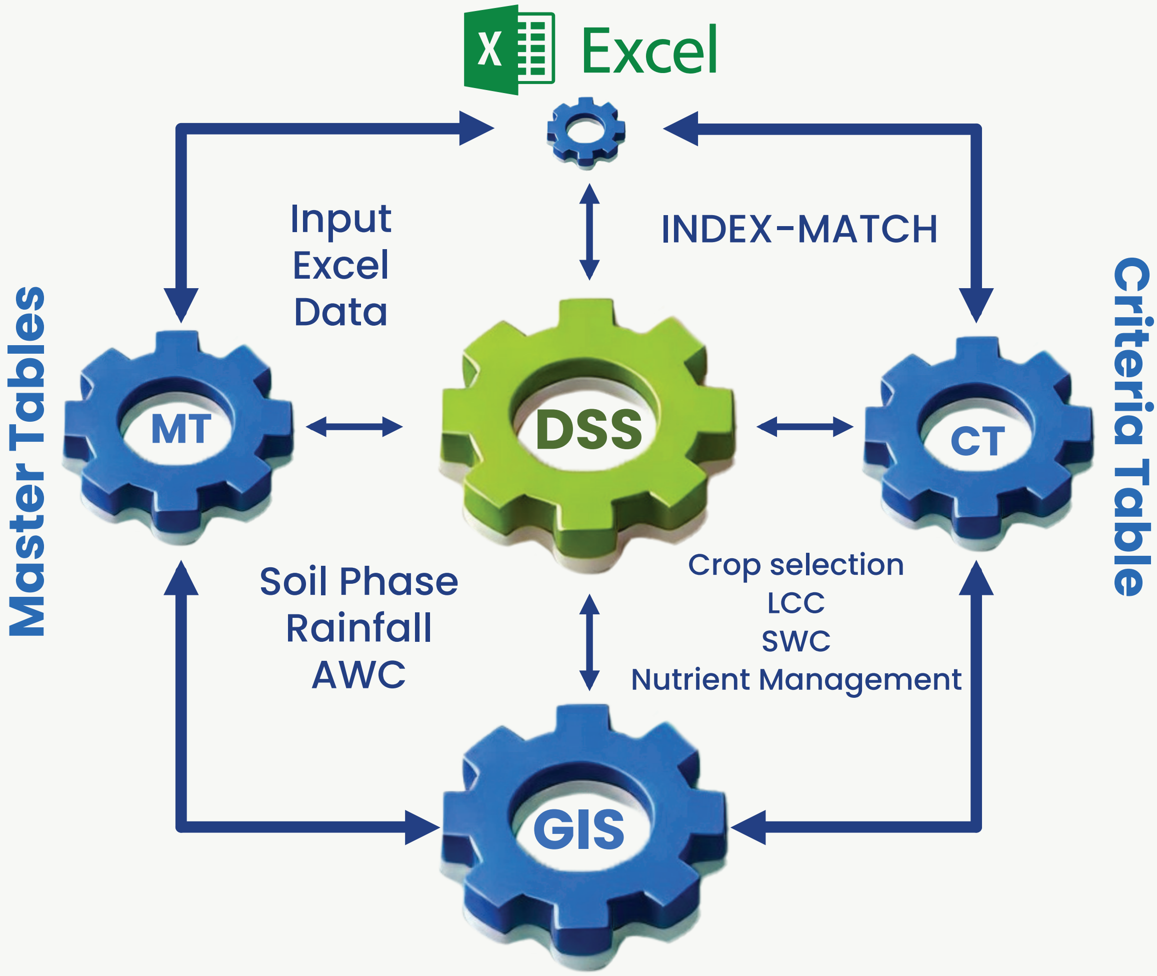
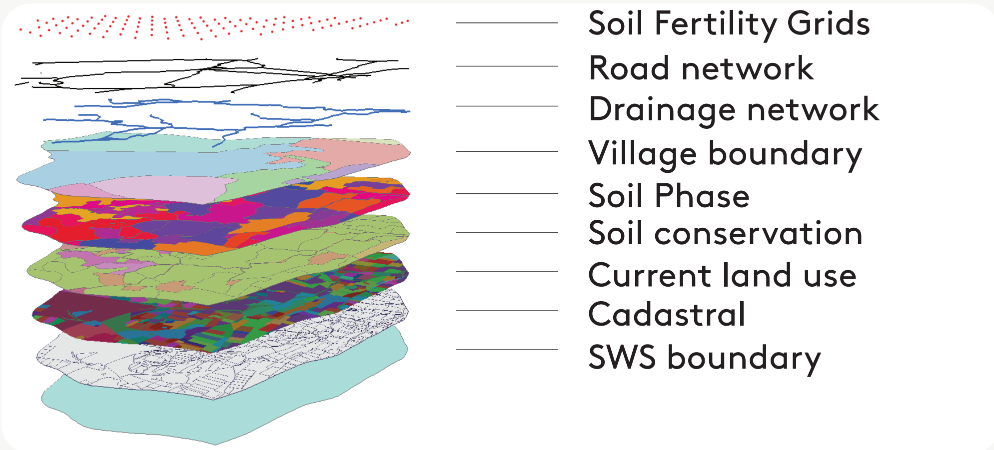
THE WORLD BANK

Emerging Approaches in Processing of LRI Inputs for Preparation of Atlas under REWARD Program





Special Officer

WATERSHED MANAGEMENT
UAS BANGALORE

Promote science based approach in watershed management

December 2024

University of Agricultural Sciences, Bangalore

Centre of Excellence on Watershed Management

Training Reference Material

on

Emerging Approaches in Processing of LRI Inputs for Preparation of Atlas under REWARD Program

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1. An overview of scientific approaches followed in REWARD program

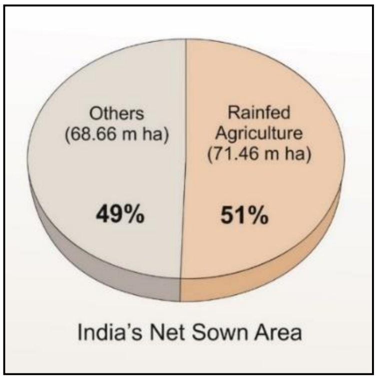
The finite land resources of our country are under severe strain due to the needs of the growing population and competing demands of land uses. Due to this about 96 million hectares of land area (MoEF 2021), representing 30 percent of the total geographical area, is degraded mostly due to erosion, salinity and alkalinity has become a serious problem in the command and arid areas, deficiency of secondary and micronutrients is widespread in the cultivated areas, ground water exploitation has become critical in most parts of the country and declining factor productivity observed in majority of the crops. Among the various forms of degradation soil erosion is the major cause for the declining factor productivity followed by salinity and alkalinity. The situation is getting aggravated year after year and as per the estimate the area critically affected by soil erosion alone has doubled from 1977 to 2007 in the country which might be even more at present (Planning Commission, 2007). As per the High-level committee on Wastelands (GoI, 1995), the uncontrolled and continuing land degradation in the form of soil erosion is a major threat to the country's economy and observed that about two-thirds of our agricultural lands are sick in one form or other and only about 48 m ha are in good health. The situation is further compounded by climate change which has emerged as the main driver of land degradation in India, with erosion of topsoil reducing the land's carbon sink ability and water storage function in the soil. The recent study carried out in Karnataka under Sujala-3 Project has highlighted the declining status of the resource base with the very poor organic carbon, low moisture retention, unremunerated and unsustainable yield levels in the vast rainfed areas of the state (The Hindu 2018, WDD 2020).

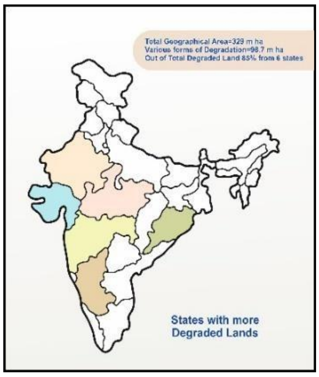
It is obvious that urgent measures are needed not only to arrest the declining health of land resources in the country but also to regenerate the degraded lands in a reasonable timeframe. Otherwise, the cost of the neglect, estimated to be about 2.5 per cent of the GDP in 2014-15, will be too high to pay in the future (TERI, 2018). Realizing this and to improve the productivity of the resources on a sustainable basis, a plethora of schemes/plans have been formulated and implemented by both state and central government in the country since independence. Even with all the budgetary provision for various schemes like Watershed Development, MGNREGA, RKVY, NFSM and others, the health of the country's resource base has not shown any perceptible change and on the other hand there is a continuing deterioration witnessed at the field level. It is obvious that there is a clear mismatch between the plans formulated and executed by various line departments and the needs or the requirements at the field/grassroots level in the country.

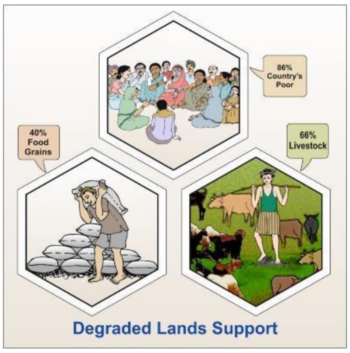
Hence, there is a need for adoption of advanced scientific approaches in watershed planning and management. In this regard, Karnataka has implemented Sujala-3 / Karnataka Watershed Development Project-II with the support of World Bank to generate site and location specific scientific data and continued in REWARD program. In the following paragraphs, the concept of Watershed Development and approaches followed in Sujala-3 and REWARD are described.

