


Fig.4.11 Drainage line map of Sawangi watershed

of channel thus providing a quantitative measure of the average length of stream channel in the watershed. The drainage density is influenced by the factors that control the characteristic length of the stream. The factors controlling stream length are resistance to weathering and permeability of rock formation apart from the environment and other factors like vegetation. It is giving an idea of slope, topography, rock characteristics etc. The high drainage density denotes rough surfaces implying shallow soils and more prone to erosion and vice versa. In generally, the low drainage density is observed in regions of more resistant or permeable soil material under vegetative cover and low relief. The drainage density of the watershed is 1.29 km, which is moderately high with high drainage frequency (0.88 km) denoted higher roughness of the area such as escarpments and pediments.

There is a decent correlation between the drainage density, drainage frequency, and drainage intensity denoted that soil characteristics of the watershed area are controlled by surface erosional phenomena.

4.5.6 Drainage frequency and drainage intensity

Drainage frequency is another parameter to draw inferences about the characteristics of the study area. The drainage frequency can be defined as number of drainage lines per unit area. Drainage intensity represents the spread of streams over the area in terms of their density and frequency, which is a multiplication of these two parameters.

Therefore, the study of drainage lines is helpful in understanding the dissection of the area, which in turn helps in deciphering the erosion situation, soil development, and eventually the land use pattern of a watershed. It is seen that (Table 4.12) drainage frequency of 0.88 corresponds to drainage density 1.29 and moderate drainage intensity 3.06. The higher drainage frequency is associated with sloping and undulating lands.

4.6 Characterization and Classification of soils of Sawangi watershed

4.6.1 Site and Soil characterization of Sawangi watershed

Sawangi watershed is the site and soil characteristics and the salient features are discussed in the following sections.

4.6.1.1 Erosion

Black soils, commonly display good runoff potential, although there are large-scale spatial and temporal variations depending on relief, depth, surface condition and infiltration characteristics of soils, nature of vegetation cover, and rainfall characteristics. Erosion reduces the pedon thickness and the volume of available soil water storage and root exploration for nutrients. Soil erosion is represented by slope and physical characteristics of soils as conditioned by physiographic position of a parcel of land. The area involved by lands with various erosion classes are shows in (Table 4.14).

During ground truthing and field survey it was observed in the watershed was classified mainly two kinds of eroded land such as severe and moderate erosion. The severely eroded land classified were in soil series of sawangi, Jalka, and dongarkharda, while others soil series were classified under moderately eroded land. Therefore, most part of the watershed area can be anticipated to lack soil fertility and agricultural productivity.

4.6.1.2 Drainage

Drainage is a natural soil property related to hydraulic conductivity of soils and directly influence by texture, structure and porosity of soil. In generally, the soils developed on higher slope classes were well drained whereas the soils on gently sloping surfaces are somewhat poorly drained. The high clay content and dominance of montmorillonites producing poor drainage condition in majority of black soils (Gupta *et al.* 1991). Vertical heterogeneity in the hydraulic conductivity in deep black soils, presented ideal condition for the development of pseudo water table following rains (Jaggi *et al.* 1976).

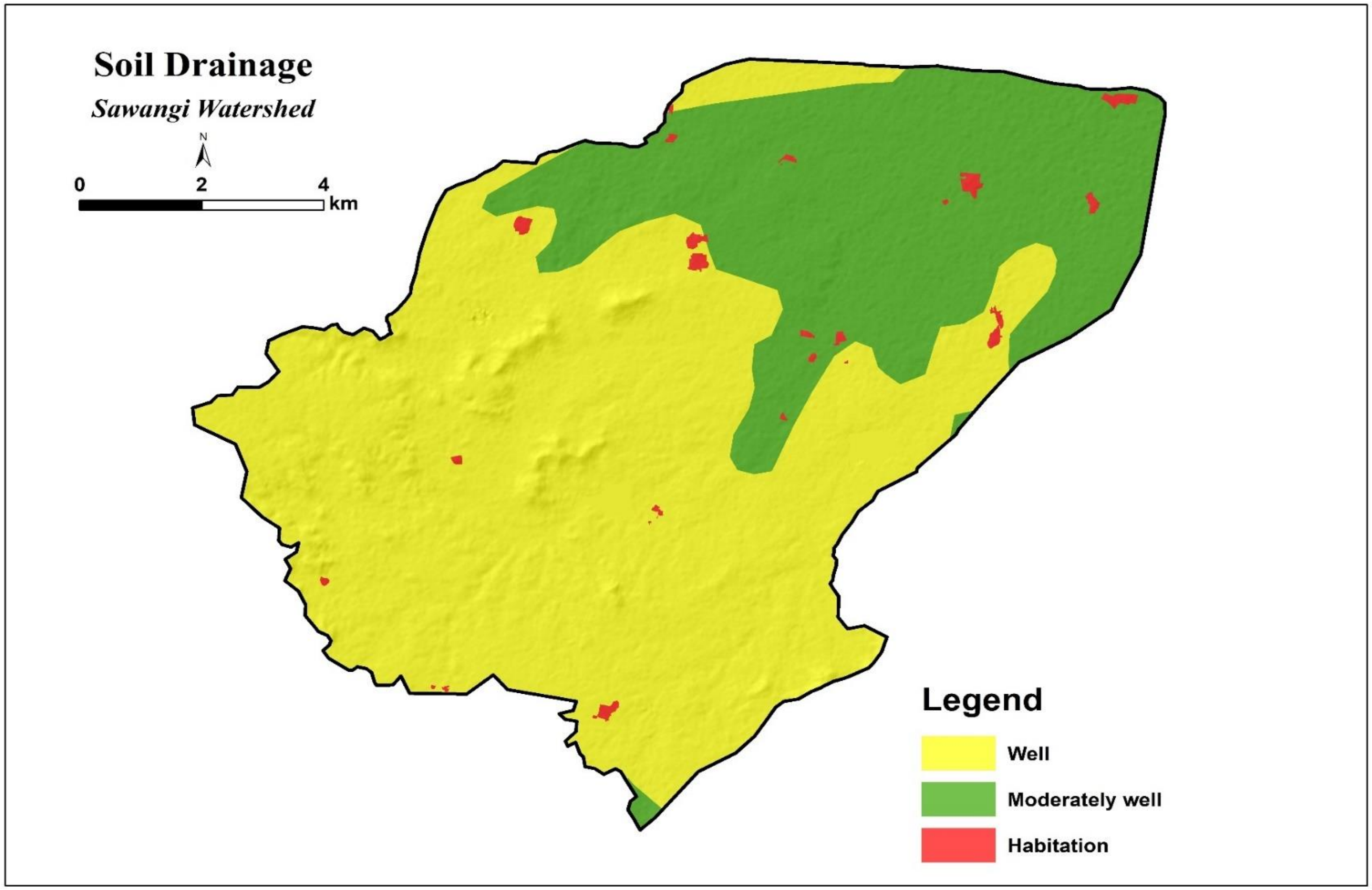


Fig.4.12 Drainage map of Sawangi watershed

The data pertaining to soil drainage conditions for individual landforms are given in Table 4.14 whereas their spatial distribution in the area along with area statistics is presented in Table 4.13 and depicted in Fig. 4.13.

Table 4.13 Soil drainage classes and distribution

Sl. No.	Drainage classes	Area (ha)	% TGA
1	Well drained	7939.95	67.42
2	Moderately well drained	3753.54	31.87
3	Habitation	84.13	0.71
Total Geographical Area (TGA)		**11777.62**	**100**

4.6.1.3 Surface stoniness

Surface stoniness in the area varies from 1 to >70 per cent (Table 4.14) depending upon physiographic position, slope, erosion etc. Surface stoniness is comparatively higher in soils developed on escarpment and plateau as compared to denuded plateau, upper and lower pediment, alluvial plain and valleys.

4.6.2 Soil characterization

4.6.2.1 Morphological properties of soils

Soil morphology refers to the inherent characteristics of the soils obtained during their evolution and retaining influence of one or few genetic factors (AIS & LUS, 1971). This includes the assessment and description of soil depth, horizon and their boundary, colour, texture, structure, consistency, presence of pans, concretions and such other features of soil profiles as can be perceived in the field. The soil morphological characteristics have been studied in the field as suggested in the USDA Soil Survey Manual (Soil Survey Division Staff, 2000). The development of soil in the area is not far different than the general pattern of soil evolution on basaltic landscape under the conditions of semi-arid climatic. Major morphologic variations in these soils, however, are attributed to topographic differences-directly through the controlling impact of topography on gravity flow, run-off, infiltration and temperature flux, as well as indirectly through its bearing on micro-climate and biotic factors (Anonymous, 1995).

morphological properties of all the pedons of the watershed area are presented in Table 4.15 and the important morphological characteristics such as soil depth, soil colour, soil texture and soil structure are discussed in following sections.

4.6.2.1.1 Soil depth

The soil depth was studied as a total depth of soil solum (A+B horizon) at various physiographic positions. The data (Table 4.15) showed that the soils are very shallow to deep (14 – 150 cm depth). The plateau top and escarpment representing rough broken terrain are characterized by very shallow profiles. Foot slopes of the plateau, pediments are dominated by colluvial materials transported from higher reaches, characterized by shallow to moderately deep profiles. Upper and lower alluvial plains have developed deep to very deep profiles.

The variations in depth on various physiographic positions are due to geomorphic processes operative on slopes, which may have caused erosion in certain places and deposition on the other. The eroded surface shows the shallow soil depth as compared with the depositional surface. Thus, we may infer that the soil depth is related to slope and degree of erosion (Srivastava *et al.* 1991).

4.6.2.1.2 Soil colour

Soil colour is generally one of the best important morphological characteristics utilized for soil identification and evaluation. The relief, drainage conditions, presence of organic matter, weathering intensity and time appears to have direct as well as indirect effect on colour of the soil. The perusal of data (Table 4.15) shows that the moist colour of the identified soil series of the study area is in hue of 10 YR, value 3 to 5 and chroma ranges from 1 to 4 such as 10 YR 3/1 (very dark grey) to 10 YR 3/3 (dark brown) in the surface and 10 YR 3/1 (very dark grey) to 10 YR 3/4 (dark yellowish brown) in the sub-surface all other pedon but the pedon 5 and 10 identified in hue of 10 YR3/1 (very dark grey) to 10 YR 3/2 (very dark greyish brown) in the surface and 10 YR 5/2 (greyish brown) to 10 YR 5/3 (brown) in the sub-surface. The pedon 8 and 9 (Nimgawhan series 1and 2) denote an exceptional colour of 2.5YR 3/3 (dark reddish brown) and 5YR 3/3 (dark reddish brown) in the surface and subsurface as well. The reddish colour of the soils is indicated by attributed to the prevailing excessive drainage conditions resulting to the conversion of ferrous oxide to ferric oxide. The dark colour of some pedons might be ascribed to highly dispersed types of humus and smectite clay minerals (Zonn, 1986).

The 10YR hue saw in the series of sawangi, pimpalkhuti, soyati and warna could be because of moderate weathering of basaltic parent material (Nayak, 2000). The series of sawangi, bhamb, and warna indicated an expansion in increase in brown colour with depth. Soil colour is a component of essential composition, iron and aluminum oxides, organic matter substance, parent material, slope characters and hydromorphic conditions (Gill *et al*. 2012). The colour of the pedons showed in the current review could be attributed to high iron and oxide content in non-hydrated forms in case of bhamb series and Jalka series. The variation in the colour of surface and subsurface horizons appears to be the function of chemical and mineralogical composition of soils (Geetha Sireesha and Naidu, 2013).

4.6.2.1.3 Soil texture

The texture is an expressed to presented the coarseness or fineness of the soil and determined by the relative proportions of the various sized of primary particles in the soil mass. It is one of the most fundamental and permanent characteristics that have direct bearing on structure, porosity and consistence. The texture of soil can be determined by feel method being judged to a close approximation in the field and quantitatively estimating by mechanical analysis of soils in the laboratory. Basalt is the parent material of the study area is known to produce higher amount of clay (Eswaran *et al*. 1988; Murthy *et al*. 1994).

The texture of the soils of the study area ranges from clay to sandy loam. The hill slopes representing rough broken terrain are characterized by skeletal stony soils due to severe erosion and favouring the transportation of finer material in the lower reaches.

Table 4.14 Site characteristics of typical pedons in Sawangi watershed

Sl. No.	Pedon No.	Landform	Slope		Erosion	Run-off	Drainage	Ground water depth (m)	Stone size (dia. cm)	Stoniness Surface cover (%)	Rock outcrop
			Gradient (%)	Length (m)							
1	Bhamb	Pedi plain	1-3	>600	Moderate	Slow	Well	> 10	< 2.5	3	N0
2	Dongarkharda	Upper Valley	3-8	300-600	Severe	Rapid	Well	> 10	< 2.5	3	N0
3	Jalka	Denuded Plateau	3-8	>600	Severe	Rapid	Well	> 10	< 2.5	3	<5
4	Nimgawhan	Escarpment	15-30	300-600	Moderate	Very rapid	Well	> 10	>25.0	>75	N0
5	Nimgawhan-2	Denuded Plateau	3-8	300-600	Moderate	Medium	Well	> 10	< 2.5	3	N0
6	Pimpalkhuti	Lower Pediment	1-3	300-600	Moderate	Rapid	Well	> 10	< 2.5	3	N0
7	Potgawhan	Plateau	1-3	>600	Moderate	Medium	Well	> 10	7.5-25.0	3-15	N0
8	Sawangi	Alluvial Plain	3-8	150-300	Severe	Rapid	Well	> 10	< 2.5	3	No
9	Soyati	Lower Valley	1-3	>600	Moderate	Medium	Well	> 10	< 2.5	3	N0
10	Warna	Upper Pediment	3-8	>600	Moderate	Rapid	Well	> 10	< 2.5	3	N0

Table 4.15 Morphological properties typical pedons in Sawangi watershed

Horizon	Depth (cm)	Boundary		Matrix Colour	Texture	Coarse fragments (%)	Structure			Consistence			Porosity		Roots		Effervescence	Nodules		Other features
		D	T				S	G	Ty	D	M	W	S	Q	S	Q		S	Q	
Pedon 1: Bhamb series - Fine smectitic, hyperthermic, Vertic Haplustepts																				
Ap	0-17	c	s	10YR 3/2	c	--	m	2	sbk	h	fr	vsvp	vf	m	c	m	ev	m	m	
Bw1	17-59	c	s	10YR 3/1	c		m	3	sbk	-	fr	vsvp	vf	m	c	m	ev	m	m	
Bw2	59-92	c	s	10YR 3/3	c	-	m	3	sbk	-	fr	vsvp	vf	m	c	m	ev	m	m	
Bw3	92+	c	s	10YR 3/4	c	-	m	2	sbk	-	fr	vsvp	vf	m	c	m	ev			
Pedon 2: Dongarkharda series - Fine mixed, hyperthermic, Lithic Ustorthents																				
Ap	0-16	-	-	10YR 3/2	c	-	m	2	sbk	-	-	-	-	-	-	-	-	-	-	-
cr	16-36	-	-	10YR 5/2	gr. sl	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pedon 3: Jalka series - Loamy mixed, hyperthermic, Lithic Ustorthents																				
Ap	0-15	c	s	10YR 3/3	cl	-	m	2	sbk	sh	fr	sssp								
R	15+																			
Pedon 4: Nimgawhan-1 series - Loamy mixed, hyperthermic, Lithic Ustorthents																				
A	0-14	a	s	2.5YR 3/3	gr. l	-	m	1	sbk	-	-	-	vf	m	f	m	-	-	-	-
cr	14+																			
Pedon 5: Nimgawhan-2 series - Loamy mixed, hyperthermic, Lithic Ustorthents																				
Ap	0-15			5YR 3/3	l	-	m	2	sbk	l	fr	sssp	f	m	-	-	-	-	-	-
R	15-23																			
Pedon 6: Pimpalkhuti series - Fine mixed, hyperthermic, Lithic Haplustepts																				
Ap	0-20	c	s	10YR 3/2	c	-	m	2	sbk	h	fr	vsvp	vf	m	m	m	ev	m	m	
Bw	20-44	c	s	10YR 3/1	c	-	m	3	sbk	-	fi	vsvp	vf	m	m	f	ev	m	m	
cr	44+	c	s		scl	>90	-	-	-	-							ev			

Horizon	Depth (cm)	Boundary		Matrix Colour	Texture	Coarse fragments (%)	Structure			Consistence			Poresity		Roots		Effervescence	Nodules		Other features
		D	T				S	G	Ty	D	M	W	S	Q	S	Q		S	Q	
Pedon 7: Potgawhan series - Fine smectitic, hyperthermic, Lithic Haplustepts																				
Ap	0-16	c	s	10YR 3/1	c	-	m	2	sbk	h	fr	vsvp	vf	m			e			
Bs	16-30	a	s	10YR 3/2	c	-	m	3	sbk		fi	vsvp	vf	f			e			
R/cr	30+					>90														
Pedon 8: Sawangi series - Fine Smectitic, hyperthermic, Typic Haplustepts																				
Ap	0-19	c	s	10YR 3/2	cl	-	m	2	sbk	l	fr	sp	f	m	f	m	ev	m	m	
Bw1	19-52	c	s	10YR 3/2	cl	-	m	3	sbk		fr	sp	f	m	f	m	ev	m	m	
Bw2	52-88	c	s	10YR 3/2	c	-	m	3	sbk		fr	sp	f	m	f	f	ev	m	m	
Bw3	88-122	c	s	10YR 3/1	c	-	m	3	abk		fi	vsvp	vf	m			ev	f	m	pf
Bw4	122-150	c	s	10YR 3/1	c	-	m	3	abk		fi	vsvp	vf	m			ev	f	m	pf
Pedon 9: Soyati series - Fine smectitic, hyperthermic, Sodic Haplusterts																				
Ap	0-18	c	s	10YR 3/2	c	-	m	2	sbk	h	fr	vsvp	vf	m	-	-	ev	m	m	
Bw1	18-48	c	s	10YR 3/2	c	-	m	3	sbk		fi	vsvp	vf	m	-	-	ev	m	m	
Bss1	48-73	c	s	10YR 3/3	c	-	m	3	abk		fi	vsvp	vf	m	-	-	ev	m	m	ss
Bss1	73-102	c	s	10YR 3/3	c	-	m	3	abk		fi	vsvp	vf	m	-	-	ev	m	m	ss
Bc	102+	c	s	10YR 3/4	c	>60	m	2	abk		fi	vsvp	vf	m	-	-	ev	m	m	pl/gr
Pedon 10: Warna series - Fine smectitic, hyperthermic, Lithic Ustorthents																				
Ap	0-18			10YR 3/1	c	-	m	2	sbk	h	fr	vsvp	vf	m						
cr	18-30			10YR 5/3		-														

The soil occurring on escarpment and plateau are dominated by moderately fine texture to fine texture, loamy and clay texture depending upon the volume and velocity of runoff, whereas, denuded plateau have developed by fine texture to very fine textured soils. Soil occurring down the slope on foot slope, pediplain and alluvial plains have dominated by fine texture to very fine textured soils. Upper valley and lower valley have dominant by coarse and fine, such as sandy loam and clay texture.

The increasing pattern of clay have been observed to down the slope whereas the just converse is the case with sand. This may be expected to various geomorphic processes operative on slopes such as overland flow, through a flow that favours the transportation of finer material down the slope. Therefore, the topographic position and slope condition are seen to impact the particle size distribution in the soil. The outcomes are in close agreement with those revealed by Biswas (1979), and Sharma and Roychoudhary (1988).

It is seen that the fineness of the soil increases with the decreasing elevation. This may be due to various geomorphic processes operating in the area favoring the development of finer materials from upper reaches towards lower reaches (Sharma *et al*. 1996).

4.6.2.1.4 Soil structure

Soil structure refers to the arrangement of primary soil particles into secondary particles, units or peds. The secondary units are characterized and classified on the basis of size, shape and degree of distinctness into classes, types and grades respectively. This is perceived as one of the main properties of the soil mass because that it impacts the soil in approximately all of its reactions, yet especially with regard to aeration, moisture, temperature, permeability and water holding capacity. The surface soils of all the pedons in the watershed area have medium to moderate subangular blocky structure (Table 4.15). Grades and size of the structure are observed to be related to the physiographic position, slope, soil texture and so on.

In generally, all the pedons the structure of sub-surface soils was observed to increase in terms of size, types and grades which may be because of the overburden created by upper soil material. The sub-surface soil horizons having pressure faces and slickensides possess coarse, strong, angular blocky structures. This might be attributed to the high shrink and swell phenomena of smectite clay present in these soils (Prasad *et al*. 1989).

4.6.2.1.5 Coarse fragments

The coarse fragments are considered as a part of the soil mass while not a constituent of soil and their study is important since these largely impact soil moisture storage, infiltration and run-off, and they have also an impact at plant growth, especially through their dilution effect on the mass of active soil. The coarse fragments content in the soils of watershed varied between 1 - 3 to 60 - 90 per cent (Table 4.15).

In generally, the coarse fragments in the soils increasing with slope and erosion which is attributed to the removal of fine soil particles from upper slopes and also with depth of soil profile which can be attributed to the higher density of coarse fragments which resulted into their downward movement and deposition at lower horizons.

4.6.2.1.6 Consistency

The soil consistence is identified of sawangi watershed in generally surface horizon viz, sawangi- series have loose (dry), friable (moist) and slightly plastic consistency (wet). The nimgawhan-2 - series has loose (dry) and friable (moist) with slightly sticky and slightly plastic consistency (wet). While jalka - series has slightly hard (dry) and friable (moist) with slightly sticky and slightly plastic consistency (wet). The series - pimpalkhuti, bhamb, soyti, warna and potgawhan have hard (dry) and friable (moist) with very sticky, very plastic consistency (wet). Whereas series - nimgawhan-1 and dongarkharda are completely absent in consistence of soil.

In the soil consistence of subsurface horizon sawangi - series have slightly hard to hard (dry) and firm to friable (moist) with slightly sticky to very sticky, very plastic consistency (wet). The series - pimpalkhuti, and bhamb have hard (dry) and friable (moist) with very sticky, very plastic consistency. In series - soyti and potgawhan have hard to very hard (dry) and firm (moist) with very sticky, very plastic consistency (wet) in subsurface horizon. While all other series are absent in consistence of soil.

4.6.2.1.7 Effervescence

The effervescence is observed in the study area such as violent effervescence is observed in series of sawangi, pimpalkhuti, bhamb and soyti, while slight effervescence is observed in potgawhan - series. The effervescence is completely absent in all others series.

4.6.2.1.8 Roots

The size and quantity of roots are observed in the study area viz, series of sawangi, pimpalkhuti, bhamb and nimgawhan-1 such as, fine - many, medium - many, coarse - many and fine - many, in subsurface horizon. whereas sub - subsurface horizon have fine - many to fine - few, medium - few and coarse - few. The roots are completely absent in all others series.

4.6.2.1.9 Special features

Slickensides are polished and grooved surfaces having dimensions to more 5 cm and produced when the soil mass slides past another (Soil Study Staff, 1998). Slickensides result directly from swelling of clay minerals and shear failure. They are too normal in swelling clays that go through marked changes in moisture content.

Pressure faces are polished shiny surfaces of peds apparent in subsurface layers of shrink swell soils. These soils exhibit cracks measuring more than 1 cm wide during dry season. The cracks separate soil mass into various polyhedrons, the series of pimpalkhuti, bhamb warna and potgawhan exhibit slickensides, pressure faces and crack formation.

4.6.2.2 Physical properties of soils

Physical properties of soils like particle-size distribution, coarse fragments, bulk density, and water retention directly or indirectly influence crop growth and hence need to be considered in land evaluation. The physical properties of various pedons are discussed under the following heads.

4.6.2.2.1 Particle-size distribution

The particle size refers to the relative amount of sand, silt and clay content present in the soils and their proportion determine the texture of soils.

The particle-size distribution gives an insight into physical, chemical and biological potentials which vitally contribute to soil management for plant growth through water retention and its availability, effective aeration and nutrient supply. The data pertaining to particle-size distribution (Table 4.16) shows that there is variation in proportion of soil separates in soil developed on different landform units. This might be due to different geomorphic processes operative on slope like overland flow, through flow that favours the transportation of fine material down the slope. However, basalt being the parent material of most of the soils have produced higher amount of clay. The outcomes are in conformity with those reported by Eswaran *et al*. (1988) and Murthy *et al*. (1994). The soils developed on alluvial plains are showing relatively higher amount of silt, which may be due to alluvial parent material.

The analytical data of physical properties of all the pedons is presented in table 4.16. The particle size distribution indicated that the sand content in surface horizon of all pedons varied from 3.0 to 45.8 per cent and subsurface horizon ranged from 1.7 to 76.2. The sand content showed irregular distribution with depth in all the pedons. The silt content in surface horizon of all pedons ranged from 15.5 to 47.8 per cent and subsurface horizon ranged from 5.9 to 40.1 per cent. The clay content in surface horizon ranged from 26.5 to 71.5 per cent and subsurface horizon ranged from 17.8 to 77.8 per cent.

The clay content in soil remained uniformly high (>35%) throughout the pedons that are classified as vertisols or vertic subgroup, which denoted pre-dominance of the process of haploidization inhibiting horizon differentiation (Landey *et al*. 1982).

In generally, the clay content of surface soils of the area is less than their sub-surface horizons which might be due to downward translocation of fine particles along with runoff water from the surface soil, reported by Murthy (1988). The higher clay content in soils is attributed to basaltic parent material, which is responsible for greater clay on weathering (Sannigrahi *et al*. 1992; Gaikwad and Tamgadge, 1993). The variation in soil separates might be due to soil developed on various physiographic units and their parent material, (Murthy *et al*. 1994).

4.6.2.2.2 Bulk Density

Bulk density is the mass of soil per unit volume including pore spaces, (Hillel, 1980), and is an important parameter to understand soil physical environment. As other definition the bulk density is the ratio of mass of dry soil to the total volume of the soil including pore spaces, (Das and Agrawal, 2002). and is considered as a very important physical property of soils that affected the moisture availability, aeration and root penetration. In generally, the values of bulk density are medium to higher. The bulk density of surface and sub-surface soils varies from 1.4 to 1.6 and 1.5 to 1.8 Mgm^{-3}, respectively presented in (Table 4.16).

The bulk density of sub-surface horizons was higher than that of surface horizons and increased with depth of soil which may be due to overburden pressure causing compaction in the subsurface layers (Ahuja *et al*. 1989) and lower bulk density in surface layer might be due to cultivation, organic matter and biotic activities (Rao *et al*. 2008). While the surface soils are less compacted probably due to high amount of organic matter and plant roots. Also reported Similar finding by Virmani *et al*. (1982) and Coughlan *et al*. (1986).

Relatively low values of bulk density of soils could be responsible to high clay content and dominated by smectite clay mineral which is expanding type of clay mineral which swell on wetting causing reduction in bulk density. These results conformity with those reported by Rao *et al*. (1978) and Bharambe *et al*. (1999).

4.6.2.2.3 Water retention characteristics

Water retention refers to the amount of moisture that is held by soil between field capacity (-33 kPa) and permanent wilting point (-1500 kPa). Soil water play very important role in plant growth, besides acting as a solvent for transporting nutrients to plant roots, and also plays an important role in metabolic activities of plants. Moisture retention characteristics depend upon the amount, type and surface area of clay fraction (Coulombe *et al.* 1996). Other factors are organic matter content, biological activity, shrink – swell potential and land use systems.

The data concerning to moisture retention characteristics of soils at -33 kPa and -1500 kPa pressure which indicate moisture at field capacity and wilting point respectively, and the available water content in various soil horizons of all the pedons are presented in Table 4.16.

The observed soils moisture retention is that the amount of water retained varies from 21.2 to 67.4 per cent and 10.9 to 39.3 per cent at -33 kPa suction and -1500 kPa suction, respectively. The variation in soil moisture content at various suctions and also in available water content in soils developed on various landform positions and also within various horizons of the same pedons might be attributed to the variation in soil texture, bulk density, clay mineralogy and organic matter content.

The data reveals that available water content of the soils of the study area which (the difference between moisture held by soil at -33 kPa and -1500 kPa pressure) ranged from 8.3 per cent to 31.2 per cent in the different horizons of the soil series, and it increased with depth. This trend can be attributed to high amounts of 2:1 type smectitic clay, which has large surface area and swell-shrink properties. A linear relationship between clay content and moisture retention was also reported by Nagar *et al.* (1995) and Balpande *et al*. (2007).

Table 4.16 Physical properties of soils of watershed

Horizon	Depth (cm)	Particle Size Distribution				Bulk Density (g/cm^{-3})	Water Retention			WHC
		Sand (%)	Silt (%)	Clay (%)	Class		-33 kPa	-1500 kPa	AWC (%)	
Pedon 1: Bhamb series - Fine smectitic, hyperthermic, Vertic Haplustepts										
Ap	0-17	4.8	29.8	65.5	clay	1.5	50.9	34	16.9	42.5
Bw1	17-59	2.3	27.1	70.6	clay	1.6	50.6	31.7	18.9	42.1
Bw2	59-92	7.3	26.5	66.2	clay	1.5	36	20.6	12.7	38.1
Bw3	92+	8.5	29.3	62.2	clay	1.5	31	22.3	13.5	37.6
Weighted mean		**4.54**	**27.40**	**68.06**		**1.58**	**45.42**	**28.14**	**16.29**	**40.76**
Pedon 2: Dongarkharda series - Fine mixed, hyperthermic, Lithic Ustorthents										
Ap	0-16	39.8	22.6	37.6	clay loam	1.5	31.7	17.9	13.8	46.5
Cr	16-36	76.2	5.9	17.8	sandy loam	1.6	28.8	19.3	9.5	43.4
Weighted mean		**60.05**	**13.33**	**26.62**		**1.56**	**30.09**	**18.68**	**11.41**	**44.79**
Pedon 3: Jalka series - Loamy mixed, hyperthermic, Lithic Ustorthents										
Ap	0-15	24.4	33.6	42.0	clay	1.6	30.1	17.8	12.3	31.9
Pedon 4: Nimgawhan series - Loamy mixed, hyperthermic, Lithic Ustorthents										
A	0-14	25.7	47.8	26.5	loam	1.5	36.4	25.7	10.7	42.7
Pedon 5: Nimgawhan-2 series - Loamy mixed, hyperthermic, Lithic Ustorthents										
Ap	0-15	36.2	27.3	36.4	clay loam	1.4	30.5	14.4	16.1	43.1
Pedon 6: Pimpalkhuti series - Fine mixed, hyperthermic, Lithic Haplustepts										
Ap	0-20	7.3	21.4	71.3	clay	1.6	36.6	24	12.6	38.1
Bw	20-44	12.6	33.6	53.8	clay	1.6	34	22	12.0	36.7
Cr	44+	62.7	9.3	28.0	sandy clay loam	1.7	22.6	13.1	9.5	24.8
Weighted mean		**10.20**	**28.05**	**61.75**		**1.61**	**35.18**	**22.91**	**12.27**	**37.32**

Horizon	Depth (cm)	Particle Size Distribution				Bulk Density (g/cm-3)	Water Retention			WHC
		Sand (%)	Silt (%)	Clay (%)	Class		-33 kPa	-1500 kPa	AWC (%)	
Pedon 7: Potgawhan series - Fine smectitic, hyperthermic, Lithic Haplustepts										
Ap	0-16	3.0	25.5	71.5	clay	1.4	43.8	29.2	11.5	40.7
Bs	16-30	1.7	21.8	76.4	clay	1.7	40.7	28.9	15.4	36.5
Weighted mean		**2.39**	**23.81**	**73.80**		**1.53**	**42.35**	**29.06**	**13.30**	**38.73**
Pedon 8: Sawangi series - Fine Smectitic, hyperthermic, Typic Haplustepts										
Ap	0-19	45.8	15.5	38.7	sandy clay loam	1.6	21.8	11.6	8.3	46.0
Bw1	19-52	46.7	22.8	30.4	sandy clay loam	1.7	21.2	10.9	10.2	40.8
Bw2	52-88	35.8	40.1	24.1	loam	1.6	24.7	13	11.7	48.9
Bw3	88-122	12.2	31.3	56.2	clay	1.7	44.1	26.1	15.5	48.3
Bw4	122-150	10.0	27.5	62.2	clay	1.8	49.8	26.5	21.0	49.2
Weighted mean		**29.31**	**28.82**	**41.73**		**1.67**	**32.65**	**17.85**	**13.55**	**46.69**
Pedon 9: Soyati series - Fine smectitic, hyperthermic, Sodic Haplusterts										
Ap	0-18	10.7	22.3	67.0	clay	1.5	49	27	22.0	43.7
Bw1	18-48	5.0	22.3	72.6	clay	1.5	49	26.7	22.3	47.2
Bss1	48-73	4.5	22.5	73.0	clay	1.6	55.4	32.2	25.2	47.4
Bss1	73-102	2.2	20.6	77.2	clay	1.7	67.4	39	28.4	55.1
Bc	102+	2.9	20.4	76.7	clay	1.8	60.4	39.3	31.2	57.4
Weighted mean		**5.09**	**21.88**	**73.04**		**1.59**	**55.80**	**31.60**	**24.69**	**48.87**
Pedon 10: Warna series - Fine smectitic, hyperthermic, Lithic Ustorthents										
Ap	0-18	25.3	16.0	58.7	clay	1.6	39.2	27.3	11.9	42.7
Cr	18-30	4.2	18.0	77.8	clay	1.7	38.1	28	16.4	34.0
Weighted mean		**16.85**	**16.79**	**66.36**		**1.67**	**38.76**	**27.58**	**13.71**	**39.25**

4.6.2.2.4 Water holding capacity (WHC)

The data in table 4.16 indicated that the WHC in all pedons ranged from 38.1 to 46.5 per cent in surface layer and from 24.8 to 57.4 in subsurface layer respectively. The WHC gradually decreased with depth in pedon 2, 3, 5, 7, 8 and 10, While pedon 1 and 4 gradually increased with depth where the clay content is increasing with depth. The decrease in WHC could be attributed to upturned bulk density and decreased organic carbon in the sub-surface horizons. The similar results were also observed by Rao *et al*. (2009) and Khan and Kamalakar (2012).

4.6.2.3 Chemical properties of soils

The data pertaining to important chemical properties of the soils are discussed here and the data are presented in Table 4.17.

4.6.2.3.1 Soil Reaction (pH)

Soil reaction (pH) is one of the most important physico-chemical properties of soil which denoted availability of various plant nutrients and regulates many physico-chemical phenomena in soils. The pH of soils is generally related to the nature of parent material, climate and topographic situation which determine soil composition. Soils of the study area are slightly acidic to strongly alkaline in reaction with the pH values varied from 6.55 to 8.63 in surface horizons and from 6.84 to 8.94 in subsurface horizons. The higher pH value in soils might be due to basalt as parent material, which is alkaline in nature (Chinchmalatpure *et al*. 2000), The pH value generally increased with depth due to higher exchangeable Na^+ and ESP in the subsurface soils. Similar trend was observed by Garg (2000). The higher content of calcium carbonate and accumulation of soluble salts in a lower layer due to washing out from upper elevation (Arnold and Venkateshwarlu, 1982). In all series, lowest horizon had higher pH value that may be attributed to the accumulation of bases, Baruah *et al*. (2014).

4.6.2.3.2 Electrical conductivity (EC)

The EC of soils is generally low to higher varied from 0.12 to 0.87 dSm^{-1} in surface horizons and from 0.11 to 0.76 dSm^{-1} in subsurface horizons. But the pedon 4 showed exceptional result which is varied from 0.39 to 4.40 dSm^{-1}. However, the EC is found within the safe limit (<1 dSm^{-1}) so does not affect the plant growth. except in pedon 4. The higher values of EC are observed in pedon that occurs in alluvial plain and it increased with depth.

The EC values are found to increase from soils of hills to lower alluvial plains. The EC values found to increase down the profile due to leaching of salts from surface to lower horizons along with percolating water. In the lower horizon relatively higher salts accumulation than the upper horizon, may be due to leaching of salts from the surface layer to lower depths due to irrigation, Similar results were also findings by Pulakeshi *et al*. (2014).

4.6.2.3.3 Organic carbon (OC)

The data presented in Table 4.17 that the organic carbon content varied from 0.44 g kg^{-1} to 1.83 g kg^{-1} in surface and 0.23 g kg^{-1} to 0.73 g kg^{-1} in the subsurface layer. In generally, the organic carbon content were high in surface horizons, which might be attributed to addition of more plant residues on the soil surface and less movement down the profile due to rapid rate of mineralization at higher temperature and adequate soil moisture level. This observation is in accordance with the results of Sarkar *et al*. (2001), Nayak *et al*. (2001), Rao *et al*. (2008) and Ram *et al*. (2014).

comparatively higher organic carbon contents are in the soils under forest contrasted with those under cultivation, which might be credited to the adding of organic matter through leaf fall and less oxidation of carbon because of undisturbed situation of the forest land. Organic matter acts as a major factor regulating the availability of organic forms of nitrogen, phosphorus, sulphur and trace elements in the soils (Stevenson, 1982), as well as to improve soil structure, infiltration rate, nutrient retention and to reduce soil erosion (Smith and Elliott, 1990).

Table 4.17 Chemical properties of soils of watershed

Horizon	Depth (cm)	pH	EC dS m^{-1}	OC g kg^{-1}	$CaCO_3$ (%)	Exchangeable bases				Total cations	CEC	Base saturation (%)	ESP
						Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}				
						cmol (p^{+}) kg^{-1}							
Pedon 1: Bhamb series - Fine smectitic, hyperthermic, Vertic Haplustepts													
Ap	0-17	7.92	0.38	1.18	5.42	34.00	25.60	0.87	1.33	**61.80**	65.22	85.6	1.33
Bw1	17-59	7.95	0.28	0.44	6.45	35.60	31.80	0.71	0.61	**68.72**	64.42	99.5	1.10
Bw2	59-92	8.26	0.16	0.44	14.68	33.80	32.80	0.63	0.15	**67.38**	61.57	81.2	1.06
Bw3	92+	8.16	0.34	0.41	12.40	32.40	34.80	0.64	0.10	**67.94**	62.36	76.9	1.28
Weighted mean		**8.06**	**0.26**	**0.58**	**9.21**	**34.66**	**31.01**	**0.71**	**0.58**	**66.96**	**63.54**	**90.38**	**1.13**
Pedon 2: Dongarkharda series - Fine mixed, hyperthermic, Lithic Ustorthents													
Ap	0-16	7.62	0.18	0.73	5.13	36.40	18.40	1.02	0.31	**56.13**	51.30	113.3	1.99
cr	16-36	7.51	0.11	0.41	6.84	39.60	14.40	1.17	0.10	**55.27**	53.40	103.5	2.19
Weighted mean		**7.56**	**0.14**	**0.55**	**6.08**	**38.18**	**16.18**	**1.10**	**0.19**	55.65	**52.47**	**107.85**	**2.10**
Pedon 3: Jalka series - Loamy mixed, hyperthermic, Lithic Ustorthents													
Ap	0-15	6.82	0.83	0.59	3.28	23.60	17.60	0.41	0.15	**41.76**	39.57	105.6	1.04
Pedon 4: Nimgawhan series - Loamy mixed, hyperthermic, Lithic Ustorthents													
A	0-14	6.82	0.17	1.83	12.44	30.80	22.40	0.49	0.20	**53.89**	50.00	107.8	0.98
Pedon 5: Nimgawhan-2 series - Loamy mixed, hyperthermic, Lithic Ustorthents													
Ap	0-15	6.96	0.12	0.7	0.00	27.20	9.60	0.41	0.26	**37.47**	36.52	102.6	1.12
Pedon 6: Pimpalkhuti series - Fine mixed, hyperthermic, Lithic Haplustepts													
Ap	0-20	8.32	0.14	0.59	11.61	53.20	7.60	0.78	0.51	**62.09**	65.22	95.2	1.20
Bw	20-44	8.24	0.13	0.50	9.45	45.20	10.40	0.63	0.26	**56.49**	59.13	95.5	1.07
cr	44+	8.20	0.14	0.23	10.24	36.00	12.40	0.51	0.15	**49.06**	48.70	92.5	1.05
Weighted mean		**8.28**	**0.14**	**0.54**	**10.43**	**48.84**	**9.13**	**0.70**	**0.37**	**59.03**	**61.90**	**95.38**	**1.12**
Pedon 7: Potgawhan series - Fine smectitic, hyperthermic, Lithic Haplustepts													
Ap	0-16	6.69	0.87	0.88	4.28	40.00	22.40	0.69	0.67	**63.76**	57.39	111.1	1.20
Bw	16-30	6.84	0.76	0.79	2.71	41.60	16.00	0.50	0.41	**58.51**	55.65	105.1	0.90
Weighted mean		**6.76**	**0.82**	**0.84**	**2.28**	**40.75**	**19.41**	**0.60**	**0.55**	**61.31**	**56.58**	**108.31**	**1.06**

Horizon	Depth (cm)	pH	EC dS m^{-1}	OC g kg^{-1}	$CaCO_3$ (%)	Exchangeable bases				Total cations	CEC	Base saturation (%)	ESP
						Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}				
						cmol (p^{+}) kg^{-1}							
Pedon 8: Sawangi series - Fine Smectitic, hyperthermic, Typic Haplustepts													
Ap	0-19	8.20	0.17	0.63	9.41	24.80	9.00	0.38	0.36	**34.54**	31.39	97.3	1.21
Bw1	19-52	8.30	0.15	0.53	11.97	23.20	11.80	0.43	0.30	**35.73**	33.48	86.4	1.28
Bw2	52-88	8.41	0.14	0.41	11.45	26.00	12.36	0.55	0.25	**39.16**	39.13	88.9	1.41
Bw3	88-122	8.74	0.31	0.47	9.69	30.60	15.20	1.83	0.21	**47.84**	51.30	101.0	3.57
Bw4	122-150	8.94	0.40	0.47	12.45	29.60	16.60	3.70	0.20	**50.10**	50.87	100.5	7.27
Weighted mean		**8.53**	**0.23**	**0.49**	**11.09**	**26.95**	**13.25**	**1.38**	**0.26**	**41.83**	**41.86**	**94.34**	**2.94**
Pedon 9: Soyati series - Fine smectitic, hyperthermic, Sodic Haplusterts													
Ap	0-18	8.63	0.39	0.44	5.42	29.60	19.60	5.74	0.72	**55.66**	51.74	90.1	9.30
Bw1	18-48	8.78	0.25	0.44	5.56	28.80	13.60	9.57	0.77	**52.74**	47.39	88.8	13.11
Bss1	48-73	8.71	1.33	0.41	6.70	23.60	17.20	14.43	0.82	**56.05**	51.30	91.4	15.54
Bss2	73-102	7.95	2.80	0.38	7.70	29.60	24.00	20.52	0.82	**74.94**	70.43	106.4	19.13
Bc	102+	8.31	4.40	0.29	10.83	27.60	25.60	21.30	0.76	**75.26**	69.83	107.8	21.50
Weighted mean		**8.50**	**1.27**	**0.42**	**6.42**	**27.89**	**18.50**	**13.20**	**0.79**	**60.38**	**55.67**	**94.68**	**14.75**
Pedon 10: Warna series - Fine smectitic, hyperthermic, Lithic Ustorthents													
Ap	0-18	6.55	0.82	0.79	2.71	31.20	44.00	0.74	0.56	**76.50**	68.65	85.2	1.08
cr	18-30	7.20	0.12	0.73	3.14	31.60	42.80	0.66	0.31	**75.37**	65.74	83.0	1.00
Weighted mean		**6.81**	**0.54**	**0.77**	**2.88**	**31.36**	**43.52**	**0.71**	**0.46**	**76.05**	**67.49**	**84.33**	**1.05**

Abbreviations are according to Soil Survey Manual (Soil Survey Divisions Staff, 2003)

Note: Structure: S-size, m-medium, c-coarse; G-grade; 0-Structure less; 1-weak; 2-moderate; 3-strong; Ty-type, sbk-sub angular blocky, abk-angular blocky.