A. Watershed Development and its importance

1. India ranks first globally in area and value of production from rainfed agriculture. It occupies about 51 per cent of country's net sown area of 140.13m ha. Out of the total geographic area of 329 m. ha, more than 30 per cent is affected by various forms of land degradation and out of this, rainfed areas account for more than 85 per cent of degraded lands in the country, mostly occurring in Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Odisha and Rajasthan.

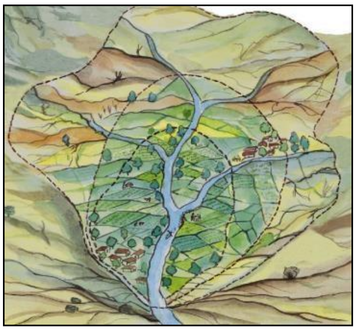




2. 

The degraded land is the home to 86% of the country's poor, produce 40% of the food grains, and support 66% of the livestock population. Among the various forms of degradation, soil erosion is the major cause for the declining factor of productivity followed by salinity and alkalinity. The situation is getting aggravated year after year and as per the estimate, the area critically affected by soil erosion alone has doubled in 30 years from 1977 to 2007 in the country. The solution is integrated watershed management/ development.

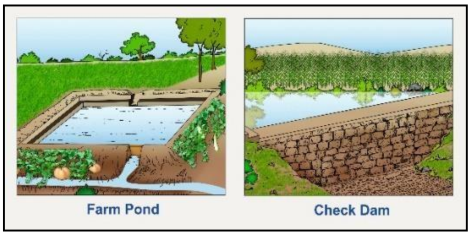
3. A watershed, is as an area in which all water flowing into it goes to a common outlet. All lands on earth are part of one watershed or the other. Watershed Development (WSD) is the preservation, renewal, and wise use of all natural resources, particularly those related to the land, the water, the vegetation, and the animals, as well as human development within the watershed.

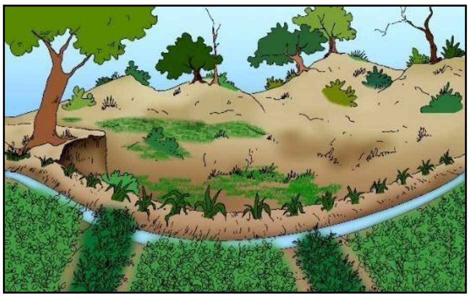


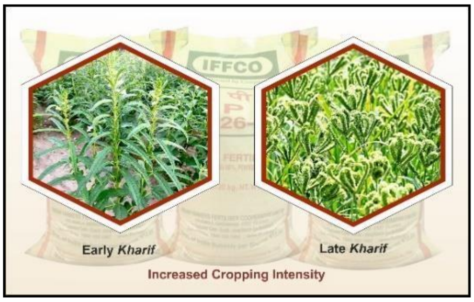
4. 

Watershed Development in India has been a part of the national approach to improve agricultural production and alleviate poverty in rainfed regions since 1970s. Watershed development programs aim to restore degraded watersheds in rainfed regions to increase their capacity to capture and store rainwater, reduce soil erosion, and improve soil nutrient and carbon content so that they can produce greater agricultural yields and other benefits.

5. The objective of watershed development is maximizing the productivity and income per unit area, per unit time and per unit of water thereby improving the socio-economic status of the farmers. The objective of watershed development can be achieved through implementation of a series of systematic approaches, (a) preserving as much water as possible at the place it falls to avoid gully formation and putting checks at suitable intervals to control soil erosion, (b) harvesting and storing excess runoff by draining out excess water with a safe velocity and diverting it to farm ponds, check dams and nala bunds, (c) promotion of alternate land use system to improve vegetation by intensifying horticulture, agro forestry, silvi-pasture etc., (d) improving crop production systems by effective crop and nutrient management, increased cropping intensity, and land equivalent ratio through intercropping and sequence cropping and (e) development of livelihood support systems by promoting appropriate bio mass based income generating activities for the vulnerable sections of the community.





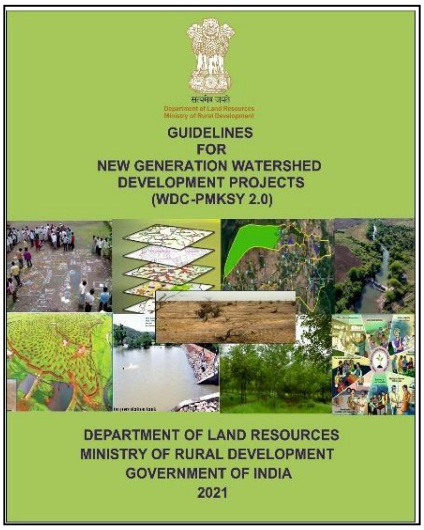


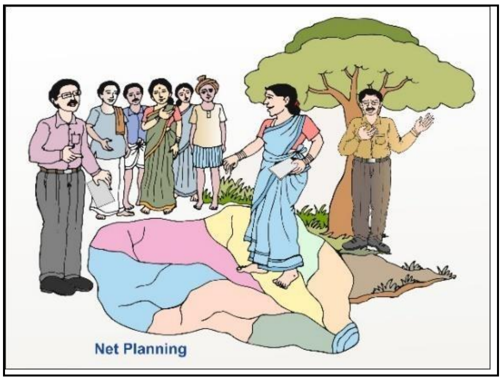
6. 

In 1970's Soil and water conservation was taken up with a focus on engineering structures mainly for protecting dams. In 1983, the Operation Research Projects (ORPs) were established in 47 watersheds spread over 16 states covering an area of 35739 ha under the technical guidance of Indian Council of Agricultural Research. The ORPs aimed at arresting the deterioration of environment and building up permanent assets in the form of water, sustainable vegetation and improved productivity of cropped land. During 1990's emphasis was given on participatory watershed development where the community was involved in planning, implementation and management.

In 2006 National Rainfed Area Authority (NRAA) by the Planning Commission was established to provide technical support to Department of Land Resources (DoLR), GoI, and issued common guidelines for all watershed development programmes for the development of rainfed farming in India.

7. The Guidelines for new Generation Watershed Development Projects (WDC-PMKSY 2.0) issued by DoLR in 2021, emphasizes shifts in approaches from mechanical to agricultural engineering structures, effective use of rain water by relying more on water productivity, crop systems diversification for risk management, promotion of water use efficient crops, integrated farming systems for adaptation and mitigation of adverse impacts of climate variability, establishing FPOs to promote agri-business and nurturing of community groups. The DoLR Guidelines issued during 2021, under WDC-PMKSY 2.0, also emphasizes the use of GIS and RS technologies for scientific planning and monitoring the performance of watershed development projects.



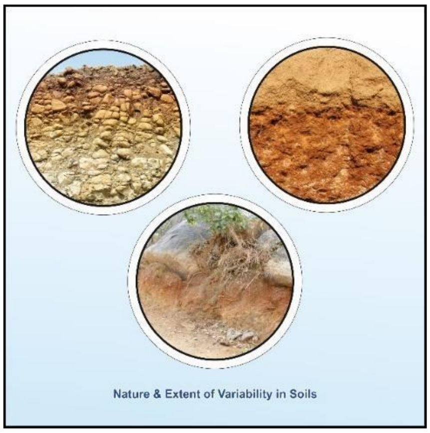
8. 

Net Planning

The common approach followed in watershed planning in earlier watershed development programmes was, net-planning which is an eyesight-based planning for each survey number. The designs of drainage line structure were standardized ones and do not take into account the run-off available at the site. Indiscriminately, water harvesting structures were built.

B. Emergence of Sujala-3 project

9. It is a recognized fact that the factors and processes affecting degradation, productivity and sustainability are very site and location specific. For any meaningful intervention needed for the restoration and management of degradation, necessitates site-specific land resource information which is not available at present for major part of the country. As the land resources are not uniform, generation of location speci fic information pertaining to the nature and extent of variability in soil, water availability, topography and land use is a prerequisite for successful planning and implementation of development programs by agriculture, horticulture, watershed, forestry, irrigation, and other programs in any area. Non availability or lack of such site-specific land resource information is responsible for the failure of many development programmes implemented in the past by Development Departments in the Country.



Nature & Extent of Variability in Soils

10. Realizing the importance of site-specific soil and other information for taking up targeted interventions, the World Bank supported Karnataka watershed Development Project-KWDP II, popularly known as Sujala-3 project, implemented from 2013 to 2019 in about 14 lakh ha spread over in 11 Districts of Karnataka. Sujala-3 has clearly demonstrated the importance of cadastral level database, thematic maps and digital tools in planning, implementation, and monitoring of various interventions at the field level. This approach has significantly reduced the watershed development cycle to four years. The advanced approaches in Sujala-3 have helped to take up site-specific soil and water conservation interventions, selection of crops as per their suitability, nutrient management as per the fertility status and crop requirement, construction of water harvesting structures as per the available excess runoff from the area, allocation of water to different sectors as per the balance and water budgeting as per the present and future demands.

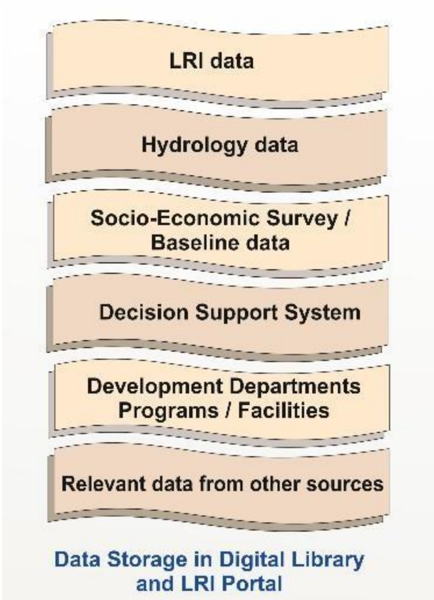
Sujala-3 Watershed Districts

11. The uniqueness Sujala-3 project was adoption of more advanced scientific approaches for capturing the data on status of land, water, and other resources at cadastral level through land resource inventory (LRI) and hydrological assessments for preparation of scientific Detailed Project Reports (DPR) for watershed development. Sujala-3 has clearly demonstrated the importance of cadastral level database, thematic maps and digital tools in planning, implementation, and monitoring of various interventions at the field level. This approach has significantly reduced the watershed development cycle to four years.

12.

The advanced approaches in Sujala-3 have helped to take up site-specific soil and water conservation interventions, selection of crops as per their suitability, nutrient management as per the fertility status and crop requirement, construction of water harvesting structures as per the available excess runoff from the area, allocation of water to different sectors as per the balance and water budgeting as per the present and future demands.

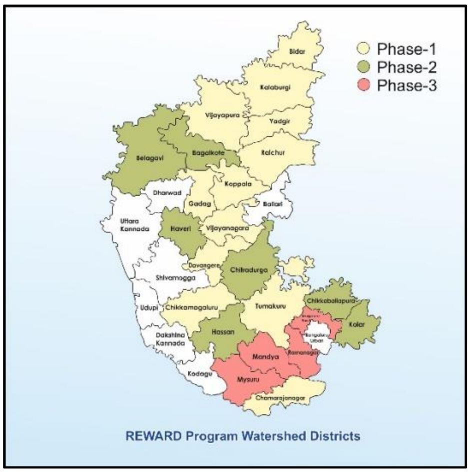
13. To carryout LRI and hydrological studies under Sujala-3 project, 15 scientific consortium partners were involved. Development of Decision Support System (DSS), to improve watershed planning, by integrating the data base generated with decision criteria, models and algorithms is one of the noteworthy outcomes of the project. A web-based portal was created for easy access to data sets for multiple purposes in targeted watersheds



C. Emergence of REWARD program

14. Appreciating the impact of Sujala-3, the Government of Karnataka has extended it to cover the whole rainfed area of the state with Land resource inventory (LRI) technology. Appreciating the impact of LRI and hydrological assessments in scientific planning for watershed development under Sujala-3 project, the Government of Karnataka, is extending it to cover the whole rainfed area of the State under the REWARD program, with the support from the World Bank from 2022.

15. The REWARD program's Development Objective is to strengthen capacities of National and State institutions to adopt improved watershed management for increasing farmers' resilience and support value chains in selected watersheds of participating States. The REWARD program in Karnataka, covers 21 Districts with a budget of Rs 600 crores. The duration of the program is for five years.



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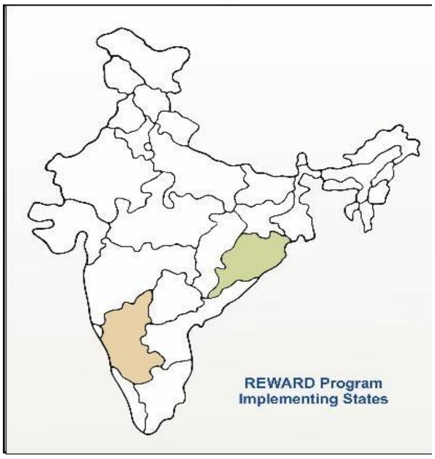
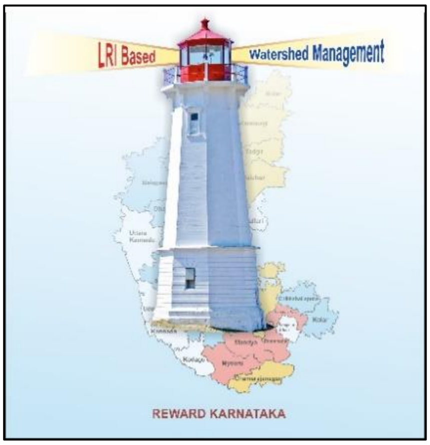
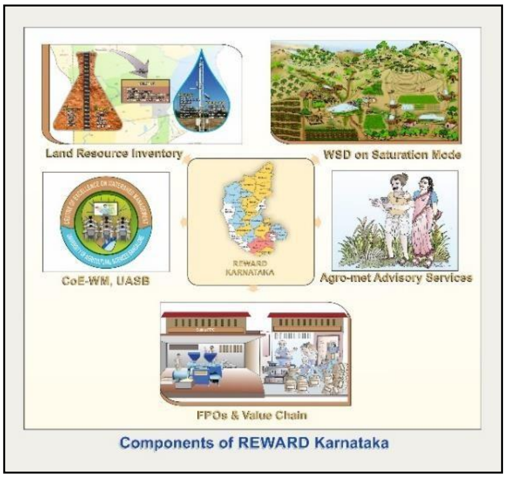




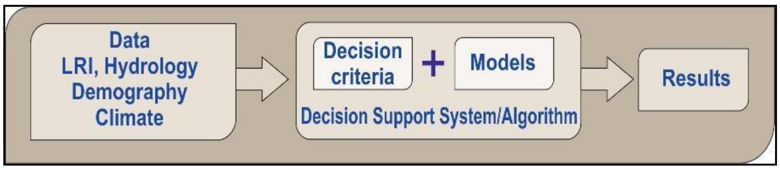
The REWARD-Rejuvenating Watersheds for Agricultural Resilience through Innovative Development program, will create a path for adoption of LRI (including hydrology) based scientific watershed management by all the States through WDC –PMKSY. Karnataka is identified as a light house partner to provide technical guidance for other States. The Odisha State has already started implementing REWARD program from 2022 with the support from the World Bank. To achieve agricultural resilience, the science-based approaches are being adopted in assessing the status of natural resources and improving them through comprehensive approaches in the watershed management program, to improve soil organic carbon, improvement in soil pH, improvement in soil moisture retention and improvement in length of growing period.

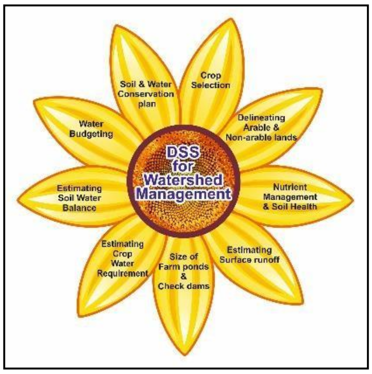
17. The major Components of REWARD program are (a) Land resource inventory (LRI) in 19 lakh ha of rainfed watershed areas spread over in 21 districts, (b) watershed development on Saturation mode covering an area of one lakh ha in 20 sub watersheds based on LRI & Hydrology recommendations, (c) FPO and Value chain development through 25 FPOs, (d) providing improved agro-met advisory services to farmers, (e) anchoring Centre of Excellence on Science based Watershed Management at UAS Bangalore.



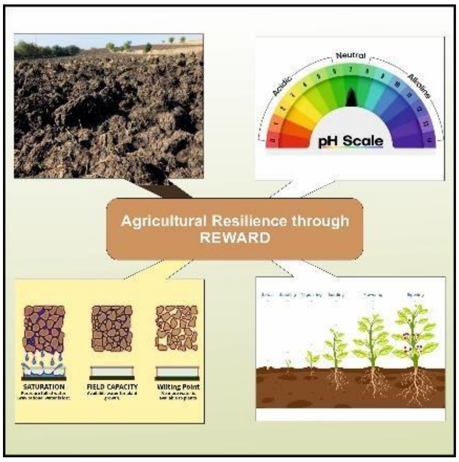
Components of REWARD Karnataka

18. Salient features of REWARD are (a) generation of cadastral level land resource information using RS, GIS and other advanced scientific tools and technologies, (b) development of criteria, models, algorithms and guidelines, (c) understanding hydrological dynamics vis–a-vis hydro-geology & climatic variability and develop tools to measure them (d) developing protocol for demystifying the science to community through consultation process and thus reducing watershed development cycle, (e) evidence based monitoring and impact evaluation of the project interventions, (f) consortium approach in achieving objectives - Scientific research institutes associate as project stakeholders, (g) establishing CoE on WM plays a critical role in building capacity of all the States on LRI and operationalization of future generation PMKSY- WDC programs in the country.





19. To achieve agricultural resilience, the science-based approaches are being adopted in assessing the status of natural resources and improving them through comprehensive approaches in the watershed management program, to improve soil organic carbon, improvement in soil pH, improvement in soil moisture retention and improvement in length of growing period.