Consistency: D-dry; h-hard, sh -slightly hard, vh-very hard; eh-extremely hard, I-loose; M-moist; fr -friable; vfr -very friable; W-wet; s-sticky, vs-very sticky, p-plastic,vp-very plastic, so- non sticky, po- non- plastic.

Texture: c - clay; ls - loamy sand; sl - sandy loam; scl - sandy clay loam.

Nodule: S - size: f - fine, m - medium, c - coarse, Q - quantity: f – few, c – common.

Root: S – size: vf – very fine, f - fine, Q - quantity: f – few, c – common, m – many.

Effervescence: e – slight effervescence, es – strong effervescence, ev – violent effervescence.

Other features: ss – slickensides, pf – pressure faces.

4.6.2.3.4 Calcium carbonate

The presence of calcium carbonate in the soils influences both the physical and chemical properties of soils. The presence of high lime concentration may not seriously limit the water moment while may inhibit the root penetrations of the plant. A high concentration of calcium carbonate, especially, in the fine portion brings the risk of lime induced chlorosis in many crops.

In general, the data presented in Table 4.17 reveal that the calcium carbonate in all the soils ranged from 2.71 to 12.44 per cent. Calcium carbonate was found in powdered or nodules form in the surface and subsurface horizons of black soils (Murthy, 1988). The distribution of calcium carbonate in soil profile invariably denoted an increasing order with soil depth, which indicates the process of leaching down of calcium and subsequent precipitation at lower depth may due to high pH levels, (Pal *et al*. 2000; Challa *et al*. 2000).

4.6.2.3.5 Exchangeable bases

The data presented in Table 4.17 reveal that the dominance of calcium and magnesium content on the exchange complex was observed in all the series. The exchangeable cations were found in the order $Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}$ indicating the presence of calcium bearing minerals in parent rocks (Sarkar *et al*. 2001; Maji *et al*. 2005). The exchangeable Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} content in all pedons varied from 23.60 to 53.20, 7.60 to 44.0, 0.38 to 5.74 and 0.15 to 1.33 cmol (p+) kg^{-1} in surface horizon respectively, while in subsurface horizons ranged from 23.30 to 45.20, 12.40 to 42.80, 0.50 to 21.30 and 0.10 to 0.82 cmol (p+) kg^{-1} respectively.

It is also seen that, as the clay content increased which was a corresponding increase in content of exchangeable cations. It may be inferred that increase in clay content gives more exchange sites for cation adsorption (Gawande and Biswas, 1967; Datta *et al.* 1990).

4.6.2.3.6 Cation exchange capacity (CEC)

The cation exchange capacity is one of the very important parameters that indirectly express the nutrient storage capacity of the soils. It is the charging behavior of the soils and clay is the significant fraction contributing towards the cation exchange. The CEC of the soils relies mainly upon the amount and the nature of the clay, organic matter substance, and pH (Brady, 1984). The high CEC in dark soils is responsible to the high clay content and the presence of smectite minerals (Dudal, 1965; ACBSR, 1982).

The table 4.17 indicates that cation exchange capacity (CEC) in all pedon varied from 31.39 (pedon 1) to 68.55 (pedon 5) cmol (p+) kg^{-1} in surface and from 33.37 to 70.43 cmol (p+) kg^{-1} in the subsurface horizon. In general, CEC increased with the increasing depth of the soils (Thampatti and Jose, 2000).

In general, it is showed that CEC of the soils of area is relatively high which may be attributed to high clay content with smectitic mineralogy (Pal and Deshpande 1987). The higher CEC value in some horizons might be due to higher clay content and smectite type of clay mineralogy, whereas low CEC value results from high amount of sand content or mixed type of mineralogy (Kaushal *et al.* 1986; Balpande *et al.* 1996).

4.6.2.3.7 Base saturation percentage (BS)

The base saturation of the soil is often utilized as an indicator of soil fertility which represented the quantity of cations available on clay complex and for plant uptake. The data pertaining to percentage base saturation is presented in Table 4.17 and denoted that the soils of study area are high in base saturation, the base saturation in all series ranged from 85.2 to 113.3 per cent in surface and subsurface layer ranged from 81.2 to 107.8 per cent which is more than 100 % because of the presence of Ca-zeolites (Pal *et al.* 2006).

The base saturation, in general, was found to increase down the slope and shows an increasing pattern with depth which might be responsible to the removed of bases by water. The base saturation is a property closely related to CEC and is considered to be an indicator of soil fertility (Tan, 1989), consequently suggesting better fertility of these soils for crop production.

4.6.2.3.8 Exchangeable sodium percentage (ESP)

The exchangeable sodium percentage (ESP) is the indication of sodium concentration in the soil exchange complex and they point out the sodium hazard. The exchangeable sodium percentage (ESP) on identifies the degree to which the exchange complex is saturated with sodium. ESP level greater than 15 severely deteriorates soil physical properties, thus adversely influences to plants growth.

The data pertaining to ESP in presented to Table 4.17 that the ESP in the soils of the study area varied from 0.98 to 9.30 and from 0.90 to 30.50 per cent in surface and subsurface horizons, respectively. In general, it is observed that ESP increased with soil depth. The higher ESP is related to a corresponding decrease in exchangeable calcium and an increase in exchangeable magnesium (Pal *et al.* 2000).

4.6.2.4 Nutrient status of soil

Horizon-wise available macro and micronutrients in all the pedons are presented in Table 4.18 and they are discussed under the following heads.

4.6.2.4.1 Available nitrogen

Nitrogen is the most vital major nutrient required by plants for proper growth and development, which is an essential component of all proteins and its deficiency results in stunted growth, slow growth, and chlorosis in plants. Table 4.18 indicates that Nitrogen content in all soils of the study area ranged from 112.72 kg ha^{-1} to 195.44 kg ha^{-1} in the surface horizon and the subsurface horizon ranged from 87.81 kg ha^{-1} to 150.18 kg ha^{-1}. The available nitrogen was higher in surface soils as compared to subsurface layers. This may be due to the higher content of organic carbon in surface soils. Similar results were also observed by Sharma and Bali (2000) and Todmal *et al.* (2008). In general, the available N is observed to be maximum in surface horizons and decreased continually with depth which is because of the decreasing trend of organic carbon with depth.

4.6.2.4.2 Available phosphorus

Phosphorus is the second most important major nutrient required by plants after nitrogen for proper growth and development. Phosphorus is important nutrients for plant bioenergetics which plays a significant role in the change of light energy to chemical energy. Table 4.18 indicates that phosphorus content in all soils of the study area ranged from 13.58 kg ha^{-1} to 27.78 kg ha^{-1} on the surface and the subsurface horizon ranged from 10.03 kg ha^{-1} to 23.30 kg ha^{-1}. The phosphorus content is observed to be increasing with a decrease in slope and height. Higher phosphorus content in soils of pediment and valley might be responsible for higher clay content in these soils and the declining trend of phosphorus with depth may due to higher fixation of available phosphorus by clay and $CaCo_3$. A similar result observed was reported by Todmal *et al.* (2008).

4.6.2.4.3 Available potassium

Potassium is one of the third important major nutrients required by plants for their proper growth and development after nitrogen and phosphorus. Table 4.18 indicates that available potassium content in all soils of the watershed area ranged from 145.92 kg ha^{-1} to 403.20 kg ha^{-1} and ranged from 110.08 kg ha^{-1} to 308.57 kg ha^{-1} in the surface and subsurface horizon respectively. The potassium content also increased with the clay content. This might be responsible for the K-rich minerals occurring in the soil (Pal, 1985) and the relative immobility of this element on account of fixation by clay.

4.6.2.4.4 Available sulphur

Sulphur is one of the fourth important major nutrients required by plants for their proper growth and development after nitrogen, phosphorus, and potassium. Table 4.18 indicates that available sulphur content in all pedons of the study area ranged from 0.09 kg ha^{-1} to 0.47 kg ha^{-1} and ranged from 0.06 kg ha^{-1} to 10.82 kg ha^{-1} in the surface and subsurface horizon. The available sulphur content progressively decreased with depth.

The higher available Sulphur of surface soils could be responsible to higher organic carbon content. About 95 percent of the total amount of sulphur in soils is observed in organic matter. As the soil organic matter is broken down, the sulphur in the organic forms is mineralized to sulfate-sulfur. It has also seen a similar trend as in other major nutrients that it is lower in soils at higher elevation and slope as compared to those located on lower elevation and slope. The available sulphur content decreased with depth. Similar results were observed by Rao *et al.* (2008).

4.6.2.4.5 Available micronutrients

The evaluation of soil resource for available micronutrient contents, as precise as possible will be much advantageous to planners, extension workers, fertilizer dealers and to individual farmers. Table 4.18 indicates that available Fe, Mn Cu and Zn content in all soils of the study area ranged from 7.79 to 28.04 mg kg^{-1}, 6.77 to 27.98 mg kg^{-1}, 1.51 to 10.49 mg kg^{-1} and 0.36 to 1.77 mg kg^{-1}, respectively and 3.93 to 19.84 mg kg^{-1}, 2.64 to 13.64 mg kg^{-1}, 1.42 to 3.42 mg kg^{-1} and 0.21 to 0.64 mg kg^{-1}, respectively.

An increasing content of available micronutrients was observed with increasing fineness of texture and organic carbon. Similar results were observed by Gajbhiye *et al.* (1993) on shallow to deep black soils of Maharashtra.

In generally, the decreasing pattern of these micronutrients content down the profile was founded in all the soils, which may be due to decreasing pattern of organic carbon and might be because of manures and fertilizers application at the surface soils.

Table 4.18 Available nutrients status of soils of watershed

Horizon	Depth (cm)	Available Macro-nutrients (kg ha^{-1})				Available Micro-nutrients			
		Avail-N	Avail-P	Avail-K	Avail-S	Avail-Fe	Avail-Mn	Avail-Cu	Avail-Zn
Pedon 1: Bhamb series - Fine smectitic, hyperthermic, Vertic Haplustepts									
Ap	0-19	165.81	27.78	403.20	0.41	6.88	27.98	3.45	1.77
Bw1	19-55	128.18	23.30	368.00	0.21	6.08	11.37	2.97	0.44
Bw2	55-90	102.18	19.23	347.00	0.21	6.71	7.46	1.94	0.40
Bw3	90-120	87.81	16.30	308.57	0.19	5.66	5.60	1.67	0.43
Weighted mean		**125.80**	**22.67**	**366.97**	**0.25**	**6.45**	**13.04**	**2.69**	**0.67**
Pedon 2: Dongarkharda series - Fine mixed, hyperthermic, Lithic Ustorthents									
Ap	0-16	150.53	19.71	166.08	0.18	13.76	15.87	3.90	0.75
Cr	16-36	112.90	17.33	110.08	0.17	9.65	6.01	2.12	0.55
Weighted mean		**129.62**	**18.39**	**134.97**	**0.17**	**11.48**	**10.39**	**2.91**	**0.64**
Pedon 3: Jalka series - Loamy mixed, hyperthermic, Lithic Ustorthents									
Ap	0-15	125.44	14.34	176.88	0.18	21.28	18.78	4.35	0.84
Pedon 4: Nimgawhan series - Loamy mixed, hyperthermic, Lithic Ustorthents									
A	0-14	112.72	13.58	145.92	0.15	21.09	19.78	10.49	0.86
Pedon 5: Nimgawhan-2 series - Loamy mixed, hyperthermic, Lithic Ustorthents									
Ap	0-15	127.81	14.45	198.56	0.47	28.04	11.45	4.07	0.73
Pedon 6: Pimpalkhuti series - Fine mixed, hyperthermic, Lithic Haplustepts									
Ap	0-20	169.72	14.24	256.80	0.09	6.79	9.26	1.99	0.36
Bw	20-44	132.72	13.58	248.16	0.11	6.62	9.42	1.76	0.28
Cr	44+	122.72	11.45	223.52	0.06	6.40	7.45	1.42	0.21
Weighted mean		**149.54**	**13.88**	**252.09**	**0.10**	**6.70**	**9.35**	**1.86**	**0.32**

Horizon	Depth (cm)	Available Macro-nutrients (kg ha^{-1})				Available Micro-nutrients			
		Avail-N	Avail-P	Avail-K	Avail-S	Avail- Fe	Avail-Mn	Avail-Cu	Avail-Zn
Pedon 7: Potgawhan series - Fine smectitic, hyperthermic, Lithic Haplustepts									
Ap	0-17	120.35	16.27	279.20	0.18	20.77	14.65	3.82	0.74
Bs	17-45	106.35	12.79	192.96	0.13	19.84	13.64	3.42	0.64
Weighted mean		**113.82**	**14.65**	**238.95**	**0.16**	**20.34**	**14.18**	**3.63**	**0.69**
Pedon 8: Sawangi series - Fine Smectitic, hyperthermic, Typic Haplustepts									
Ap	0-19	195.44	22.00	203.04	0.23	8.02	10.92	4.56	0.44
Bw1	19-52	155.81	19.75	159.36	0.17	7.19	8.72	4.55	0.33
Bw2	52-88	141.72	19.34	151.52	0.16	7.02	7.15	2.76	0.36
Bw3	88-122	132.26	16.27	141.72	0.17	6.97	6.34	2.45	0.29
Bw4	122-150	126.72	14.58	138.08	0.16	6.93	6.55	1.69	0.33
Weighted mean		**146.68**	**18.19**	**155.04**	**0.17**	**7.16**	**7.68**	**3.17**	**0.35**
Pedon 9: Soyati series - Fine smectitic, hyperthermic, Sodic Haplusterts									
Ap	0-19	162.72	16.25	323.20	0.10	9.18	6.77	1.51	0.49
Bw1	19-52	137.63	13.45	245.60	0.12	8.02	7.16	1.37	0.45
Bw2	52-88	150.18	12.03	175.60	1.46	8.22	6.29	1.76	0.47
Bw3	88-122	137.63	11.90	165.60	4.56	7.78	3.78	1.89	0.43
Bw4	122-150	125.09	10.03	131.92	10.82	3.93	2.64	1.61	0.37
Weighted mean		**145.13**	**13.15**	**219.39**	**1.71**	**8.21**	**5.92**	**1.64**	**0.45**
Pedon 10: Warna series - Fine smectitic, hyperthermic, Lithic Ustorthents									
Ap	0-18	127.81	14.45	198.56	0.47	28.04	11.45	4.07	0.73
Cr	18-30	112.72	12.03	160.48	0.24	14.72	9.67	2.48	0.58
Weighted mean		**121.77**	**13.48**	**183.33**	**0.38**	**22.71**	**10.74**	**3.43**	**0.67**

4.7 Soil Mapping

Soils are considered as an integral part of the landscape and thus their characteristics are largely governed by the landforms on which they have developed (Sharma *et al.* 1999). The importance of soil-physiographic relationship in soil survey and mapping, provide a fair understanding of variability across the landscape needed for sustainable agricultural planning (Murthy, 1982). Systematic study of morphology and taxonomy of soils gives idea about nature and type of soils, their constraints, potential capabilities and suitability for various uses (Sehgal, 1996). Information about extent, distribution, potential and constraints of soils of an area is needed in the process of land use planning. Soil mapping comprises the identification, description and delineation of different kinds of soils based on morphological observations in field and laboratory investigations (Challa *et al*. 1995). Soil map provides a means of communicating our knowledge about the distribution of soil attributes and occurrence of different soil classes in nature. Information on soil properties becomes essential as these properties continuously vary in space and hence any mapping unit will have internal variability (Wright, 1993).

Soil mapping is basically an inference process based on Jenny's model (Jenny, 1941). According to this model, if the environmental conditions at a given location and its soil-environmental relationship are known, then it is possible to infer the condition of soil at any other location with similar environment conditions. This has great significance in mapping the soils in different physiographic units.

After systematic study of soils in different landform units, the landform-soil relationship was established. The landform-soil relationship indicated the changes in important soil properties *viz*. profile development (morphological), physical and chemical properties with the variation in landform unit. Based on soil correlation, tentatively ten soil series namely Sawangi (Saw), Pimpalgaon (Pim), Bhamb (Bham), Soyati (Soy), Warna (War), Jalka (Jal), Potgawhan (Pot), Nimgawhan (Nim), Nimgawhan-2 (Nim-2) and Dongarkharda (Don) were identified in the area (Table 4.19 and Fig. 4.14). Taking into account surface texture, slope, erosion, surface stoniness and kind of degradation in terms of sodicity, 10 soil series are mapped in to 14 mapping unit at the level of phases and their distribution and aerial extent is presented in Fig. 4.15 and Table 4.20. The soil-site characteristics, field morphology as well as laboratory analysis data were used to delineate the boundaries of different mapping units. The soil map (1:10000 Scale) of the watershed has been presented in figure 4.15. The distribution of soil series reveals that Nimgawhan-2 series has the largest areal extent and covers about 3040.0 ha which is (25.8% of TGA) of the total watershed area and occurs on denuded plateau followed by the Pimpalkhuti series which constitutes an area of about 1870.2 ha (15.88 % of TGA) of total watershed and occurs on lower pediment.

It is seen that the soil improvement in the area is essentially controlled by physiography and affected by different intensities of erosion. The study showed that sentinel 2 digital data of two seasons supplemented by ground truth has been found to be more efficient and cost effective for the preparation of soil maps on 1:10,000 scale.

Table 4.19 Differentiating characteristics of typical pedons of different soil series of Sawangi watershed

Soil series	Landform	Geology/ Parent Material	Soil Depth (cm)	Soil texture	Surface stoniness (%)	Colour	Reaction	Slope (%)	Erosion	Drainage	Salinity/ Sodicity
Bhamb	Pediplain	Basalt	150	clay	<3	10YR3/2	ev	1-3	Moderate	Well drained	-
Dongarkharda	Upper Valley	Basalt	50	clay loam	<3	10YR3/2	ev	3-8	severe	Well drained	-
Jalka	Denuded Plateau	Basalt	25	clay	<3	10YR3/3	-	3-8	severe	Well drained	-
Nimgawhan	Escarpment	Basalt	25	loam	>75	2.5YR3/3	-	8-15	Severe	Well drained	-
Nimgawhan-2	Denuded Plateau	Basalt	25	clay	<3	5YR3/3	-	1-3	Moderate	Well drained	-
Pimpalkhuti	Lower Pediment	Basalt	50	clay	<3	10YR3/2	ev	1-3	Moderate	Well drained	-
Potgawhan	Plateau	Basalt	50	clay	3-15	10YR3/1	e	1-3	Moderate	Well drained	-
Sawangi	Alluvial Plain	Basalt	150	sandy clay loam	<3	10YR3/2	ev	3-8	Severe	Well drained	-
Soyati	Lower valley	Basalt	100	clay	<3	10YR3/2	ev	1-3	Moderate	Moderately well drained	Moderate
Warna	Upper pediment	Basalt	50	clay	<3	10YR3/1	e	3-8	Moderate	Well	-

Table 4.20 Soil series and phases of Sawangi watershed

Landform	Soil series	Soil map unit	Mapping legend	Brief description of soil series	Area (ha)	TGA (%)
Pediplain	Bhamb	1	Bha5mB2	Deep, well drained, very dark grayish brown, clayey soils on very gently sloping pediplain with clay surface with moderate erosion.	1480.8	12.6
Upper Valley	Dongarkharda	2	Don2fC3	Shallow, well drained, very dark grayish brown, clay loam soils on gently sloping upper valley with clay loam surface with severe erosion.	322.3	2.7
Denuded Plateau	Jalka	3	Jal1mC3	Very shallow, well drained, dark brown, clayey soils on gently sloping denuded plateau with clay surface with severe erosion.	565.0	4.8
Escarpment	Nimgawhan	4	Nim1dF4	Very shallow, well drained, dark reddish brown, loamy soils on steeply sloping escarpment with loam surface with very severe erosion	878.0	7.5
	Nimgawhan	5	Nim1fC2	Very shallow, well drained, dark reddish brown, clay loamy soils on gently sloping escarpment with clay loam surface with moderate erosion	258.7	2.2
Denuded Plateau	Nimgawhan-2	6	Nim1mB2	Very shallow, well drained, dark reddish brown, clay soils on very gently sloping denuded plateau with clay surface and moderate erosion	117.0	1.0
	Nimgawhan-2	7	Nim1mC2	Very shallow, well drained, dark reddish brown, clay soils on gently sloping denuded plateau with clay surface and moderate erosion	2993.0	24.8
Lower Pediment	Pimpalkhuti	8	Pim2mB2	Shallow, well drained, very dark grayish brown, clayey soils on very gently sloping	1006.0	8.5

				lower pediment with clay surface and moderate erosion.		
	Pimpalkhuti	9	Pim2mC2	Shallow, well drained, very dark grayish brown, clayey soils on gently sloping lower pediment with clay surface and moderate erosion.	864.2	7.3
Plateau	Potgawhan	10	Pot2mB2	Shallow, well drained, very dark grayish brown, clayey soils on very gently sloping plateau with clay surface and moderate erosion.	540.6	4.6
Alluvial Plain	Sawangi	11	Saw5hC3	Deep, well drained, very dark grayish brown, sandy clay loam soils on gently sloping alluvial plain with sandy clay loam surface and severe erosion.	702.9	6.0
Lower Valley	Soyati	12	Soy4mB2n1	Deep, moderately well drained, very dark grayish brown, clayey soils on very gently sloping lower valley with clay surface, moderate erosion and moderate sodicity.	738.3	6.3
	Soyati	13	Soy4mC3	Deep, moderately well drained, very dark grayish brown, clayey soils on gently sloping lower valley with clay surface and severe erosion	529.5	4.5
Upper Pediment	Warna	14	War2mC2	Shallow, well drained, very dark gray, clayey soils on gently sloping upper pediment with clay surface and moderate erosion.	442.2	3.8
Miscellaneous (habitation / waterbodies / hills)					409.0	3.5
Total					**11777.6**	**100.0**

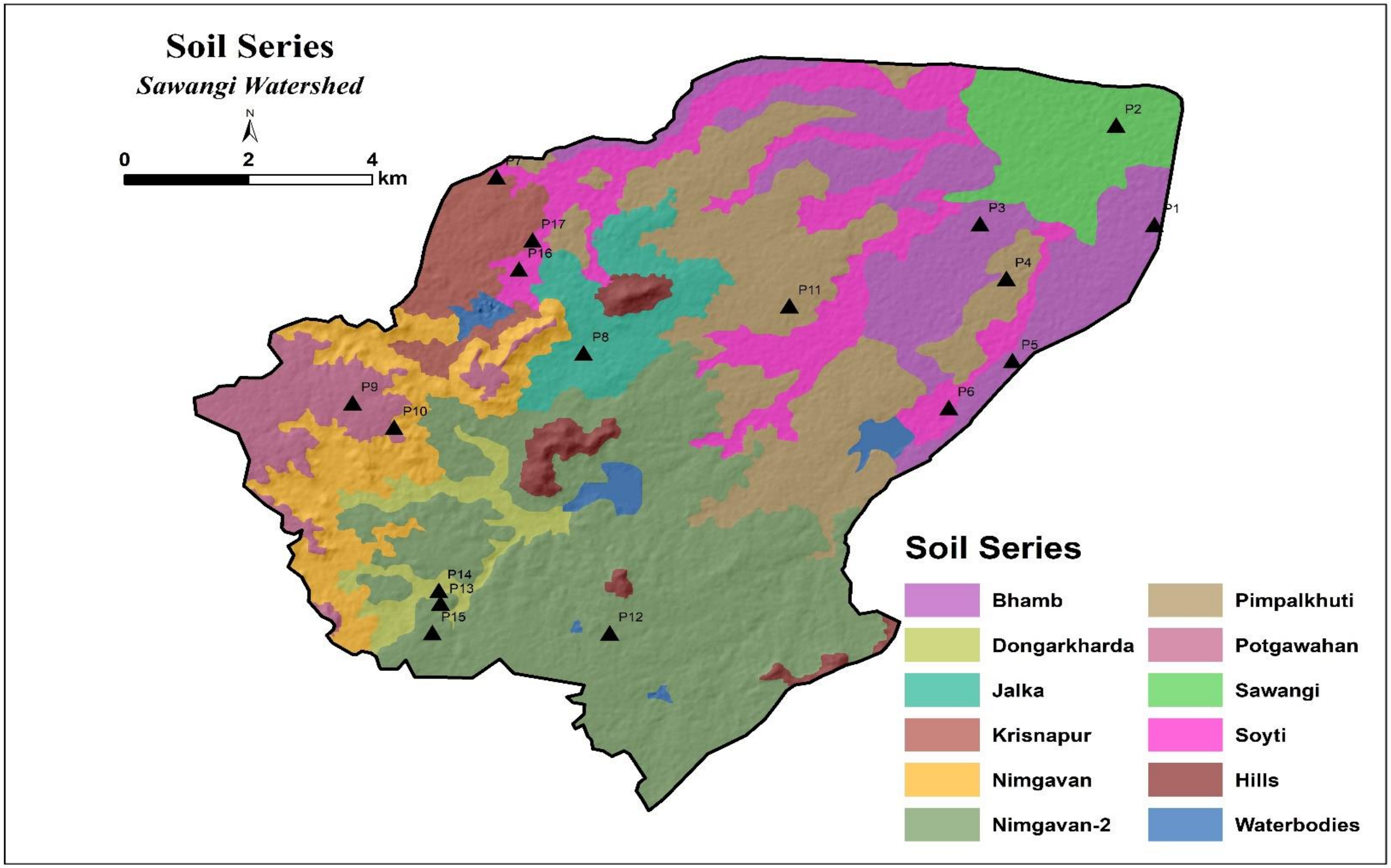


Fig. 4.13 Soil map (Series) of Sawangi watershed

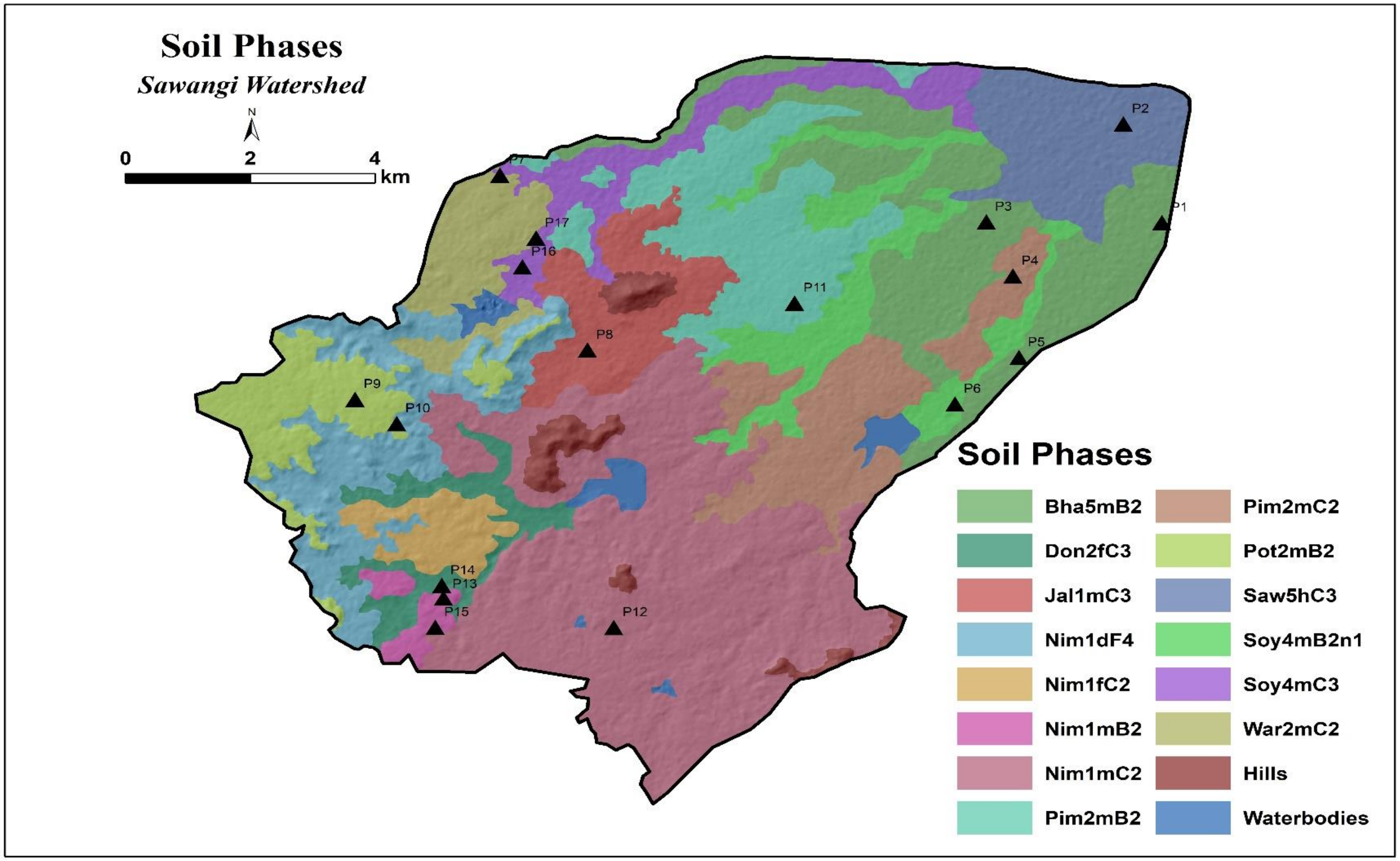


Fig. 4.14 Soil map (Phases) of Sawangi watershed

4.7.1 Soil series description

4.7.1.1 Bhamb series

Bhamb series soils represents deep, well drained, very dark grayish brown, slight to moderately alkaline, calcareous, clayey soils on very gently sloping pediplain with clay surface and moderate erosion. They are developed from weathered basaltic parent material on Pediplain used for cultivation (Double crop). These soils are classified as a fine smectitic, hyperthermic, family of Vertic Haplustepts. The series covered 1480.8 ha (12.6 %) of TGA of the watershed.

4.7.1.2 Dongarkharda series

Dongarkharda series comprises shallow, well drained, very dark grayish brown, slightly alkaline, clay loam soils on gently sloping upper valley with clay loam surface with severe erosion. They are developed from weathered basaltic parent material on Upper Valley used for cultivation (Single crop). These soils are classified as a fine mixed, hyperthermic family of Lithic Ustorthents. The series has covered an area of 322.3 ha (2.7%) of TGA of the watershed.

4.7.1.3 Jalka series

Jalka series comprises very shallow, well drained, dark brown, neutral in reaction, clayey soils on developed on gently sloping denuded plateau with clay surface with severe erosion. They are developed from weathered basaltic parent material on Denuded Plateau used for cultivation (Single crop). These soils are classified as a Loamy mixed hyperthermic family of Lithic Ustorthents. The series covered 565.0 ha (4.8%) of TGA of the watershed.

4.7.1.4 Nimgawhan series

Nimgawhan series comprises very shallow, well drained, dark reddish brown, neutral, loamy soils on steeply sloping escarpment with loam surface with very severe erosion. They are developed from weathered basaltic parent material on escarpment not used for cultivation (Degraded Forest). These soils are classified as a loamy mixed, hyperthermic family of Lithic Ustorthents. The series is the second largest covered area 1136.6 ha (9.65%) of TGA of the watershed.

4.7.1.5 Nimgawhan-2 series

Nimgawhan-2 series soils are very shallow, well drained, dark reddish brown, neutral, clay soils developed on very gently sloping denuded plateau with clay surface and moderate erosion. They are developed from weathered basaltic parent material on Denuded Plateau used for cultivation (Single crop). These soils are classified as a loamy mixed, hyperthermic family of Lithic Ustorthents. The series has covered largest area of 3040.0 ha (25.8%) of TGA of the watershed.

4.7.1.6 Pimpalkhuti series

Pimpalkhuti series comprises very shallow, mod. well-drained, very dark grayish brown, moderate erosion, very gently sloping, clay texture, and strongly calcareous soils. They are developed from weathered basaltic parent material on lower pediments used for cultivation (single crop). These soils are classified as a clayey mixed, hyperthermic, family of Lithic Haplustept. The series occupies 322.32 ha (2.74 %) of TGA of the watershed.

4.7.1.7 Potgawhan series

Potgawhan series comprises very shallow, well-drained, very dark gray, moderate erosion, very gently sloping, loamy texture, and moderately calcareous soils. They are developed from weathered basaltic parent material on Plateau used for cultivation (Single crop). These soils are classified as a fine smectitic, hyperthermic family of Lithic Haplustept. The series is the first largest covered area 3298.68 ha (28.01%) of TGA of the watershed.

4.7.1.8 Sawangi series

Sawangi series soils comprises very deep, well-drained, very dark grayish brown, moderately alkaline, clayey soils occurring on gently sloping alluvial plain with sandy clay loam surface texture, calcareous soils with severe erosion. They are developed from weathered basaltic parent material on Alluvial Plain used for cultivation (single crop). These soils are classified as fine Smectitic, hyperthermic, family of Typic Haplustepts. The series occupies 702.9 ha (6.0 %) of TGA of the watershed.

4.7.1.9 Soyati series

Soyati series comprises deep, moderately well drained, very dark grayish brown, strongly alkaline, calcareous, clayey soils on very gently sloping lower valley with clay surface, moderate erosion and moderate sodicity. They are developed from weathered basaltic parent material on lower valley used for cultivation (Single crop). These soils are classified as a Fine smectitic, hyperthermic, family of Typic Haplusterts. The series covered 1267.92 ha (10.7 %) of TGA of the watershed.

4.7.1.10 Warna series

Warna series soils are shallow, well drained, very dark gray, neutral in reaction, clayey soils occurring on gently sloping upper pediment with clay surface and moderate erosion. They are developed from weathered basaltic parent material on Upper Pediment used for cultivation (Double crop). These soils are classified as a Fine smectitic, hyperthermic, family of Lithic Ustorthents. The series covered 442.2 ha (3.75%) of TGA of the watershed.

4.7.2 Taxonomic classification of soils

Soil classification is a technique for arrangement and communicating our knowledge and perception about the attribute of soils. The taxonomic classification of soils helps with reducing the investigation of individuals to the same well-defined classes or units which facilitate grouping together of soils having comparable characteristics, such that present information of soils is organized in a systematic way. On the basis of the field morphology and laboratory analyses data, the soils have been classified according to U.S. comprehensive system of soil classification (Soil Survey

Staff, 1998). The Taxonomic classification of soils of study area is presented in Table 4.21.

4.7.2.1 Vertisols

The soils are deep to very deep. black coloured, clayey (>30 % clay), and characterized by deep wide cracks when dry, that open and close periodically, shrink-swell properties, gilgai microrelief and very well-developed slickensides close enough to intersect. The soil series Soyati (pedon-4) are classified under the order vertisols. The soils qualify for suborder Haplusterts.

Table 4.21 Taxonomic classification of soils of watershed

Pedon No.	Soil series	Order	Sub order	Great group	Sub group
1	Bhamb	Inceptisols	Ustepts	Haplustepts	Vertic Haplustepts
2	Dongarkharda	Entisols	Orthents	Ustorthents	Lithic Ustorthents
3	Jalka	Entisols	Orthents	Ustorthents	Lithic Ustorthents
4	Nimgawhan	Entisols	Orthents	Ustorthents	Lithic Ustorthents
5	Nimgawhan-2	Entisols	Orthents	Ustorthents	Lithic Ustorthents
6	Pimpalkhuti	Inceptisols	Ustepts	Haplustepts	Lithic Haplustepts
7	Potgawhan	Inceptisols	Ustepts	Haplustepts	Lithic Haplustepts
8	Sawangi	Inceptisols	Ustepts	Haplustepts	Typic Haplustepts
9	Soyati	Vertisols	Usterts	Haplusterts	Sodic Haplusterts
10	Warna	Entisols	Orthents	Ustorthents	Lithic Ustorthents

4.7.2.2 Inceptisols

The soils having ochric epipedon underlain by cambic subsurface horizon with its upper surface boundary within 100 cm of the mineral soil surface and its lower boundary at a depth of 25 cm or more below the mineral soil surface have been classified in the order Inceptisols. Through of the prevailing ustic moisture regime in the watershed area, these soils are classified in the suborder Ustepts and qualify for Haplustepts great group. The Haplustepts great group is further divided into two subgroups *viz*. Vertic Haplustepts and Typic Haplustepts as per Soil Survey Staff, 1998. Soil series Sawangi, Pimpalkhuti, Bhamb and Potgawhan are classified under order Inceptisols The soils qualify for suborder Haplustepts.

4.7.2.3 Entisols

The soils lacking subsurface diagnosting horizons which do not qualify for other orders are classified under the order Entisols. The soil series coming under order Entisols are classified under suborder orthents which are lacking subsurface diagnostic horizons. The soil series classified under suborders orthents are further subdivided into Ustorthent great groups because of ustic moisture regime prevailing in the study area. These soils were further divided into Lithic subgroups based on presence or absence of lithic or paralithic contact and other features qualifying for respective category (Soil Survey Staff, 1998). Soil series *viz*, Warna, Jalka, Nimgawhan, Nimgawhan-2 and Dongarkharda comes under the order of Entisols.

4.8 Land Evaluation

Soil information is commonly transferred to users *via* soil interpretation and land evaluation (Zinck and Valenzuela, 1990). Land evaluation is the ranking of the soil units on the basis of their capabilities to provide the highest returns per unit area and conserving the natural resources for future use (Wambeke and Russister, 1987). Interpretative groupings thus serve as an evaluation of the potentials of the different soils and enable predictions about their behaviour under different management systems.

Further, it also denotes the degree of limitations for the sustained use of soil under a specified system.

Most commonly used interpretative groupings are:

1. Land Capability Classification (Klingebiel and Montgomery, 1961)
2. Soil and Land Irrigability Classification (IARI Manual, 1971)
3. Soil suitability analysis, soil suitability classification (Sys *et al.* 1991)
4. Land Productivity Index (Riquier *et al.* 1970)

Soils of the study area have been evaluated for major crops cultivated in the area for land capability, land irrigability, land productivity and soil suitability. The results of the land evaluation are described in the subsequent sections. For the soil-site suitability, the criteria suggested by Naidu *et al.* 2006 were followed for evaluating different crops.

4.8.1 Land Capability Classification

The land capability classification is an interpretative grouping made primarily for agricultural purposes (Klingebiel and Montgomery, 1961). The soils of the study area are grouped on the basis of their potential and limitation for sustained production. These are on the basis of effects of a combination of climate and permanent soil characteristics on risks of soil damage, existing land use, production capacity, and management requirements, *etc*. Land suited for cultivation are grouped in class I to class IV according to the degree of limitations. Land in class V to class VII are suggested for silvipasture, social forestry plantation, *etc*.

The criteria for land capability classification are outlined in Appendix. Different soil series evaluated for land capability classification are given in Table 4.23. Land capability classes are divided into sub-class that represent groups of soils having similar kinds of dominant limitations for agricultural use. Three kinds of limitations are identified at the sub-class level i.e., ‘e’ for water or wind erosion, ‘t’ for topography and ‘s’ for soil limitations affecting the plant growth. The results concerning to land capability classes and sub-classes are presented in Table 4.23 and their extent and distribution in the watershed are presented in Table 4.22 and the spatial distribution of land capability subclasses are illustrated in Fig. 4.15.

The soil of Sawangi watershed were grouped under different land capability sub-classes *viz*. SMU- 1 and 13 have been classified into sub-class IIes either because of erosion or problems of soil. SMU- 8, 9, 11, and 12 are classified under land capability sub-class IIIes with moderate limitation of soil depth, slope, erosion, organic carbon and texture. The SMU- 2, 3, 6, 7, 10 and 14 are classified under land capability sub-class IVes because of the soil and topography problems *i.e.* due to severe limitations of soil depth, slope and erosion problems. The SMU- 4 and 5 are classified under land capability sub-class VIes and VItes with very severe limitation of soil depth, slope or topography and erosion problems.

Table 4.22 Extend and distribution of land capability classes

Sl. No.	Soil Map Units (SMU)	Land capability class	Area (ha)	% TGA
1	1, 13	IIes	1986.41	16.87
2	8, 9, 11, 12	IIIes	3250.43	27.60
3	2, 3, 6, 7, 10, 14	IVes	2189.15	18.59
4	5	VIes	2891.34	24.55
5	4	VItes	757.68	6.43
	Total Geographical Area (TGA)		**11075**	

The land capability classes and sub-classes in different soil mapping units were mapped *viz*. IIes, IIIes, IVes, VIes and VItes, and observed that about 1986.41 ha area (16.87 % of TGA), 3250.43 ha area (27.60 % of TGA), 2189.15 ha area (18.59 % of TGA), 2891.34 ha area (24.55 % of TGA) and 757.68 ha area (6.43 % of TGA) respectively.

Table 4.23 Land capability classification of Sawangi watershed

Characteristics / SMU	SMU 1	SMU 2	SMU 3	SMU 4	SMU 5	SMU 6	SMU 7	SMU 8	SMU 9	SMU 10	SMU 11	SMU 12	SMU 13	SMU 14
Topography (t)														
Slope (%)	II	III	III	VI	III	II	III	II	III	II	III	II	III	III
Erosion	III	IV	IV	IV	III	III	III	III	III	III	III	III	IV	III
Wetness (w)														
Flooding	I	I	I	I	I	I	I	I	I	I	II	I	I	I
Drainage	I	I	I	I	I	I	I	I	I	I	I	II	I	I
Permeability	I	I	I	I	I	I	I	I	I	I	I	II	II	I
Physical soil conditions (s)														
Surface texture	III	II	II	I	II	III	III	III	III	III	IV	III	III	III
Surface stoniness	II	I	I	III	II	II	II	II	II	II	II	I	I	II
Soil depth (cm)	II	IV	IV	VI	VI	IV	IV	III	III	IV	II	II	II	IV
Soil reaction pH	II	I	I	I	I	I	I	III	I	I	III	III	II	I
CEC (Cmole (P+) kg^{-1})	I	I	I	I	I	I	I	I	I	I	I	I	I	I
Base saturation (%)	I	I	I	I	I	I	I	I	I	I	I	I	I	I
O.C. (0-15 cm) (%)	III	III	III	I	III	II	I	III	I	II	III	IV	III	III
Salinity EC (dSm^{-1})	I	I	I	I	I	I	I	I	I	I	I	II	I	I
Land capability class	**II**	**IV**	**IV**	**VI**	**VI**	**IV**	**IV**	**III**	**III**	**IV**	**III**	**III**	**II**	**IV**
Land capability sub-class	**IIes**	**IVes**	**IVes**	**VItes**	**VIes**	**IVes**	**IVes**	**IIIes**	**IIIes**	**IVes**	**IIIes**	**IIIes**	**IIes**	**IVes**

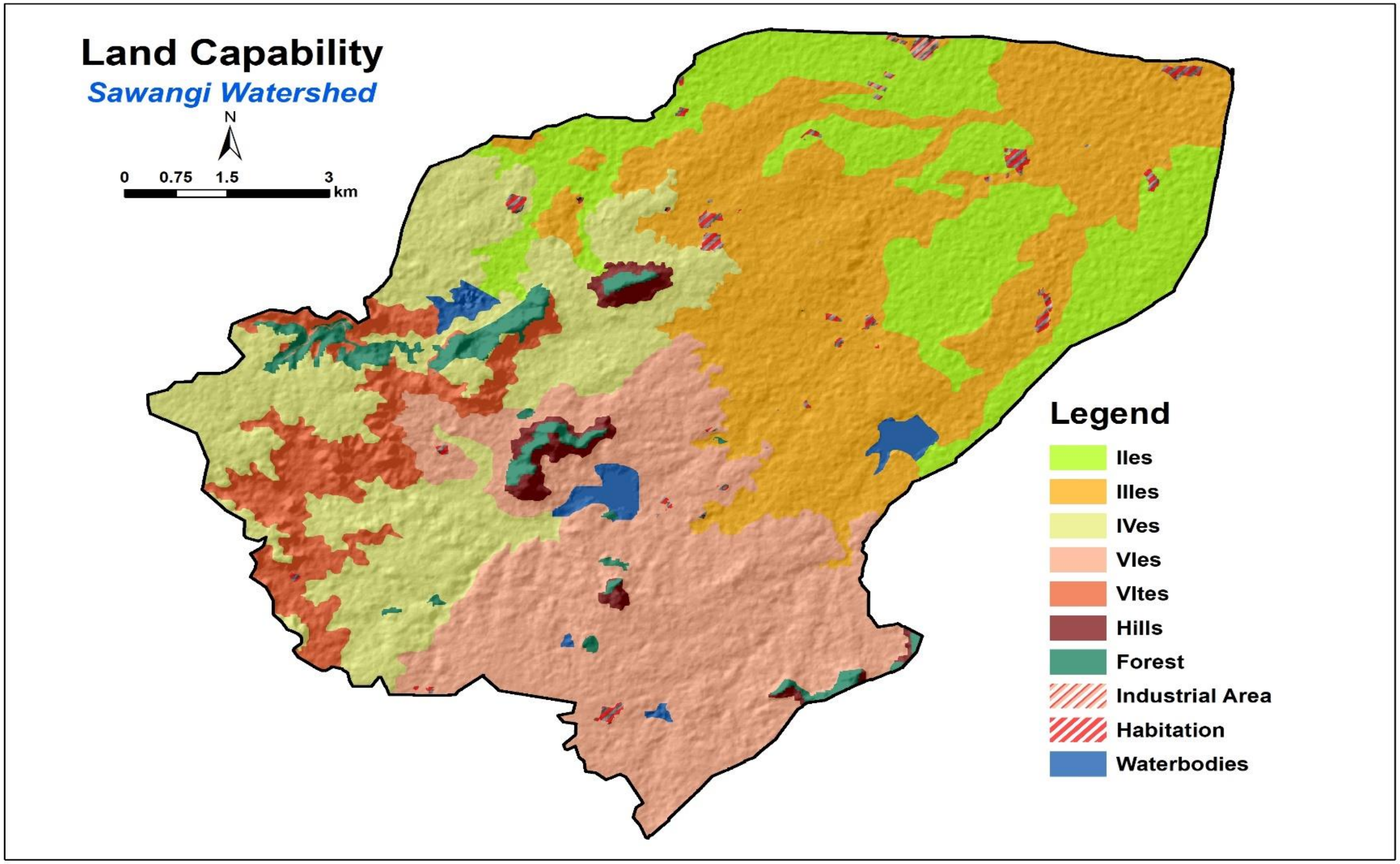


Fig. 4.15 Land capability map of Sawangi watershed

4.8.2 Land irrigability classification

Land irrigability classification is an interpretative grouping on the basis of soil and land characteristics which denotes relative suitability of land for irrigation as well as predicted behaviour of soils under irrigation. The irrigability classification is a combined impact and reciprocal influence of soil and land characteristics. The factors considered in deciding irrigability classes are effective soil depth, texture, moisture holding capacity, soil surface cover (gravel, cobbles, and stones), soil permeability, soil salinity and alkalinity hazards, drainage, soil erosion, ground water table and landform (relief and scope).

Criteria for classes are quantitatively defined, and are exclusive in that soil can qualify for only one class. The most important limiting factor determines the class. For practical irrigation, suitability is determined by first grouping the soils into: (a) soil irrigability classes according to their sustained use under irrigation and (b) then grouping the irrigable soils into land irrigability classes. The land irrigability classes are on the basis of soil irrigability classes, needs of land development, ground water conditions and drainability of lands. The criteria for soil irrigability classification are outlined in Appendix and different soil series evaluated for land irrigability classes are given in Table 4.26.

4.8.2.1 Soil irrigability

Soil irrigability classes are established without regard to availability of irrigation water, water quality, land preparation costs, availability of drainage and other non-soil related factors. The irrigability classification of the soils of the area and the definition of soil irrigability classes are indicated in Table 4.24.

4.8.2.2 Land irrigability

The evaluation of soil and land conditions is concerned primarily with predicting the behaviour of soil under the greatly altered moisture regime brought about by introduction of irrigation. According to this, land is grouped into six land irrigability classes. Land from 1 to 4 is generally irrigable but limitations in their use for sustained irrigation increase from 1 to 4. However, special and detailed investigations are necessary to assign irrigability class 5 lands on permanent basis. Class 6 lands are not suited to sustained use under irrigation. Land irrigability sub-classes are assigned based on the dominant limitations for sustained use under irrigation. The subclass recognized relate to soil deficiencies (s), topography (t) and drainage (d).

Table 4.24 Irrigability classification of the soils

Irrigability class	Definition	Soil map units
Class-A	None to slight soil limitations for sustained use under irrigation	Nil
Class-B	Moderate soil limitations for sustained use under Irrigation	SMU – 1, 8, 9, 12
Class-C	Severe soil limitations for sustained use under Irrigation	SMU – 2, 5, 6, 10, 11, 13, 14
Class-D	Very severe soil limitations for sustained use under Irrigation	SMU – 3, 7
Class-E	Non suited for irrigation (or non-irrigable soil class)	SMU – 4

Table 4.25 Land irrigability groupings of soils

Sl. No.	Soil map units (SMU)	Land irrigability class	Land irrigability sub-class
1	1	2	2st
2	2	3	3st
3	3	4	4s
4	4	5	5t
5	5	3	3st
6	6	3	3s
7	7	4	4s
8	8	2	2st
9	9	2	2st
10	10	3	3s
11	11	3	3t
12	12	2	2st
13	13	3	3t
14	14	3	3st

Table 4.26 Land irrigability classification of Sawangi watershed

Characteristics / SMU	SMU 1	SMU 2	SMU 3	SMU 4	SMU 5	SMU 6	SMU 7	SMU 8	SMU 9	SMU 10	SMU 11	SMU 12	SMU 13	SMU 14
Physical soil conditions (s)														
Effective soil depth	A	C	D	D	C	C	D	B	B	C	A	A	B	C
Texture of surface layers	B	A	A	B	A	C	C	B	B	C	A	B	B	B
AWC to the depth of 90cm (cmm^{-1})	A	B	B	B	B	C	C	A	B	C	B	A	A	C
Coarse fragments (%) cobbles & stones (>75 mm)	A	A	A	C	B	B	B	B	B	B	A	A	A	B
Gravel and Kanker (>25 to 75mm)	A	A	A	A	A	A	A	A	A	B	A	A	A	A
Rock out crops (distance apart in meters)	A	A	C	C	C	B	C	A	A	B	A	A	A	A
EC (dS/m)	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Salt affected (visual) (% of area affected)	A	A	A	A	A	A	A	A	A	A	A	B	A	A
Severity of alkali problem	A	A	A	A	A	A	A	A	A	A	A	B	A	A
Sub-soil or substrata drainage characteristics	A	A	A	A	A	A	A	B	A	A	B	A	A	A
Soil erosion status	A	B	B	B	A	A	A	A	A	A	B	A	B	A
Topography (t)														
Slope (%)	B	C	C	E	C	B	C	B	B	B	C	B	C	C
Drainage (w)														
Depth of water table	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Land irrigability class	**2**	**3**	**4**	**5**	**3**	**3**	**4**	**2**	**2**	**3**	**3**	**2**	**3**	**3**
Land irrigability sub-class	**st**	**st**	**s**	**t**	**st**	**s**	**s**	**st**	**st**	**s**	**t**	**st**	**t**	**st**

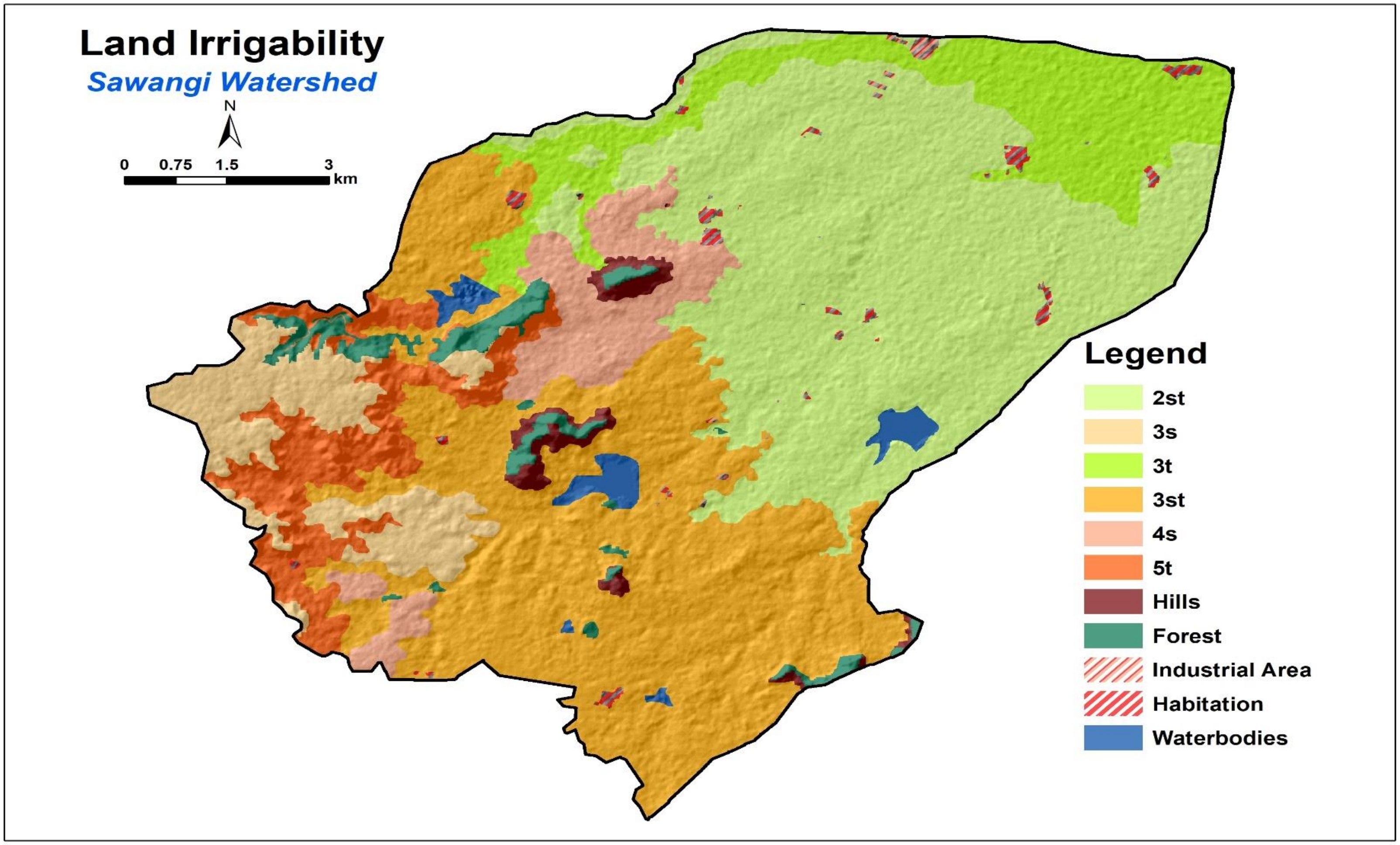


Fig. 4.16 Land irrigability map of Sawangi watershed

The soil of Sawangi watershed were categorized under different land irrigability classes and sub-classes *viz*. SMU- 1, 8, 9 and 12 with moderate limitations of soil texture, depth, slope, drainage, coarse fragments and available water holding capacity were categorized under land irrigability sub-class 2st. The SMU- 6, and 10 both are categorized under 3s. The SMU- 2, 5 and 14 were categorized under 3t. SMU- 11 and 13 both were categorized under land irrigability sub-class 3st with severe limitations of soil depth, slope, surface texture and available water holding capacity. The SMU- 3 and 7 were categorized under 4s with very severe limitations of soil depth, slope and severe limitation surface texture, slope, rock out crops and available water holding capacity. The SMU- 4 was grouped under 5t were non suited for irrigation with very severe limitations of soil depth, surface texture, slope, soil permeability, coarse fragments and available water holding capacity (Table 4.26).

Table 4.27 Extent and distribution of land irrigability sub-classes

Sl. No.	Soil map units (SMU)	Land irrigability subclass	Area (ha)	% TGA
1	1, 8, 9, 12	2st	4019.39	34.13
2	6, 10	3s	776.90	6.60
3	11, 13	3st	3626.11	30.79
4	2, 5, 14	3t	1217.46	10.34
5	3, 7	4s	677.47	5.75
6	4	5t	757.68	6.43
	Total Geographical Area		11075.02	

The soils of Sawangi watershed are categorized under five land irrigability classes, in different soil mapping units (SMU) were mapped *viz.* 2st, 3s, 3st, 3t, 4s and 5t and observed that about 4019.39 ha area (34.13 % of TGA), 776.90 ha area (6.60 % of TGA), 3626.11 ha area (30.79 % of TGA), 1217.46 ha area (10.34 % of TGA), 677.47

ha area (5.75 % of TGA) and 757.68 ha area (6.43 % of TGA) respectively (Table 4.27 and Fig. 4.16).

4.8.3 Soil Suitability evaluation

The performance of a crop on a land unit is mainly dependent on its soil and site characteristics making their study necessary for predicting the yield potential of the area. Natural resource survey gives basic information on land resources, which without interpretation have limited value to land users, planners, and decision makers. They require guidance as to which crops are suitable for a particular land parcel for profitable land use. Similar evaluation involves on assessment of land performance under exclusive land utilization types.

Land evaluation for crop suitability is related to evaluating land in particular to determine decide it meets the requirements of identified crops. To build an information base through logical thinking that helps the ranking of land units, an attempt was made, to assess the suitability of soil series for major crops of the area, as far as their attributes and characteristics by utilizing a modified soil suitability criteria developed for the purpose. The climatic and soil site characteristics of the soils of the area have been coordinated with the soil site suitability criteria for major crops grown in the area such as, cotton, soybean, pigeon pea, sorghum, wheat, chickpea, The degree of limitations of each soil series was inferred.

However, the crop suitability groupings presented here, are just indicative and not absolute because of the limitations of scale dependent abstraction level of soil units in the investigations. The suitability classes show that the soils are not similarly suitable for the similar crops, for example while some soil series are moderately suitable, the others are marginally suitable or even unsuitable. The suitability classes for various crops can however be improved assuming that the limitations, for example, erosion, slope, fertility, etc. is improved by adopting suitable soil conservation measures. The limitations of PAWC could be overcome by irrigation. However, the severity of limitations because of permanent characteristics, for example, soil depth, stoniness, etc. may not easily be correctable.

4.8.3.1 Soil-site suitability evaluation for cotton

Cotton is grown on various types of soils. The black cotton soils are not necessarily the most suitable soils for cotton growing, because these clayey soils rich in montmorillonite are very difficult to manage, being too sticky when wet and too hard when dry to create a good tilth (Munro, 1987). Under rainfed conditions, cotton has been observed to give the best yield on deep, fine-textured soils having good structure. Very fine soils having 60 per cent or more clay content with the massive structure and coarse loamy/sandy soils are considered to be critical for cotton cultivation (Sehgal, 1990).

Cotton being a long-duration crop with a deep rooting system shows a significant decrease in the yield on the soils which are shallow with low (<100 mm m-1) moisture storage. Maximum yield could however be acquired in soils having 200 mm or more of plant available water capacity (PAWC). It tolerates fairly various types of soil acidity and alkalinity better than other major crops (Munro 1987). The field studies on black soils (NBSS & LUP, 1987; Bhaskar *et al*. 1987; Sehgal *et al*. 1989; Sehgal, 1990) observed that the cotton is successfully grown in deep soils with good drainage. A depth of 100-120 cm has been observed to be optimum, while <50 cm depth was accepted to be uneconomical to grow cotton (Bhaskar *et al*. 1987). Taking into account the above mentioned, soil depth of 50 cm was therefore considered critical below which cultivation of cotton becomes marginal or uneconomical.

The soils of the study area have been evaluated for their suitability according to the criteria outlined by (Sys *et al*. 1993), which was a part of the land suitability classification interpretative class. The overall suitability of different soil mapping units for cotton was worked out and presented in Table 4.28.

Based on the assessment of the degree of limitations, soil climatic and soil-site characteristics of the soils occurring in the study area were matched with the crop requirement parameters of suitability classes for growing cotton. In the study, all the pedons are the representative of the specific soil mapping units. The general suitability class for cotton (Table 4.28) shows that the soil mapping units *viz.* SMU- 3, 4, 5, 6 and 7 are not suitable (N) for cotton crop due to very severe limitations of soil available water capacity, depth, slope, and surface stoniness. The SMU- 2, 8, 9, 10, 11, 13 and 14 are marginally suitable (S3) with moderate limitations of soil depth, available water capacity, slope and calcium carbonate. The SMU- 1 and 12 are moderately suitable (S2) with moderate soil fertility limitations of soil pH, organic carbon and calcium carbonate.

Table 4.29 Extent and distribution of soil-site suitability classes for cotton

Sl. No.	Soil mapping units (SMU)	Suitability class	Area (ha)	% TGA
1	1, 12	Moderately suitable (S2)	2183.21	18.54
2	2, 8, 9, 10, 11, 13,14	Marginally suitable (S3)	4306.63	36.57
3	3, 4, 5, 6, 7	Not suitable (N)	4585.17	38.93
		Total Geographical Area (TGA)	**11777.62**	

The data (Table 4.29) indicates that nearly 2183.21 ha (18.54 % of TGA) area of watershed is under moderately suitable (S2), 4306.63 ha (36.57 % of TGA) under marginally suitable (S3), and 4585.17 ha (38.93 % of TGA) area under not suitable (N) class. The soil site suitability map for cotton is presented in fig. 4.17.

Table 4.28 Degree of limitations and suitability of soil for growing cotton

Characteristics / SMU	SMU 1	SMU 2	SMU 3	SMU 4	SMU 5	SMU 6	SMU 7	SMU 8	SMU 9	SMU 10	SMU 11	SMU 12	SMU 13	SMU 14
Total Rainfall (mm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Rainfall in Growing Season (mm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Mean Temperature in Growing Season ˚C	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Mean Relative Humidity in Growing Season (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Length of Growing Period (days)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Slope (%)	S1	S3	S3	N	S3	S1	S3	S1	S1	S1	S3	S1	S3	S3
Drainage	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
AWC (mm m^{-1})	S1	S3	N	N	N	S3	N	S3	S3	S3	S1	S1	S1	S3
Surface stoniness (%)	S1	S1	S1	N	S1	S1	S1	S1	S1	S1	S1	S1	S2	S1
Texture (Class)	S1	S2	S2	S3	S2	S2	S1	S1	S1	S1	S2	S1	S1	S1
Effective soil depth (cm)	S1	S3	N	N	N	N	N	S3	S3	S3	S1	S1	S1	S3
$CaCO_3$ in root zone (%)	S1	S1	S1	S3	S1	S1	S1	S1	S2	S1	S3	S1	S1	S1
CEC (cmol(p+) kg^{-1})	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
BS (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
OC (0-20 cm)	S1	S1	S2	S1	S2	S1	S1	S2	S1	S1	S1	S2	S2	S1
EC (dSm^{-1})	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S2	S1	S1
ESP (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S2	S1	S1
pH (1:2.5)	S2	S1	S1	S1	S1	S1	S1	S1	S2	S1	S2	S2	S2	S1
Soil Suitability (Rating)	**S2**	**S3**	**N**	**N**	**N**	**N**	**N**	**S3**	**S3**	**S3**	**S3**	**S2**	**S3**	**S3**
Limitation	CaCo3 pH	Slope AWC Depth	AWC Depth	Slope AWC Depth Stone	Depth Depth	Depth	AWC Depth	AWC Depth	AWC Depth	AWC Depth	Slope CaCo3	CaCo3 OC pH	Slope	Slope AWC Depth

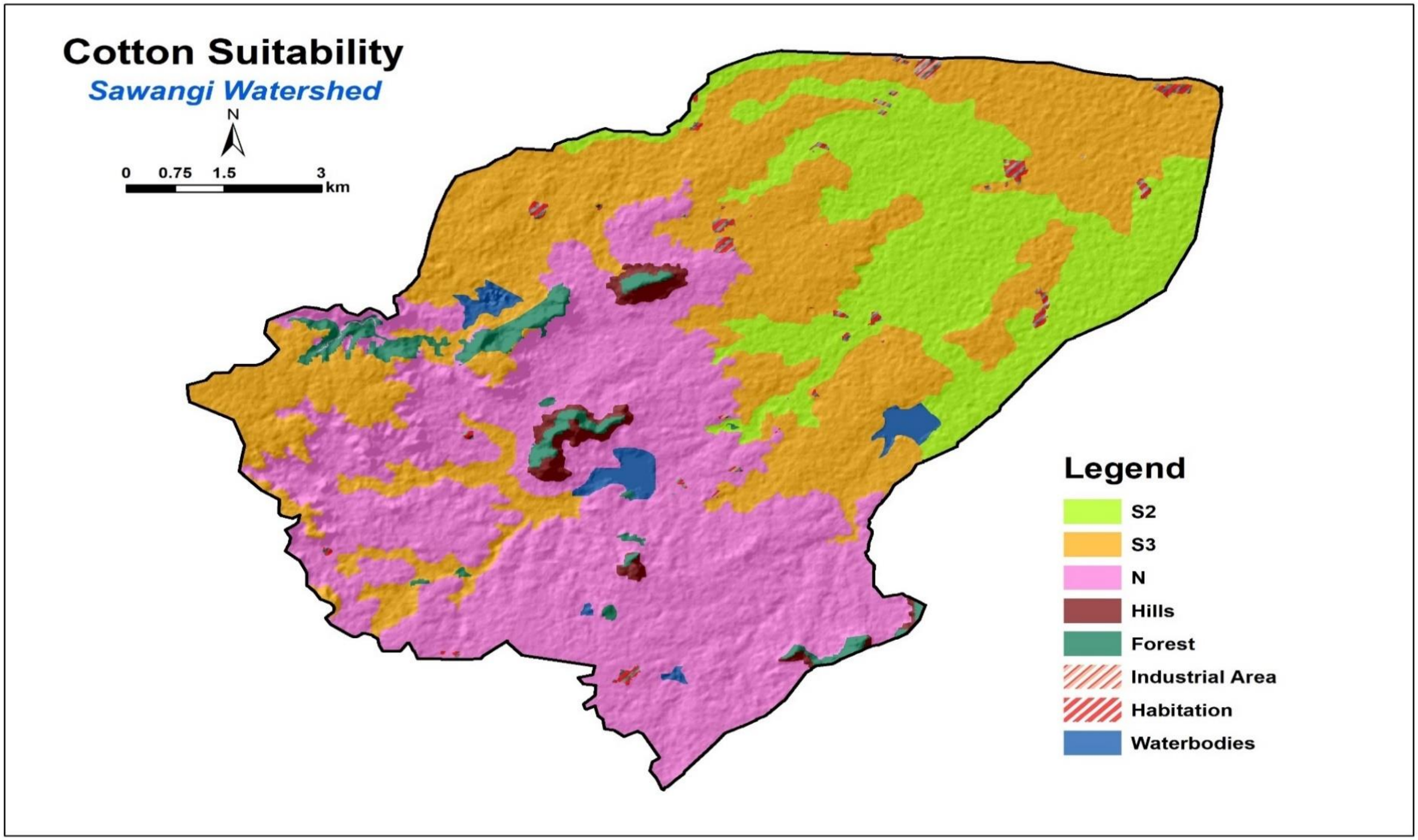


Fig. 4.17 Cotton suitability map of Sawangi watershed

4.8.3.2 Soil-site suitability evaluation for pigeon pea

Pigeon pea is an important pulse crop, commonly grown as an intercrop with cotton, soybean and sorghum in the Vidarbha region as it can withstand prolonged water stress. Being a deep-rooted crop, it also acts as a soil renovator by breaking the hard sub-soil and being used as a hedge to check erosion.

Based on the assessment of the degree of limitations, soil climatic and soil-site characteristics of the soils occurring in the study area were matched with the crop requirement parameters of suitability classes for growing Pigeon pea. In the study, all the pedons are the representative of the specific soil mapping units. The general suitability class for Pigeon pea (Table 4.30) shows that the soil mapping units *viz.* SMU-3, 4, 5, 6 and 7 are not suitable (N) for Pigeon pea crop due to very severe limitations of soil depth, slope and surface stoniness. The SMU- 2, 8, 9, 10, 11, 13 and 14 are marginally suitable (S3) with moderate limitations of soil depth and slope. The SMU- 1 and 12 are moderately suitable (S2) with moderate soil fertility limitations of soil texture, pH and soil salinity.

The data (Table 4.31) indicates that nearly 2183.21 ha (18.54 % of TGA) area of watershed is under moderately suitable (S2), 4306.63 ha (36.57 % of TGA) under marginally suitable (S3), and 4585.17 ha (38.93 % of TGA) area under not suitable (N) class. The soil site suitability map for Pigeon pea is presented in Fig. 4.18.

Table 4.31 Extent and distribution of soil-site suitability classes for pigeon pea

Sl. No.	Soil mapping units (SMU)	Suitability class	Area (ha)	% TGA
1	1, 12	Moderately suitable (S2)	2183.21	18.54
2	2, 8, 9, 10, 11, 13,14	Marginally suitable (S3)	4306.63	36.57
3	3, 4, 5, 6, 7	Not suitable (N)	4585.17	38.93
Total Geographical Area (TGA)			**11777.62**	

Table 4.30 Degree of limitations and suitability of soil for growing pigeon pea

Characteristics / SMU	SMU 1	SMU 2	SMU 3	SMU 4	SMU 5	SMU 6	SMU 7	SMU 8	SMU 9	SMU 10	SMU 11	SMU 12	SMU 13	SMU 14
Total Rainfall (mm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Rainfall in Growing Season (mm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Mean Temperature in Growing Season °C	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Mean Relative Humidity in Growing Season (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Length of Growing Period (days)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Slope (%)	S1	S3	S3	N	S3	S1	S3	S1	S1	S1	S3	S1	S3	S3
Drainage	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Surface stoniness (%)	S1	S1	S1	N	S1	S1	S1	S2	S1	S1	S1	S1	S2	S1
Texture (Class)	S2	S1	S1	S1	S1	S2	S2	S2	S2	S2	S1	S2	S2	S2
Effective soil depth (cm)	S1	S3	N	N	N	S3	N	S3	S3	S3	S1	S1	S1	S3
EC (dSm^{-1})	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S2	S1	S1
ESP (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S2	S1	S1
pH (1:2.5)	S2	S1	S1	S1	S1	S1	S1	S1	S2	S1	S2	S2	S2	S1
Soil Suitability (Rating)	**S2**	**S3**	**N**	**N**	**N**	**N**	**N**	**S3**	**S3**	**S3**	**S3**	**S2**	**S3**	**S3**
Limitation	Texture pH	Slope Depth	Depth	Slope Stone Depth	Depth	Depth	Depth	Depth	Depth	Depth	Slope	Texture EC pH	Depth	Slope Depth

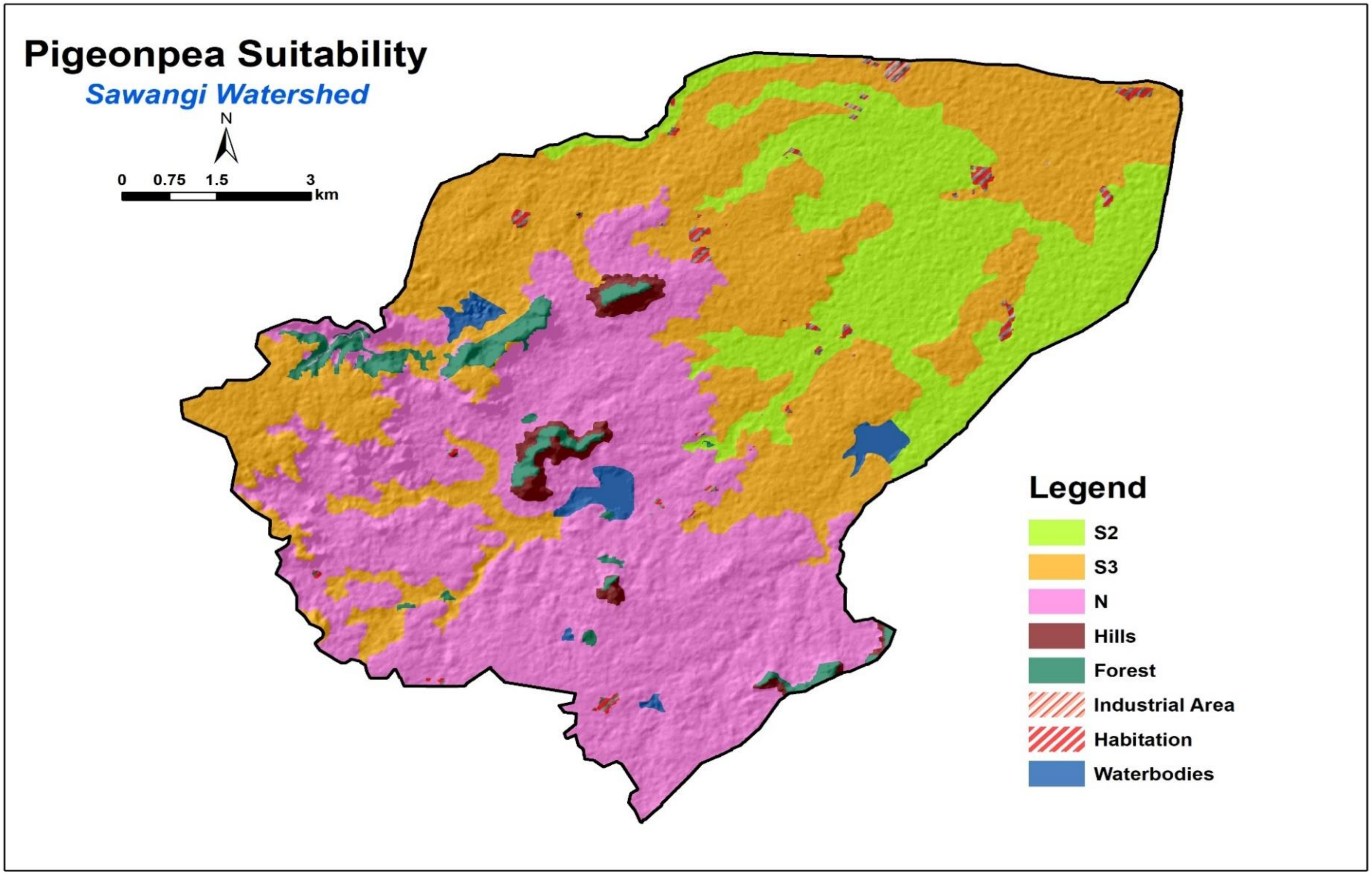


Fig. 4.18 Pigeon pea suitability map of Sawangi watershed

4.8.3.3 Soil-site suitability for soybean

Soybean is an important pulse and oil seed crop, that contains occurs 43.2 per cent protein and 19.5 per cent fat (Swaminathan, 1974). It is successfully grown under atmospheric temperature ranging between 24 to 28 ºC. The growth is totally impaired below 10 ºC. Rainfall ranging from 800 to 1200 mm is suited to it and it can be grown on variety of soils but clay loam, silt loam and loam soils, medium to fine black soybean soils have been found to be better suited. Soils having a depth of more than 75 cm are ideal and those having the depth of less than 25 cm are not suitable for soybean cultivation (Naidu *et al*. 2006).

The assessment of the degree of limitations, soil climatic and soil-site characteristics of the soils occurring in the study area were matched with the crop requirement parameters of suitability classes for growing soybean. In the study, all the pedons are the representative of the specific soil mapping units. The general suitability class for soybean (Table 4.32) shows that the soil mapping units *viz.* SMU- 3, 4, 5, and 7 are not suitable (N) for soybean crop due to very severe limitations of soil depth, slope and surface stoniness. The SMU- 2, 6, 8, 9, 10, 11, 13 and 14 are marginally suitable (S3) with moderate limitations of soil depth, slope and available water capacity. The SMU- 1 and 12 are moderately suitable (S2) with moderate soil fertility limitations of soil texture, pH and soil salinity.

The data (Table 4.33) indicates that nearly 2183.21 ha (18.54 % of TGA) area of watershed is under moderately suitable (S2), 4422.91 ha (37.55 % of TGA) under marginally suitable (S3), and 4468.89 ha (37.94 % of TGA) area under not suitable (N) class. The soil site suitability map for soybean is presented in Fig. 4.19.

Table 4.32 Degree of limitation and suitability of soil for growing soybean

Characteristics / SMU	SMU 1	SMU 2	SMU 3	SMU 4	SMU 5	SMU 6	SMU 7	SMU 8	SMU 9	SMU 10	SMU 11	SMU 12	SMU 13	SMU 14
Total Rainfall (mm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Rainfall in Growing Season (mm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Mean Temperature in Growing Season ^{0}C	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Mean Relative Humidity in Growing Season (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Length of Growing Period (days)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Slope (%)	S1	S3	S3	N	S3	S1	S3	S1	S1	S1	S3	S1	S3	S3
Drainage	S1	S1	S1	S1	S1	S1	S1	S2	S1	S1	S2	S1	S1	S1
AWC (mm m^{-1})	S1	S3	N	N	N	S3	N	S3	S3	S3	S1	S1	S1	S3
Surface stoniness (%)	S1	S1	S1	N	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Texture (Class)	S2	S1	S1	S1	S1	S2	S2	S2	S2	S2	S1	S2	S2	S2
Effective soil depth (cm)	S1	S3	N	N	N	S3	N	S3	S3	S3	S1	S1	S1	S3
EC (dSm^{-1})	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S2	S1	S1
ESP (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S2	S1	S1
pH (1:2.5)	S2	S1	S1	S1	S1	S1	S1	S1	S2	S1	S2	S2	S2	S1
Soil Suitability (Rating)	**S2**	**S3**	**N**	**N**	**N**	**S3**	**N**	**S3**	**S3**	**S3**	**S3**	**S2**	**S3**	**S3**
Limitation	Texture pH	Slope AWC Depth	AWC Depth	Slope AWC Stone Depth	AWC Depth	Slope	AWC Depth	AWC Depth	AWC Depth	AWC Depth	Slope	Texture EC pH	Slope	Slope AWC Depth

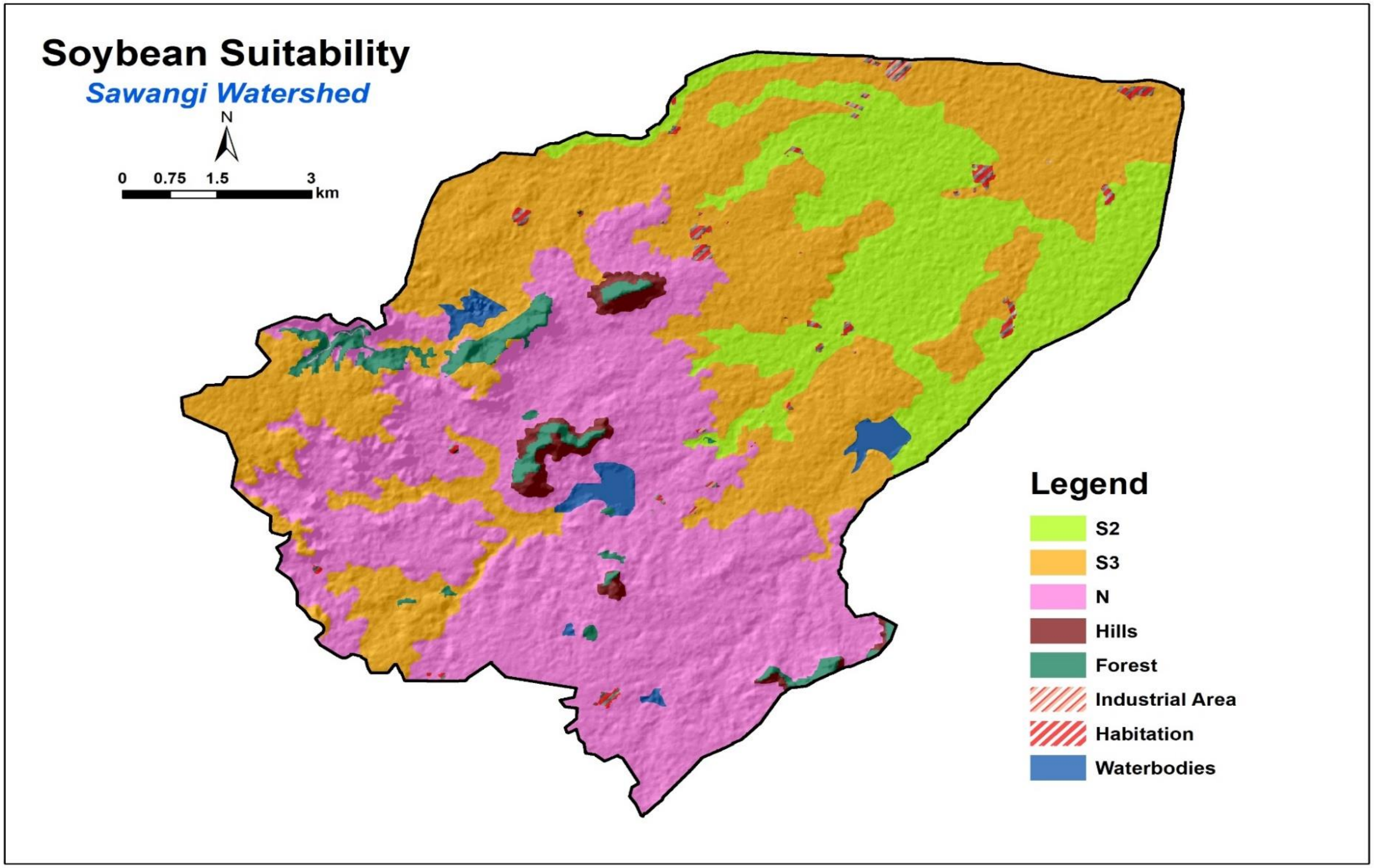


Fig. 4.19 Soybean suitability map of Sawangi watershed

Table 4.33 Extent and distribution of soil-site suitability classes for soybean

Sl. No.	Soil mapping units (SMU)	Suitability class	Area (ha)	% TGA
1	1, 12	Moderately suitable (S2)	2183.21	18.54
2	2, 6, 8, 9, 10, 11, 13,14	Marginally suitable (S3)	4422.91	37.55
3	3, 4, 5, 7	Not suitable (N)	4468.89	37.94
	Total Geographical Area (TGA)		**11777.62**	

4.8.3.4 Soil-site suitability for sorghum

Sorghum is called a camel crop, comparatively a hardy crop among crops as it can withstand higher temperature and drought to a great extent. It is one of the four major food crops of the world. It is grown in two main seasons, *kharif* and *rabi*. It is successfully grown under atmospheric temperature ranging between 22 to 32 ^{0}C and rainfall ranging from 400 to 1000 mm and about 600 mm of rain is ideal for optimum crop performance. Sorghum is grown on a variety of soils but the clay loam soils rich in humus have been found to be most ideal (Singh, 1988). It withstands waterlogging conditions better than most of the major crops grown areas. Moderately deep soils having a depth of more than 75 cm are best and those having a depth less than 45 cm are not economical to grow sorghum (Gaikwad and Bhaskar, 1988).