20. The REWARD program's Development Objective is to strengthen capacities of National and State institutions to adopt improved watershed management for increasing farmers' resilience and support value chains in selected watersheds of participating States.

21. The committees for smooth implementation of the REWARD program

    a. National Level Steering Committee (NLSC): Headed by Secretary, DoLR, Senior Officers from: DoLR, NRAA & relevant national departments and research organizations; and State Watershed Departments of Karnataka and Odisha

       Responsibilities of NLSC: (a) To improve convergence between agriculture, watershed, water resources, rural development and other related ministries and (b) provide high level oversight and guidance for the implementation of the Program

    b. National Level Technical Committee (NLTC): The committee will be constituted by DoLR.

       Responsibilities of NLTC: (a) review and standardize scientific protocols; (b) develop national technical standards; (c) strengthen the national web-based portal; and (d) provide high level support to the National Level Steering Committee

    c. National Program Management Unit: Chaired by the Joint Secretary of DoLR, Program Director supported by an additional Program Director, watershed management expert, hydrologist/water resource expert, institution and capacity building expert, monitoring and evaluation expert, financial management expert, and procurement expert

    d. Karnataka State Level Nodal Agency: Chaired by the Commissioner & Program Director of Karnataka's Watershed Development Department, and include senior officers of the rank of Joint Director, Deputy Directors and consultants, for covering subjects related to soil and water conservation (including land resource inventory), agronomy, horticulture, forestry, animal husbandry, hydrology, social development, capacity building, RS/GIS, value chains (FPOs), procurement, monitoring and evaluation, and others

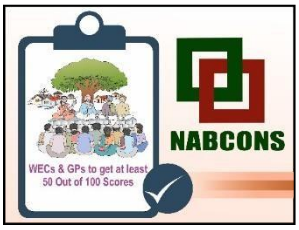
    e. District and Block Level (PIA): Officers of Karnataka's DoA will supervise the implementation of the Program Implementing Agency's Respective Part of the Program at the District and Block levels

f. WCs and GPs: Program Implementing Agency shall support WC and GPs to actively participate in the implementation of Program, including operation and maintenance, reporting.

22. The REWARD program in Karnataka, covers 21 Districts with a budget outlay of Rs 600 Crores. Out of the total budget, the World Bank share is 70% and GoKs share is 30%. The duration of the program is for five years. The major Components of REWARD program are (a) Land resource inventory (LRI) in 19 lakh ha of rainfed watershed areas spread over in 21 districts, (b) watershed development on Saturation mode covering an area of one lakh ha in 20 sub watersheds based on LRI & Hydrology recommendations, (c) FPO and Value chain development through 25 FPOs, (d) providing improved agro-met advisory services to farmers, (e) anchoring Centre of Excellence on Science based Watershed Management at UAS Bangalore.

23. The World Bank financing for the REWARD program is “P for R” (Program for Results) mode and disbursement of funds by the World Bank is based on achievements of the results (a) strengthened institutions and supportive policy for watershed development and (b) scientific watershed development and enhanced livelihoods. A set of Disbursement Linked Indicators (DLI) are identified for the components of REWARD program. The NABCONS (NABARD Consultancy Services) has been entrusted for verification of the indicators at different phases of the project cycle.

24. Disbursement of funds based on achievements of the results. For this purpose, Disbursement Linked Indicators are set for important components. The NABCONS (NABARD Consultancy Services) has been entrusted for verification of the indicators.



According to the first indicator, the WCs & GPs demonstrate satisfactory watershed management as measured through a performance rating system-30% WCs and GPs get more than 50% score on the indicators at three stages of project cycle-preparatory, works and operation and maintenance.

According to the second indicator, the land area in 200 MWS should be treated as per the scientific recommendations (LRI and Hydrology). It is also called watershed development on saturation mode.

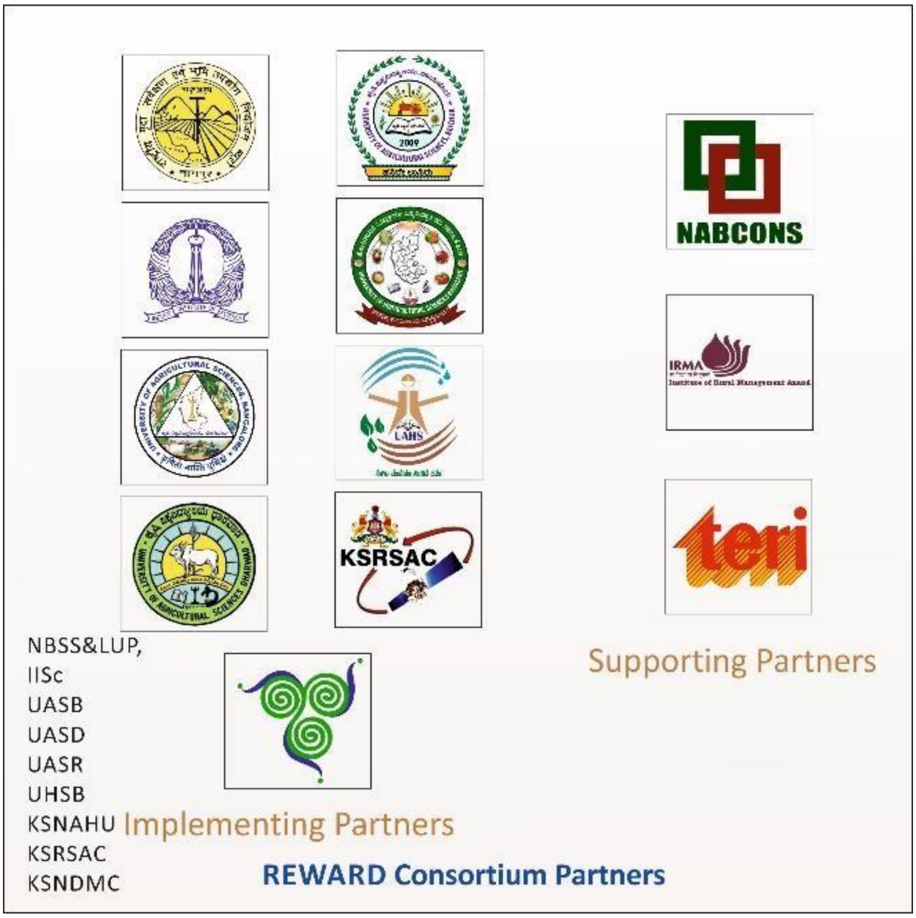
According to the third indicator, 27000 farmers to adopt and practice resilient agriculture technologies.

According to fourth indicator, there should be 25 per cent increase in business turnover relative to baseline among existing FPOs and additional 15 FPOs should be started.

According to fifth indicator, certified training to 1125 professionals on improved watershed management by the Centre on Excellence on Watershed Management.

25. The REWARD program is distinctly different from other watershed development programs initiated in the country. Its distinctness is attributed to seven in built salient features of the program namely, (a) generation of cadastral level land resource information using RS, GIS and other advanced scientific tools and technologies, (b) development of criteria, models, algorithms and guidelines, (c) understanding hydrological dynamics vis–a-vis hydro-geology & climatic variability and develop tools to measure them (d) developing protocol for demystifying the science to community through consultation process and thus reducing watershed development cycle, (e) evidence-based monitoring and impact evaluation of the project interventions, (f) consortium approach in achieving objectives - Scientific research institutes associate as project stakeholders, (g) establishing CoE on WM plays a critical role in building capacity of all the States on LRI and operationalization of future generation PMKSY-WDC programs in the country.

26. The REWARD program creates an opportunity for establishment of a consortium of scientific partners'/user agencies with defined roles & responsibilities, which will form a template to take forward science-based watershed development approach. Two types of consortium partners are involved namely implementing partners and supporting partners. Implementing Partners include (a) National Bureau of Soil Survey & Land Use Planning (ICAR-NBSS&LUP)-lead institute for LRI, (b) Indian Institute of Science (IISc), Bengaluru- lead institute for hydrology, (c) Five State Agricultural Universities (UAS-B/D/R/UHS-B/ KSNA&HU-S)- for LRI and hydrology, (d) Karnataka State Remote Sensing and Application Centre (KSRSAC)-providing m aps and satellite imageries, (e) Karnataka State Natural Disaster Monitoring Centre (KSNDMC)- for metrological data.



The Supporting partner institutes under REWARD program are (a) NABARD Consultancy Services (NABCONS)- as an Independent Verification Agency (IVA) for verifying disbursement linked indicators (DLI) achievement and reporting to the World Bank, (b) Centre of Excellence for Watershed Management, UAS Bangalore for upscaling LRI, (c) Institute of Rural Management, Anand (IRMA) as a consulting Research Agency (CRA) for impact evaluation, and (d) The Energy and Resources Institute (TERI) as a Process Monitoring Agency (PMA) for process monitoring.