The assessment of the degree of limitations, soil climatic and soil-site characteristics of the soils occurring in the study area were matched with the crop requirement parameters of suitability classes for growing sorghum. In the study, all the pedons are the representative of the specific soil mapping units. The general suitability class for sorghum (Table 4.34) shows that the soil mapping units *viz.* SMU- 3, 4, 5, 6 and 7 are not suitable (N) for sorghum crop due to very severe limitations of soil depth, slope, available water capacity and surface stoniness. The SMU- 2, 8, 9, 10 and 14 are marginally suitable (S3) with moderate limitations of soil depth and available water capacity. The SMU- 1, 11, 12 and 13 are moderately suitable (S2) with moderate soil fertility limitations of soil depth, slope, surface stoniness and pH.

Table 4.35 Extent and distribution of soil-site suitability classes for sorghum

Sl. No.	Soil mapping units (SMU)	Suitability class	Area (ha)	% TGA
1	1, 11, 12, 13	Moderately suitable (S2)	2710.87	23.02
2	2, 8, 9, 10,14	Marginally suitable (S3)	3778.98	32.09
3	3, 4, 5, 6, 7	Not suitable (N)	4585.17	38.93
Total Geographical Area (TGA)			**11777.62**	

The data (Table 4.35) indicates that nearly 2710.87 ha (23.02 % of TGA) area of watershed is under moderately suitable (S2), 3778.98 ha (32.09 % of TGA) under marginally suitable (S3), and 4585.17 ha (38.93 % of TGA) area under not suitable (N) class. The soil site suitability map for sorghum is presented in Fig. 4.20.

Table 4.34 Degree of limitation and suitability of soil for growing sorghum

Characteristics / SMU	SMU 1	SMU 2	SMU 3	SMU 4	SMU 5	SMU 6	SMU 7	SMU 8	SMU 9	SMU 10	SMU 11	SMU 12	SMU 13	SMU 14
Total Rainfall (mm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Rainfall in Growing Season (mm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Mean Temperature in Growing Season ^{0}C	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Mean Relative Humidity in Growing Season (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Length of Growing Period (days)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Slope (%)	S1	S2	S2	N	S2	S1	S2	S1	S1	S1	S2	S1	S2	S2
Drainage	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
AWC (mm m^{-1})	S1	S3	N	N	N	S3	N	S3	S3	S3	S1	S1	S1	S3
Surface stoniness (%)	S1	S1	S1	N	S1	S1	S1	S1	S1	S1	S1	S1	S2	S1
Texture (Class)	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Effective soil depth (cm)	S1	S3	N	N	N	N	N	S3	S3	S3	S1	S1	S2	S3
$CaCO_3$ in root zone (%)	S1	S1	S1	S2	S1	S1	S1	S1	S2	S1	S2	S1	S1	S1
CEC (cmol(p+) kg^{-1})	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
BS (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
OC (0-20 cm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
EC (dSm^{-1})	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
ESP (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S2	S1	S1
pH (1:2.5)	S2	S1	S1	S1	S1	S1	S1	S1	S2	S1	S2	S2	S2	S1
Soil Suitability (Rating)	**S2**	**S3**	**N**	**N**	**N**	**N**	**N**	**S3**	**S3**	**S3**	**S2**	**S2**	**S2**	**S3**
Limitation	pH	AWC Depth	AWC Depth	Slope AWC Stone Depth	AWC Depth	Depth	AWC Depth	AWC Depth	AWC Depth	AWC Depth	Slope CaCo3 pH	ESP (%) pH	Slope Stone Depth pH	AWC Depth

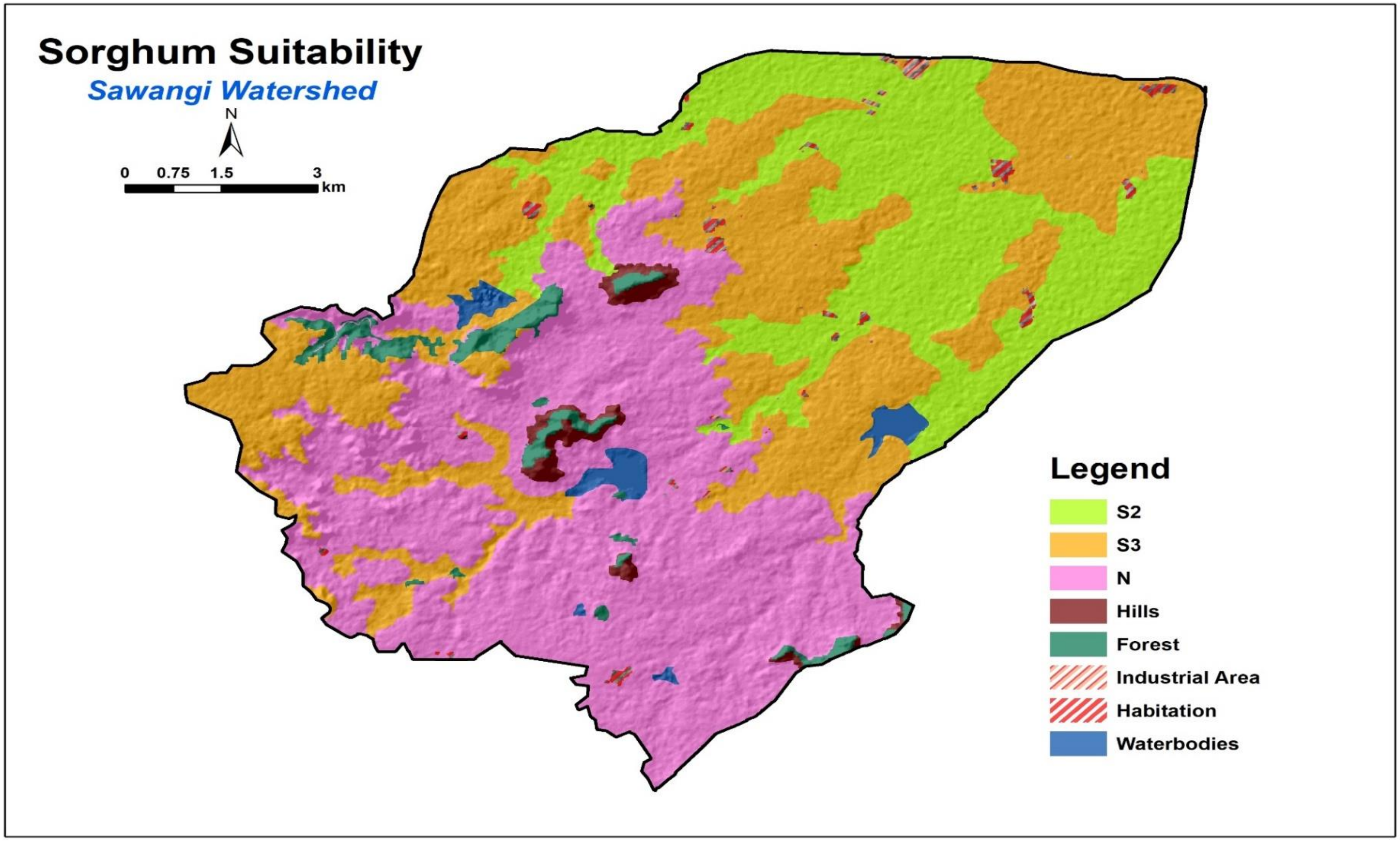


Fig. 4.20 Sorghum suitability map of Sawangi watershed

4.8.3.5 Soil-site suitability evaluation for wheat

The assessment of the degree of limitations, soil climatic and soil-site characteristics of the soils occurring in the study area were matched with the crop requirement parameters of suitability classes for growing wheat. In the study, all the pedons are the representative of the specific soil mapping units. The general suitability class for wheat (Table 4.37) shows that the soil mapping units *viz.* SMU- 3, 4, 5, and 7 are not suitable (N) for wheat crop due to very severe limitations of soil depth, slope and surface stoniness. The SMU- 2, 6, 8, 9, 10, 11, 13 and 14 are marginally suitable (S3) with moderate limitations of soil depth and slope. The SMU- 1 and 12 are moderately suitable (S2) with moderate soil fertility limitations of soil texture and pH.

Table 4.36 Extent and distribution of soil-site suitability classes for wheat

Sl. No.	Soil mapping units (SMU)	Suitability class	Area (ha)	% TGA
1	1, 12,	Moderately suitable (S2)	2183.21	18.54
2	2, 6, 8, 9, 10,11,13, 14	Marginally suitable (S3)	4422.91	37.55
3	3, 4, 5, 7	Not suitable (N)	4468.89	37.94
Total Geographical Area (TGA)			**11777.62**	

The data (Table 4.36) indicates that nearly 2183.21 ha (18.54 % of TGA) area of watershed is under moderately suitable (S2), 4422.91 ha (37.55 % of TGA) under marginally suitable (S3), and 4468.89 ha (37.94 % of TGA) area under not suitable (N) class. The soil site suitability map for wheat is presented in Fig. 4.21.

Table 4.37 Degree of limitations and suitability of soil series for growing wheat

Characteristics / SMU	SMU 1	SMU 2	SMU 3	SMU 4	SMU 5	SMU 6	SMU 7	SMU 8	SMU 9	SMU 10	SMU 11	SMU 12	SMU 13	SMU 14
Total Rainfall (mm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Rainfall in Growing Season (mm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Mean Temperature in Growing Season ^{0}C	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Mean Relative Humidity in Growing Season (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Length of Growing Period (days)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Slope (%)	S1	S3	S3	N	S3	S1	S3	S1	S1	S1	S3	S1	S3	S3
Drainage	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Surface stoniness (%)	S1	S1	S1	N	S1	S1	S1	S1	S1	S1	S1	S1	S2	S1
Texture (Class)	S2	S1	S1	S1	S1	S2	S2	S2	S2	S2	S1	S2	S2	S2
Effective soil depth (cm)	S1	S3	N	N	N	S3	N	S3	S3	S3	S1	S1	S1	S3
EC (dSm^{-1})	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
ESP (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
pH (1:2.5)	S2	S1	S1	S1	S1	S1	S1	S1	S2	S1	S2	S2	S2	S1
Soil Suitability (Rating)	**S2**	**S3**	**N**	**N**	**N**	**S3**	**N**	**S3**	**S3**	**S3**	**S3**	**S2**	**S3**	**S3**
Limitation	Texture pH	Slope Depth	Depth	Slope Stone Depth	Depth	Depth	Depth	Depth	Depth	Depth	Slope	Texture pH	Slope	Slope Depth

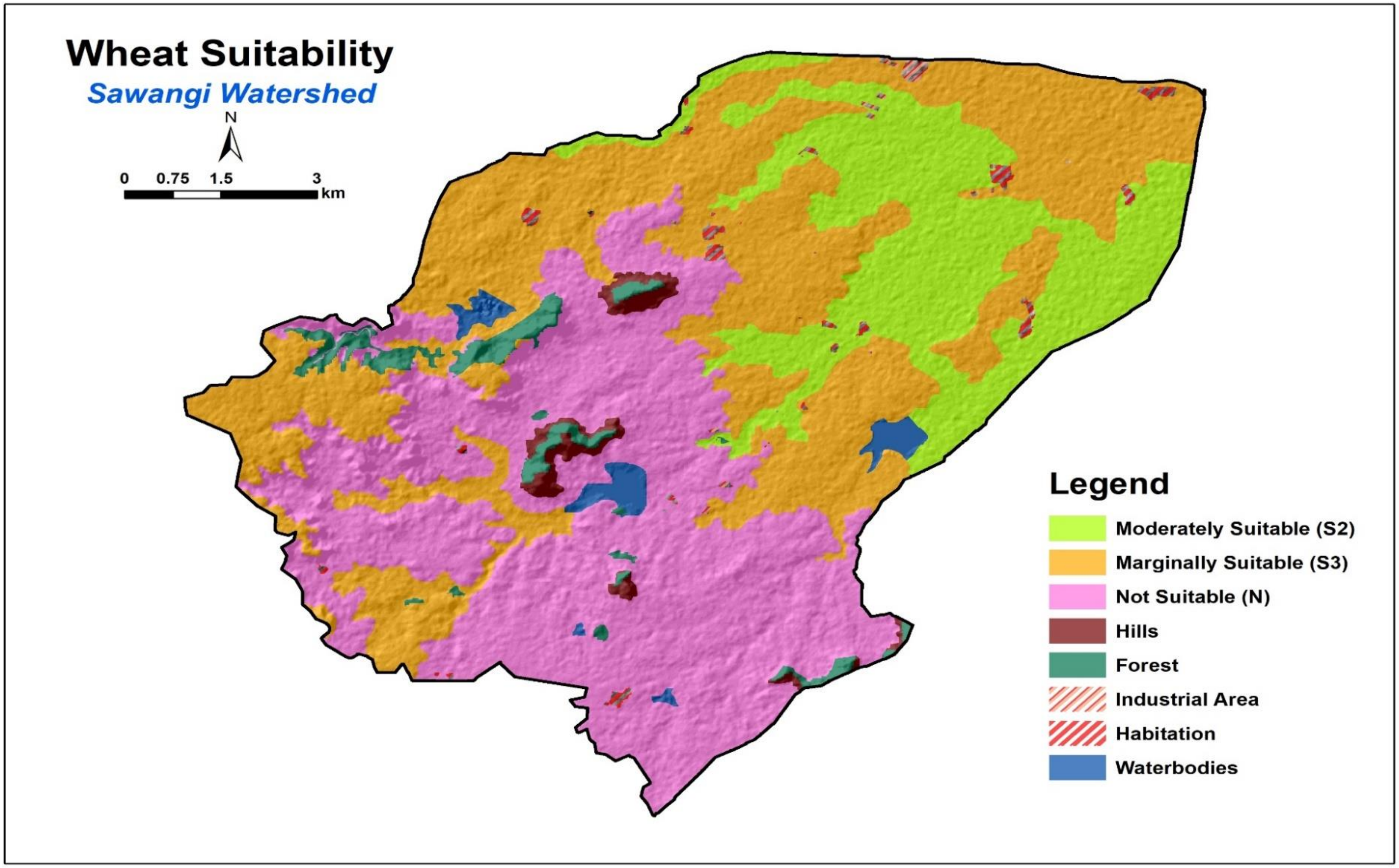


Fig. 4.21 Wheat suitability map of Sawangi watershed

4.8.3.6 Soil-site suitability evaluation for chickpea

The assessment of the degree of limitations, soil climatic and soil-site characteristics of the soils occurring in the study area were matched with the crop requirement parameters of suitability classes for growing chickpea. In the study, all the pedons are the representative of the specific soil mapping units. The general suitability class for chickpea (Table 4.39) shows that the soil mapping units *viz.* SMU- 3, 4, 5, and 7 are not suitable (N) for chickpea crop due to very severe limitations of soil depth, slope and surface stoniness. The SMU- 2, 6, 8, 9, 10, 11, 13 and 14 are marginally suitable (S3) with moderate limitations of soil depth and slope. The SMU- 1 and 12 are moderately suitable (S2) with moderate soil fertility limitations of soil texture and pH.

Table 4.38 Extent and distribution of soil-site suitability classes for chickpea

Sl. No.	Soil mapping units (SMU)	Suitability class	Area (ha)	% TGA
1	1, 12,	Moderately suitable (S2)	2183.21	18.54
2	2, 6, 8, 9, 10,11,13, 14	Marginally suitable (S3)	4422.91	37.55
3	3, 4, 5, 7	Not suitable (N)	4468.89	37.94
	Total Geographical Area (TGA)		**11777.62**	

The data (Table 4.38) indicates that nearly 2183.21 ha (18.54 % of TGA) area of watershed is under moderately suitable (S2), 4422.91 ha (37.55 % of TGA) under marginally suitable (S3), and 4468.89 ha (37.94 % of TGA) area under not suitable (N) class. The soil site suitability map for chickpea is presented in Fig. 4.22.

Table 4.39 Degree of limitations and suitability of soil series for growing chickpea

Characteristics / SMU	SMU 1	SMU 2	SMU 3	SMU 4	SMU 5	SMU 6	SMU 7	SMU 8	SMU 9	SMU 10	SMU 11	SMU 12	SMU 13	SMU 14
Total Rainfall (mm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Rainfall in Growing Season (mm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Mean Temperature in Growing Season ^{0}C	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Mean Relative Humidity in Growing Season (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Length of Growing Period (days)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Slope (%)	S1	S3	S3	N	S3	S1	S3	S1	S1	S1	S3	S1	S3	S3
Drainage	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Surface stoniness (%)	S1	S1	S1	N	S1	S1	S1	S1	S1	S1	S1	S1	S2	S1
Texture (Class)	S2	S1	S1	S1	S1	S2	S2	S2	S2	S2	S1	S2	S2	S2
Effective soil depth (cm)	S1	S3	N	N	N	S3	N	S3	S3	S3	S1	S1	S1	S3
EC (dSm^{-1})	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S2	S1	S1
ESP (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S2	S1	S1
pH (1:2.5)	S2	S1	S1	S1	S1	S1	S1	S1	S2	S1	S2	S2	S2	S1
Soil Suitability (Rating)	**S2**	**S3**	**N**	**N**	**N**	**S3**	**N**	**S3**	**S3**	**S3**	**S3**	**S2**	**S3**	**S3**
Limitation	Texture pH	Slope Depth	Depth	Slope Stone Depth	Depth	Depth	Depth	Depth	Depth	Depth	Slope	Texture pH	Slope	Slope Depth

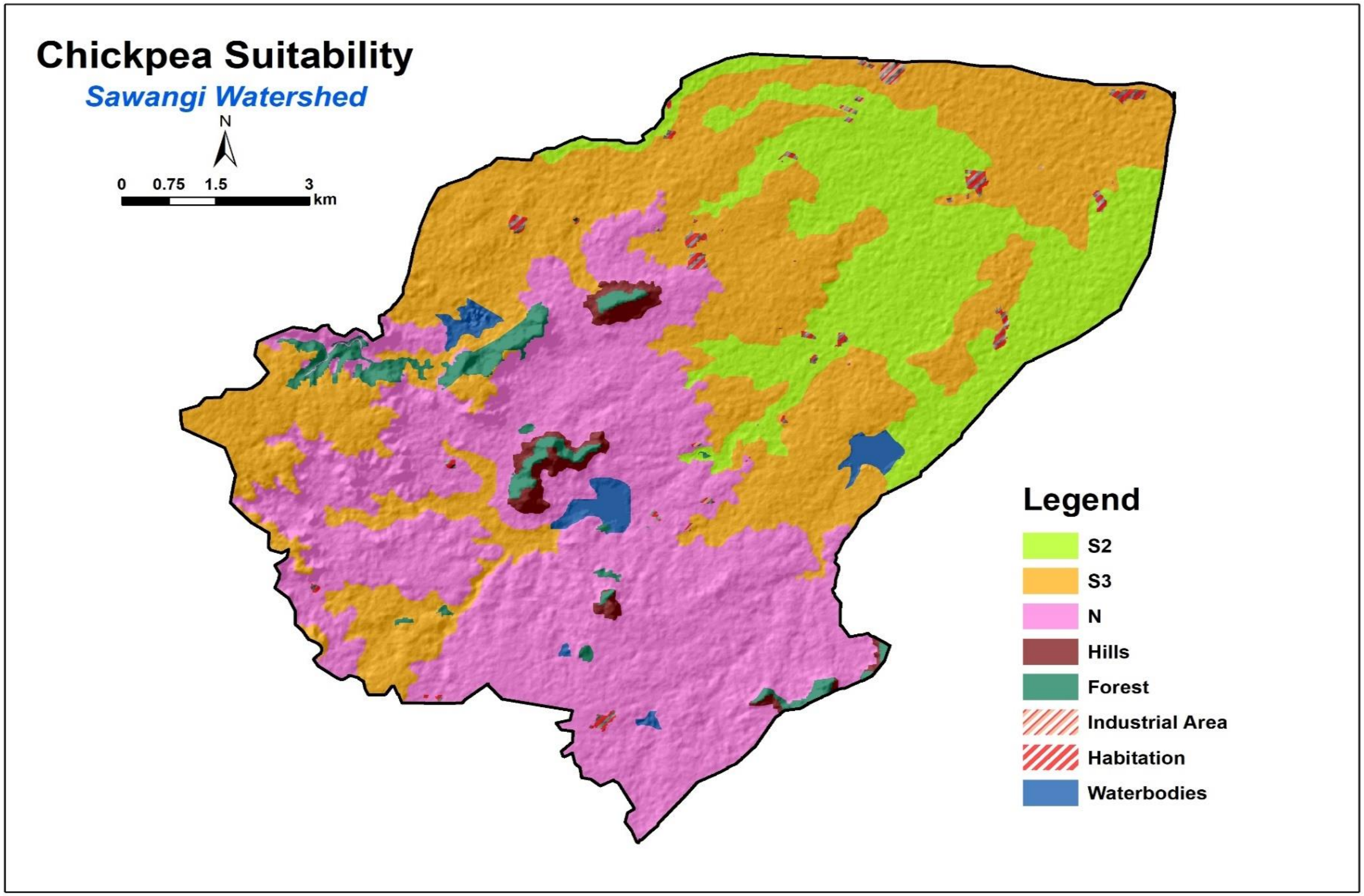


Fig. 4.22 Chickpea suitability map of Sawangi watershed

4.8.4 Land productivity index evaluation:

According to Riquier *et al.* (1970), the land productivity index was calculated based on considering nine factors for determining soil productivity, *viz.* moisture (H), drainage (D), effective depth (P), texture/structure (T), base saturation (N), soluble salt concentration (S), organic matter content (O), mineral exchange capacity/nature of clay (A) and mineral reserve (M). Each factor is evaluated on a scale from 0 to 100, the actual percentages being multiplied by each other. The resultant index of productivity, between 0 to 100, is stabilized against a scale placing the soil in the various five productivity classes. While calculating the actual productivity index the value of the ranking refers to the present-day condition. The index of potentiality refers to the potential productivity with ratings as per the condition after soil management.

The quantitative method of land evaluation for the various crops *viz*. cotton, soybean, pigeon pea, sorghum, wheat, and chickpea, based on the ten identified soil series in the Sawangi watershed of Yavatmal are described below.

4.8.4.1 Land productivity index for cotton

The soils of the Sawangi watershed were evaluated for the land productivity for cotton crop (Table 4.40). The results indicated that the SMU- 11 is excellent in soil productivity with potentiality class- I in which the productivity index rating is 72.0. These soils have limitations of soil moisture. The SMU- 1, 12 and 13 were found to be good in soil productivity with potentiality class- II in which the productivity index rating ranges between 49.2 to 57.6. These soils have moderate limitations of soil moisture and texture/structure. The SMU- 2, 8, 9, 10 and 14 are average in soil productivity with potentiality class- III in which the productivity index rating ranges between 25.2 to 30.2. These soils have several limitations of soil moisture, texture/structure, and soil depth. The SMU- 3, 4, 5, 6 and 7 were found to be poor in soil productivity with potentiality class- IV in which the productivity index rating ranged between 8.0 to 19.4. These soils have very several limitations of soil moisture, texture/structure, and soil depth

Table 4.40 Productivity index for cotton (Rating class with assigned values), Productivity classes and index of potentiality.

Soil mapping units (SMU)	Soil moisture content (H)	Drainage (D)	Effective depth of Soil (P)	Texture and Structure of root zone (T)	Average nutrient content of A horizon (N)	Organic Matter in A1 horizon (O)	Mineral exchange capacity (A)	Reserves of weatherable minerals in B horizon (M)	Productivity Index (PI)	Productivity class (P)	Potentiality (P')
SMU-1	H4a 80	D4 100	P4 80	T5b 80	N5 100	O3 100	A3 100	M3c 100	51.2	Good	II
SMU-2	H3c 70	D4 100	P4 60	T6b 90	N5 100	O2 90	A3 100	M3c 100	34.0	Average	III
SMU-3	H3b 60	D4 100	P2 20	T5b 80	N5 100	O2 90	A2 95	M3c 100	8.2	Poor	IV
SMU-4	H2c 40	D4 100	P2 20	T7 100	N5 100	O3 100	A3 100	M3c 100	8.0	Poor	IV
SMU-5	H3b 60	D4 100	P2 20	T6b 90	N5 100	O2 90	A2 95	M3c 100	9.2	Poor	IV
SMU-6	H3b 60	D4 100	P3 40	T6b 90	N5 100	O2 90	A3 100	M3c 100	19.4	Poor	IV
SMU-7	H3b 60	D4 100	P2 20	T5b 80	N5 100	O3 100	A2 95	M3c 100	9.1	Poor	IV
SMU-8	H3c 70	D4 100	P4 60	T5b 80	N5 100	O2 90	A3 100	M3c 100	30.2	Average	III
SMU-9	H3c 70	D4 100	P4 60	T5b 80	N5 100	O2 90	A3 100	M3c 100	30.2	Average	III
SMU-10	H3c 70	D4 100	P3 50	T5b 80	N5 100	O2 90	A3 100	M3c 100	25.2	Average	III
SMU-11	H4a 80	D4 100	P5 100	T7 100	N5 100	O2 90	A3 100	M3c 100	72.0	Excellent	I
SMU-12	H4a 80	D4 100	P5 100	T5b 80	N5 100	O2 90	A3 100	M3c 100	57.6	Good	II
SMU-13	H4a 80	D4 100	P4 80	T6b 90	N5 100	O2 90	A2 95	M3c 100	49.2	Good	II
SMU-14	H3c 70	D4 100	P3 50	T5b 80	N5 100	O2 90	A3 100	M3c 100	25.2	Average	III

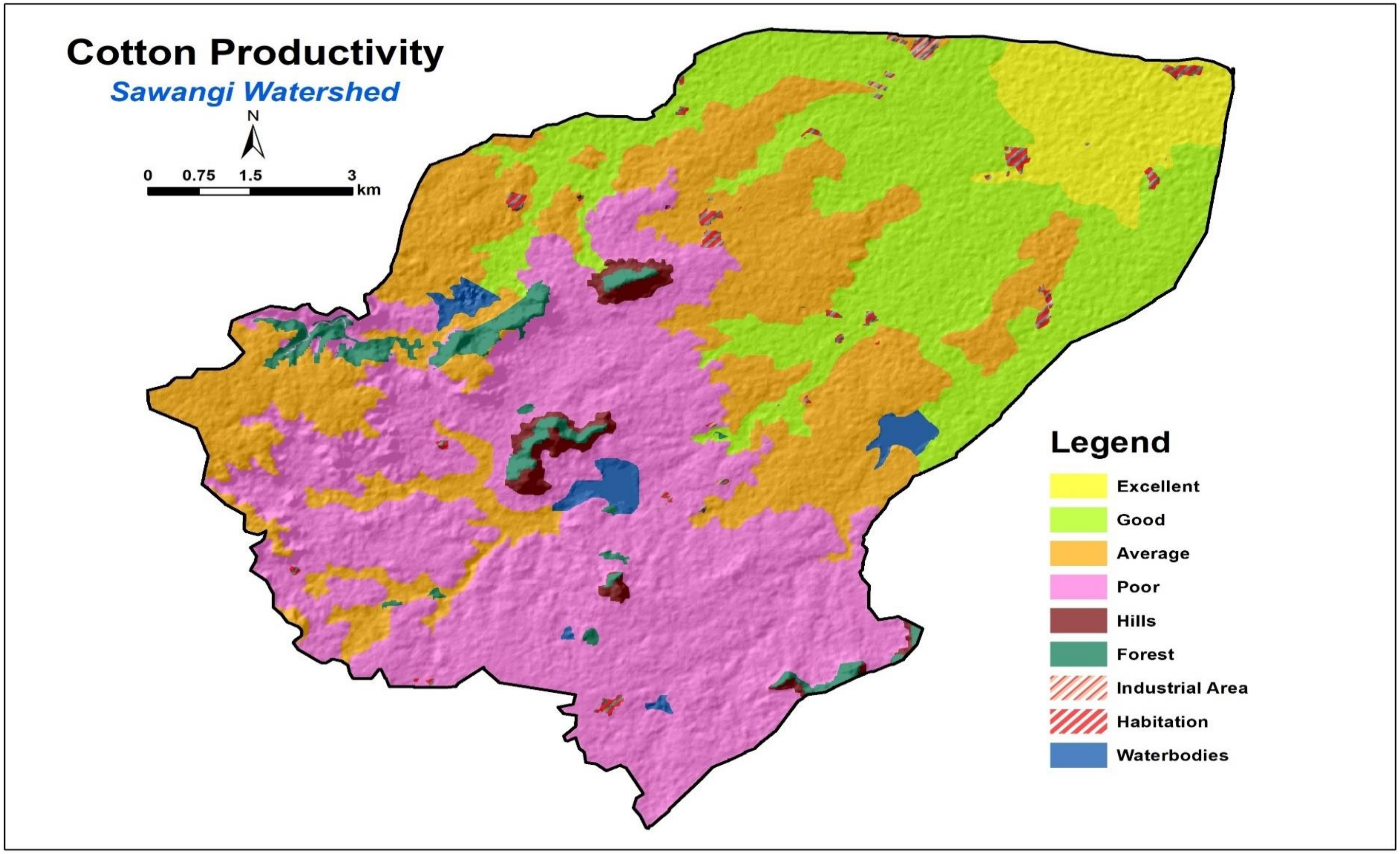


Fig. 4.23 Cotton productivity map of Sawangi watershed

Table 4.41 Extent and distribution of soil productivity classes for cotton

Sl. No.	Soil mapping units (SMU)	Productivity class	Area (ha)	% TGA
1	11	Excellent	689.81	5.86
2	1, 12, 13	Good	2710.87	23.02
3	2, 8, 9, 10, 14	Average	3089.17	26.23
4	3, 4, 5, 6, 7	Poor	4585.17	38.93
Total Geographical Area (TGA)		**11777.62**		

The data for cotton crop (Table 4.41) denoted that about 689.81 ha area (5.86 % TGA) of the watershed categorized under excellent, 2710.87 ha (23.02 % TGA) under good, 3089.17 ha (26.23 % TGA) under average and 4585.17 ha area (38.93 % TGA) categorized under poor productivity class. The cotton productivity map prepared from the productivity index is depicted in Fig. 4.23.

4.8.4.2 Land productive index for growing soybean

The soils of the Sawangi watershed were evaluated for the land productivity for soybean crop (Table 4.42). The results indicated that the SMU- 1, 11, 12 and 13 are excellent in soil productivity with potentiality class- I in which the productivity index rating ranges between 72.0 to 90.0. These soils have limitations of soil moisture. The SMU- 2, 8 and 9 were found to be good in soil productivity with potentiality class- II in which the productivity index rating ranges between 38.9 to 51.8. These soils have moderate limitations of soil moisture and texture/structure. The SMU- 6, 10 and 14 are average in soil productivity with potentiality class- III in which the productivity index rating ranges between 25.2 to 30.2. These soils have several limitations of soil moisture, texture/structure, and soil depth. The SMU- 3, 4, 5 and 7 were found to be poor in soil productivity with potentiality class- IV in which the productivity index rating ranged between 8.0 to 12.3. These soils have very several limitations of soil moisture, texture/structure, and soil depth.

Table 4.42 Productivity index for soybean (Rating class with assigned values), Productivity classes, and index of potentiality

Soil mapping units (SMU)	Soil moisture content (H)	Drainage (D)	Effective depth of Soil (P)	Texture and Structure of root zone (T)	Average nutrient content of A horizon (N)	Organic Matter in A1 horizon (O)	Mineral exchange capacity (A)	Reserves of weatherable minerals in B horizon (M)	Productivity Index (PI)	Productivity class (P)	Potentiality (P')
SMU-1	H4c 100	D4 100	P5 100	T5b 80	N5 100	O3 100	A3 100	M3c 100	80.0	Excellent	I
SMU-2	H4b 90	D4 100	P4 60	T6b 90	N5 100	O2 90	A3 100	M3c 100	48.6	Good	II
SMU-3	H3b 60	D4 100	P2 20	T5b 80	N5 100	O2 90	A2 95	M3c 100	8.2	Poor	IV
SMU-4	H2a 40	D4 100	P2 20	T7 100	N5 100	O3 100	A3 100	M3c 100	8.0	Poor	IV
SMU-5	H4a 80	D4 100	P2 20	T6b 90	N5 100	O2 90	A2 95	M3c 100	12.3	Poor	IV
SMU-6	H4a 80	D4 100	P4 60	T6b 90	N5 100	O2 90	A3 100	M3c 100	25.9	Average	III
SMU-7	H3b 60	D4 100	P2 20	T5b 80	N5 100	O3 100	A2 95	M3c 100	9.1	Poor	IV
SMU-8	H4b 90	D4 100	P4 60	T5b 80	N5 100	O2 90	A3 100	M3c 100	38.9	Good	II
SMU-9	H4b 90	D4 100	P4 80	T5b 80	N5 100	O2 90	A3 100	M3c 100	51.8	Good	II
SMU-10	H4a 80	D4 100	P3 50	T5b 80	N5 100	O2 90	A3 100	M3c 100	28.8	Average	III
SMU-11	H4c 100	D4 100	P6 100	T7 100	N5 100	O2 90	A3 100	M3c 100	90.0	Excellent	I
SMU-12	H4c 100	D4 100	P5 100	T5b 80	N5 100	O2 90	A3 100	M3c 100	72.0	Excellent	I
SMU-13	H4c 100	D4 100	P5 100	T6b 90	N5 100	O2 90	A2 95	M3c 100	77.0	Excellent	I
SMU-14	H4b 90	D4 100	P3 50	T5b 80	N5 100	O2 90	A3 100	M3c 100	32.4	Average	III

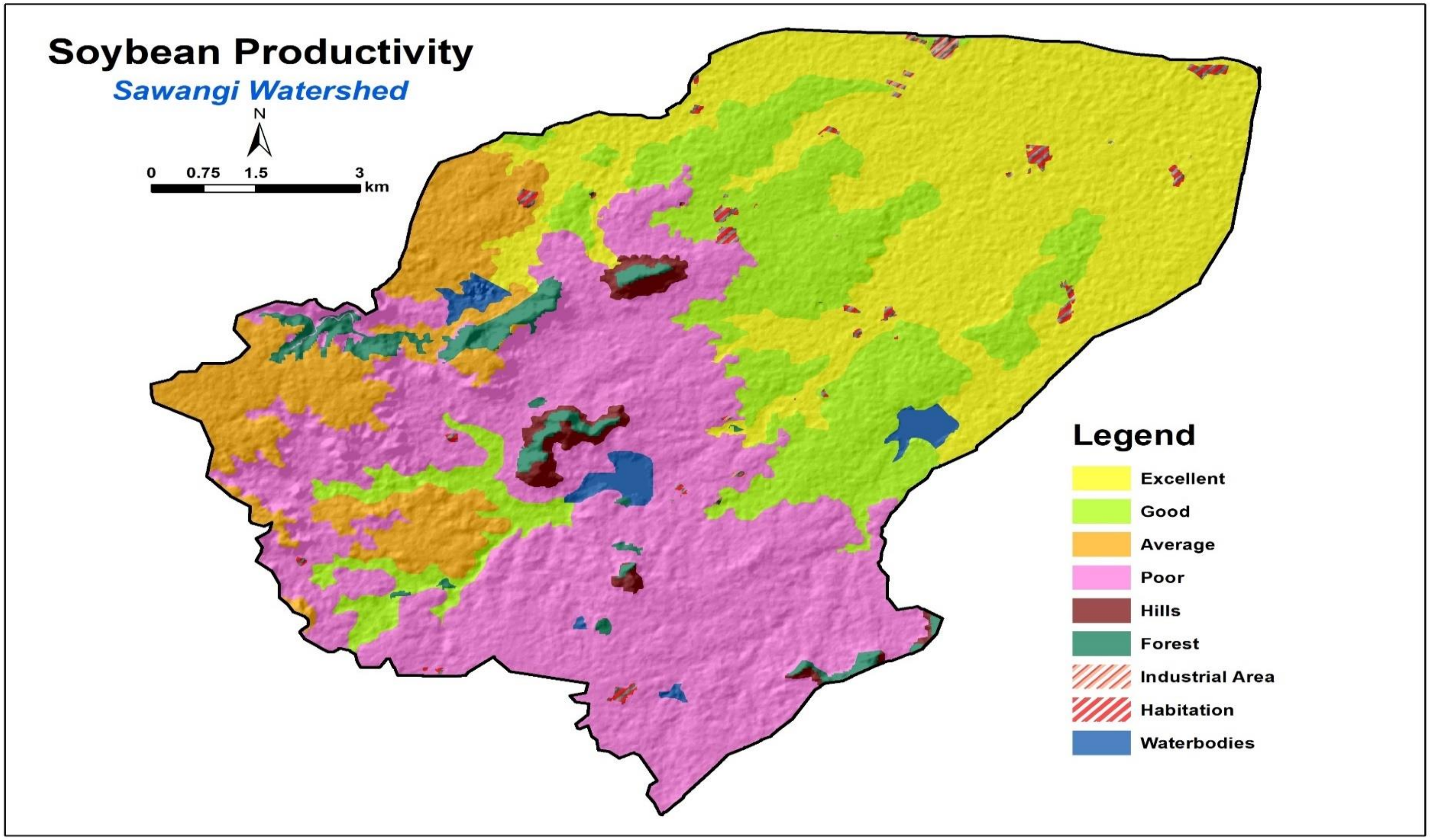


Fig. 4.24 Soybean productivity map of Sawangi watershed

Table 4.43 Extent and distribution of soil productivity classes for soybean

Sl. No.	Soil mapping units (SMU)	Productivity class	Area (ha)	% TGA
1	1, 11, 12, 13	Excellent	3400.67	28.87
2	2, 8, 9	Good	2154.09	18.29
3	6, 10, 14	Average	1193.76	10.14
4	3, 4, 5, 7	Poor	4326.50	36.73
Total Geographical Area (TGA)		**11777.6**		

The data for soybean crop (Table 4.43) denoted that about 3400.67 ha area (28.87 % TGA) of the watershed categorized under excellent, 2154.09 ha (18.29 % TGA) under good, 1193.76 ha (10.14 % TGA) under average and 4326.50 ha area (36.73% TGA) categorized under poor productivity class. The soybean productivity map prepared from the productivity index is depicted in Fig. 4.24.

4.8.4.3 Land productive index for growing pigeon pea

The soils of the Sawangi watershed were evaluated for the land productivity for pigeon pea crop (Table 4.44). The results indicated that the SMU- 11 is excellent in soil productivity with potentiality class- I in which the productivity index rating is 72.0. These soils have limitations of soil moisture. The SMU- 1, 12 and 13 were found to be good in soil productivity with potentiality class- II in which the productivity index rating ranges between 34.0 to 57.6. These soils have moderate limitations of soil moisture and texture/structure. The SMU- 2, 8, 9, 10 and 14 are average in soil productivity with potentiality class- III in which the productivity index rating ranges between 25.2 to 30.2. These soils have several limitations of soil moisture, texture/structure, and soil depth. The SMU- 3, 4, 5, 6 and 7 were found to be poor in soil productivity with potentiality class- IV in which the productivity index rating ranged between 8.0 to 19.4. These soils have very several limitations of soil moisture, texture/structure, and soil depth.

Table 4.44 Productivity index for pigeon pea (Rating class with assigned values), Productivity classes and index of potentiality

Soil mapping units (SMU)	Soil moisture content (H)	Drainage (D)	Effective depth of Soil (P)	Texture and Structure of root zone (T)	Average nutrient content of A horizon (N)	Organic Matter in A1 horizon (O)	Mineral exchange capacity (A)	Reserves of weatherable minerals in B horizon (M)	Productivity Index (PI)	Productivity class (P)	Potentiality (P')
SMU-1	H4a	D4	P4	T5b	N5	O3	A3	M3c	51.2	Good	II
	80	100	80	80	100	100	100	100			
SMU-2	H3c	D4	P4	T6b	N5	O2	A3	M3c	34.0	Average	III
	70	100	60	90	100	90	100	100			
SMU-3	H3b	D4	P2	T5b	N5	O2	A2	M3c	8.2	Poor	IV
	60	100	20	80	100	90	95	100			
SMU-4	H2c	D4	P2	T7	N5	O3	A3	M3c	8.0	Poor	IV
	40	100	20	100	100	100	100	100			
SMU-5	H3b	D4	P2	T6b	N5	O2	A2	M3c	9.2	Poor	IV
	60	100	20	90	100	90	95	100			
SMU-6	H3b	D4	P3	T6b	N5	O2	A3	M3c	19.4	Poor	IV
	60	100	40	90	100	90	100	100			
SMU-7	H3b	D4	P2	T5b	N5	O3	A2	M3c	9.1	Poor	IV
	60	100	20	80	100	100	95	100			
SMU-8	H3c	D4	P4	T5b	N5	O2	A3	M3c	30.2	Average	III
	70	100	60	80	100	90	100	100			
SMU-9	H3c	D4	P4	T5b	N5	O2	A3	M3c	30.2	Average	III
	70	100	60	80	100	90	100	100			
SMU-10	H3b	D4	P3	T5b	N5	O2	A3	M3c	21.6	Average	III
	60	100	50	80	100	90	100	100			
SMU-11	H4a	D4	P6	T7	N5	O2	A3	M3c	72.0	Excellent	I
	80	100	100	100	100	90	100	100			
SMU-12	H4a	D4	P5	T5b	N5	O2	A3	M3c	57.6	Good	II
	80	100	100	80	100	90	100	100			
SMU-13	H4a	D4	P4	T6b	N5	O2	A2	M3c	49.2	Good	II
	80	100	80	90	100	90	95	100			
SMU-14	H3c	D4	P3	T5b	N5	O2	A3	M3c	25.2	Average	III
	70	100	50	80	100	90	100	100			

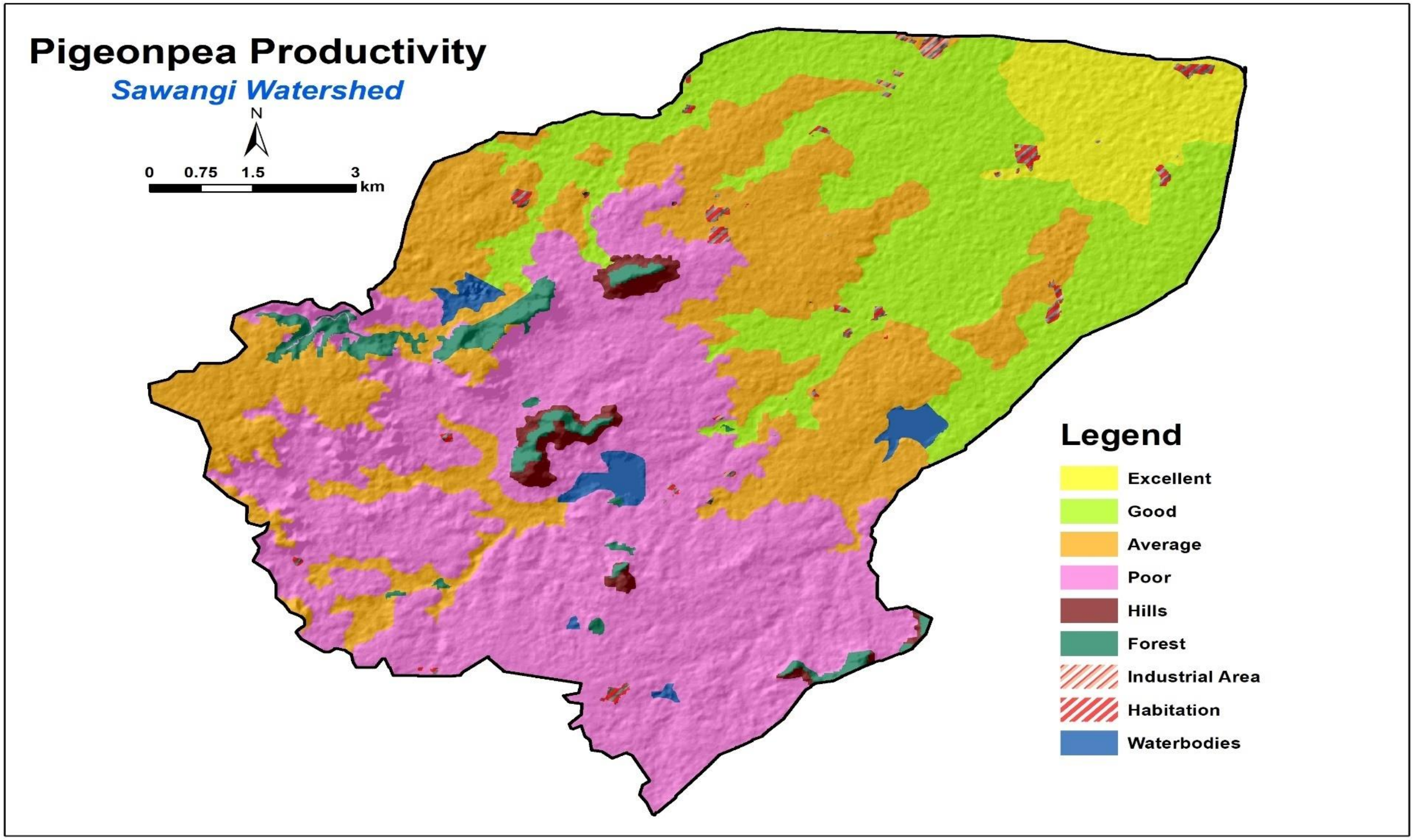


Fig. 4.25 Pigeonpea productivity map of Sawangi watershed

Table 4.45 Extent and distribution of soil productivity classes for pigeon pea

Sl. No.	Soil mapping units (SMU)	Productivity class	Area (ha)	% TGA
1	11	Excellent	689.81	5.86
2	1, 12, 13	Good	2710.87	23.02
3	2, 8, 9, 10, 14	Average	3089.17	26.23
4	3, 4, 5, 6, 7	Poor	4585.17	38.93
Total Geographical Area (TGA)		**11777.62**		

The data for pigeon pea crop (Table 4.45) denoted that about 689.81 ha area (5.86 % TGA) of the watershed categorized under excellent, 2710.87 ha (23.02 % TGA) under good, 3089.17 ha (26.23 % TGA) under average and 4585.17 ha area (38.93 % TGA) categorized under poor productivity class. The pigeon pea productivity map prepared from the productivity index is depicted in fig. 4.25.

4.8.4.4 Land productive index for growing sorghum

The soils of the Sawangi watershed were evaluated for the land productivity for sorghum crop (Table 4.46). The results indicated that the SMU- 1, 11 and 12 are excellent in soil productivity with potentiality class- I in which the productivity index rating ranges between 72.0 to 90.0. These soils have limitations of soil moisture. The SMU- 2, 8, 9 and 13 were found to be good in soil productivity with potentiality class- II in which the productivity index rating ranges between 43.7 to 61.6. These soils have moderate limitations of soil moisture and texture/structure. The SMU- 10 and 14 are average in soil productivity with potentiality class- III in which the productivity index rating ranges between 28.8 to 30.4. These soils have several limitations of soil moisture, texture/structure, and soil depth. The SMU- 3, 4, 5, 6 and 7 were found to be poor in soil productivity with potentiality class- IV in which the productivity index rating ranged between 10.9 to 16.0. These soils have very several limitations of soil moisture, texture/structure, and soil depth.

Table 4.46 Productivity index for sorghum (Rating class with assigned values), Productivity classes and index of potentiality

Soil mapping units (SMU)	Soil moisture content (H)	Drainage (D)	Effective depth of Soil (P)	Texture and Structure of root zone (T)	Average nutrient content of A horizon (N)	Organic Matter in A1 horizon (O)	Mineral exchange capacity (A)	Reserves of weatherable minerals in B horizon (M)	Productivity Index (PI)	Productivity class (P)	Potentiality (P')
SMU-1	H4c 100	D4 100	P5 100	T5b 80	N5 100	O3 100	A3 100	M3c 100	80.0	Excellent	I
SMU-2	H4b 90	D4 100	P4 60	T6b 90	N5 100	O2 90	A3 100	M3c 100	43.7	Good	II
SMU-3	H4a 80	D4 100	P2 20	T5b 80	N5 100	O2 90	A2 95	M3c 100	10.9	Poor	IV
SMU-4	H3b 60	D4 100	P2 20	T7 100	N5 100	O3 100	A3 100	M3c 100	16.0	Poor	IV
SMU-5	H4a 80	D4 100	P2 20	T6b 90	N5 100	O2 90	A2 95	M3c 100	12.3	Poor	IV
SMU-6	H4a 80	D4 100	P2 20	T6b 90	N5 100	O2 90	A3 100	M3c 100	13.0	Poor	IV
SMU-7	H4a 80	D4 100	P2 20	T5b 80	N5 100	O3 100	A2 95	M3c 100	12.2	Poor	IV
SMU-8	H4b 90	D4 100	P4 70	T5b 80	N5 100	O2 90	A3 100	M3c 100	45.4	Good	II
SMU-9	H4b 90	D4 100	P4 70	T5b 80	N5 100	O2 90	A3 100	M3c 100	45.4	Good	II
SMU-10	H4a 80	D4 100	P3 50	T5b 80	N5 100	O2 90	A3 100	M3c 100	28.8	Average	III
SMU-11	H4c 100	D4 100	P6 100	T7 100	N5 100	O2 90	A3 100	M3c 100	90.0	Excellent	I
SMU-12	H4c 100	D4 100	P5 100	T5b 80	N5 100	O2 90	A3 100	M3c 100	72.0	Excellent	I
SMU-13	H4c 100	D4 100	P4 80	T6b 90	N5 100	O2 90	A2 95	M3c 100	61.6	Good	II
SMU-14	H4b 90	D4 100	P3 50	T5b 80	N5 100	O2 90	A3 100	M3c 100	32.4	Average	III

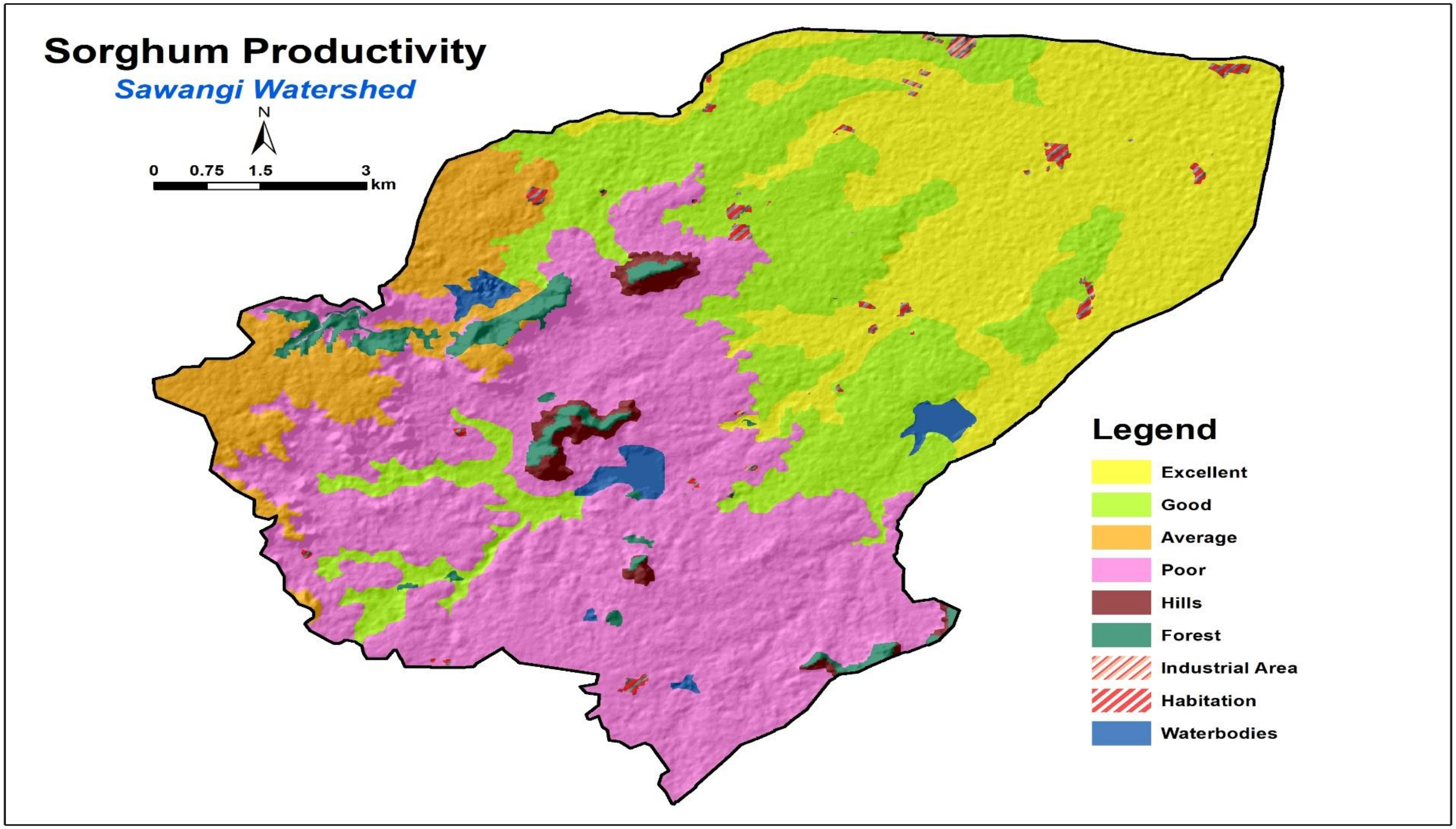


Fig. 4.26 Sorghum productivity map of Sawangi watershed

Table 4.47 Extent and distribution of soil productivity index classes for sorghum

Sl. No.	Soil mapping units (SMU)	Productivity class	Area (ha)	% TGA
1	1, 11,12	Excellent	2873.02	24.39
2	2, 8, 9, 13	Good	2681.75	22.77
3	10, 14	Average	935.08	7.94
4	3, 4, 5, 6, 7	Poor	4585.17	38.93
Total Geographical Area (TGA)		**11777.6**		

The data for sorghum crop (Table 4.47) denoted that about 2873.02 ha area (24.39 % TGA) of the watershed categorized under excellent, 2681.75 ha (22.77 % TGA) under good, 935.08 ha (7.94 % TGA) under average and 4585.17 ha area (38.93 % TGA) categorized under poor productivity class. The sorghum productivity map prepared from the productivity index is depicted in fig. 4.26.

4.8.4.5 Land productive index for growing wheat

The soils of the Sawangi watershed were evaluated for the land productivity for wheat crop (Table 4.48). The results indicated that the SMU- 1, 11, 12 and 13 were found to be good in soil productivity with potentiality class- II in which the productivity index rating ranges between 36.9 to 61.6. These soils have moderate limitations of soil moisture and texture/structure. The SMU- 2, 6, 8, 9, 10 and 14 are average in soil productivity with potentiality class- III in which the productivity index rating ranges between 28.8 to 30.4. These soils have several limitations of soil moisture, texture/structure, and soil depth. The SMU- 3, 4, 5 and 7 were found to be poor in soil productivity with potentiality class-IV in which the productivity index rating ranged between 8.0 to 13.7. These soils have very several limitations of soil moisture, texture/structure, and soil depth.

Table 4.48 Productivity index for wheat (Rating class with assigned values), Productivity classes and index of potentiality

Soil mapping units (SMU)	Soil moisture content (H)	Drainage (D)	Effective depth of Soil (P)	Texture and Structure of root zone (T)	Average nutrient content of A horizon (N)	Organic Matter in A1 horizon (O)	Mineral exchange capacity (A)	Reserves of weatherable minerals in B horizon (M)	Productivity Index (PI)	Productivity class (P)	Potentiality (P')
SMU-1	H3b	D4	P4	T5b	N5	O3	A3	M3c	38.4	Good	II
	60	100	80	80	100	100	100	100			
SMU-2	H3a	D4	P4	T6b	N5	O2	A3	M3c	24.3	Average	III
	50	100	60	90	100	90	100	100			
SMU-3	H3a	D4	P3	T5b	N5	O2	A2	M3c	13.7	Poor	IV
	50	100	40	80	100	90	95	100			
SMU-4	H2b	D4	P3	T7	N5	O3	A3	M3c	8.0	Poor	IV
	20	100	40	100	100	100	100	100			
SMU-5	H2c	D4	P3	T6b	N5	O2	A2	M3c	12.3	Poor	IV
	40	100	40	90	100	90	95	100			
SMU-6	H3a	D4	P4	T6b	N5	O2	A3	M3c	24.3	Average	III
	50	100	60	90	100	90	100	100			
SMU-7	H2c	D4	P3	T5b	N5	O3	A2	M3c	12.2	Poor	IV
	40	100	40	80	100	100	95	100			
SMU-8	H3a	D4	P4	T5b	N5	O2	A3	M3c	28.8	Average	III
	50	100	80	80	100	90	100	100			
SMU-9	H3a	D4	P4	T5b	N5	O2	A3	M3c	28.8	Average	III
	50	100	80	80	100	90	100	100			
SMU-10	H3a	D4	P4	T5b	N5	O2	A3	M3c	21.6	Average	III
	50	100	60	80	100	90	100	100			
SMU-11	H3b	D4	P6	T7	N5	O2	A3	M3c	54.0	Good	II
	60	100	100	100	100	90	100	100			
SMU-12	H3b	D4	P5	T5b	N5	O2	A3	M3c	43.2	Good	II
	60	100	100	80	100	90	100	100			
SMU-13	H3b	D4	P4	T6b	N5	O2	A2	M3c	36.9	Good	II
	60	100	80	90	100	90	95	100			
SMU-14	H3a	D4	P4	T5b	N5	O2	A3	M3c	21.6	Average	III
	50	100	60	80	100	90	100	100			

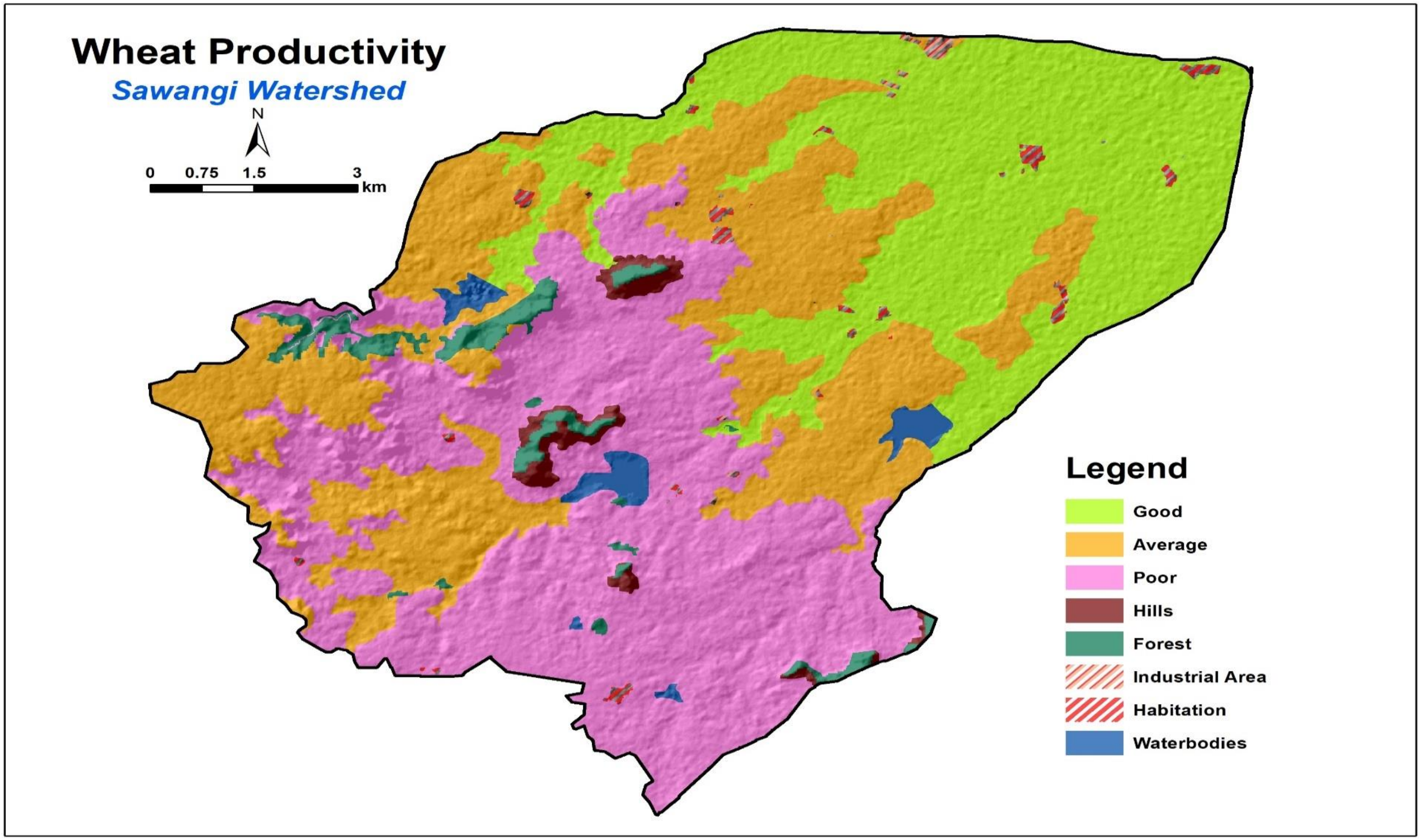


Fig. 4.27 Wheat productivity map of Sawangi watershed

Table 4.49 Extent and distribution of soil productivity classes for wheat

Sl. No.	Soil mapping units (SMU)	Productivity class	Area (ha)	% TGA
1	1, 11, 12, 13	Good	3400.67	28.87
2	2, 6, 8, 9, 10, 14	Average	3347.85	28.43
3	3, 4, 5, 7	Poor	4326.50	36.73
Total Geographical Area (TGA)		**11777.6**		

The data for wheat crop (Table 4.49) indicated that about 3400.67 ha area (28.87 % TGA) of the watershed categorized under good, 3347.85 ha (28.43 % TGA) under average and 4326.50 ha area (36.73 % TGA) categorized under poor productivity class. The wheat productivity map prepared from the productivity index is depicted in fig. 4.27.

4.8.4.6 Land productive index for growing chickpea

The soils of the Sawangi watershed were evaluated for the land productivity for chickpea crop (Table 4.50). The results indicated that the SMU- 1, 11, 12 and 13 were found to be good in soil productivity with potentiality class- II in which the productivity index rating ranges between 36.9 to 61.6. These soils have moderate limitations of soil moisture and texture/structure. The SMU- 2, 6, 8, 9, 10 and 14 are average in soil productivity with potentiality class- III in which the productivity index rating ranges between 21.6 to 28.8. These soils have several limitations of soil moisture, texture/structure, and soil depth. The SMU- 3, 4, 5 and 7 were found to be poor in soil productivity with potentiality class-IV in which the productivity index rating ranged between 8.0 to 15.4. These soils have very several limitations of soil moisture, texture/structure, and soil depth.

Table 4.50 Productivity index for chickpea (Rating class with assigned values), Productivity classes and index of potentiality

Soil mapping units (SMU)	Soil moisture content (H)	Drainage (D)	Effective depth of Soil (P)	Texture and Structure of root zone (T)	Average nutrient content of A horizon (N)	Organic Matter in A1 horizon (O)	Mineral exchange capacity (A)	Reserves of weatherable minerals in B horizon (M)	Productivity Index (PI)	Productivity class (P)	Potentiality (P')
SMU-1	H3b 60	D4 100	P4 80	T5b 80	N5 100	O3 100	A3 100	M3c 100	38.4	Good	II
SMU-2	H3a 50	D4 100	P4 60	T6b 90	N5 100	O2 90	A3 100	M3c 100	24.3	Average	III
SMU-3	H3a 50	D4 100	P3 40	T5b 80	N5 100	O2 90	A2 95	M3c 100	13.7	Poor	IV
SMU-4	H2b 20	D4 100	P3 40	T7 100	N5 100	O3 100	A3 100	M3c 100	8.0	Poor	IV
SMU-5	H3a 50	D4 100	P3 40	T6b 90	N5 100	O2 90	A2 95	M3c 100	15.4	Poor	IV
SMU-6	H3a 50	D4 100	P4 60	T6b 90	N5 100	O2 90	A3 100	M3c 100	24.3	Average	III
SMU-7	H2c 40	D4 100	P3 40	T5b 80	N5 100	O3 100	A2 95	M3c 100	12.2	Poor	IV
SMU-8	H3a 50	D4 100	P4 80	T5b 80	N5 100	O2 90	A3 100	M3c 100	28.8	Average	III
SMU-9	H3a 50	D4 100	P4 80	T5b 80	N5 100	O2 90	A3 100	M3c 100	28.8	Average	III
SMU-10	H3a 50	D4 100	P4 60	T5b 80	N5 100	O2 90	A3 100	M3c 100	21.6	Average	III
SMU-11	H3b 60	D4 100	P6 100	T7 100	N5 100	O2 90	A3 100	M3c 100	54.0	Good	II
SMU-12	H3b 60	D4 100	P5 100	T5b 80	N5 100	O2 90	A3 100	M3c 100	43.2	Good	II
SMU-13	H3b 60	D4 100	P4 80	T6b 90	N5 100	O2 90	A2 95	M3c 100	36.9	Good	II
SMU-14	H3a 50	D4 100	P4 60	T5b 80	N5 100	O2 90	A3 100	M3c 100	21.6	Average	III

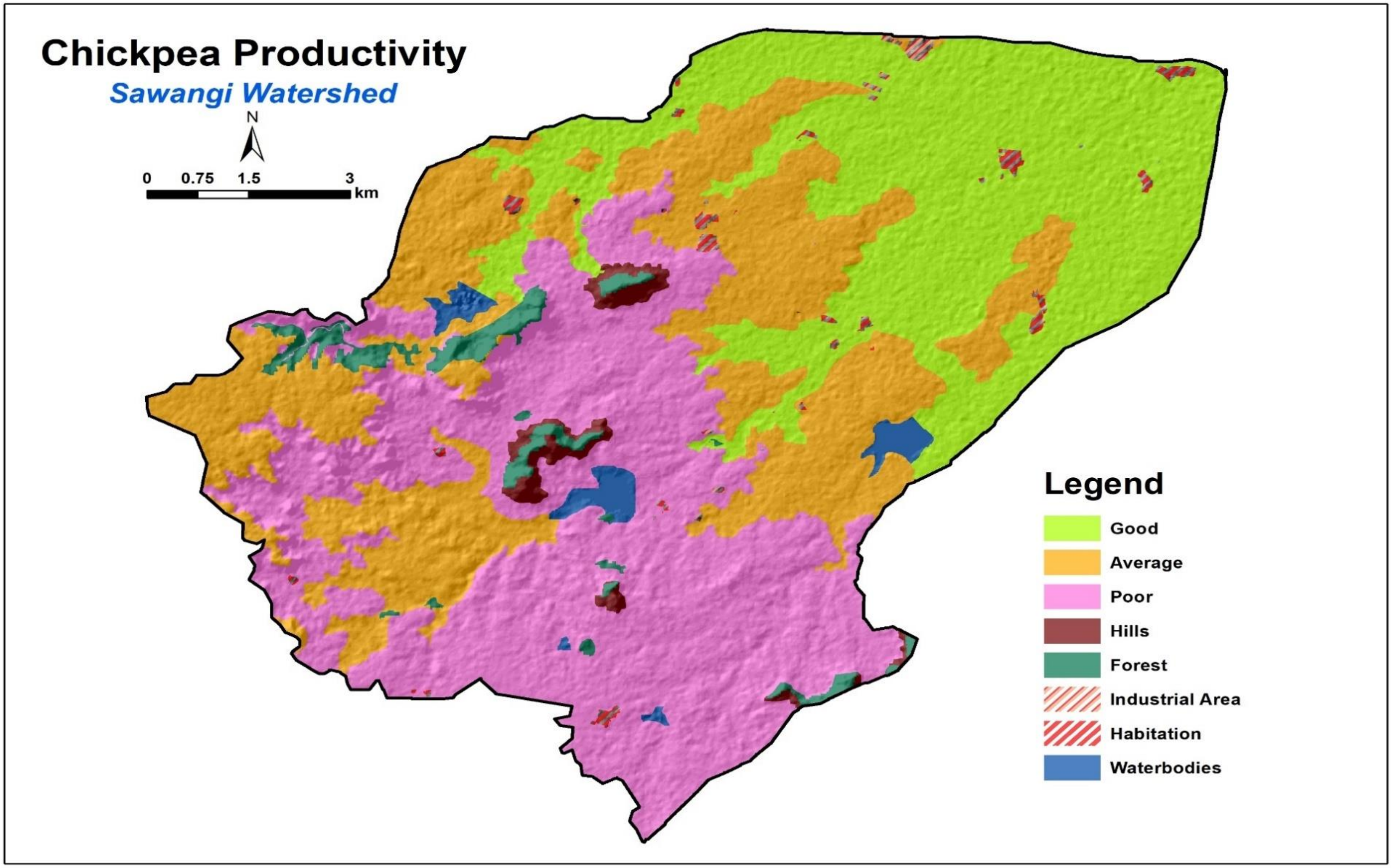


Fig. 4.28 Chickpea productivity map of Sawangi watershed

Table 4.51 Extent and distribution of soil productivity classes for chickpea

Sl. No.	Soil mapping units (SMU)	Productivity class	Area (ha)	% TGA
1	1, 11, 12, 13	Good	3400.67	28.87
2	2, 6, 8, 9, 10, 14	Average	3347.85	28.43
3	3, 4, 5, 7	Poor	4326.50	36.73
Total Geographical Area (TGA)		**11777.6**		

The data for chickpea crop (Table 4.51) indicated that about 3400.67 ha area (28.87 % TGA) of the watershed categorized under good, 3347.85 ha (28.43 % TGA) under average and 4326.50 ha area (36.73 % TGA) categorized under poor productivity class. The chickpea productivity map prepared from the productivity index is depicted in fig. 4.28.

4.9 GIS application in digital database generation

4.19.1 Generation of thematic maps

Database generation is a very important and essential step in constructing an information system including the mapping of different resources/subjects. The GIS software is one of the most important tools is widely used as a spatial analysis for effective and efficient means of data generation and management, analysis, and display. GIS gives reasonable tools to collect spatial data and integrate them with attribute data. It additionally provides special tools for the integration of various data into a format to be compared and analyzed. The different thematic maps were created during the periods of study include land use/land cover, slope, physiography, soil, contour, and drainage network, based on the satellite data and SOI toposheets as primary layers. which about the maps are given in respective sections.

4.9.2 Sawangi watershed ground water potential zone

The GWP zones of the Sawangi watershed were delineated using the various thematic maps or multi influencing factors viz. geology, soil, geomorphology, land use land cover, lineament density, drainage density, and slope were integrated for analysis using RS and GIS tools. The GIS-based multi-criteria evaluation was used to compute the weighted overlay analysis for thematic layers.

Table 4.52 Area statistics of GWP Zones in Sawangi watershed

SL. No.	GWP zone	Area (ha)	Per cent (%)
1	Highly potential	501.87	4.26
2	Moderately potential	10059.66	85.41
3	Low potential	1216.08	10.33
	Total (TGA)	**11777.62**	**100**

The groundwater potential zone of Sawangi watershed showed in (Fig. 4.29, Table 4.52) that more than 85.41 per cent (10059.66 ha) area have "moderate" potential and 10.33 per cent (1216.08 ha) area was observed in the "poor" potential, while only 4.26 per cent (501.87 ha) area was observed in the "high" potential zone.

Expectedly, the high GWP zone is exhibited is almost around the drainage channels, and water bodies. The high GWP zone due to the distribution of high lineament density and agriculture land with high infiltration ability. While poor GWP zone due to the presence of low lineament density, high sloping area along with the low infiltration rate of clay soils was found near about in the closely hilly regions, forest lands, shrublands, and wastelands. The watershed area was observed there found to be more than 85% area to have ‘moderate’ potential due to weathered geomorphology, moderate to high lineaments and drainage density. This class was a moderate source of groundwater recharge (Jasrotia *et al.* 2006; Khadri and Mohrir, 2016; Patil, 2018; Thomas and Duraisamy, 2018).

The collection of wells irrigation data from the web portal of the Government of Maharashtra was referred for verification. Since the Sawangi watershed for monsoon season crops (first crops) mainly depends on rainfall, the observed in the month of January cropped fields there found to be mostly indicated irrigated crops.

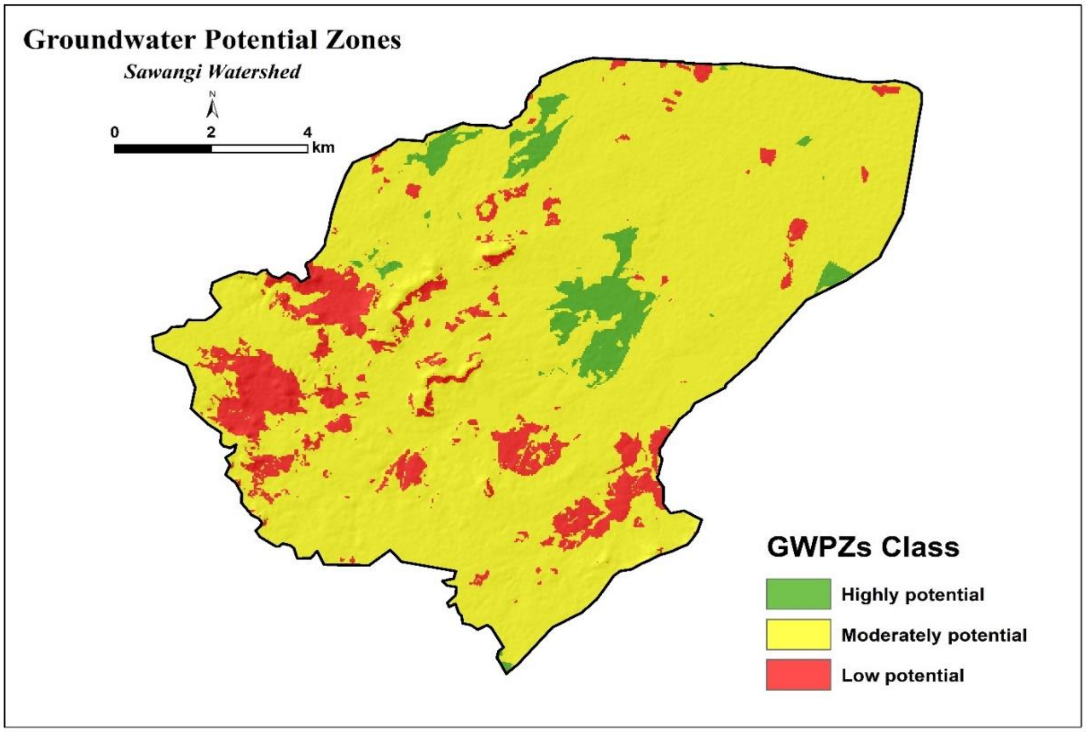


Fig. 4.29 GWP zone map of Sawangi watershed

But the further year 2013 was a drought year (369.6 mm rainfall as against the last decade of the mean normal annual rainfall of 917 mm), consequently, the probability of crops growing raised on residual soil moisture was ruled out during the field survey. some places are observed an irrigated area without visible any wells and land parcels with more than 1 ha area (Google Earth image) were marked for verification that the wells yield in this watershed area are the most part in generally low. It was noticed that land parcels with more than 1 ha irrigated area were either irrigated by canals or tube-wells.

4.8.3 Validation of GWP zone of Sawangi watershed

The collection of wells and irrigation data showed in Table 4.53 and Fig. 4.30. The number of wells has continuously increased order over the last decade. The evidence of the GWP zonation is apparent from the decadal mean irrigated area per well that followed an order of 1.13 ha in 2008, 1.18 ha in 2012 and 1.45 ha area in 2017.

The indicated an increase in each GWP zones over the decade with to the increasing number of wells. For example, in "high" GWP zone, the irrigated area per

Table 4.53 Number of open wells and irrigated area in different GWP zone of watershed

Year	2008	2012	2017
High GWP Zone (H)			
Total no. of wells	39	50	60
Functional Wells	19	21	22
Defunct Wells	20	29	38
Irrigated area (ha)	21.9	29.1	48.7
Irrigated area per well (ha)	1.15	1.38	2.21
Well Density (per ha)	0.08	0.10	0.12
Moderate GWP Zone (M)			
Total no. of wells	451	575	655
Functional Wells	248	290	304
Defunct Wells	203	285	351
Irrigated area (ha)	438.8	561.7	645.1
Irrigated area per well (ha)	1.77	1.93	2.12
Well Density (per ha)	0.04	0.06	0.06
Low GWP Zone (L)			
Total no. of wells	6	8	13
Functional Wells	3	4	6
Defunct Wells	3	4	7
Irrigated area (ha)	1.4	1.0	2.2
Irrigated area per well (ha)	0.46	0.25	0.36
Well Density (per ha)	0.004	0.006	0.01
Total irrigated area in the watershed (ha)	**462.1**	**591.8**	**696.0**
Mean irrigated area per well (ha)	**1.13**	**1.18**	**1.45**

well was 1.15 ha in year 2007, which is increased to 2.21 ha by year 2017. While in "moderate" GWP zone, the irrigated area per well was 1.77 ha in year 2007, which is increased to 2.12 ha by year 2017.

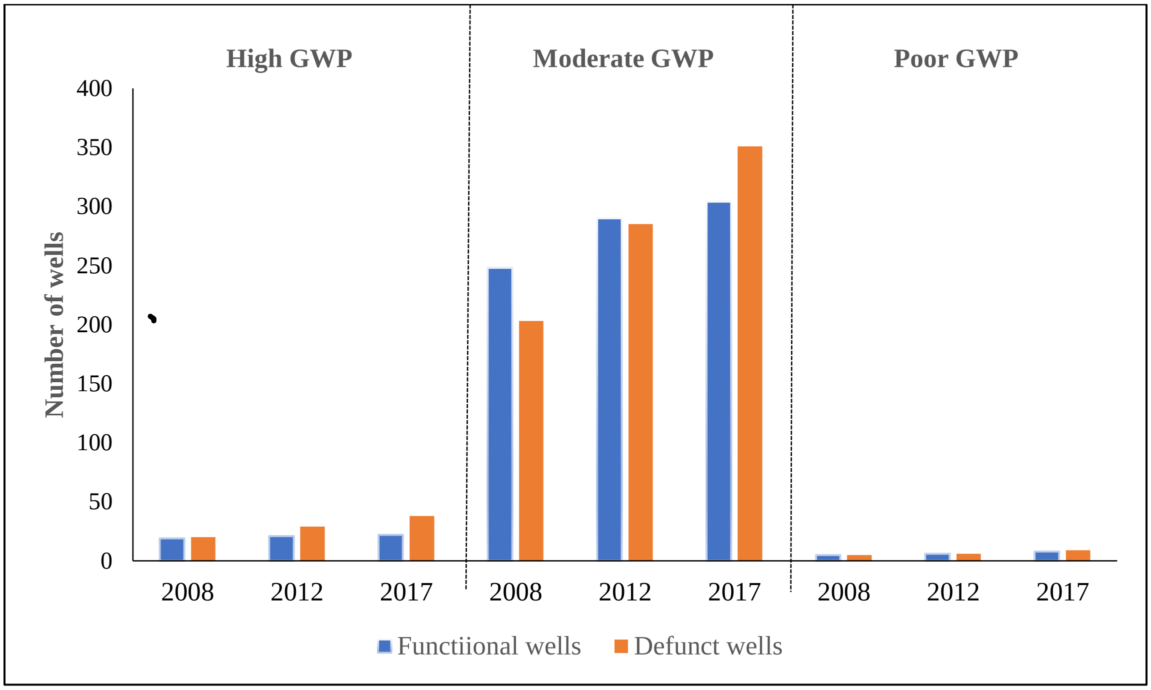


Fig. 4.30 Number of open wells in different zones of GWP

4.10 Well Census and Irrigated Area Mapping

Georeferenced wells enumerate mapping data is shown in (Table 4.54 and Fig. 4.31, 4.32, 4.33). In which the temporal and spatial distribution pattern of wells show in distinct trend in the Sawangi watershed. The total number of wells in the year 2008 was identified 497, which was increased to 629 in 2012 and 728 in 2017 and indicated growth in the number of wells 54.40 per cent. But defunct wells outnumbered functional wells. Only 43 and 55 new functional wells were added during year of 2008 - 2012 and 2008 - 2017. While the defunct wells grew by 41 and 119.