2. Land Resources Inventory for watershed planning and management

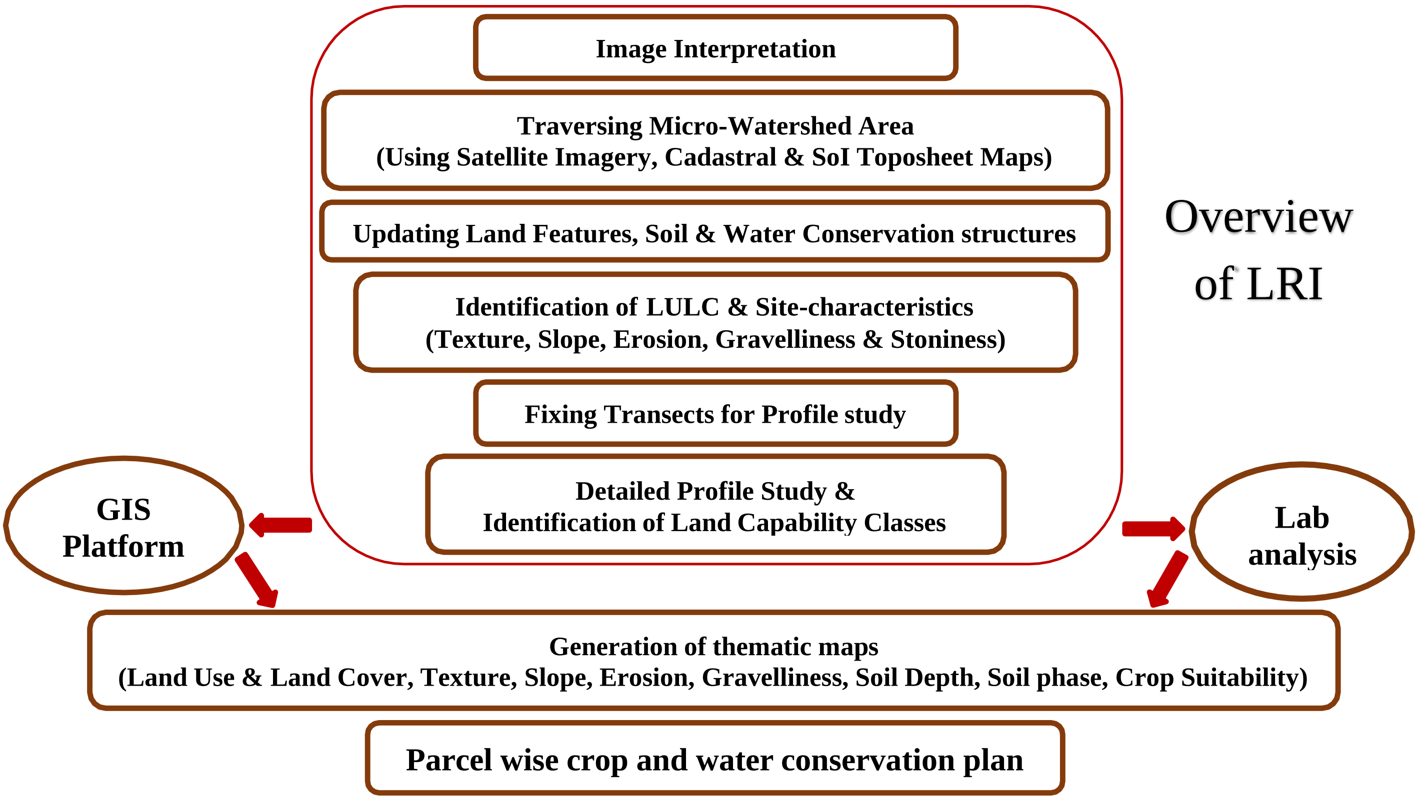
The Land Resource Inventory (LRI) is an assessment of the status and changing condition of soil, water and related resources at the field level. The LRI database is generated on a geo-referenced cadastral map, superimposed on satellite imagery. The land parcels are grouped into management units based on similarity in soil and site characteristics.

Significance of LRI

- Identification of land resources
- Provides scientific database for adopting suitable soil and water conservation measures
- Helps in developing site-specific agricultural technologies
- Helps in increasing productivity
- Helps in enhancing farmers income and increasing the socio-economic status of the farmer

Maps inputs needed for LRI

- Village cadastral maps at a particular scale
- Satellite imagery like Cartosat/Quick Bird images at a convenient scale
- Seamless image for micro watersheds and sub watersheds
- Overlay of seamless cadastral maps on micro watershed, sub watersheds
- Survey of India Topographical sheets of 1: 50,000 or larger if available
- Geology map of the Taluk/District sheets on 1:50,000 scale or larger
- Overlay of 1:50,000 scale geology map on 1: 50,000 scale imagery
- Geomorphology map, wherever available
- Land use/Land cover map
- Drainage and water bodies map

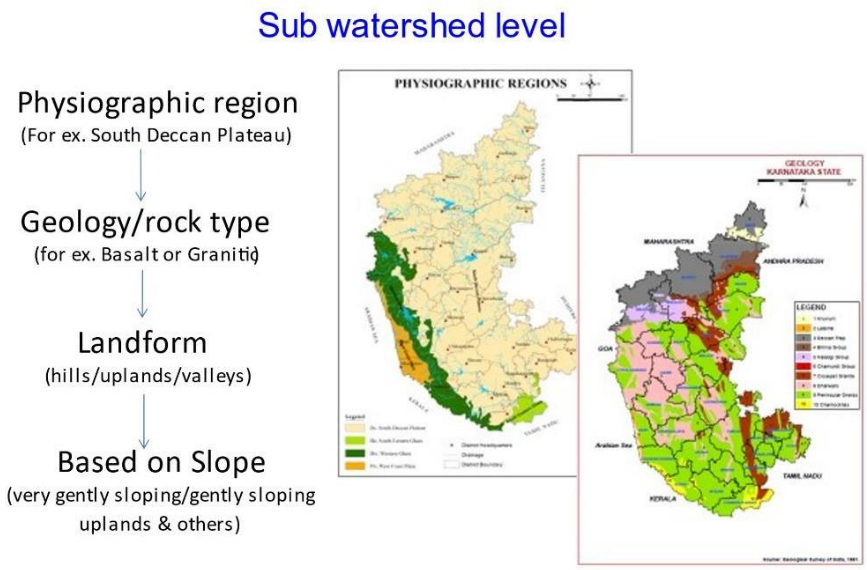


LRI approach - data generation process

Pre-field activities: Image interpretation for various physiographic units and identification of transect for profile studies

This is the most important pre-field activity, carried out to identify and delineate different physiographic regions, rock types, landscapes, landforms and their subdivisions at different levels-from district, taluk, watershed and village before the start of the field work in the survey area. At the time of interpretation itself transects representing the variations observed on the imagery to be selected and marked on the base map.

Interpretation at Sub watershed level:
At SWS level, interpretation is done to identify major physiographic regions/units, geology or rock types, different landforms occurring within the geological formations and landform units based on land use, slope, image characteristics and other converging evidence.



Then within the physiographic region/unit, any variation in geology/rock formations is identified and separated on the imagery and within each geological area landforms like hills, mounds and ridges, inselbergs, uplands, valleys, lowlands, *etc*. are delineated based on contour intervals as observed from the contour map/toposheet and image characteristics. This will result in the generation of physiography-landform map with the legend at the SWS level. During the interpretation itself few transects representing major landforms selected and marked on the imagery.

Interpretation at MWS level:
At MWS level, the landform units identified at SWS level is further subdivided based on change in slope, land use and other surface features as evidenced through the image characteristics and other converging evidence of the area.

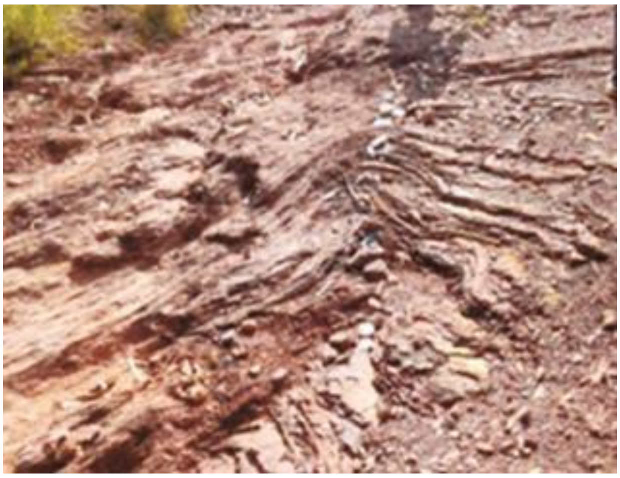
For example, the hills identified at sub-watershed level and not subdivided due to the scale limitation can be further subdivided into summits, escarpments, side slopes (upper, middle, and lower side slopes) and foot slopes at the MWS level based on their extent and slope. Similarly, the uplands can be subdivided into rolling, undulating, gently sloping, very gently sloping and nearly level lands based on their extent and slope at the MWS level.