The total cultivated area of the Sawangi watershed is 7890 ha, out of this only 696.0 ha (8.8 %) area is irrigated by groundwater, irrigated area enumerate mapping data is shown in (Table 4.54 and Fig. 4.37, 4.38, 4.39). The irrigated area increased from 2008 to 2012 by 129.64 ha and again slightly increased from 2012 to 2017 by 104.22 ha. But little below increased compared from 2008 to 2012. At the same time seen, the big area increased from 2008 to 2017 by nearly 233.86 ha. The irrigated area per well

Table 4.54 Temporal distribution of wells and irrigated area of the Sawangi watershed

Components	2008	Per cent (%)	2012	Per cent (%)	2017	Per cent (%)
Total wells	497		631		728	
Functional wells	270	54.33	313	49.60	332	45.60
Defunct wells	227	45.67	318	50.40	396	54.40
Farm pond	25		46		64	
TGA (ha)	**11777.62**					
Irrigated area (ha)	462.14	5.9	591.78	7.5	696.0	8.8

was 1.13/ ha in 2008, The continued increase in the year 2012 and 2017 was followed by 1.18/ ha and 1. 45/ ha area. The continued increased number of wells is high but the increased irrigation area is very low compared to wells. The presented data provide a proof that the same aquifer is tapped unsustainably by greater number of farmers. A similar trend is reported in Kupti Nala watershed (Darwha block of Yavatmal district, Maharashtra) by Patil *et al.*, (2018). They observed that there were 834 total numbers of wells in watershed out of which only 568 wells were functional and nearly 32 per cent wells are dried up.

The development scheme called as "Maagel tyala shet taale" (Farm Pond on demand) implemented in the state since 2014 has created number of water bodies. In Sawangi watershed also, the number of farm ponds increased from 25 to 46 in the year 2008-2012 and 25 to 64 from 2008-2017 but these farm ponds seem to correlate is very low results add to irrigated areas. However, it is plausible that these ponds helped in life-saving irrigation and partly aided in restoring groundwater status as indicated by slight addition to irrigated area after 2012.

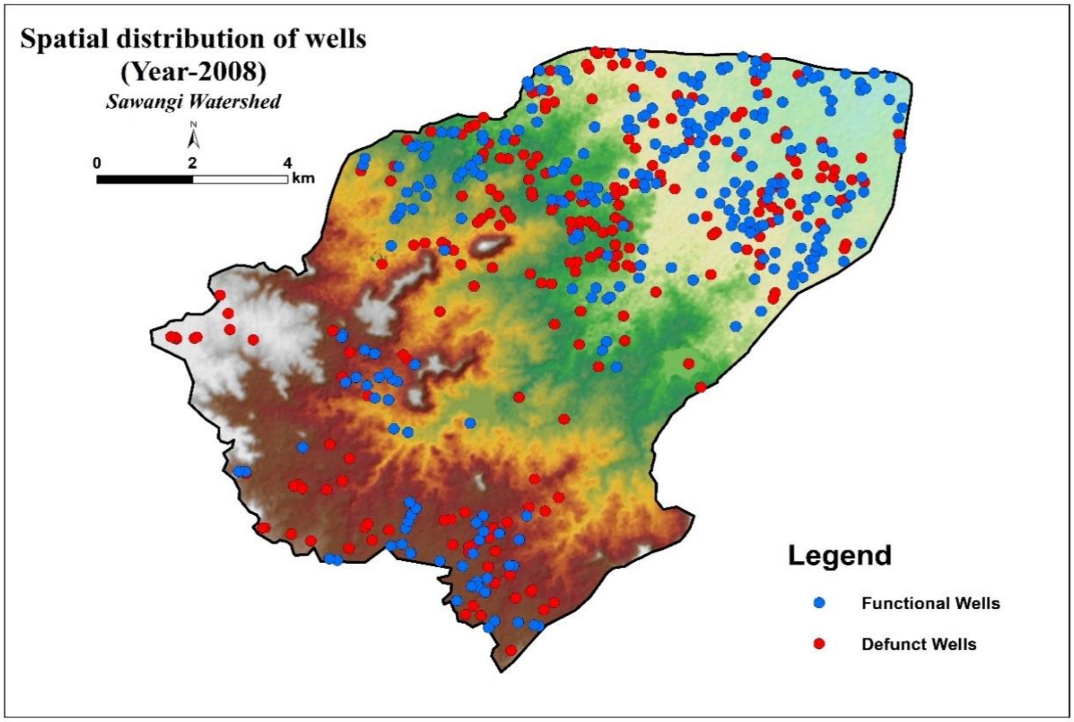


Fig. 4.31 Spatial distribution of wells in the Sawangi watershed (2008)

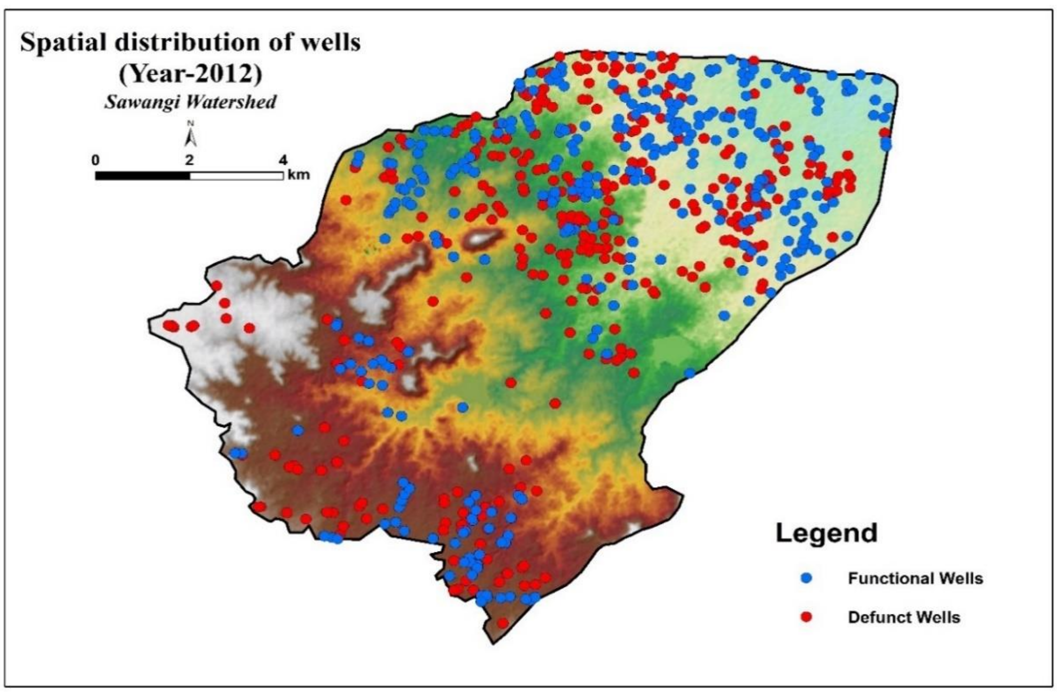


Fig. 4.32 Spatial distribution of wells in the Sawangi watershed (2012)

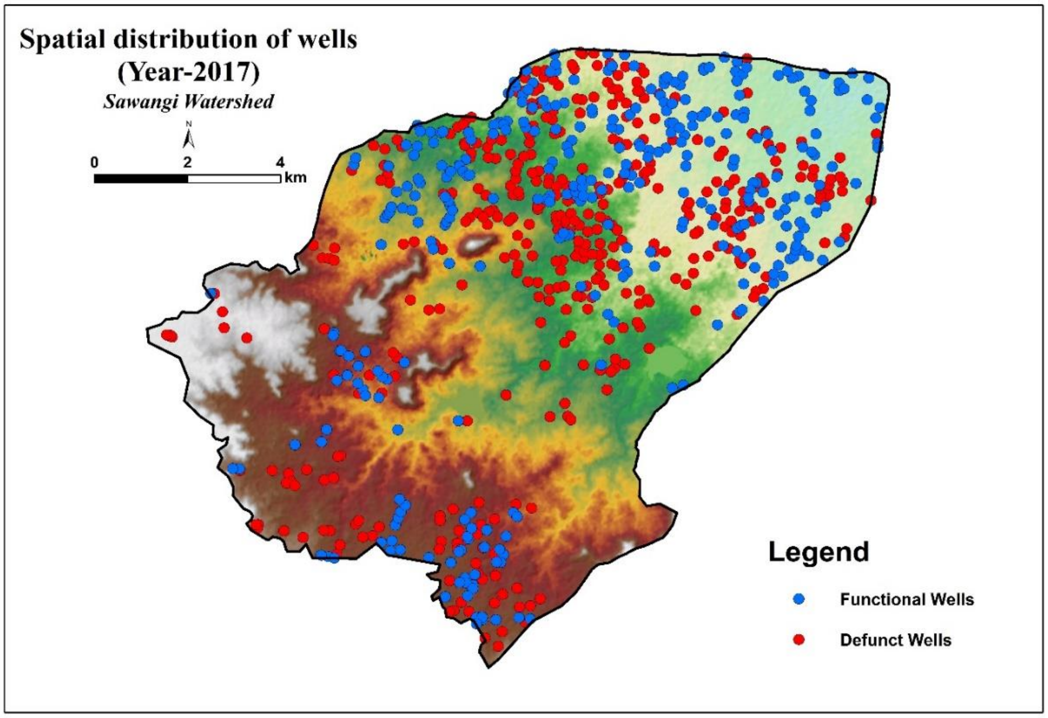


Fig. 4.33 Spatial distribution of wells in the Sawangi watershed (2017)

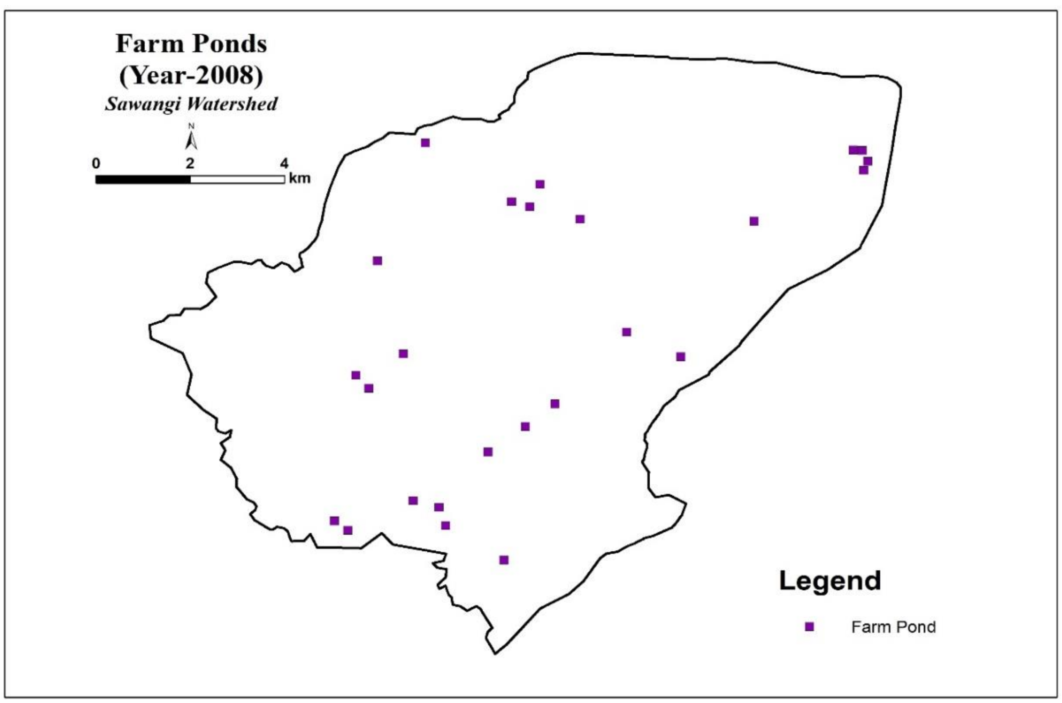


Fig. 4.34 Spatial distribution of farm ponds in the Sawangi watershed (2008)

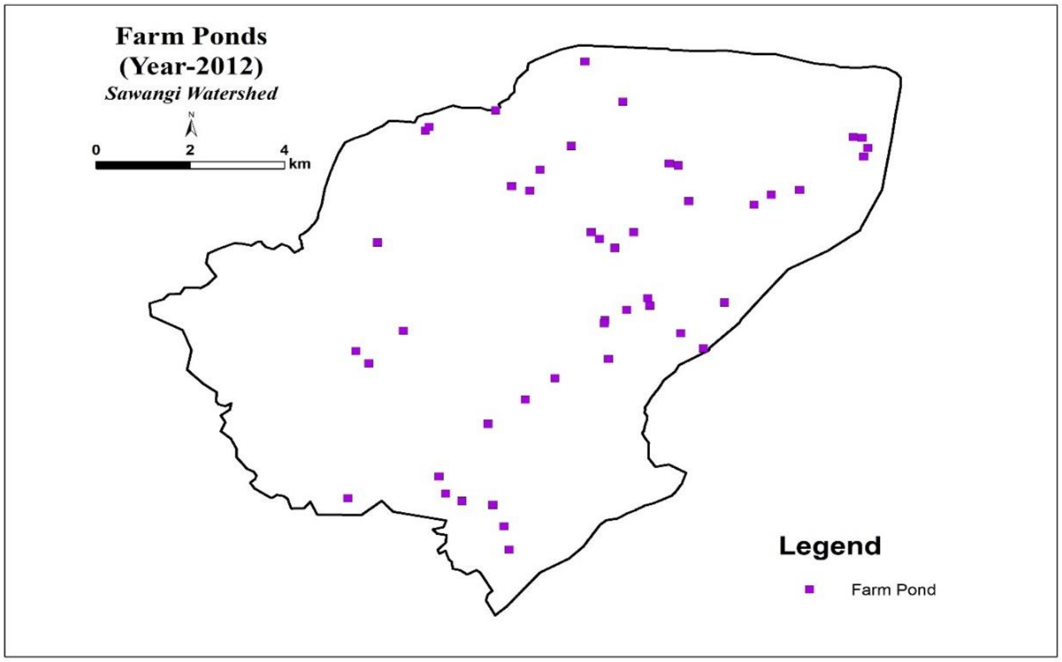


Fig. 4.35 Spatial distribution of farm ponds in the Sawangi watershed (2012)

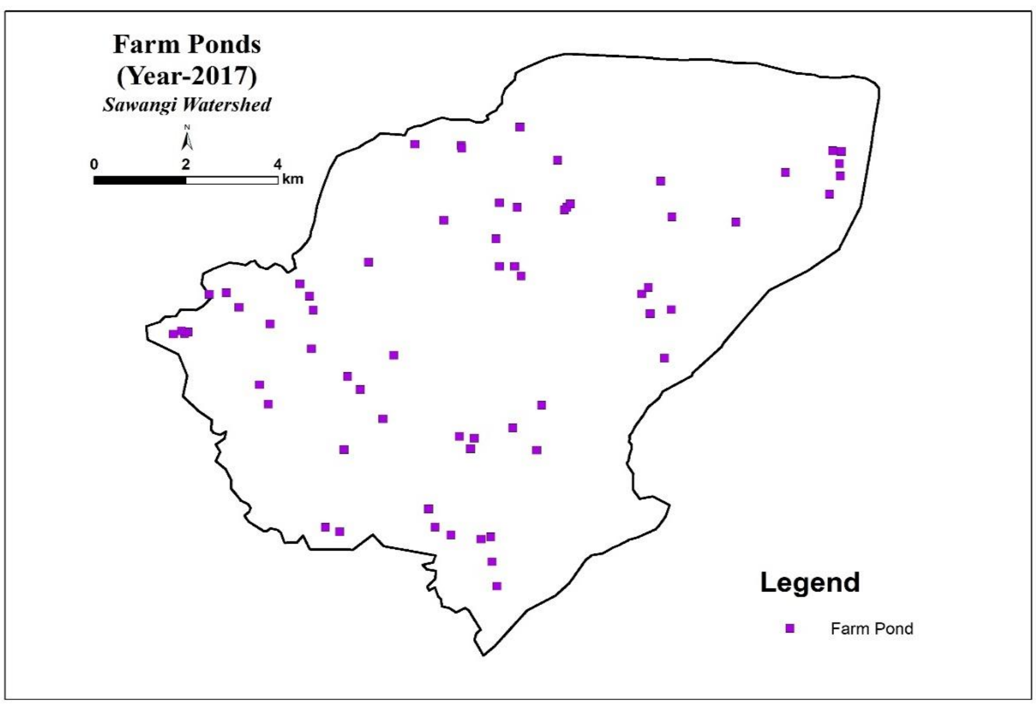


Fig. 4.36 Spatial distribution of farm ponds in the Sawangi watershed (2017)

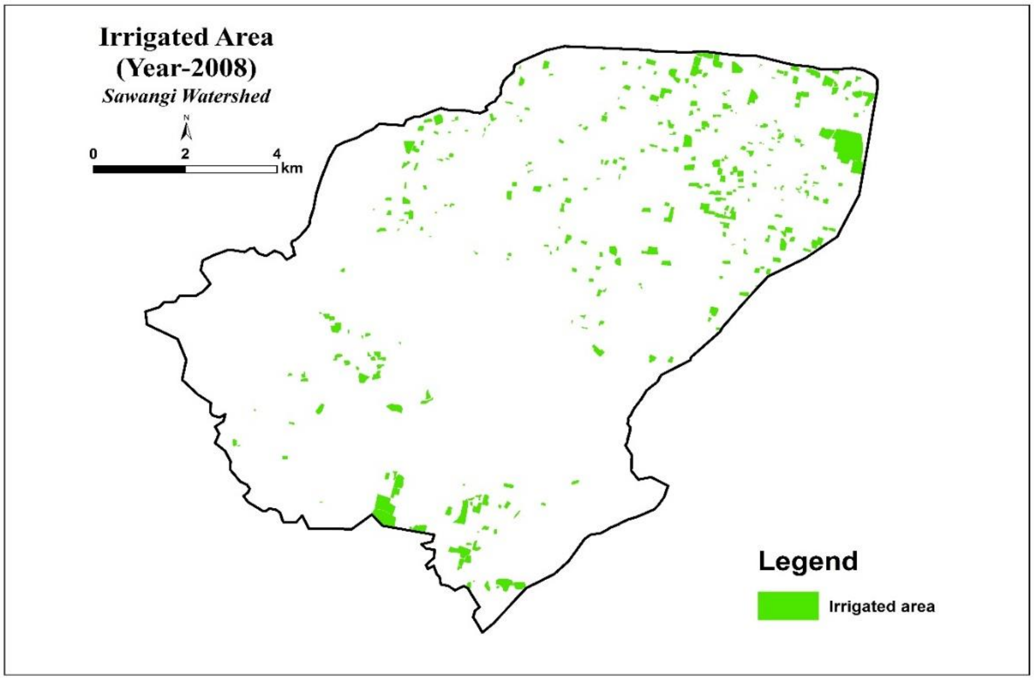


Fig. 4.37 Irrigated crop area in the Sawangi watershed (2008)

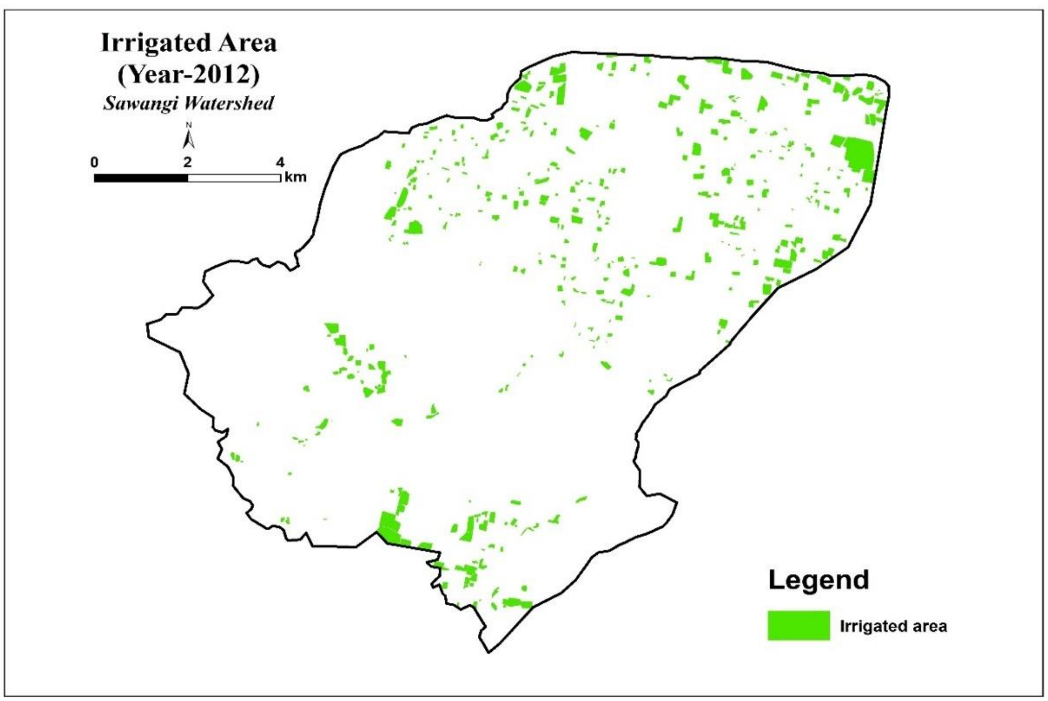


Fig. 4.38 Irrigated crop area in the Sawangi watershed (2012)

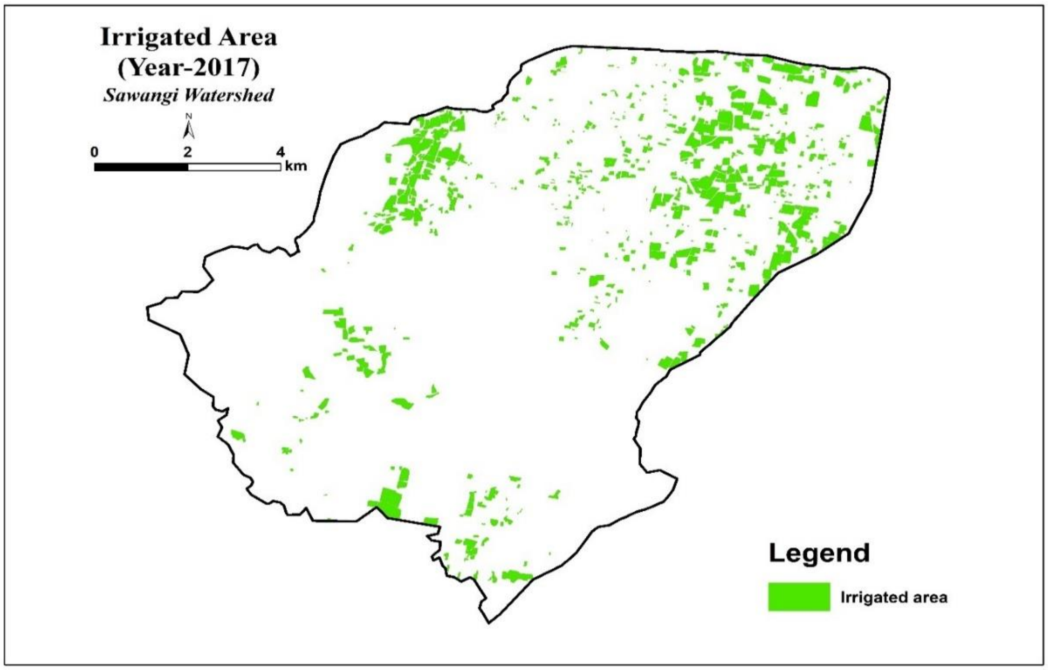


Fig. 4.39 Irrigated crop area in the Sawangi watershed (2017)

4.11 Decision support system (DSS) for land use planning

The production capability of soil in a specific area depends on the internal or external characteristics of the soil either altogether or in different combinations that directly determine soil productivity (Merolla *et al*., 1994). The land is used for miscellaneous activities, for example, agriculture, forestry, pasture, recreation, industrialization, urbanization, mining, *etc*. Evaluation of land suitability for different purposes is essential for the preparation of a land use plan of an area.

For suggesting appropriate measures for better management of the watershed, land use plan of the watershed was prepared by integrating the various available data *viz*, physiography, slope, soil, land use land cover, distance from forest, distance from habitation, groundwater potential as well as land capability, land productivity, and land suitability maps in GIS environment. The suggested land use map was revised applying the decision criteria developed based on the information from various maps, available literature, available secondary data, and experience gained during field work. The stakeholder could utilize the developed DSS for various purposes. Some illustrations are introduced beneath.

4.11.1 Land use options for the land parcel near to forest with shallow soils and poor groundwater potential.

It was observed that parameters like distance to the habitation, the distance between land parcels and forest area, distance from water sources, *etc*., impacted the crop choice. Vegetable crops were observed to be grown in land parcels near villages, while the crops requiring less care were grown in forest/wildlife periphery. Therefore, metrics namely distance from village/habitation, distance from the water source, and distance from the forest were worked out for each land parcel and grouped into ‘near’, ‘medium’, and ‘away’ classes depending on the average relative distance.

The land parcels are marginally suitable for all major crops, for example, cotton, pigeon pea, soybean, and sorghum during Kharif and wheat and chickpea during Rabi season. The major problem of these parcels are shallow soils (<50 cm depth), poor groundwater potential, and forest proximity (<1000 m) (Table 4.55). As most land parcels are in poor groundwater potential zone, availability of water is a major problem so farm pond is suggested for life-saving irrigation. According to geological information, there is a hard rock just below 25 to 50 cm depth, hence cost of constructing a farm pond through blasting the rocks is high. The farmers are not likely to be benefit from the farm ponds because of the low storage depth. The state government scheme ‘Pond on Demand’ provides Rs. 1 lakh to farmers but these findings can help to identify the farmers who will incur more expenditure. These findings could guide the planners to decide about financial assistance and targeting the weakest group. These farmers are not likely to strike groundwater. Thus, any investment for opening wells is likely to result in unjustified expenditure.

The examination of prevailing soil-site conditions suggests adopting silvipasture systems with restricted grazing designed for dryland conditions.

Silvipasture serves two purposes. It provides pastoral activity for fodder and growing trees for timber and fuel. The practice also allows the rearing of cattle for developing dairy as a side business, supporting agriculture.

Table 4.55 Land use options for the land parcels near to the forest with shallow soils and having poor groundwater potential.

Parameters	Present situation	Land use options
Soil resource		
Slope	3-8 %	
LPI	Poor	
Suitability for major crops		
Cotton	S3	Silvipasture. Protection from wild animals is necessary if currently grown crops (cotton/soybean/sorghum) are to be changed.
Pigeonpea	S3	
Soybean	S3	
Sorghum	S3	
Wheat	S3	
Chickpea	S3	
Distance		
Distance from forest	<1000 m	
Distance from village	> 500 m	

4.11.2 Land use options for the land parcels near to village with shallow soils and having poor to moderate groundwater potential

These land parcels are marginally suitable for all major crops, for example, cotton, pigeon pea, soybean, and sorghum during Kharif and wheat and chickpea during the Rabi season. The major problem of these parcels is shallow soil (<50 cm depth), and poor to moderate groundwater potential. Locations near the village (<500 m) can benefit to some extent from groundwater irrigation enabling vegetable crop or limited water requiring crop (Table 4.56). The yield of existing wells in these areas could be raised with a ground water recharge structure.

Table 4.56 Land use options for the land parcels, near to village with shallow soils and having poor to moderate groundwater potential.

Parameters	Present situation	Land use options
Soil resource		
Slope	3-8 %	
LPI	Poor	
Suitability for major crops		
Cotton	S3	Vegetables. Forage crops. Animal Husbandry and Dairying. Farm pond.
Pigeonpea	S3	
Soybean	S3	
Sorghum	S3	
Wheat	S3	
Chickpea	S3	
Distance		
Distance from forest	>1000 m	
Distance from village	< 500 m	

4.11.3 Land use options for the land parcels, near to forest with moderately shallow to moderately deep soil and moderate to good groundwater potential

These land parcels are marginally suitable for all major crops *i.e*, cotton, pigeon pea, soybean, and sorghum during Kharif and wheat and chickpea during Rabi season. The major characteristics of these parcels are- slight to moderately deep soil (50-100 cm depth), moderate to good groundwater potential, and not far away from the forest (<1000 m) (Table 4.57). Though the potential is good for growing vegetable crops, nearness to the forest make it difficult to grow vegetables (crop requiring more care) due to crop depredation. Protection from wild animals is necessary for diversified cropping. The identification of these parcels as prone to depredation can help forest officials in deciding compensation for crop loss or framing the compensation policy.

Table 4.57 Land use options for the land parcels, near to forest with moderately shallow to moderately deep soils and having moderate to good groundwater potential.

Parameters	Present situation	Land use options
Soil resource		
Slope	3-8 %	
LPI	Average	
Suitability for major crops		
Cotton	S3	Average production potential. Far off from the village make these unsuitable for crops requiring more care. Protection from wild animals is necessary.
Pigeonpea	S3	
Soybean	S3	
Sorghum	S3	
Wheat	S3	
Chickpea	S3	
Distance		
Distance from forest	>1000 m	
Distance from village	< 500 m	

4.11.4 Land use options for the land parcels, near to the village with slightly to moderately deep soils and moderate to good groundwater potential

These land parcels are marginally suitable for cotton, pigeon pea, and moderately suitable for soybean, sorghum, wheat, and chickpea of the watershed. The major characteristics of these parcels are slight to moderately deep soil (50-100 cm depth), moderate to good groundwater potential, and near the village (<500 m) (Table 4.58). Nearness to the village and distant from the forest minimizes the risk of crop depredation. Crops that require more care such as vegetables, can be grown with proper water resource development.

4.11.5 Land use options for the land parcels, near to the forest with deep soils and moderate to good groundwater potential

These land parcels are moderately suitable for all major crops, for example, cotton, pigeon pea, soybean, and sorghum during Kharif and wheat and chickpea

Table 4.58 Land use options for the land parcels, which are near to the village and having slightly to moderately deep soils with moderate to good groundwater potential.

Parameters	Present situation	Land use options
Soil resource		
Slope	3-8 %	
LPI	Average	
Suitability for major crops		
Cotton	S3	Vegetables. Animal husbandry and dairy Farm pond
Pigeonpea	S3	
Soybean	S3	
Sorghum	S3	
Wheat	S3	
Chickpea	S3	
Distance		
Distance from forest	>1000 m	
Distance from village	< 500 m	

Table 4.59 Land use options for the land parcels, near the forest with deep soils and having moderate to good groundwater potential.

Parameters	Present situation	Land use options
Soil resource		
Slope	0-3 %	
LPI	Good	
Suitability for major crops		
Cotton	S2	Good potential for diversified cropping. Protection from wild animals is necessary. Drip irrigation. Farm pond. Vegetables. Animal husbandry and dairying. Farm pond
Pigeonpea	S2	
Soybean	S2	
Sorghum	S2	
Wheat	S2	
Chickpea	S2	
Distance		
Distance from forest	<1000 m	
Distance from village	> 500 m	

during Rabi season. These parcels have deep soil (>100 cm depth), moderate to good groundwater potential, and are near the forest (<1000 m) (Table 4.59). There is a good potential for diversified cropping. The main constraint is crop depredation. Because these are located in moderate to good groundwater potential areas, the yield of the existing well could be raised with a recharge structure.

4.11.6 Land use options for the land parcels, near to the village with deep soils and moderate to good groundwater potential

These land parcels are moderately suitable for all major crops, for example, cotton, pigeon pea, soybean, and sorghum during Kharif and wheat and chickpea during Rabi season. These parcels have deep soil (>100 cm depth), good groundwater potential, and are near to the village (<500 m) (Table 4.60). As these parcels are in close proximity to habitation, there is a good potential for diversified cropping. These lands are suitable for promoting open wells.

Table 6.60 Land use options for the land parcels, near village with deep soils and having moderate to good groundwater potential.

Parameters	Present situation	Land use options
Soil resource		
Slope	0-3 %	
LPI	Good	
Suitability for major crops		
Cotton	S2	Good potential for diversified cropping. Drip irrigation.
Pigeonpea	S2	
Soybean	S2	
Sorghum	S2	
Wheat	S2	
Chickpea	S2	
Distance		
Distance from forest	>1000 m	
Distance from village	< 500 m	

CHAPTER - V

SUMMERY AND CONCLUSIONS

Resource-based land use planning is not only ecologically sound and operationally viable but also minimizes the social costs. Watershed management implies rational utilization of land and water resources for optimum and sustained production with minimum hazards to natural resources. Developments in satellite remote sensing offer tools for the mapping and monitoring of natural resources because of their unique capability to provide a wide range of information available in the electromagnetic spectrum in a synoptic view.

The present investigation was carried out in the Sawangi watershed of Yavatmal district, Maharashtra to characterize, classify and evaluate the soil and land resources based on remote sensing and GIS technologies, which comprises a mapping of natural resources, characterization, and classification of soils, land evaluation, and database generation related to land resources of the watershed. The results of the present investigation are summarized below:

Socio-economic analysis

- ❖ The Sawangi watershed has population density of 169 per sq. km. compared to 204 per sq. km. for the district but little more than 141 per sq. km. for the tehsil.
- ❖ The watershed community is mainly dependent on *Kharif* crops, for example, cotton, pigeon pea, soybean, and sorghum. These are the important crops of the *Kharif* season, while the dominant crops of the *Rabi* season are wheat and gram.
- ❖ The livestock population decreased from 2003 to 2012 in the Yavatmal district (15.1 per cent decline), whereas in Maharashtra it declines by 12.3 per cent. The crop economics and declining livestock population in the study area thereby emerged as major factors that impacted land use planning.
- ❖ The average per acre net benefit for cotton is Rs. 4175, while the cultivation cost is Rs. 16975 per acre. average yield is limited to 4.5 quintals. On the other hand, the

per acre benefit from pigeon pea, soybean, sorghum, and chick pea is Rs. 3375, Rs. 3200, Rs. 3850, and 5400 respectively.

Characterization and mapping of natural resources

- Based on the visual interpretation of LANDSAT-5, LANDSAT-8, Google image, and satellite data supported by field checks in the area, the study area was delineated into eight major land use/land cover classes *viz*., agriculture, current fallow, habitation, forest cover, shrubland, wasteland, industrial area, and waterbody.
- The slope map was delineated using ALOS-DEM 30m resolution. The five major classes are-very gently sloping (1-3%) covering an area of 7563 ha, gently sloping (3-8%) covering an area of 3482 ha, moderately sloping (8-15%) covering an area of 492 ha, moderately steeply sloping (15-30%) covering an area of 239 ha and steeply sloping (>30%) covering an area of 0.09 ha.
- A landform map has been prepared based on ALOS-DEM, sentinel 2A data, and subsequent ground truth verification. Ten major landform units identified are-mound, plateau, denuded plateau, escarpment, upper pediment, lower pediment, alluvial plain, pediplain, upper valley, lower valley, and waterbody.
- The watershed is characterized by a dendritic drainage pattern and drained by 103 streams with 152.15 km channel length. The least bifurcation ratio is below 2 implying no structural disturbance. The high drainage density (1.29 km km^{-2}) and frequency (0.88 km^{-2}) indicated the ruggedness of escarpments, mounds, and denuded plateau.
- The soil is very gently sloping to steep sloping, very shallow to very deep solum, well-drained with moderate to severe erosion, clay to sandy clay loam texture, the high shrink and swelling phenomena of smectite clay present in the soil. The structure of surface soils in all soil series is weak to medium, sub angular blocky structure to the strong angular blocky structure at sub-surface,

and exhibits colour in hue 2.5 to 10YR, value 3 to 5 and chroma 1 to 4 dark reddish-brown to very dark grayish brown in colour. This soil comes under *Vertisols, Inceptisols,* and *Entisols* soil orders.

- The sand, silt, and clay content ranged from 1.7 to 76.2 per cent, 5.9 to 47.8 per cent, and 26.5 to 71.3 per cent, respectively. Bulk density ranged from 1.39 to 1.81 Mg m^{-3} (mean, 1.5 Mg m^{-3}). The available water content ranged from 8.3 per cent to 22.0 per cent.
- The soils were slightly acidic to strongly alkaline reaction and pH (6.7 to 8.9) increased down the profile. The EC of all the soils ranges from 0.12 to 0.87 dSm^{-1}, but pedon 9 observed exceptional results which is ranges from 0.39 to 4.40 dSm^{-1}. The organic carbon content in soils ranged from 0.29 to 1.83 per cent, which is a low to medium range and showed a decreasing trend with depth.
- The calcium carbonate in all the pedons ranges from 0 to 14.68 per cent and showed increasing trends with the depth of soil. The cation exchange capacity of soils ranges from 31.39 to 70.43 cmol (p+) kg^{-1}. The exchangeable calcium was the dominating cation on the exchange complex followed by magnesium, sodium, and potassium. The exchangeable calcium and potassium decreased while magnesium and sodium increased with the depth of soil. But soyti series showed dominating sodium cation on the exchange complex compared to others.
- The available N, P, K, and S content of the surface soils of the study area ranges from 112.72 to 195.44 kg ha^{-1}, 13.58 to 27.78kg ha^{-1}, 145.92 to 403.20 kg ha^{-1}, and 0.09 to 0.47 kg ha^{-1}, respectively. All the pedons of the watershed are medium in available N and moderately high in available P. Available K was found medium to very high in different pedons.
- Available micronutrients *viz*., Fe, Mn, Cu and Zn ranged from 7.79 to 28.04 mg kg^{-1}, 6.72 to 27.98 mg kg^{-1}, 1.51 to 10.49 mg kg^{-1} and 0.36 to 1.77 mg kg^{-1}, respectively. Available Fe, Mn, and Cu were high in all the soils, whereas, available Zn was deficient in all the soils.

Evaluation of land resources

- ❖ The soil of the study area was grouped under different land capability sub-classes *viz*., IIes, IIIes, IVes, VIes, and VItes, and only 63.03 per cent area of the watershed is suitable for agriculture.
- ❖ The soil of the study area was classified into land irrigability sub-classes *viz*., 2st, 3s, 3st, 3t, 4s, and 5t, and indicated that only 81.86 per cent area of the watershed fit for irrigation.
- ❖ The Sys's method of soil-site suitability evaluation was employed to judge the suitability of major crops of the Sawangi watershed, for major crops (cotton, pigeon pea, soybean, sorghum, wheat, and chick pea). Nearly 18.5 per cent area is suitable for cotton, 23.0 per cent for pigeon pea, 18.5 per cent for soybean, 18.5 per cent for sorghum, and 18.5 per cent for wheat.
- ❖ The corresponding area in the marginally suitable class is 36.57 per cent for cotton, 36.57 per cent for pigeon pea, 36.57 per cent for soybean, 32.09 per cent for sorghum, 36.57 per cent for wheat, and 36.57 per cent for chick pea.
- ❖ The not suitable class is indicated in 38.93 per cent area for cotton, 38.93 per cent for pigeon pea, 37.94 per cent for soybean, 38.93 per cent for sorghum, 37.94 per cent for wheat, and 37.94 per cent for chick pea.
- ❖ Using Riquier's parametric approach, the evaluation of the land productivity index for various crops in the study area was computed for the soils. For most of the crops, it ranged between average to excellent category except soil 3, 4, 5, 6, and 7. Soil 3, 4, 5, 6, and 7 have poor land productivity index indicating the low potential for raising any of the major crops due to the limitations of soil depth and moisture.
- ❖ Groundwater potential zones assessment of the Sawangi watershed indicates that the 'High' potential zone (4.26% of TGA) is located around the drainage channels and water bodies. 'Poor' potential zone (10.33% of TGA) occurred in hilly regions, forests and wasteland. More than 85 per cent of the watershed area was observed to have 'Moderate' potential zones. Well density was higher (0.12 per ha) in the 'High' potential zone and Moderate potential zone (0.06

per ha), While it was lower (0.01 per ha) in the ‘Poor’ potential zone. The groundwater potential map could substantially help in decisions related to investment in direct recharge of abandoned open wells and is also useful for policymakers.

- ❖ The development of LUP in the Sawangi watershed using DSS enables the user to taking suitable decisions.

GIS application in digital database generation

- ❖ GIS technology has great utility in enhancing decision-making capabilities, which can be useful for planning purposes in watershed areas.
- ❖ The evaluation of thematic data (present land use/land cover, slope, physiography, and soils) for fertility, erosion, land capability, irrigability, suitability, and productivity classes for the crops grown in the study area and their integration in the GIS environment enabled preparation of land use plan.
- ❖ From the study, it can be stated that remote sensing technology is an efficient tool for land use land cover mapping, landform analysis in conjunction with toposheet, and expediting the soil resource mapping with good ground truth checking. The suggested land use plan will help in achieving the potential yields on a sustainable basis for similar soils under similar agro-climatic conditions elsewhere.