Red sand stone

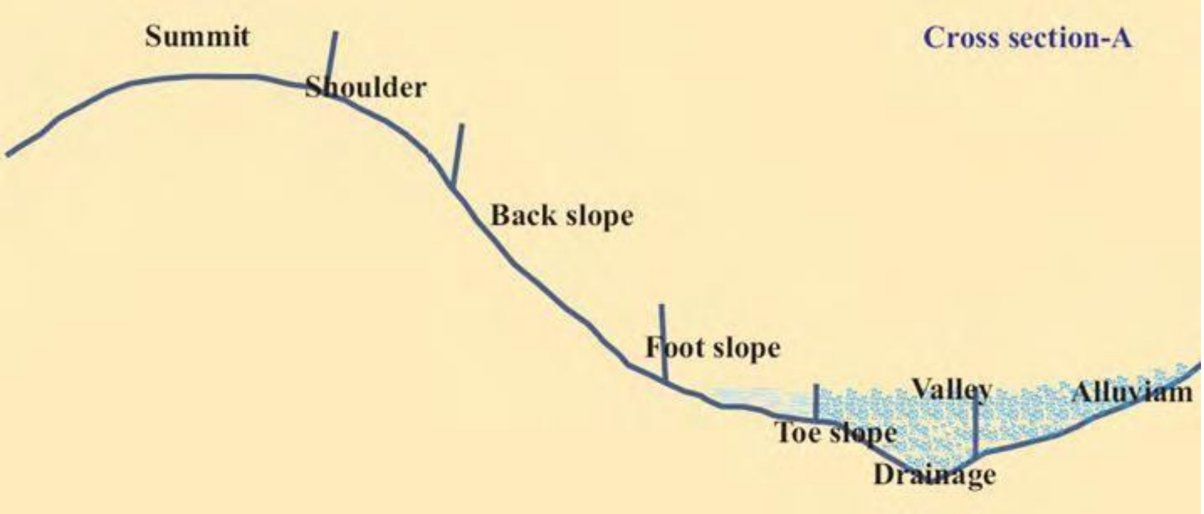
Basalt Rock

Granite

Laterite

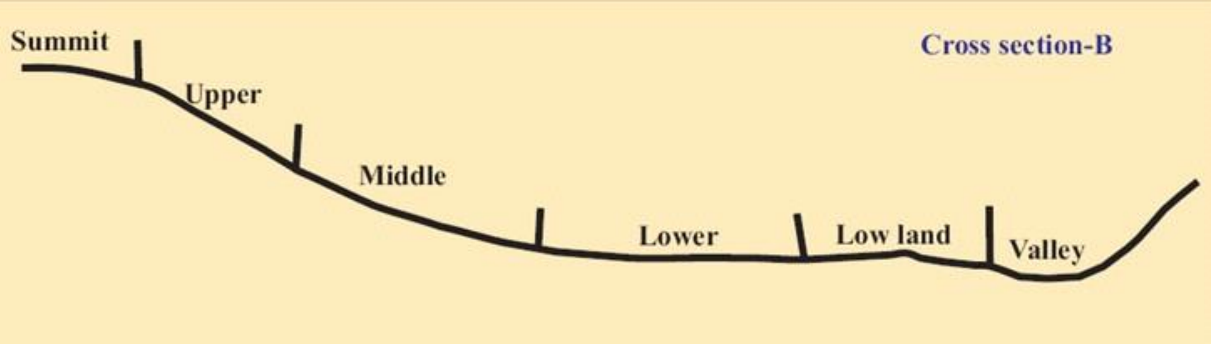


Schist



Different slope elements as seen in hills landform in a micro watershed

In the next level, the landform units can be further subdivided based on variations like erosion, presence of gravel/stones/boulders, rock outcrops, drainage, salinity *etc*., as evidenced further through the image characteristics and other converging evidence of the area.



Different slope elements as seen in uplands landform in a micro watershed

For example, within the undulating or gently sloping area of the upland if there are any variations observed in the tonal characteristics of the imagery and such variations are mappable, then such areas are to be delineated on the imagery. The variations at this level could be due to the severity of erosion in some areas of the unit or the presence of gravel or stones *etc*. Many times, the reasons for these variations could not be ascertained clearly on the imagery at this level and in such situations, the delineated unit can be checked in the field later and corrected accordingly.

In lowland areas, slope will not be a critical factor, instead soil texture, colour, drainage, flooding, salinity and sodicity *etc*., will be critical for management. If there is any significant change in one of these properties as seen on the imagery, then it needs to be identified and delineated based on the tonal characteristics.

Image Interpretation Legend for Physiography

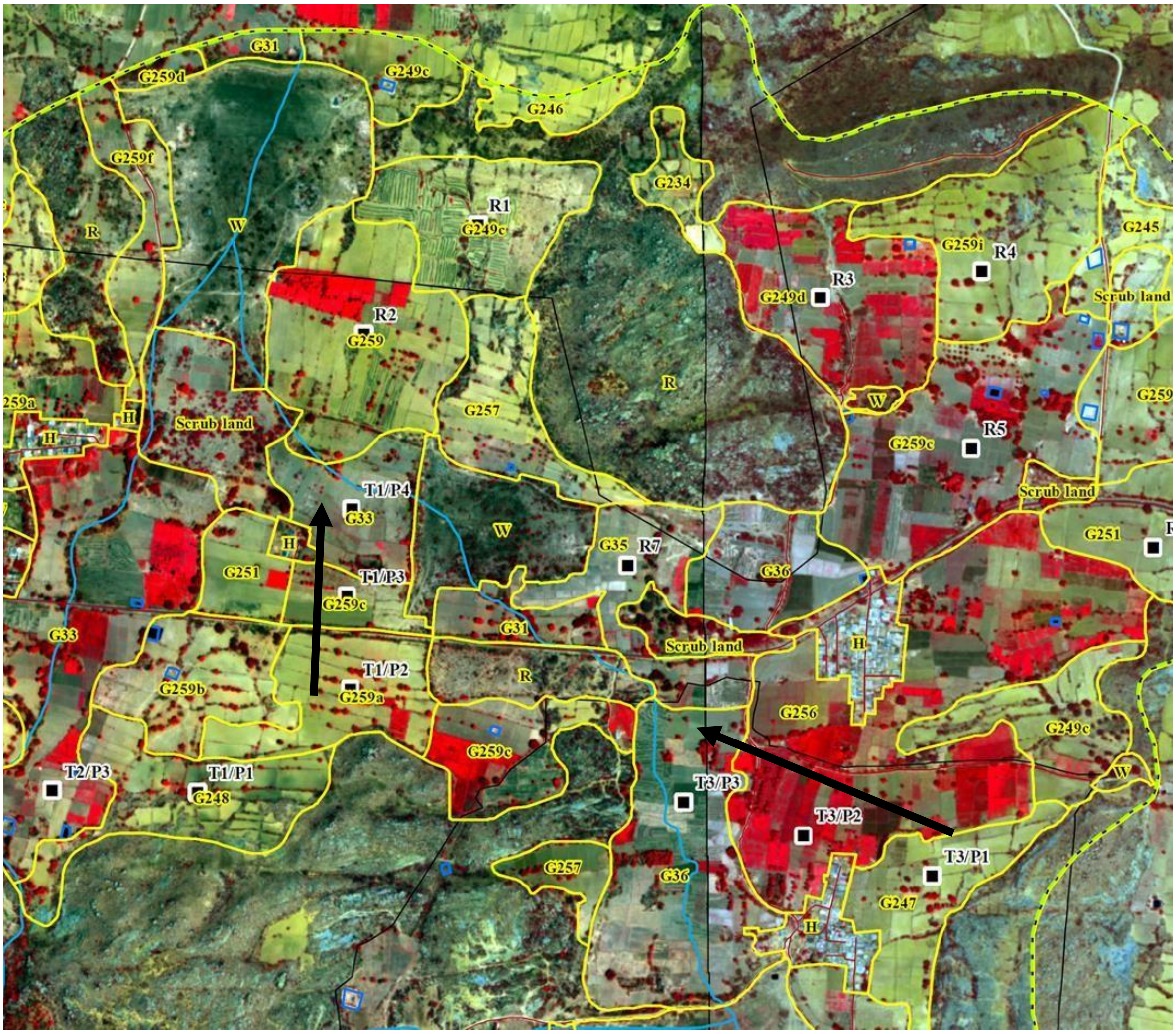
- **D** **Deccan Plateau**
- **DS** **South Deccan Plateau**
- **G** **Granite and Granite Gneiss Landscape**
  - **G1** **Hills/Ridges/ Mounds**
    - G11 Summits
    - G12 Hill/Side Slopes
      - G121 Side slopes with dark grey tones
    - G13 Isolated hillocks
  - **G2** **Uplands**
    - G21 Summits/ Nearly Level Lands
    - G22 Very gently sloping uplands
      - G22l Very gently sloping uplands, yellowish green
      - G222 Very gently sloping uplands, medium green and pink
      - G223 Very gently sloping uplands, pink and green (scrub land)
      - G224 Very gently sloping uplands, medium greenish grey
      - G225 Very gently sloping uplands, yellowish white (eroded)
      - G236 Very gently sloping uplands, dark green
      - G237 Very gently sloping uplands, medium pink (coconut garden)
    - G23 Gently sloping uplands
      - G231 Gently sloping uplands, yellowish green (eroded)
      - G232 Gently sloping uplands, yellowish white (severely eroded)
    - G24 Undulating uplands
  - **G3** **Valleys**
    - G31 Interhill Valley
    - G32 Valley /Lowlands
- **A** **Alluvial landscape**
  - A1 Nearly level Uplands
  - A2 Very gently sloping lands

Identification of transect for profile studies:

After the interpretation of maps for physiographic units, transects can be fixed tentatively based on variations observed in the map. Transects can be marked on different landform units falling adjacent and along the slope.