CONCLUSIONS

- ❖ From the findings summarized above, The Sawangi watershed has population density of 169 per sq. km. It is mainly dependent on *Kharif* crops, for example, cotton, pigeon pea, soybean, and sorghum. These are the important crops of the *Kharif* season, while the dominant crops of the *Rabi* season are wheat and gram. The average per acre net benefit for cotton is Rs. 4175, while the cultivation cost is Rs. 16975 per acre. average yield is limited to 4.5 quintals.

- ❖ Based on the visual interpretation of LANDSAT-5, LANDSAT-8, Google image, and satellite data supported by field checks in the area, the study area was delineated into eight major land use/land cover classes *viz*., agriculture, current fallow, habitation, forest cover, shrubland, wasteland, industrial area, and waterbody. The land use and land cover change comparison of each class over different years result showed that agriculture area has been decreased continuously between 2008 to 2017. The current fallows land and wasteland has continuously increased between 2008 to 2012.

❖ Eventually, it is concluded that the change in approach for land use planning from 'edaphic' to 'resource based' has added new dimensions to the decision making. Integration of socio-economic factors, water status, and land parcel matrix has provided new insight into the LUP process.

How did resource-based planning help

1. The inclusion of socio-economic factors (as against planning based on bio-physical resources) indicated that crop depredation is a single dominant factor overshadowing others factors in crop selection. No crop other than cotton and soybean is currently feasible in the watershed.
2. Socio-economic factors namely size of land parcel and poverty (especially farmers below the poverty line) were also major factors influencing land-use planning.
3. Metrics, for example, the distance of land parcels from forests, villages, and water bodies emerged as major factors affecting crop choice when farmers decided to risk growing crops other than cotton and soybean.
4. Assessment of water resources and their integration with socio-economic data showed that a more focused approach for the development of target groups who have poor biophysical resources is possible and therefore the development department could utilize the developed maps or data for development prioritization/decisions.
5. The developed DSS is recommended to use by administrators, agriculture department officers, and farmers.

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APPENDIX - A

Pedons Descriptions
Sawangi – Series

Classification	:	Fine Smectitic, hyperthermic, (calcareous) Typic Haplustept
Type Location	:	Village : Sawangi; Tehsil : Ralegaon and District : Yavatmal; State : M.H. ; 20^0 24' 08'' N lat ; 78^0 32' 42''E long.
Profile No.	:	Series-1 (Sawangi)
Physiographic position	:	Alluvial Plain
Elevation	:	244 m above MSL
Ground water table	:	>10 m
Rainfall	:	800-930 mm
Slope, erosion & relief	:	Gently sloping, 3-8% (150-300 m); Erosion: Sever;
Drainage	:	Moderately well drained
Land use and vegetation	:	Single crop, Neem, Ber, Palas, Bel.
Geology & parent material	:	Basalt

Description

Horizon	Depth (cm)	
Ap	0-19	very dark grayish brown (10YR 3/2M), clay loam, moderate medium sub angular blocky structure, loose friable; slightly sticky and slightly plastic; medium nodules; pH 8.20; clear smooth boundary.
Bw_1	19-52	very dark grayish brown (10YR 3/2M), clay loam, moderate medium sub angular blocky structure, loose friable; slightly sticky and slightly plastic; medium nodules; pH 8.30; clear smooth boundary.
Bw_2	52-88	very dark grayish brown (10YR 3/2M), clay, moderate medium sub angular blocky structure, loose friable; slightly sticky and slightly plastic; medium nodules; pH 8.41; clear smooth boundary.
Bw_3	88-122	very dark gray (10YR 3/1M), clay, moderate medium sub angular blocky structure, loose friable; very sticky and very plastic; medium nodules; pH 8.74; clear smooth boundary.
Bw_4	122-158	very dark gray (10YR 3/1M), clay, moderate medium sub angular blocky structure, loose friable; very sticky and very plastic; medium nodules; pH 8.94; clear smooth boundary.

Remarks: Pressure faces observed in **Bw_3** and **Bw_4**

Pedons Descriptions
Pimpalkhuti - Series

Classification	:	Fine mixed, hyperthermic, (calcareous) Lithic Haplustept
Type Location	:	Village : Pimpalkhuti; Tehsil : Ralegaon and District : Yavatmal; State : M.H. ; 20^0 21' 48'' N lat ; 78^0 31' 45''E long.
Profile No.	:	Series-2 (Pimpalkhuti)
Physiographic position	:	Lower Pediment
Elevation	:	258 m above MSL
Ground water table	:	>10 m
Rainfall	:	800-930 mm
Slope, erosion & relief	:	Very gently sloping, 1-3% (300-600 m); Erosion: Moderate;
Drainage	:	Moderately well drained
Land use and vegetation	:	Double crop, Neem, Ber, Sagon.
Geology & parent material	:	Basalt

Description

Horizon	Depth (cm)	
Ap	0-20	very dark grayish brown (10YR 3/2M), clay, moderate medium sub angular blocky structure, loose friable; slightly sticky and slightly plastic; medium nodules; pH 8.32; clear smooth boundary.
Bw	20-44	very dark gray (10YR 3/1M), clay clay, moderate medium sub angular blocky structure, loose friable; slightly sticky and slightly plastic; medium nodules; pH 8.24; clear smooth boundary.
Cr	44+	grayish brown (10YR 5/2M), clay, Weathered parent material

Pedons Descriptions
Bhamb - Series

Classification	:	Fine smectitic, hyperthermic, (calcareous) Vertic Haplustept
Type Location	:	Village : Bhamb; Tehsil : Ralegaon and District : Yavatmal; State : M.H. ; 20^0 21' 48'' N lat ; 78^0 31' 45''E long.
Profile No.	:	Series-3 (Bhamb)
Physiographic position	:	Pedi plain
Elevation	:	258 m above MSL
Ground water table	:	>10 m
Rainfall	:	800-930 mm
Slope, erosion & relief	:	Very gently sloping, 1-3% (>600 m); Erosion: Moderate;
Drainage	:	Well drained
Land use and vegetation	:	Double crop, Neem, Ber, Sagon.
Geology & parent material	:	Basalt

Description

Horizon	Depth (cm)	
Ap	0-17	very dark grayish brown (10YR 3/2M), clay, moderate medium sub angular blocky structure, loose friable; very sticky and very plastic; medium nodules; pH 7.92; clear smooth boundary.
Bw_1	17-59	very dark gray (10YR 3/1M), clay, moderate medium sub angular blocky structure, loose friable; very sticky and very plastic; medium nodules; pH 7.95; clear smooth boundary.
Bw_2	59-92	dark brown (10YR 3/3M), clay, moderate medium sub angular blocky structure, loose friable; very sticky and very plastic; medium nodules; pH 8.26; clear smooth boundary.
Bw_3	92+	very dark gray (10YR 3/4M), clay, moderate medium sub angular blocky structure, loose friable; very sticky and very plastic; medium nodules; pH 8.16; clear smooth boundary.

Remarks: Pressure faces observed in **Bw_2** and **Bw_3**

Pedons Descriptions
Soyti - Series

Classification	:	Fine smectitic, hyperthermic, Typic Haplustert
Type Location	:	Village : Soyti; Tehsil : Ralegaon and District : Yavatmal; State : M.H. ; 20^0 20’ 53’’ N lat ; 78^0 31’ 34’’E long.
Profile No.	:	Series-4 (Soyti)
Physiographic position	:	Lower Valley
Elevation	:	255 m above MSL
Ground water table	:	>10 m
Rainfall	:	800-930 mm
Slope, erosion & relief	:	Very gently sloping, 1-3% (>600 m); Erosion: Moderate;
Drainage	:	Well drained
Land use and vegetation	:	Single crop, Babul, Bihada, Rohun.
Geology & parent material	:	Basalt

Description

Horizon	Depth (cm)	
Ap	0-18	very dark grayish brown (10YR 3/2M), clay, moderate medium sub angular blocky structure, loose friable; very sticky and very plastic; medium nodules; pH 8.63; clear smooth boundary.
Bw	18-48	very dark grayish brown (10YR 3/2M), clay, moderate medium sub angular blocky structure, loose friable; very sticky and very plastic; medium nodules; pH 8.78; clear smooth boundary.
Bss_1	48-73	dark brown (10YR 3/3M), clay, moderate medium sub angular blocky structure, loose friable; very sticky and very plastic; medium nodules; pH 8.71; clear smooth boundary.
Bss_2	73-102	dark brown (10YR 3/3M), clay, moderate medium sub angular blocky structure, loose friable; very sticky and very plastic; medium nodules; pH 7.95; clear smooth boundary.
BC	102+	very dark gray (10YR 3/4M), clay, moderate medium sub angular blocky structure, loose friable; very sticky and very plastic; medium nodules; pH 8.31; clear smooth boundary.

Remarks: Pressure faces observed in **BC** horizon and Slicken slide observed in **Bss_1** and **Bss_2** horizon.

Pedons Descriptions
Warna - Series

Classification	:	Fine smectitic, hyperthermic, Lithic Usterthent
Type Location	:	Village : Warna; Tehsil : Ralegaon and District : Yavatmal; State : M.H. ; 20^{0} 23’ 45’’ N lat ; 78^{0} 29’ 37’’E long.
Profile No.	:	Series-5 (Warna)
Physiographic position	:	Upper Pediment
Elevation	:	256 m above MSL
Ground water table	:	>10 m
Rainfall	:	800-930 mm
Slope, erosion & relief	:	Gently sloping, 3-8 % (>600 m); Erosion: Moderate;
Drainage	:	Well drained
Land use and vegetation	:	Double crop, Neem, Bel, Tesu, Mahuwa.
Geology & parent material	:	Basalt

Description

Horizon	Depth (cm)	
Ap	0-18	very dark gray (10YR 3/1M), clay, moderate medium sub angular blocky structure, loose friable; very sticky and very plastic; medium nodules; pH 6.55; clear smooth boundary.
Cr	18-30	brown (2.5YR 5/3M), clay, Weathered parent material.

Pedons Descriptions
Jalka - Series

Classification	:	Loamy mixed, hyperthermic, Lithic Usterthent
Type Location	:	Village : Jalka; Tehsil : Ralegaon and District : Yavatmal; State : M.H. ; 20^0 22' 02'' N lat ; 78^0 27' 43''E long.
Profile No.	:	Series-6 (Jalka)
Physiographic position	:	Denuded Plateau
Elevation	:	294 m above MSL
Ground water table	:	>10 m
Rainfall	:	800-930 mm
Slope, erosion & relief	:	Gently sloping, 3-8 % (>600 m); Erosion: Sever
Drainage	:	Well drained
Land use and vegetation	:	Single crop, Neem, Arjun, Mahuwa.
Geology & parent material	:	Basalt

Description

Horizon	Depth (cm)	
Ap	0-15	very dark gray (10YR 3/1M), clay, moderate medium sub angular blocky structure, slightly hard friable; very sticky and very plastic; medium nodules; pH 6.82; clear smooth boundary.
R	15+	Hard rock with boulders

Pedons Descriptions
Potgawhan - Series

Classification	:	Fine smectitic, hyperthermic, (calcareous) Lithic Haplustept
Type Location	:	Village : Potgawhan; Tehsil : Ralegaon and District : Yavatmal; State : M.H. ; 20^0 21’ 35’’ N lat ; 78^0 25’ 34’’E long.
Profile No.	:	Series-7 (Potgawhan)
Physiographic position	:	Plateau
Elevation	:	402 m above MSL
Ground water table	:	>10 m
Rainfall	:	800-930 mm
Slope, erosion & relief	:	Very gently sloping, 1-3 % (>600 m); Erosion: Moderate
Drainage	:	Well drained
Land use and vegetation	:	Single crop, Neem, Bel.
Geology & parent material	:	Basalt

Description

Horizon	Depth (cm)	
Ap	0-16	very dark gray (10YR 3/1M), clay, moderate medium sub angular blocky structure, hard friable; very sticky and very plastic; very fine nodules; pH 6.69; clear smooth boundary.
Bw	16-30	very dark grayish brown (10YR 3/2M), clay, moderate strong sub angular blocky structure, hard friable; very sticky and very plastic; very fine nodules; pH 6.84; abrupt smooth boundary.
R	30+	-----------

Pedons Descriptions
Nimgwan - Series

Classification	:	Loamy mixed, hyperthermic, Lithic Usterthent
Type Location	:	Village : Nimgwan ; Tehsil : Ralegaon and District : Yavatmal ; State : M.H. ; 20^0 21’ 21’’ N lat ; 78^0 25’ 57’’E long
Profile No.	:	Series-8 (Nimgwan)
Physiographic position	:	Escarpment
Elevation	:	388 m above MSL
Ground water table	:	>10 m
Rainfall	:	800-930 mm
Slope, erosion & relief	:	Moderately steep sloping, 15-30 % (300-600 m); Erosion: Sever;
Drainage	:	Well drained
Land use and vegetation	:	Degraded forest, Bamboo, Ber, Babul, Arjun.
Geology & parent material	:	Basalt

Description

Horizon	Depth (cm)	
Ap	0-14	very dark gray (10YR 3/1M), clay, moderate weak sub angular blocky structure, slightly hard friable; slightly sticky and slightly plastic; medium nodules; pH 6.82; abrupt smooth boundary.
Cr	14+	Hard rock with boulders

Pedons Descriptions
Nimgwan 2 - Series

Classification	:	Loamy mixed, hyperthermic, Lithic Usterthent
Type Location	:	Village : Nimgwan-2 ; Tehsil : Ralegaon and District : Yavatmal ; State : M.H. ; 20^0 19’ 38’’ N lat ; 78^0 26’ 21’’E long
Profile No.	:	Series-9 (Nimgwan-2)
Physiographic position	:	Denuded Plateau
Elevation	:	347 m above MSL
Ground water table	:	>10 m
Rainfall	:	800-930 mm
Slope, erosion & relief	:	Gently sloping, 3-8 % (300-600 m); Erosion: Moderate;
Drainage	:	Well drained
Land use and vegetation	:	Degraded forest, Palas, Sagon, Neem.
Geology & parent material	:	Basalt

Description

Horizon	Depth (cm)	
Ap	0-15	dark radish brown (5YR 3/4M), clay loam, moderate medium sub angular blocky structure, loose friable; slightly sticky and slightly plastic; medium nodules; pH 6.92; abrupt smooth boundary.
R	15-23	Hard rock with boulders

Pedons Descriptions
Dongarkharda - Series

Classification	:	Fine mixed, hyperthermic, Lithic Usterthent
Type Location	:	Village : Dongarkharda ; Tehsil : Ralegaon and District : Yavatmal ; State : M.H. ; 20^0 21' 21'' N lat ; 78^0 25' 57''E long
Profile No.	:	Series-10 (Dongarkhorda)
Physiographic position	:	Upper Valley
Elevation	:	321 m above MSL
Ground water table	:	>10 m
Rainfall	:	800-930 mm
Slope, erosion & relief	:	Gently sloping, 3-8 % (300-600 m); Erosion: Moderate;
Drainage	:	Well drained
Land use and vegetation	:	Degraded forest, Palas, Sagon.
Geology & parent material	:	Basalt

Description

Horizon	Depth (cm)	
Ap	0-16	very dark grayish brown (10YR 3/2M), clay loam, moderate medium sub angular blocky structure, loose friable; slightly sticky and slightly plastic; medium nodules; pH 7.62; abrupt smooth boundary.
Cr	16-36	greyish brown (2.5YR 5/2M), sandy loam, Weathered parent material.

APPENDIX – B

Criteria of Land Capability Classification

Characteristics	Class I	Class II	Class III	Class IV	Class V	Class VI	Class VII	Class VIII
Topography (t)								
Slope (%)	0-1	1 to 3	3 to 8	8 to 15	Upto 3	15 to 30	30 to 50	30 to 50
Erosion	Nil	Slight	Moderate	Severe	Nil	Severe	Very severe	Extreme rugged rocky
Wetness (w)								
Flooding	Nil (F0)	Almost nil (Fo/F1)	Slight (F1)	Moderate (F2)	Mod to severe (F2/F3	Nil, severe (F0 / F4)	Nil, very severe (F5)	-
Drainage	Well	Mod. Well	Imperfect	Poor	Very poor	Excessive	Excessive	Excessive
Physical soil condition (s)								
Surface texture	Loam	sil and cl	sl and c	scl	s, c (m)	ls-cl	ls, s, c	ls, s, c (m)
Surface Coarse fragments (Vol.%)	1 to 3	3 to 15	15 to 40	40 to 75	15 to 75	75+	-	-
Soil depth (cm)	>150	150-100	100-50	50-25	50-150+	25 - 10	< 10	Nil
Bulk Density (Mg m^{-3})	< 1.4	1.4 - 1.5	1.5 - 1.6	1.6 - 1.7	1.7 - 1.8	1.8 - 1.9	>1.9	-
Hydraulic conductivity (cm hr^{-1})	>2.0, <6.25	0.5-2.0, 6.25-12.5	0.125-0.5, 12.5-25.0	-	-	-	-	-
Fertility (f)								
pH	6.6 - 7.5	6.1-6.5, 7.6- 8.0	5.6-6.0, 8.1-8.5	5.1 - 5.5, 8.6-9.0	4.5-5.0, 9.1-9.5	4.5-5.0, 9.1-9.5	<4.5, >9.5	-
ECe dS m^{-1}	<1.0	1 to 2	2 to 4	4 to 8	8 to 15	15 to 35	35+	-
O.C. (0-15 cm) (%)	>1.0	0.75 -1.0	0.5 - 0.75	0.3 - 05	<0.3	-	-	-
$CaCO_3$ (%)	<5	5 to 10	10 to 15	15 to 20	20 to 25	25 to 50	>50	-

Source: Sehgal, (2005)

APPENDIX – C

Criteria of Land Irrigability Classification

Characteristics	Irrigability soil class				Non-irrigable soil class	
	A	B	C	D	E	F
Physical soil conditions (s)						
Effective soil depth (useful to crops) (cm)	<90	45 - 90	22.5 - 45	7.5 - 22.5	<7.5	-
Surface texture (30 cm)	sl to cl	ls,c	s,c	s,c	Any texture	-
Soil permeability (at least permeable layer (HC cm hr^{-1})	>2.0, <6.5	0.5-2.0, 6.25-12.5	0.125-0.5, 12.5-25.0	<0.125, >25.0	-	-
Available water holding capacity to depth of 90 cm	>12	9 to 12	6 to 9	2 to 6	<2	-
Coarse fragments (%) cobbles and stones (>75 mm)	<5	5 to 15	15 to 35	35 to 65	>65	-
Gravel and Kankar (25 - 75 mm)	<15	15 to 35	35 to 55	55 to 70	>70	-
Rock out crops (distance apart in meters)	40	20	15	5	<5	-
ECe dS m^{-1}	<4	4 to 8	8 to 12	12 to 16	>16	-
salt affected (visual) (% of area affected)	<20	<20	20 - 50	20 -50	>50	-
Severity of alkali problem (ESP)	ESP<15	ESP<15	ESP>15	ESP>15	-	-
Topography (t)						
Slope (%)	<1	1 to 3	3 to 5	5 to 10	-	-
Drainage (w)						
Depth of water table (M)	>5	3.0 to 5.0	1.5 to 3.0	<1.5	-	-

Source: IARI, (1970)

APPENDIX – D (1)

Soil-Site Suitability Criteria (crop requirements) for Cotton

Soil-site characteristics	Degree of limitation/Suitability class					
	0 (None)	1 (Slight)	2 (Moderate)	3 (Severe)	4 (Very severe)	
	S1		S2	S3	N1	N2
Climatic characteristics						
Total rainfall (mm)	850-1050	700-850	550-700	<550	-	-
Rainfall during growing season (mm)	750-950	600-750	450-600	<450	-	-
Rainfall during critical period (boll development) (mm)	100-120	-	-	-	-	-
Length of growing season (days)	160-180	160-140	140-120	<120	-	-
Mean temperature growing season (ºC)	22-28	28-32	>32	-	-	-
Mean max.temp. growing season (ºC)	-	-	-	>36	-	-
Mean min. temp. growing season (ºC)	-	-	-	<19	-	-
Mean R.H. in growing season	60-80	80-90	-	<50	-	-
Site characteristics						
Slope (%)	<1	1-3	3-5	>5	-	-
Erosion	e0	e1	e2	e3		
Drainage	Well	Mod. well	Imperfect	Poor and excessive	-	-
AWC (mm/m)	>200	150-200	100-150	50-100	-	-
Surface stoniness (%)	<15	<15	15-40	>40	-	-
Soil characteristics						
Texture (clay %)	35-50	25-35	<25, >60	-	-	-
Coarse fragments (vol. %) within 50 cm	<5	5-15	15-40	-	-	-
Coarse fragments below 50 cm	5-15	15-40	45-75	-	-	-
Depth (cm)	>100	80-100	60-80	30-60	<30	-
$CaCO_3$ (%) within 50 cm	<5	5-10	10-20	>20	-	-
Soil fertility						
CEC (soil) cmol (p+) kg^{-1}	>30	20-30	<20	-	-	-
B.S. (%)	>80	50-80	35-50	<35	-	-
O.C. (%) (0-15 cm)	>1.0	0.75-1.0	0.5-0.75	<0.5		
ECe (dS m^{-1})	<2	-	2-4	4-8	-	-
ESP (%)	<5	5-10	10-15	-	-	-
pH (1:2.5)	6.5-7.5	7.5-8.5	8.5-9.0	>9.0, <6.5	-	-

Source: Sys *et al.* (1991)

APPENDIX – D (2)

Soil-Site Suitability Criteria (crop requirements) for Soybean

Soil-site characteristics	Degree of limitation/Suitability class				
	0 (None) / 1 (Slight)	2 (Moderate)	3 (Severe)	4 (Very severe)	
	S1	**S2**	**S3**	**N1**	**N2**
Climatic characteristics					
Total rainfall (mm)	1200-1500	800-1200	600-800	<600	-
Rainfall during growing season (mm)	700-800	500-700	400-500	<400	-
Length of growing season (days)	120-140	100-120	85-100	<85	-
Mean temperature growing season (ºC)	27-30	30-32	32-34	>34	-
Mean R.H. in growing season	>80	70-80	50-70	<50	-
Site characteristics					
Slope (%)	<3	3-5	>5	>8	-
Drainage	Well to Mod. well	Imperfect	Poor and excessive	-	-
AWC (mm/m)	>200	150-200	100-150	50-100	<5 0
Surface stoniness (%)	<5	5-10	10-25	>25	-
Soil characteristics					
Texture (clay %)	cl, sil, l	sl, c (st)	c (w,st), ls	s	-
Depth (cm)	>75	60-75	40-60	<40	-
Soil fertility					
ECe (dS m^{-1})	<2	2-4	4-8	>8	-
ESP (%)	<5	5-10	10-15	>15	-
pH (1:2.5)	6.0-7.5	7.5-8.5 <6.0-5.5	>8.5 <5.5	-	-

Source: Sys *et al.* (1991)

Note: st- structure, w. st- without structure

APPENDIX – D (3)

Soil-Site Suitability Criteria (crop requirements) for Pigeonpea

Soil-site characteristics	Degree of limitation/Suitability class					
	0 (None)	1 (Slight)	2 (Moderate)	3 (Severe)	4 (V. severe)	
	S1		S2	S3	N1	N2
Climatic characteristics						
Total rainfall (mm)	1200-1000	1000-850	850-700	700-550	<550	-
Rainfall during growing season (mm)	1000-850	850-750	750-600	600-500	<500	-
Length of growing season (days)	>200	200-150	150-120	120-100	<100	-
Mean temperature growing season (°C)	28-26	26-24	24-22	22-20	<20	-
Mean max.temp. growing season (°C)	35-32	32-28	28-26	26-24	<24 >40	-
Site characteristics						
Slope (%)	0.5-2.0	2.0-3.0 <0.5	3.0-5.0	5.0-8.0	>8.0	-
Erosion	e0	e1	e2	e2-e3	e3	-
Drainage	Well	Mod. well	Imperfect	Poor and excessive	-	-
AWC (mm/m)	>200	150-200	100-150	50-100	<50	-
Surface stoniness (%)	<3	3-15	15-40	40-75	>75	-
Soil characteristics						
Texture (clay %)	L, sicl, sil, sc, sic, F. loamy, F. silty	C, sc, fine	V. fine, coarse loamy, csl, scl	Sandy skeletal	-	-
Coarse fragments (vol. %) within 50 cm	<5	5-15	15-40	40-75	>75	-
Coarse fragments below 50 cm	5-15	15-40	45-75	>75	-	-
Depth (cm)	>125	100-125	50-100	30-50	<30	-
Soil fertility						
CEC (soil) cmol (p+) kg^{-1}	30-20	20-15	15-10	<10	<5	-
B.S. (%)	>80	50-80	35-50	<35	-	-
O.C. (%) (0-15 cm)	>.75	0.75-0.5	0.5-0.2	<0.2		
ECe (dS m^{-1})	<0.5	0.5-1.0	1.1-2.0	>2.0	-	-
ESP (%)	<2.5	2.5-5.0	5.0-7.5	7.5-10.0	>10.0	-
pH (1:2.5)	6.5-7.5	7.5-8.5 <6.5	8.5-9.0 <5.5	>9.0	-	-

Source: Sys *et al.* (1991)

APPENDIX – D (4)

Soil-Site Suitability Criteria (crop requirements) for Sorghum

Soil-site characteristics	Degree of limitation/Suitability class					
	0 (None)	1 (Slight)	2 (Moderate)	3 (Severe)	4 (Very severe)	
	S1		S2	S3	N1	N2
Climatic characteristics						
Total rainfall (mm)	750-850	650-750 >850	650-550	450-550	<450	-
Rainfall during growing season (mm)	700-600	500-600	400-500	300-400	<300	-
Length of growing season (days)	150-120	120-100	100-90	<90	-	-
Mean temperature growing season (^oC)	32-26	26-24	24-22	22-20	<20	-
Mean max.temp. growing season (^oC)	31	31-33	33-35	>35	-	-
Mean min. temp. growing season (^oC)	>22	22-18	18-15	<15	-	-
Mean R.H. in growing season	70-60	60-50	50-40	<40	-	-
Site characteristics						
Slope (%)	0.5-2.0	2-3	3-5	5-8	>8	-
Erosion	e0	e0	e1	e2	e3	
Drainage	Well	Mod. well	Imperfect	Poor and excessive	-	-
AWC (mm/m)	>200	150-200	100-150	50-100	<50	-
Surface stoniness (%)	<5	5-15	15-30	30-60	>60	-
Soil characteristics						
Texture (clay %)	Fine loamy	Fine	V. fine and clay loamy	Sandy, skeletal	Fragmental	-
Coarse fragments (vol. %) within 50 cm	<5	5-15	15-40	40-75	-	-
Coarse fragments below 50 cm	5-15	15-40	40-75	>75	-	-
Depth (cm)	>100	100-50	50-30	<30	-	-
$CaCO_3$ (%) within 50 cm	<5	5-10	10-25	>25	-	-
Soil fertility						
CEC (soil) cmol (p+) kg^{-1}	>30	30-20	20-10	<10	-	-
B.S. (%)	>80	80-50	50-35	<35	-	-
O.C. (%) (0-15 cm)	>0.75	0.75-0.50	0.5-0.2	<0.2	-	-
ECe (dS m^{-1})	<0.2	0.2-0.4	0.4-0.8	0.8-1.0	>1.0	-
ESP (%)	<5	5-10	10-15	15-25	>25	-
pH (1:2.5)	6.5-7.5	6.5-5.5 7.5-8.0	5.5-5.0 8.0-8.5	<5.0 8.5-9.0	>9.0 -	- -

Source: Sys *et al.* (1991)

APPENDIX – D (5)

Soil-Site Suitability Criteria (crop requirements) for Wheat

Soil-site characteristics		Unit	Rating Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime	Mean temperature in growing season	°C	20-25	15-19	5-15 26-30	<5 >30
	Total rainfall	Mm	800-1000	600-800	400-600	<400
Land quality	Land characteristics					
Moisture availability	Length of growing period for short duration varieties	Days	>100	90-100	70-90	<70
	Length of growing period for long duration varieties	Days	>150	120-150	90-120	<90
Oxygen availability to roots	Soil drainage	Class	Well drained	Moderately well drained; imperfectly drained	Poorly drained; excessively drained	Very poorly drained
Nutrient availability	Texture	Class	l, cl, sil, scl	sic, c, sicl,	sl, c >60 %	
	pH	1:2.5	6.0-7.5	7.6-8.0; 5.5-5.7	8.1-9.0; 4.5-5.4	<9.0
Rooting conditions	Effective soil depth	Cm	>75	51-75	25-50	<25
	Coarse fragments	Vol. %	<15	15-35	>35	
Soil toxicity	Salinity (EC saturation extract)	dS/m	<1.0	1.0-2.0	>2.0	
	Sodicity (ESP)	%	<10	10-15	>15	
Erosion hazard	Slope	%	<3	3-5	5-10	>60 %

Source: Naidu *et al.* (2006)

Note: c+ = clay (45-60 %), c++ = clay (> 60 %)

APPENDIX – D (6)

Soil-Site Suitability Criteria (crop requirements) for Chickpea

Soil-site characteristics		Unit	Rating			
			Highly suitable S1	**Moderately suitable S2**	**Marginally suitable S3**	**Not suitable N**
Climatic regime	Mean temperature in growing season	°C	20-25	15-19	5-15 26-30	<5 >30
	Total rainfall	Mm	800-1000	600-800	400-600	<400
Land quality	Land characteristics					
Moisture availability	Length of growing period for short duration varieties	Days	>100	90-100	70-90	<70
	Length of growing period for long duration varieties	Days	>150	120-150	90-120	<90
Oxygen availability to roots	Soil drainage	Class	Well drained	Moderately well drained; imperfectly drained	Poorly drained; excessively drained	Very poorly drained
Nutrient availability	Texture	Class	l, cl, sil, scl	sic, c, sicl,	sl, c >60 %	
	pH	1:2.5	6.0-7.5	7.6-8.0; 5.5-5.7	8.1-9.0; 4.5-5.4	<9.0
Rooting conditions	Effective soil depth	Cm	>75	51-75	25-50	<25
	Coarse fragments	Vol. %	<15	15-35	>35	
Soil toxicity	Salinity (EC saturation extract)	dS/m	<1.0	1.0-2.0	>2.0	
	Sodicity (ESP)	%	<10	10-15	>15	
Erosion hazard	Slope	%	<3	3-5	5-10	>60 %

Source: Naidu *et al.* (2006)

Plate 1. Very shallow depth soil (30 cm depth)

Plate 2. shallow depth soil (44+ cm depth)

Plate 3. Deep depth soil (110 cm depth)

Plate 4. Very deep depth soil (150+ cm depth)

Plate 5. Very shallow depth soil (28 cm depth)

Plate 6. Very shallow depth soil (14 cm depth)

Plate 7. (Very well-developed slickensides)

Plate 8. Deep depth soil (120+ cm depth)

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Characterization and classification of soils under different landforms using RS and GIS: A case study of Sawangi watershed of Yavatmal district, Maharashtra

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Abstract
In the present investigation was carried out in Sawangi watershed of Yawatmal district, Maharashtra, the main objectives of this investigation is to characterize and classification the soils of the Sawangi watershed as well as evaluate for sustainable management of the natural resources. An attempt has been made to integrate the visual interpretation of ALOS-DEM, sentinel 2A data and subsequent ground truth verification for delineation of landforms map and soil series. Soil resource inventory at 1:10,000 scale was developed using base map by establishing the soil-landform relationship. Ten soil series have been identified with fourteen soil phases from the landform units. The soils were very shallow to very deep (14 to150 cm) in depth, soil slope is very gently sloping (1–3%) to steeply sloping (30-50%), exhibits colour in (dark reddish brown to dark yellowish brown) hue 2.5 YR, 5 YR and 10 YR, value 3 to 5, and chroma 1 to 4. The soil reaction (pH) are slightly acidic to strongly alkaline (6.55 to 8.94) in nature and electrical conductivity (EC) were (0.12 to 4.40) dSm^{-1} increasing trend with depth is noticed, very low to medium in organic carbon content, calcium carbonate ranged from (2.71 to 12.44%), exchangeable cations were found in the order to Ca2+>Mg2+>Na+>K+ indicated and cation exchange capacity (CEC) varies from (31.39 to 70.43) cmol (p+) kg^{-1} indicates in all the soils. The soils having clayey to sand clay loam in texture, bulk density were (1.4 to 1.8) Mg m^{-3} and AWC ranged from (8.3 to 31.2%) in the different horizons of the soil, This soil comes under *Vertisols, Inceptisols* and *Entisols* soil orders. Based on the different landforms and soil characteristics, these soils are classified as Typic Haplusterts, Lithic Ustorthents, Vertic Haplustepts, and Sodic Haplusterts at the subgroup level.

Keywords: Soil characterization, classification, land evaluation, landform

Introduction

Soil characterization determines the soil's individual inherent potentials and constraints for crop production besides giving detailed information about the different soil properties. Characterization and systematic classification of dominant soil groups is an essential tool and a pre-requisite for soil fertility evaluation and efficient soil-fertilizer-water management practices and, thus, crop management. The ability of the land to produce is limited and the limits to produce are set by soils, climate, landforms conditions and farming situations. Further, the capacity of soil to produce is also limited and constrains are due to intrinsic characteristics, agro-ecological settings, use and management (FAO Statistics, 2007-08). Information on the soil characteristics and quality has been recognized as an important requirement in the planning process for sustainable management of land resource towards crop planning. Studies on soil genesis have shown that soils from different parent materials show variation in depth, colour, texture, structure, consistence and development of diagnostic sub-surface horizons and morphological properties (Tamgadge *et al*., 1999) [7] and these variations are attributable to orientation of topography and landforms. Landform features are manifestations of underlaying parent material and the nature and duration of their processes. Site-specific geomorphological interpretation is a pre-requisite for landforms mapping and subsequent analysis of the landform-soil relationships. The soil and landform relationship on a toposequence plays a vital role in classification of landforms (Adams and Walker 1975). Generally, soils developing in any given landform show very close relationship with different slope units of the landforms and the toposequence (Dent and Young 1981). Detailed geomorphological site analysis is generally adopted for high intensity soil mapping of an area in a precise manner (Wright 1993). The inter-relationships between landforms and soils are linked to the interaction of landforms, bedrock geology and hydrological systems under a specific climatic condition (Gerrard 1990).

Landforms situated at varying elevation have pronounced effect on the physical and physico-chemical properties of the soils (Gaikward *et al*., 1986). Sharma *et al*., (1996) [15] studied morphology, physicochemical and chemical characteristics of soils in basaltic terrain and observed that the soils at elevated topography were shallow to moderately shallow, clayey to loamy skeletal and yellowish brown, whereas the soils at lower topography were deep to very deep, fine loamy to fine and grayish. The present investigation was undertaken to analyse the geomorphological features, soils and their physical and chemical characteristics for their characterization and classification in a toposequence of Sawangi watershed in Yavatmal district of Maharashtra.

Material and Methods

Study area

The Sawangi watershed area is located between 20º 15' 47" to 20º 20' 42" N latitude and 77º 35' 27" to 77º 42' 54" E longitude, The elevation ranges from 161 to 356 m (WGS 84 datum) above mean sea level (MSL). which covers an area of 11777.62 ha in Yavatmal district, Maharashtra. The average annual rainfall of 917.36 mm (decennial average of 2008-2017), out of which maximum rainfall (85.95 per cent) is received during rainy season (late June to October) and 3.14 per cent during winter (December to February). The climate is mainly hot moist to semi-arid type with annual mean maximum and minimum temperatures of 33.8 ºC and 23.31 ºC respectively. Soil moisture regime is *ustic* and *hyperthermic* soil temperature regime (Soil Survey Staff 2014). The geology of the study area is covered by Deccan trap formation known as basalt flows, which belongs to Sahyadri group of Ajanta and Chikhli formations. (District Resource Map, Yavatmal District, Maharashtra of Geological survey of India, 2001). These areas crops growing are mostly under cotton, soybean, pigeon pea, sorghum, gram, wheat, and vegetables.

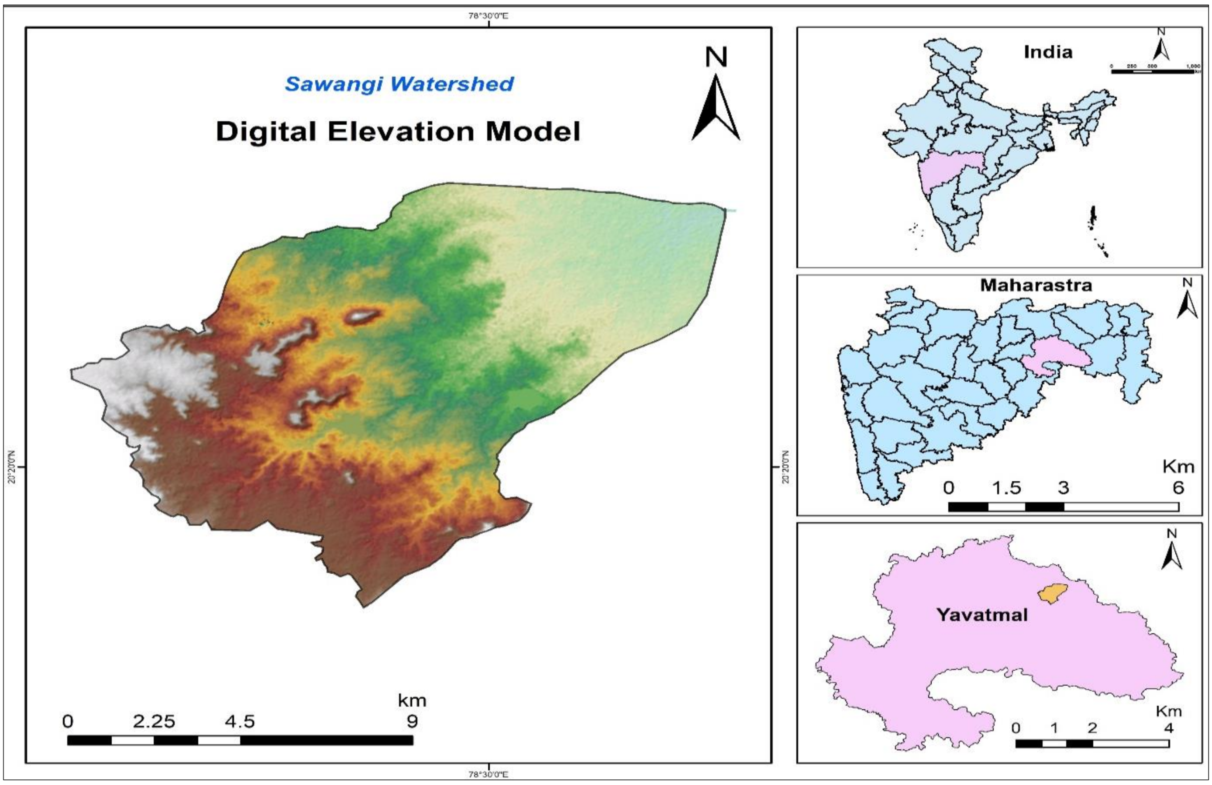

Fig 1: Location map of Sawangi watershed

Data used

The remote sensing data used were - Sentinel-2A (10m), ALOS PALSAR DEM (Digital Elevation Model) (12.5M), Landsat-5 TM (Thematic Mapper) and Landsat-8 OLI (Operational Land Imager). The satellite image was used as delineation of landforms and base map for location of sample areas, ground truth sites and planning to traverse in the field and other details.

Methods

Soil survey at 1:50,000 scale was carried out using base map and landform-soil relationship was established. Soil pedons were georeferenced (Table 1). Nearly 2.0 kg of representative soil sample from each horizon from representative pedons were collected for laboratory analysis. Soil clods were collected from different horizons for the determination of bulk density. The analysis of physical, chemical and nutrient properties of collected samples were carried out using standard procedures (Black 1965; Jackson 1967; Lindsay and Norvell 1978) [8]. The soils were classified as per Soil Taxonomy (Soil Survey Staff 2003). Physical properties of the soils, such as particle size distribution were determined by the international pipette method (Klute, 1986) [11]. The bulk density was determined by clod coating method (Black and Hartge, 1986) [10]. Chemical properties like pH and EC of the soil suspension (1:2 ratio) was determined by the methodology of Jackson (1973) [8]. For the determination of soil organic carbon (SOC), the modified Walkley and Black wet oxidation method was used (Walkley and Black, 1934; Jackson, 1973) [31, 8]. The free calcium carbonate was determined by rapid titration method (Piper, 1966) [19]. The exchangeable cations and cation exchange capacity of soils were determined using methods outlined by Richards (1954).

Results and Discussion
Landform studies
A detailed landform site analysis was carried out based on relief amplitude, position in toposequence, contours and drainage channel networks (Wright 1993). The landforms identified based on visual interpretation of ALOS-DEM, sentinel 2A data and subsequent ground truth verification, a landform map has been prepared and the different landforms identified were as follows *viz.*, mound, plateau, denuded plateau, escarpment, upper pediment, lower pediment, alluvial plain, pediplain, upper valley, lower valley and waterbody depict (Fig. 2).