Criteria's for transect identification:

- ✓ Should represent large area and lengthy slope
- ✓ Should be along the slope
- ✓ Preferably in odd numbers
- ✓ Should not cross river, drainages and water bodies
- ✓ Each profile point in a transect should represent different landform units



Transects and randoms marked for profile study

Field activities: Traversing and validation of interpreted map

a) At Sub watershed level:

The physiography-landform map is to be checked for the accuracy of the delineation and their description in the field by taking up rapid traverse of the sub watershed area and corrected wherever necessary. During the traverse available road/well cuts, excavations, and profiles in few transects are examined, and variations observed in soil-site characteristics recorded. Based on the information collected a tentative map with legend of the SWS is prepared along with identifying characteristics for the major soils observed. This preliminary legend forms the basis for detailed field investigations at MWS level.

Differentiating Characteristics for identifying Soils at SWS level

Sl. No.	Soil Series	Depth (cm)	Colour	Texture	Gravel (%)	Horizon	Others
Soils of Granite gneiss Landscape							
1	Devihal (Dvh)	<25	2.5YR2.5/4 5YR3/4 ,4/6	cl	<15	Ap-Cr	
2	Harve (Hrv)	25-50	2.5YR3/6 5YR4/4	cl	>35	Ap-Bt-Cr	

b) At Micro watershed level:

The delineated units are checked and corrected and extent of habitations, permanent features, rock outcrops, gullies and ravines, quarried areas, fishponds, check dams *etc*., are marked on the map which eliminates areas that are not to be surveyed.

Study of site characteristics (phases):

During the traverse any variations observed in slope, erosion, texture, presence of stones, boulders, rock outcrops, drainage, salinity *etc*., are recorded on the map (preferably cadastral map) and in the proforma (if required). Then profiles are opened in the selected transects and their morphological and physical characteristics will be recorded.

Based on field observations and profile study, the initial legend prepared earlier at the SWS level is updated at the MWS level. After finalizing the soil series and updating the map legend, the soils series identified can be linked to the delineations along with site characteristics recorded earlier. This process results in the conversion of the interpreted map into a soil map for the MWS area. The delineated mapping units are shown on the map in the form of symbols.

For example, in the map unit **GHTcB2**

GHT - indicates the name of the soil series
c - indicates the texture of the surface soil
B - indicates the slope of the land
2 - indicates the degree of erosion

Any other feature observed in the field (like salinity, gravel *etc*.) can be shown by using appropriate symbols on the map. It is not possible to depict all the variations observed in the field on the map itself. The legend accompanying the map provides detailed description of the properties (like depth, texture, gravel, slope, salinity *etc*.) and their variations for each mapping unit.

Codification of soil samples (in master profiles):
Soil samples are collected from a representative pedon for each series for laboratory analysis. For labelling, the codification given below may be followed

For example - **Gg-Sht-Rtr-T1-P1 -P1/1, P1/2, P1/3, P1/n**

Gg - indicates the name of the district, Gadag

Sht - indicates the name of the taluk, Shirahatti

Rtr - indicates the name of the village, Ranatur

T1 - Transect No.1 in Ranatur village

P1 - profile No.1 in transect No.1 in Ranatur village

P1/1 (0-11 cm) - soil sample No.1 from Profile No.1

P1/2 (11-33 cm) - soil sample No. 2 from profile No.1

or

R1 Random profile No.1 from Ranatur village

R1/1 (0-18 cm) - soil sample No.1 from Random profile No. R1

R1/2 (18-42 cm) - soil sample No. 2 from Random profile No. R1

Grid soil sampling:
Composite soil samples are to be collected from grids drawn on the cadastral map at every 320 m interval (10.24 ha) for rainfed/dry land areas and 160 m interval (2.56 ha) for irrigated/command areas respectively. On an average, about 50 to70 soil samples are collected for an area of about 500 ha. The codification indicated below may be followed on the sample bag.

For example - **Kp/Gn/Kav/F1**

Kp - indicates the name of the district, Koppal District

Gn - indicates the name of the taluk, Gangavati Taluk

Kav - indicates the name of the village, Kavalur village

F1 - indicates the surface soil sampled at Grid Point No.1

Well Inventory:
The number of wells, both open and bore wells, tube wells with their exact locations to be collected along with water samples in the project area

Socio- economic data:
Socio-economic data on demography, land holdings, land use, cropping pattern, source of irrigation, cattle population *etc*., are to be collected from Census reports, village records and

Directorate of Statistics either during or even prior to the start of the LRI. If the available data is not complete or insufficient, then efforts can be made to collect the required additional data for the area.

Land use particulars (land use and land cover):

During the execution of the LRI, the land cover and land use particulars are to be collected. Apart from this, data on cropping pattern, inputs and level of management followed, yields obtained for different crops and other information pertaining to land use are to be collected wherever possible. For this, first broad land use areas like arable and non-arable lands, forest areas, community, and wastelands *etc*., are identified, and then within each land use area, like arable lands, major crops or combination of crops that are under cultivation are identified and marked for each survey number. Similarly, the tree species, shrubs and other vegetation types observed in non-arable, forest, community and wasteland areas are identified during the survey and land use map prepared for the watershed.

Identification of existing structures:

All the existing soil and water conservation and harvesting structures are to be identified and marked on the map

Profile study

Description of Site characteristics:

Soils are formed by the influence of various soil forming factors like climate, biota, topography, parent material and time. Since these factors are not uniform in any landscape, the soils formed will be different from place to place. To understand their variability and to map the distribution of soils, we need to have not only a detailed study and description of the soils but also the landform or site characteristics of the area. This chapter provides the guidelines needed for describing soil-site characteristics observed in the field.

The standard format to describe the soil-site characteristics is attached at the end of the chapter in which the first page lists the site characteristics to be recorded and soil characteristics on the back side. The field team should be familiar with the list of soil site characteristics that are to be studied and described in the standard proforma.

Field investigation Tick in the appropriate box

Author and date - Give the name of the Officer in- charge of the field party and date/time of observation

Example: Date/Month/Year (02/12/2022)

Series name - This box to be filled at the end of the soil profile study by comparing the pedon description with the series identification table provided for the survey area.

Map unit symbol - Indicate two or three letter symbols for the series, followed by the phase symbols

Soil classification - This box to be filled at the end of the soil profile study as per Soil Taxonomy

Observation No - Follow codification as described in previous section Codification of soil samples (in master profiles)

The list of districts with their symbols in the state, name of taluks and their symbols from each district and list of villages and their symbols in each taluk will be provided to the field parties before the start of LRI. This observation number will be unique for each site and to be followed both on the site description proforma as well as in the collection of soil samples for analysis from the site.

Toposheet, imagery, base map and cadastral sheet particulars are self-explanatory

Location - Indicate the exact location of the profile on the cadastral map within the survey number and describe the location of the profile with reference to some nearby fixed features. Precise GPS reading of the location is to be taken and entered in the box provided for latitude and longitude. The other locational details like plot number, village, hobli, taluk *etc.*, are to be entered in their respective spaces.

Physiographic region - Based on geology, relief and land use, the state is divided broadly into four physiographic regions *viz*., South Deccan Plateau, Western Ghats, Eastern Ghats and West Coast. Enter the appropriate physiographic region of area in the provided box.

Geology - The major geological formations are Granite Gneiss (GG), Granite (G), Charnockite (C), Basalt (B), Schist (S), Limestone (LS), Sandstone (SS), Laterite (L), Quartzsite (QZ) and Alluvium (A). Indicate the type of rock types observed in the area. Geology maps provided to the field parties can be used as a reference.

Parent material - The loose unconsolidated mineral material formed by weathering of rocks, from which the soils form is known as the parent material of the soil. The parent material is designated as C horizon in the soil profile and can be grouped into those formed in place through the disintegration and decomposition of rocks and those that have been transported from the place of their origin by various agents like water, wind and gravity *etc*.

Topography of the surrounding country - The surrounding area of the profile will normally have complex slopes and the terms used to describe the topography are indicated below. This contrasts with the simple slopes (soil slopes) used to describe the location of the profile in the pedon description form. This indicates the general variation in slope of the landform from its summit to its lowest one. Tick the one which is appropriate for the area after checking the slope with the counter map or with the help of Abney level or Clinometer.

Level	0-1 % slope 1-3 % slope
Nearly Level	3-8 % slope
Undulating	8-16 % slope
Rolling	16-30 % slope
Hilly	30-60 % slope
Steep	>60 % slope
Very steep	0-1 % slope 1-3 % slope

Landform - Based on geology, elevation, location and other features, the four major physiographic regions of the state are further subdivided broadly into nine landscape areas.

For example, the South Deccan Plateau region is subdivided broadly into Granite and granite gneiss landscape, basalt landscape, schistose landscape and lateritic landscape. Similarly, the Western Ghats region is divided into Northern and Southern Ghats, coastal plains into coastal uplands and marine plains. Since there is not much variation in the landscape features of the Eastern Ghats region, it is not subdivided further and retained as such as one landscape area. Enter the appropriate landscape name in the proforma.