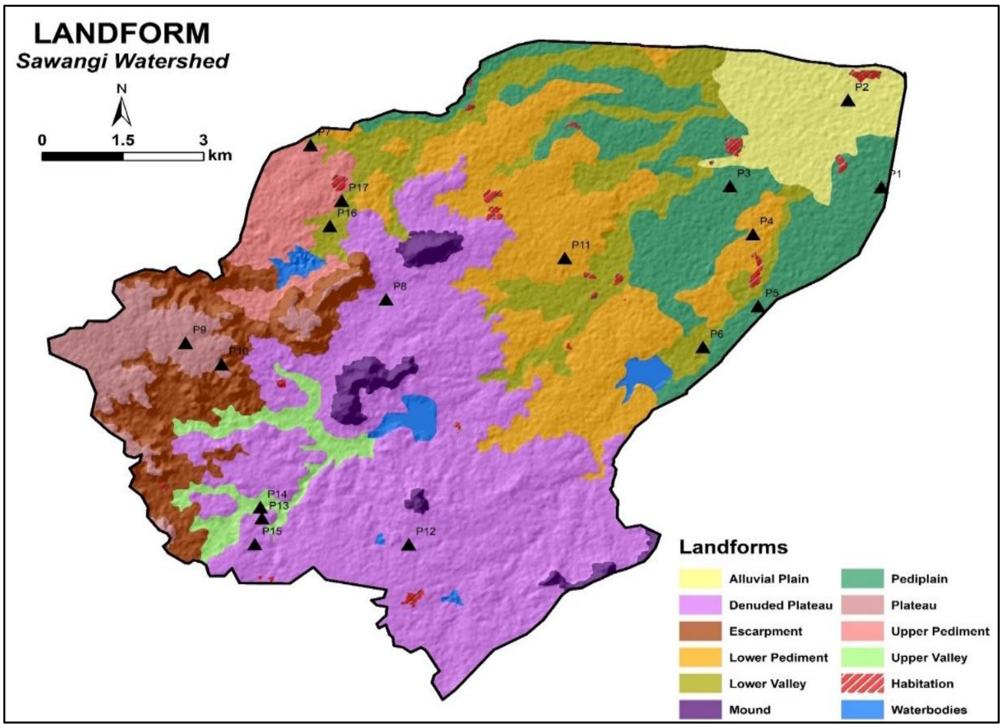

Fig 2: Landform map of Sawangi watershed

A review of data shows (Table 2) that the denuded plateau is the major landform portion of the watershed involving an area of 3849.19 ha representing about 32.68 per cent of the total geographic area (TGA) of the watershed, followed by lower pediment 1854.51 ha (15.75 % of TGA). The upper valley and lower valley cover an area of 322.32 ha (2.74 % of TGA) and 1254.04 ha (10.65 % of TGA) respectively. Escarpment occupies 876.25 ha (7.44 % of TGA) and pediplain involving 1463.94 ha (12.43 % of TGA). Upper pediment and alluvial plain cover an area of 435.13 ha (3.69 % of TGA) and 619.44 ha (5.25 % of TGA) respectively. The mound and plateau cover area of 238.73 ha (2.03 % of TGA) and 540.58 ha (4.59 % of TGA). Waterbody occupies an area of 170.27 ha (1.44 % of TGA) and habitation 80.51 ha (0.68 % of TGA.

Table 1: Extend and distribution of different landform units of Sawangi watershed

Sl. No.	Landform units	Area (ha)	% TGA
1	Mound	238.73	2.03
2	Plateau	540.58	4.59
3	Denuded Plateau	3849.19	32.68
4	Escarpment	876.25	7.44
5	Upper Pediment	435.13	3.69
6	Lower Pediment	1854.51	15.75
7	Alluvial Plain	619.44	5.25
8	Pediplain	1463.94	12.43
9	Upper Valley	322.32	2.74
10	Lower Valley	1254.04	10.65
11	Habitation	80.51	0.68
12	Waterbody	170.27	1.44
	Total Geographic Area (TGA)	11777.62	100

Soil Morphological Characteristics
The soil morphological description of the study area will be presented in the (table 2). The depth of different pedons of study area of Sawangi watershed ranges from 10 cm to 150+ cm and found to have deep to very deep solum. Pedon 2, 3, 4, 5 and 10 were shallow to moderately deep (25 -50 cm), Pedons 6 and 7 were deep (50-100 cm) whereas the pedons 1, 8 and 9 were very deep (>100 cm) respectively. Nasre *et al*. (2013). The identified that, soil depth is correlated between slope and degree of soil erosion. It was noticed that soils developed on mount, denuded plateau, escarpments and upper pediment were shallow and soils developed on pediplain, lower pediment, alluvial plains, plateau, and valleys were deep to very deep. The soil colour of different pedons of the study area were varied from dark reddish brown to very dark grayish brown in colour. Whereas hue in the range of 2.5 YR, 5 YR, and 10 YR, value of 3 to 5 and chroma in the range of 1 to 4 respectively. This may be due to moist conditions prevailing for a longer period favoring reduction of iron under impeded drainage (Prasad *et al*., 1989), and complexion and chelation of organic colloids on the surface of smectite (Singh *et al*., 1994) [94]. The surface horizon soils of all pedons have well developed sub angular blocky structures. The sub-surface horizon had sub angular blocky to angular blocky structures. Some of the pedons (P8 and P9) in the sub-surface horizon having cracks, slickensides, and pressure faces were associated with course, strong, and angular blocky structures. This may be attributed to the high shrink and swelling phenomena of smectite clay present in the soil (Prasad *et al*., 1989). All the pedons observed soil consistence varied from loos to hard, firm to friable, and non-sticky and non-plastic to very sticky and very plastic in dry, moist and wet conditions, respectively. The effervescence all the pedons observed slight

to strong effervescence (with 10 per cent HCl). This has been mainly due to the leaching of bicarbonates during rainy season from the upper layers due to subsequent precipitation and prevailing semi-arid climatic conditions (Balpande *et al*., 1996)

Soil Physical Characteristics

The particle size distribution observed that the clay content varied from 26.5 to 71.3 per cent in the surface horizons and sub-surface ranged from 17.8 to 77.2 per cent. The silt and sand content varied from from 5.9 to 47.8 per cent and from 1.7 to 76.2 per cent respectively. All the pedons have clay contents increased with depth. Basalt, being the parent material of these soils, is known to produce higher amount of clay (Pal and Deshpande, 1987; Eswaran *et al*., 1988; Sannigrahi *et al*., 1992; Gaikwad and Tamgadge, 1993) [7]. The variation in soil separation may be due to soil developed on different physiographic units and its parent material (Murthy *et al.* 1994) [13]. The development of varied particle size fractions may be due to the illuviation and transportation of finer particles from higher to lower elevations and partly because of an active churning process resulting from swelling and shrinking nature of the clay minerals. The bulk density of the soils varied from 1.39 to 1.81 Mg m^{-3}. The increase of bulk density with depth of soil may be attributed to over-burden pressure causing compaction in the subsurface horizons (Ahuja *et al*., 1988) [17], on the other hand, the surface soils are less compact probably due to high amount of organic matter and plant root concentration (Coughlan *et al*., 1986). The available water content varies from 8.3 per cent to 22.0 per cent in the surface horizons and its related to clay content and organic matter. The AWC increased with an increase in clay content. This trend can be attributed to high amounts of 2:1 type smectitic clay. A linear relationship between clay content and moisture retention was also reported (Nagar *et al*., 1995; Balpande *et al*., 2007) [3, 15]. The water holding capacity ranged from 31.9 to 46.5 per cent in the surface horizons of soil. These differences in water holding capacity were due to variation in the depth, clay, silt and organic carbon content of the pedons.

Soil Chemical Characteristics

The soil reaction of the study area was slightly acidic to strongly alkaline reaction with the pH values varying from 6.55 to 8.63 in surface horizons and from 6.84 to 8.94 in subsurface horizons. The pH value generally increased with depth may be due to higher exchangeable Na+ and ESP in the subsurface soils (Garg, 2000). The electrical conductivity of soil was normal to high and varied from 0.12 to 0.87 dSm^{-1} in all the pedons but pedon 9 observed exceptional results which is varied from 0.39 to 4.40 dSm^{-1}. The organic carbon content in soils ranged from 0.29 to 1.83 per cent. Almost all the pedons observed a decreasing trend in organic carbon with depth of soil, mainly due to the accumulation of plant residues on the soil surface and less movement to the subsurface horizon due to the rapid rate of mineralization at a higher temperature and adequate soil moisture level (Rao *et al*., 2008; Dahifale *et al*., 2009) [22]. The calcium carbonate in all the pedons ranged from nill to 14.68 per cent in different horizons and showed increasing trends with soil depth, which indicates leaching down of calcium salt and subsequent precipitation at lower depth may be due to high pH level (Pal *et al.,* 2000; Challa *et al.,* 2000 and Kuchanwar *et al*., 2017). The exchangeable calcium and magnesium were the dominant exchange complex followed by sodium and potassium cation observed in all the pedons. The exchangeable cations were found in the order Ca2+>Mg2+>Na+>K+ indicating the presence of calcium bearing minerals in parent rocks (Sarkar *et al*., 2001; Maji *et al*., 2005) [12]. The exchangeable calcium and potassium decreased while magnesium and sodium increased with depth. Similar results were reported by Kadam *et al*., (2013) [5], Nimkar *et al*., (1992) [16]; Thumbal and Patil, (2015). The cation exchange capacity of soils varies from 31.39 to 70.43 cmol (p+) kg^{-1} indicates (Table 3) in all the pedons. The higher CEC value in some horizons are attributed to the higher amount of clay and smectite type of clay minerals, whereas low CEC value results from the high amount of sand content and mixed type of minerals (Kaushal *et al*., 1986; Balpande *et al*., 1996) [10]. This indicates that base saturation in all the pedons varied from 76.9 to 113.3 per cent, which is more than 100 per cent due to the presence of Ca-zeolites (Pal *et al.,* 2006). The exchangeable sodium percentage ranged from 0.90 to 21.50 per cent. The exchangeable sodium percentage observed in all the pedons increased with soil depth.

Table 2: Morphological properties typical pedons in Sawangi watershed

Horizon	Depth (cm)	Boundary		Matrix Colour	Texture	Coarse fragments (%)	Structure			Consistence			Porosity		Roots		Effervescence	Nodules		Other features
		D	T				S	G	Ty	D	M	W	S	Q	S	Q		S	Q	
Pedon 1: Bhamb series - Fine smectitic, hyperthermic, Vertic Haplustepts																				
Ap	0-17	c	s	10YR 3/2	c	-	m	2	sbk	h	fr	vsvp	vf	m	c	m	ev	m	m	
Bw1	17-59	c	s	10YR 3/1	c	-	m	3	sbk	-	fr	vsvp	vf	m	c	m	ev	m	m	
Bw2	59-92	c	s	10YR 3/3	c	-	m	3	sbk	-	fr	vsvp	vf	m	c	m	ev	m	m	
Bw3	92+	c	s	10YR 3/4	c	-	m	2	sbk	-	fr	vsvp	vf	m	c	m	ev			
Pedon 2: Dongarkharda series - Fine mixed, hyperthermic, Lithic Ustorthents																				
Ap	0-16	-	-	10YR 3/2	c	-	m	2	sbk	-	-	-	-	-	-	-	-	-	-	-
Cr	16-36	-	-	10YR 5/2	gr. sl	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pedon 3: Jalka series - Loamy mixed, hyperthermic, Lithic Ustorthents																				
Ap	0-15	c	s	10YR 3/3	cl	-	m	2	sbk	sh	fr	sssp								
R	15+																			
Pedon 4: Nimgawhan-1 series - Loamy mixed, hyperthermic, Lithic Ustorthents																				
A	0-14	a	s	2.5YR 3/3	gr. l	-	m	1	sbk	-	-	-	vf	m	f	m	-	-	-	-
Cr	14+																			
Pedon 5: Nimgawhan-2 series - Loamy mixed, hyperthermic, Lithic Ustorthents																				
Ap	0-15			5YR 3/3	l	-	m	2	sbk	l	fr	sssp	f	m	-	-	-	-	-	-
R	15-23																			
Pedon 6: Pimpalkhuti series - Fine mixed, hyperthermic, Lithic Haplustepts																				
Ap	0-20	c	s	10YR 3/2	c	-	m	2	sbk	h	fr	vsvp	vf	m	m	m	ev	m	m	

Bw	20-44	c	s	10YR 3/1	c	-	m	3	sbk	-	fi	vsvp	vf	m	m	f	ev	m	m	
Cr	44+	c	s		scl	>90	-	-	-	-							ev			

Horizon	Depth (cm)	Boundary		Matrix Colour	Texture	Coarse fragments (%)	Structure			Consistence			Porosity		Roots		Effervescence	Nodules		Other features
		D	T				S	G	Ty	D	M	W	S	Q	S	Q		S	Q	
Pedon 7: Potgawhan series - Fine smectitic, hyperthermic, Lithic Haplustepts																				
Ap	0-16	c	s	10YR 3/1	c	-	m	2	sbk	h	fr	vsvp	vf	m			e			
Bs	16-30	a	s	10YR 3/2	c	-	m	3	sbk		fi	vsvp	vf	f			e			
R/Cr	30+					>90														
Pedon 8: Sawangi series - Fine Smectitic, hyperthermic, Typic Haplustepts																				
Ap	0-19	c	s	10YR 3/2	cl	-	m	2	sbk	l	fr	sp	f	m	f	m	ev	m	m	
Bw1	19-52	c	s	10YR 3/2	cl	-	m	3	sbk		fr	sp	f	m	f	m	ev	m	m	
Bw2	52-88	c	s	10YR 3/2	c	-	m	3	sbk		fr	sp	f	m	f	f	ev	m	m	
Bw3	88-122	c	s	10YR 3/1	c	-	m	3	abk		fi	vsvp	vf	m			ev	f	m	pf
Bw4	122-150	c	s	10YR 3/1	c	-	m	3	abk		fi	vsvp	vf	m			ev	f	m	pf
Pedon 9: Soyati series - Fine smectitic, hyperthermic, Sodic Haplusterts																				
Ap	0-18	c	s	10YR 3/2	c	-	m	2	sbk	h	fr	vsvp	vf	m	-	-	ev	m	m	
Bw1	18-48	c	s	10YR 3/2	c	-	m	3	sbk		fi	vsvp	vf	m	-	-	ev	m	m	
Bss1	48-73	c	s	10YR 3/3	c	-	m	3	abk		fi	vsvp	vf	m	-	-	ev	m	m	ss
Bss1	73-102	c	s	10YR 3/3	c	-	m	3	abk		fi	vsvp	vf	m	-	-	ev	m	m	ss
Bc	102+	c	s	10YR 3/4	c	>60	m	2	abk		fi	vsvp	vf	m	-	-	ev	m	m	pl/gr
Pedon 10: Warna series - Fine smectitic, hyperthermic, Lithic Ustorthents																				
Ap	0-18			10YR 3/1	c	-	m	2	sbk	h	fr	vsvp	vf	m						
Cr	18-30			10YR 5/3		-														

Table 3: Physical properties of soils of watershed

Horizon	Depth (cm)	Particle Size Distribution				Bulk Density (Mg m^{-3})	Water Retention			WHC
		Sand (%)	Silt (%)	Clay (%)	Class		-33 kPa	-1500 kPa	AWC (%)	
Pedon 1: Bhamb series - Fine smectitic, hyperthermic, Vertic Haplustepts										
Ap	0-17	4.8	29.8	65.5	clay	1.5	50.9	34	16.9	42.5
Bw1	17-59	2.3	27.1	70.6	clay	1.6	50.6	31.7	18.9	42.1
Bw2	59-92	7.3	26.5	66.2	clay	1.5	36	20.6	12.7	38.1
Bw3	92+	8.5	29.3	62.2	clay	1.5	31	22.3	13.5	37.6
Weighted mean		4.54	27.40	68.06		1.58	45.42	28.14	16.29	40.76
Pedon 2: Dongarkharda series - Fine mixed, hyperthermic, Lithic Ustorthents										
Ap	0-16	39.8	22.6	37.6	clay loam	1.5	31.7	17.9	13.8	46.5
Cr	16-36	76.2	5.9	17.8	sandy loam	1.6	28.8	19.3	9.5	43.4
Weighted mean		60.05	13.33	26.62		1.56	30.09	18.68	11.41	44.79
Pedon 3: Jalka series - Loamy mixed, hyperthermic, Lithic Ustorthents										
Ap	0-15	24.4	33.6	42.0	clay	1.6	30.1	17.8	12.3	31.9
Pedon 4: Nimgawhan series - Loamy mixed, hyperthermic, Lithic Ustorthents										
A	0-14	25.7	47.8	26.5	loam	1.5	36.4	25.7	10.7	42.7
Pedon 5: Nimgawhan-2 series - Loamy mixed, hyperthermic, Lithic Ustorthents										
Ap	0-15	36.2	27.3	36.4	clay loam	1.4	30.5	14.4	16.1	43.1
Pedon 6: Pimpalkhuti series - Fine mixed, hyperthermic, Lithic Haplustepts										
Ap	0-20	7.3	21.4	71.3	clay	1.6	36.6	24	12.6	38.1
Bw	20-44	12.6	33.6	53.8	clay	1.6	34	22	12.0	36.7
Cr	44+	62.7	9.3	28.0	sandy clay loam	1.7	22.6	13.1	9.5	24.8
Weighted mean		10.20	28.05	61.75		1.61	35.18	22.91	12.27	37.32

Horizon	Depth (cm)	Particle Size Distribution				Bulk Density (Mg m^{-3})	Water Retention			WHC
		Sand (%)	Silt (%)	Clay (%)	Class		-33 kPa	-1500 kPa	AWC (%)	
Pedon 7: Potgawhan series - Fine smectitic, hyperthermic, Lithic Haplustepts										
Ap	0-16	3.0	25.5	71.5	clay	1.4	43.8	29.2	11.5	40.7
Bs	16-30	1.7	21.8	76.4	clay	1.7	40.7	28.9	15.4	36.5
Weighted mean		2.39	23.81	73.80		1.53	42.35	29.06	13.30	38.73
Pedon 8: Sawangi series - Fine Smectitic, hyperthermic, Typic Haplustepts										
Ap	0-19	45.8	15.5	38.7	sandy clay loam	1.6	21.8	11.6	8.3	46.0
Bw1	19-52	46.7	22.8	30.4	sandy clay loam	1.7	21.2	10.9	10.2	40.8
Bw2	52-88	35.8	40.1	24.1	loam	1.6	24.7	13	11.7	48.9
Bw3	88-122	12.2	31.3	56.2	clay	1.7	44.1	26.1	15.5	48.3
Bw4	122-150	10.0	27.5	62.2	clay	1.8	49.8	26.5	21.0	49.2
Weighted mean		29.31	28.82	41.73		1.67	32.65	17.85	13.55	46.69
Pedon 9: Soyati series - Fine smectitic, hyperthermic, Sodic Haplusterts										
Ap	0-18	10.7	22.3	67.0	clay	1.5	49	27	22.0	43.7

Bw1	18-48	5.0	22.3	72.6	clay	1.5	49	26.7	22.3	47.2
Bss1	48-73	4.5	22.5	73.0	clay	1.6	55.4	32.2	25.2	47.4
Bss1	73-102	2.2	20.6	77.2	clay	1.7	67.4	39	28.4	55.1
Bc	102+	2.9	20.4	76.7	clay	1.8	60.4	39.3	31.2	57.4
Weighted mean		5.09	21.88	73.04		1.59	55.80	31.60	24.69	48.87
Pedon 10: Warna series - Fine smectitic, hyperthermic, Lithic Ustorthents										
Ap	0-18	25.3	16.0	58.7	clay	1.6	39.2	27.3	11.9	42.7
Cr	18-30	4.2	18.0	77.8	clay	1.7	38.1	28	16.4	34.0
Weighted mean		16.85	16.79	66.36		1.67	38.76	27.58	13.71	39.25

Table 4: Chemical properties of soils of watershed

Horizon	**Depth (cm)**	**pH**	**EC dS m^{-1}**	**OC g kg^{-1}**	**$CaCO_3$ (%)**	**Exchangeable bases**				**Total cations**	**CEC**	**Base saturation (%)**	**ESP**
						Ca^{2+}	**Mg^{2+}**	**Na^{+}**	**K^{+}**				
						cmol (p$^+$) kg^{-1}							
Pedon 1: Bhamb series - Fine smectitic, hyperthermic, Vertic Haplustepts													
Ap	0-17	7.92	0.38	1.18	5.42	34.00	25.60	0.87	1.33	61.80	65.22	85.6	1.33
Bw1	17-59	7.95	0.28	0.44	6.45	35.60	31.80	0.71	0.61	68.72	64.42	99.5	1.10
Bw2	59-92	8.26	0.16	0.44	14.68	33.80	32.80	0.63	0.15	67.38	61.57	81.2	1.06
Bw3	92+	8.16	0.34	0.41	12.40	32.40	34.80	0.64	0.10	67.94	62.36	76.9	1.28
Weighted mean		8.06	0.26	0.58	9.21	34.66	31.01	0.71	0.58	66.96	63.54	90.38	1.13
Pedon 2: Dongarkharda series - Fine mixed, hyperthermic, Lithic Ustorthents													
Ap	0-16	7.62	0.18	0.73	5.13	36.40	18.40	1.02	0.31	56.13	51.30	113.3	1.99
cr	16-36	7.51	0.11	0.41	6.84	39.60	14.40	1.17	0.10	55.27	53.40	103.5	2.19
Weighted mean		7.56	0.14	0.55	6.08	38.18	16.18	1.10	0.19	55.65	52.47	107.85	2.10
Pedon 3: Jalka series - Loamy mixed, hyperthermic, Lithic Ustorthents													
Ap	0-15	6.82	0.83	0.59	3.28	23.60	17.60	0.41	0.15	41.76	39.57	105.6	1.04
Pedon 4: Nimgawhan series - Loamy mixed, hyperthermic, Lithic Ustorthents													
A	0-14	6.82	0.17	1.83	12.44	30.80	22.40	0.49	0.20	53.89	50.00	107.8	0.98
Pedon 5: Nimgawhan-2 series - Loamy mixed, hyperthermic, Lithic Ustorthents													
Ap	0-15	6.96	0.12	0.7	0.00	27.20	9.60	0.41	0.26	37.47	36.52	102.6	1.12
Pedon 6: Pimpalkhuti series - Fine mixed, hyperthermic, Lithic Haplustepts													
Ap	0-20	8.32	0.14	0.59	11.61	53.20	7.60	0.78	0.51	62.09	65.22	95.2	1.20
Bw	20-44	8.24	0.13	0.50	9.45	45.20	10.40	0.63	0.26	56.49	59.13	95.5	1.07
cr	44+	8.20	0.14	0.23	10.24	36.00	12.40	0.51	0.15	49.06	48.70	92.5	1.05
Weighted mean		8.28	0.14	0.54	10.43	48.84	9.13	0.70	0.37	59.03	61.90	95.38	1.12
Pedon 7: Potgawhan series - Fine smectitic, hyperthermic, Lithic Haplustepts													
Ap	0-16	6.69	0.87	0.88	4.28	40.00	22.40	0.69	0.67	63.76	57.39	111.1	1.20
Bw	16-30	6.84	0.76	0.79	2.71	41.60	16.00	0.50	0.41	58.51	55.65	105.1	0.90
Weighted mean		6.76	0.82	0.84	2.28	40.75	19.41	0.60	0.55	61.31	56.58	108.31	1.06
Pedon 8: Sawangi series - Fine Smectitic, hyperthermic, Typic Haplustepts													
Ap	0-19	8.20	0.17	0.63	9.41	24.80	9.00	0.38	0.36	34.54	31.39	97.3	1.21
Bw1	19-52	8.30	0.15	0.53	11.97	23.20	11.80	0.43	0.30	35.73	33.48	86.4	1.28
Bw2	52-88	8.41	0.14	0.41	11.45	26.00	12.36	0.55	0.25	39.16	39.13	88.9	1.41
Bw3	88-122	8.74	0.31	0.47	9.69	30.60	15.20	1.83	0.21	**47.84**	51.30	101.0	3.57
Bw4	122-150	8.94	0.40	0.47	12.45	29.60	16.60	3.70	0.20	**50.10**	50.87	100.5	7.27
Weighted mean		8.53	0.23	0.49	11.09	26.95	13.25	1.38	0.26	41.83	41.86	94.34	2.94
Pedon 9: Soyati series - Fine smectitic, hyperthermic, Sodic Haplusterts													
Ap	0-18	8.63	0.39	0.44	5.42	29.60	19.60	5.74	0.72	55.66	51.74	90.1	9.30
Bw1	18-48	8.78	0.25	0.44	5.56	28.80	13.60	9.57	0.77	52.74	47.39	88.8	13.11
Bss1	48-73	8.71	1.33	0.41	6.70	23.60	17.20	14.43	0.82	56.05	51.30	91.4	15.54
Bss2	73-102	7.95	2.80	0.38	7.70	29.60	24.00	20.52	0.82	74.94	70.43	106.4	19.13
Bc	102+	8.31	4.40	0.29	10.83	27.60	25.60	21.30	0.76	75.26	69.83	107.8	21.50
Weighted mean		8.50	1.27	0.42	6.42	27.89	18.50	13.20	0.79	60.38	55.67	94.68	14.75
Pedon 10: Warna series - Fine smectitic, hyperthermic, Lithic Ustorthents													
Ap	0-18	6.55	0.82	0.79	2.71	31.20	44.00	0.74	0.56	76.50	68.65	85.2	1.08
cr	18-30	7.20	0.12	0.73	3.14	31.60	42.80	0.66	0.31	75.37	65.74	83.0	1.00
Weighted mean		6.81	0.54	0.77	2.88	31.36	43.52	0.71	0.46	76.05	67.49	84.33	1.05

Soil classification

Based on morphological and physico-chemical properties, the soil series were grouped into different taxonomical classes as per the criteria of Soil Taxonomy (Soil Survey Staff 1992) (Table 6). The soils of series 9, this is developed on lower valley. These soils are deep, black in coloured, clayey in texture (>30% clay) and characterized by deep wide cracks (2-5 cm wide and 48-102 cm depth in soil) when dry, that open and close periodically, shrink-swell properties, gilgai microrelief and very well developed slickensides close enough to intersect underlain by cambic horizon is classified under order the *Vertisol*. The soils qualify for very fine, smectitic, hyperthermic, Sodic Haplusterts. The soils of series 1, 6, 7 and 8 are moderately shallow to deep, with occurrence ochric epipedon underlain by cambic subsurface horizon with its upper surface boundary within 100 cm of the mineral soil surface and its lower boundary at a depth of 25 cm or more below the mineral soil surface have been classified in the order Inceptisols. Through the prevailing ustic moisture regime in the watershed, these soils are classified under order the *Inceptisol* and suborder Ustepts and qualify for Haplustepts great group. The Haplustepts great group is further divided into two subgroups viz. Vertic Haplustepts and Typic Haplustepts as per Soil Survey Staff, 1998. The soils of series 2, 3, 4, 5, and 10 are very shallow to moderately shallow. These soils lacking subsurface diagnostic horizons that do not qualify for other orders are classified under the order *Entisols*. The series are classified under suborders orthents are further subdivided into Ustorthent great groups because of ustic moisture regime. These soils were further divided into Lithic subgroups based on presence or absence of lithic or paralithic contact.

Table 5: Differentiating characteristics of typical pedons of different soil series of Sawangi watershed

Soil series	Landform	Geology/ Parent material	Soil Depth (cm)	Soil texture	Surface stoniness (%)	Colour	Reaction	Slope (%)	Erosion	Drainage	Salinity/ Sodicity
Bhamb	Pediplain	Basalt	150	clay	<3	10YR3/2	ev	1-3	Moderate	Well drained	-
Dongarkharda	Upper Valley	Basalt	50	clay loam	<3	10YR3/2	ev	3-8	severe	Well drained	-
Jalka	Denuded Plateau	Basalt	25	clay	<3	10YR3/3	-	3-8	severe	Well drained	-
Nimgawhan	Escarpment	Basalt	25	loam	>75	2.5YR3/3	-	8-15	Severe	Well drained	-
Nimgawhan-2	Denuded Plateau	Basalt	25	clay	<3	5YR3/3	-	1-3	Moderate	Well drained	-
Pimpalkhuti	Lower Pediment	Basalt	50	clay	<3	10YR3/2	ev	1-3	Moderate	Well drained	-
Potgawhan	Plateau	Basalt	50	clay	3-15	10YR3/1	e	1-3	Moderate	Well drained	-
Sawangi	Alluvial Plain	Basalt	150	sandy clay loam	<3	10YR3/2	ev	3-8	Severe	Well drained	-
Soyati	Lower valley	Basalt	100	clay	<3	10YR3/2	ev	1-3	Moderate	Moderately well drained	Moderate
Warna	Upper pediment	Basalt	50	clay	<3	10YR3/1	e	3-8	Moderate	Well	-

Table 6: Soil series and phases of Sawangi watershed

Landform	Soil series	Soil map unit	Mapping legend	Brief description of soil series	Area (ha)	TGA (%)
Pediplain	Bhamb	1	Bha5mB2	Deep, well drained, very dark grayish brown, clayey soils on very gently sloping pediplain with clay surface with moderate erosion.	1480.8	12.6
Upper Valley	Dongarkharda	2	Don2fC3	Shallow, well drained, very dark grayish brown, clay loam soils on gently sloping upper valley with clay loam surface with severe erosion.	322.3	2.7
Denuded Plateau	Jalka	3	Jal1mC3	Very shallow, well drained, dark brown, clayey soils on gently sloping denuded plateau with clay surface with severe erosion.	565.0	4.8
Escarpment	Nimgawhan	4	Nim1dF4	Very shallow, well drained, dark reddish brown, loamy soils on steeply sloping escarpment with loam surface with very severe erosion	878.0	7.5
	Nimgawhan	5	Nim1fC2	Very shallow, well drained, dark reddish brown, clay loamy soils on gently sloping escarpment with clay loam surface with very moderate erosion	258.7	2.2
Denuded Plateau	Nimgawhan-2	6	Nim1mB2	Very shallow, well drained, dark reddish brown, clay soils on very gently sloping denuded plateau with clay surface and moderate erosion	117.0	1.0
	Nimgawhan-2	7	Nim1mC2	Very shallow, well drained, dark reddish brown, clay soils on gently sloping denuded plateau with clay surface and moderate erosion	2993.0	24.8
Lower Pediment	Pimpalkhuti	8	Pim2mB2	Shallow, well drained, very dark grayish brown, clayey soils on very gently sloping lower pediment with clay surface and moderate erosion.	1006.0	8.5
	Pimpalkhuti	9	Pim2mC2	Shallow, well drained, very dark grayish brown, clayey soils on gently sloping lower pediment with clay surface and moderate erosion.	864.2	7.3
Plateau	Potgawhan	10	Pot2mB2	Shallow, well drained, very dark grayish brown, clayey soils on very gently sloping plateau with clay surface and moderate erosion.	540.6	4.6
Alluvial Plain	Sawangi	11	Saw5hC3	Deep, well drained, very dark grayish brown, sandy clay loam soils on gently sloping alluvial plain with sandy clay loam surface and severe erosion.	702.9	6.0
Lower Valley	Soyati	12	Soy4mB2n1	Deep, moderately well drained, very dark grayish brown, clayey soils on very gently sloping lower valley with clay surface, moderate erosion and moderate sodicity.	738.3	6.3
	Soyati	13	Soy4mC3	Deep, moderately well drained, very dark grayish brown, clayey soils on gently sloping lower valley with clay surface and severe erosion	529.5	4.5
Upper Pediment	Warna	14	War2mC2	Shallow, well drained, very dark gray, clayey soils on gently sloping upper pediment with clay surface and moderate erosion.	442.2	3.8
Miscellaneous (habitation / waterbodies / hills)					409.0	3.5
Total					11777.6	100.0

Table 7: Taxonomic classification of soils

Pedon No.	Soil series	Order	Sub order	Great group	Sub group
P1	Bhamb	Inceptisols	Ustepts	Haplustepts	Vertic Haplustept
P2	Dongarkharda	Entisols	Orthents	Ustorthents	Lithic Usterthent
P3	Jalka	Entisols	Orthents	Ustorthents	Lithic Usterthent
P4	Nimgawhan	Entisols	Orthents	Ustorthents	Lithic Usterthent
P5	Nimgawhan-2	Entisols	Orthents	Ustorthents	Lithic Usterthent
P6	Pimpalkhuti	Inceptisols	Ustepts	Haplustepts	Lithic Haplustept
P7	Potgawhan	Inceptisols	Ustepts	Haplustepts	Lithic Haplustept
P8	Sawangi	Inceptisols	Ustepts	Haplustepts	Typic Haplustept
P9	Soyati	Vertisols	Usterts	Haplusterts	Sodic Haplustert
P10	Warna	Entisols	Orthents	Ustorthents	Lithic Usterthent

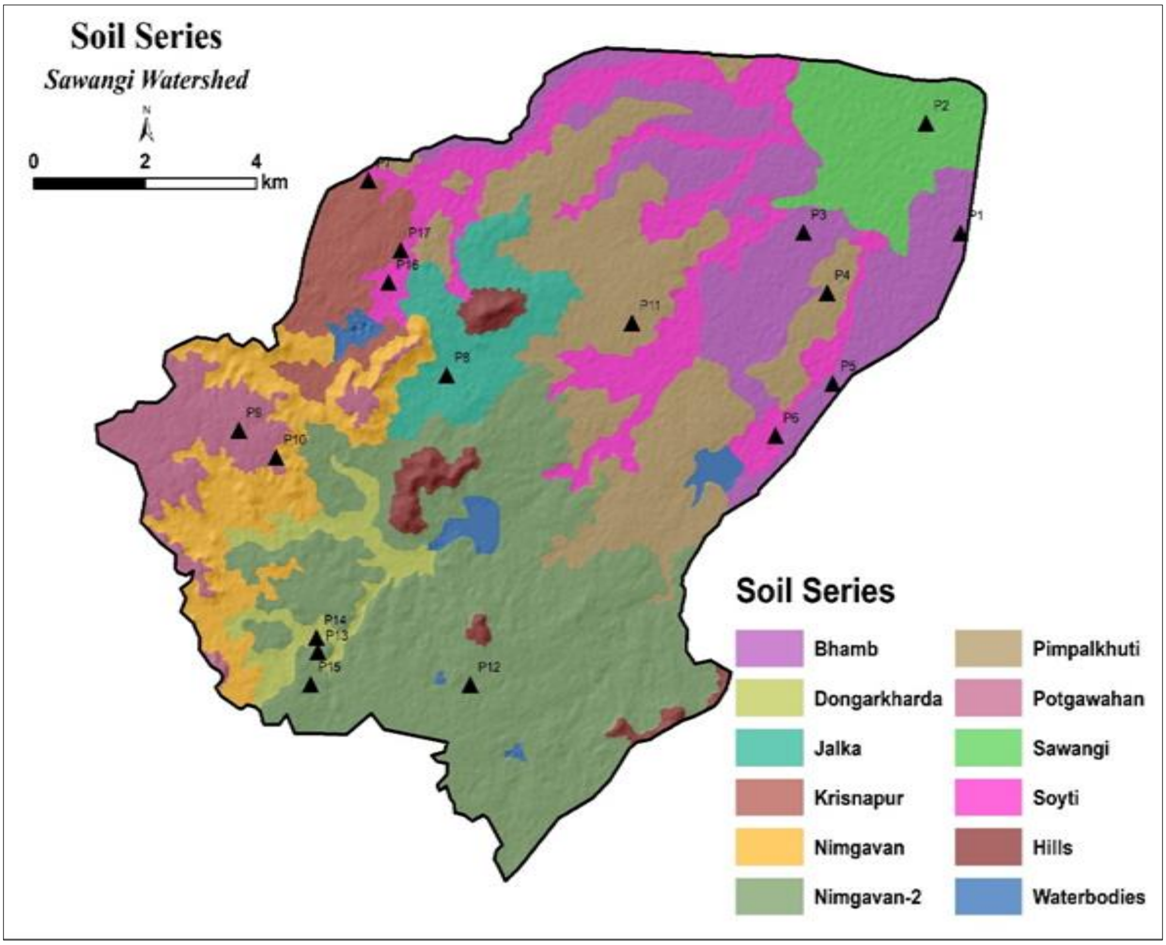

Fig 3: Soil Series map of Sawangi watershed

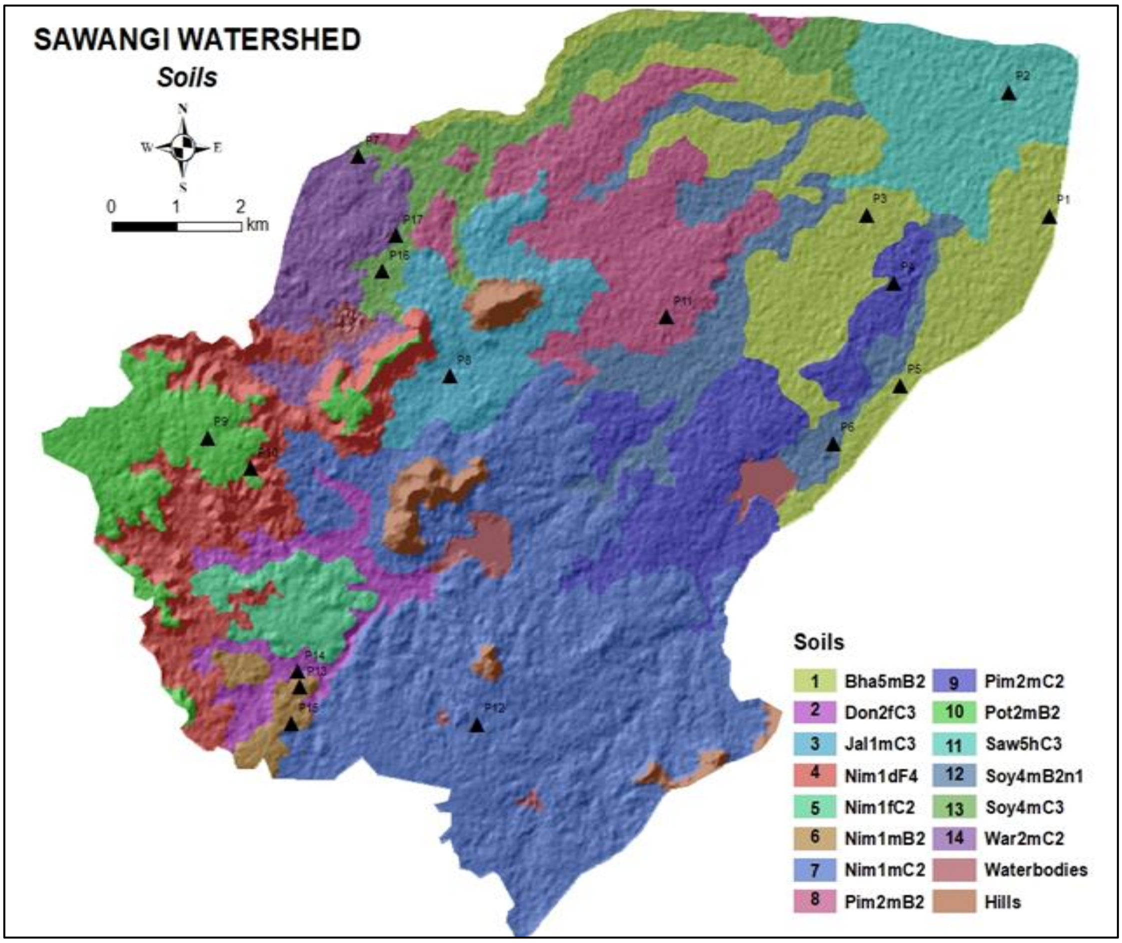

Fig 4: Soil map of Sawangi watershed

Conclusion

The soils of Sawangi watershed are grouped under ten soil series and further, they were characterized and classified. This soil comes under *Vertisols*, *Inceptisols* and *Entisols* soil orders. Based on the different landforms and soil characteristics, these soils are classified as Typic Haplusterts, Lithic Ustorthents, Vertic Haplustepts, and Sodic Haplusterts at the subgroup level. The major landform units identified in the study are mound, plateau, denuded plateau, escarpment, upper pediment, lower pediment, alluvial plain, pediplain, upper valley, lower valley and waterbody. These landforms have developed mainly due to the control slope position and moisture availability. The most soils covering on denuded plateau and escarpments on gently sloping to moderately steeply sloping lands are shallow, reddish brown to dark reddish brown (2.5YR 3/3M and 5YR 3/3M) in colour, well drained, clay loam to loam, very severely eroded and classified as Lithic Ustorthent. The soils of upper valley, plateua, lower and upper pediment occurring on very gently to gently sloping are shallow, very dark grayish brown (10YR3/2), clay in texture, moderately eroded are classified as Lithic Ustorthent and Lithic Haplustert. The soils of pediplain, alluvial plain and lower valley occurring on gently sloping are deep, very dark grayish brown (10YR3/2), clay to sandy clay loam in texture, moderately to severe erosion are classified as Typic Haplustept, Typic Haplustert and Vertic Haplustert. The surface horizons of all soil series show medium, moderate subangular blocky structure while, medium, moderate subangular blocky to angular blocky structure found in sub-surface horizons.

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