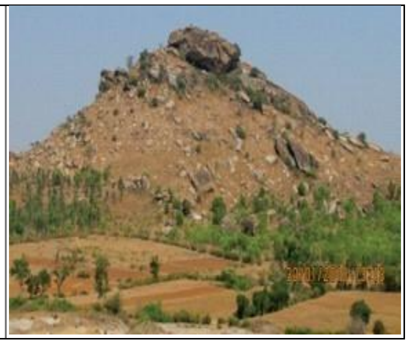
Any physical, recognizable feature of a landscape, having a characteristic shape and mappable area at the scale of survey is to be recorded

Major landscape areas	*Landforms identified*
Basalt landscape	Plateau, Mesas, butte, summits, escarpments, side slopes, sloping uplands, plains, valleys

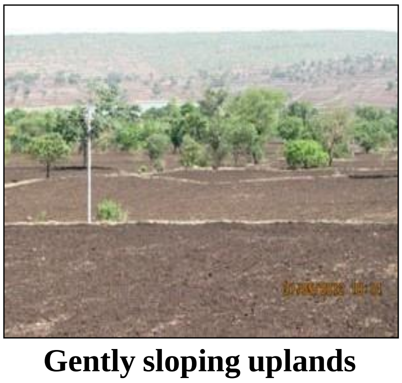
Granite and gneiss landscape	Hills (high hills, low hills), summits, escarpments, hill slopes, ridges, tors, inselbergs, foot slopes, sloping uplands, valleys
Schistose landscape	Hills (high hills, low hills), summits, escarpments, hill slopes, ridges, foot slopes, sloping uplands, valleys
Lateritic landscape	Hills, ridges, mounds, summits, side slopes, sloping uplands, valleys
Western Ghats-northern region	Hills (high hills, low hills), summits, escarpments, hill slopes, ridges, tors, inselbergs, foot slopes, sloping uplands, valleys
Western Ghats-southern region	Hills (high hills, low hills), summits, escarpments, hill slopes, ridges, tors, inselbergs, foot slopes, sloping uplands, Valleys
Eastern Ghats landscape	Hills (high hills, low hills), summits, escarpments, hill slopes, ridges, tors, inselbergs, foot slopes, sloping uplands, Valleys
Coastal uplands landscape	Mounds, ridges, summits, side slopes, foot slopes, uplands, lowlands, valleys
Coastal plains landscape	Beach, dunes, plains, salt pans, swamps, marshes, island

Gently sloping severely eroded uplands

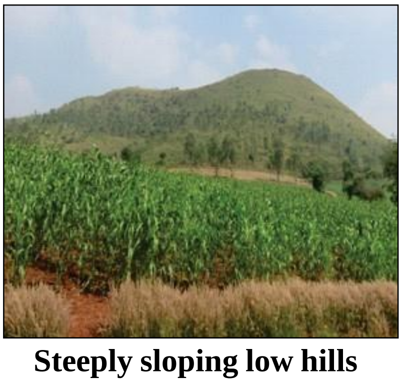
Elongated plateau in basalt landscape



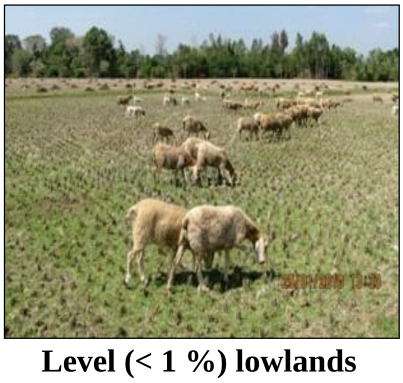
Conical residual hillock



Gently sloping uplands



Steeply sloping low hills



Level (< 1 %) lowlands

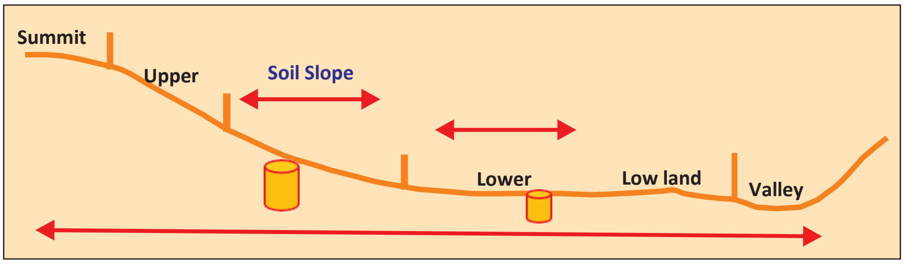
Typical landform units of granite gneiss and basalt landscape

Micro-features - Any discrete, natural or artificial surface feature, occupying very small area on the land surface, which cannot be delineated at the scale of mapping are known as micro features. These small features individually cover less than 100 m^2 area and the height difference will be within few metres from the ground level. For example, small gullies or sand dunes if they occur in a very small extent in the survey area are described as micro features and if the same occupy large areas, then they are delineated and described as a mapping unit.

The other examples of micro features are ridge-and-furrow, erosion rills, ant hills, channel, depression, hillock, interdune, intermittent stream, minor scarp, mound, hummocks, dune, gilgai, cracks, pond, pool, ripple mark, shoreline, tank, contour terracing, levees and land slip features. Describe the nature and frequency of occurrence of such micro features in the survey area and the relationship of the profile site to such features in the proforma.

Profile position - In a hilly area the profile position can be indicated as summit, shoulder, backslope, footslope or toeslope as the case may be. In uplands, the profile position can be indicated as summits, upper, middle and lower part of the upland and lowlands or valleys.

Soil slope - Soil slope refers specifically to the slope of the land immediately surrounding the profile (*i.e.* within 100 m of the profile pit) or representative section of the landform from which the profile is described. Since soil slope is generally in one direction, it is considered as simple slope. Slope has gradient, complexity, length, form and aspect.



Slope gradient is the inclination of the surface of the soil from the horizontal. The difference in elevation between two points is expressed as a percentage of the distance between those points. If the difference in elevation is 1 meter over a horizontal distance of 100 meters, then slope gradient is 1 per cent.

The slope gradient is measured at the profile site by using Abney Level and ranging rods or Clinometer. The Abney Level readings, degrees of inclination or declination can be converted into slope percentages and slope classes. The equivalence between percentage gradient, degree of slope angle and class of slope to be used in the field are as follows:

Class of slope	Range of slope %	Abney Level reading
A	0-1	0 to 35 min
B	1-3	35 min to 1 degree 44 min
C	3-5	1 degree 44 min to 2 degrees 52 min
D	5-10	2 degrees 52 min to 5 degrees 43 min
E	10-15	5 degrees 43 min to 8 degrees 32 min
F	15-25	8 degrees 32 mins to 14 degrees 03 mins
G	25-33	14 degrees 03 mins to 18 degrees 16 mins
H	33-50	18 degrees 16 mins to 26 degrees 34 mins

Slope length - Indicates the distance up to which there is no break in the slope. For example, if the length of B slope is 100 m, then this indicates that the distance between the starting point of the slope and the point where it breaks is about 100 m. Record the gradient and length in the proforma.

Erosion - The detachment and movement of soil materials from one place to another is known as soil erosion. Sheet, rill and gully erosion is common in the state.

a) **Sheet erosion** is responsible for almost uniform removal of soil from an area without leaving any significant marks at the surface.

b) **Rill erosion** is the removal of soil through many small incipient channels or rills.

c) **Gully erosion** is the consequence of water that cuts down into the soil along the line of flow.

Moderately eroded (e2), > 50 % surface soil eroded due to sheet erosion

Very severely eroded (e4), due to deep and wide gully erosion

Erosion classes - The erosion classes are estimated in the field based on the proportion of upper horizons/layers that have been removed. Since these horizons may range widely in their thickness, estimating the absolute amount of erosion in the field is not possible. The erosion classes indicated below are applicable for both water and wind erosion.

Erosion Class	*Estimated % loss of the surface soil (A horizon)*
1	Up to 25%
2	25 to 75%
3	75 to 100%
4	>75 % and total removal of surface or even subsoil

Class 1 (slight erosion) - This consists of soils that have lost some, but on the average less than 25 per cent of the surface soil (A horizon). Evidence for class 1 erosion includes

1. a few rills
2. an accumulation of sediment at the base of slopes or in depressions
3. scattered small areas where the plough layer contains material from below
4. evidence of the formation of widely spaced deep rills.

Class 2 (moderate erosion) - This class consists of soils that have lost, on the average, 25 to 75 per cent of the surface soil (A horizon). In cultivated areas, the surface layer consists of a mixture of the original A and/or horizons and material from below. Some areas may have intricate patterns, ranging from uneroded small areas to severely eroded small areas.

Class 3 (severe erosion) - This class consists of soils that have lost, on the average, 75 per cent or more of the original A horizon. In class 3 erosion, material below the A horizon is exposed at the surface in cultivated areas and some mixing with underlying material is also observed.

Class 4 (very severe erosion) - This class consists of soils that have lost all the A horizon and in addition includes some or all the deeper horizons in most of the area. Indicate the kind or degree and class of erosion observed at the profile site in the proforma.

Surface Runoff - Surface runoff or external soil drainage refers to the loss of water from an area by flow over the land surface. Six classes are used to describe the runoff of an area.

a) **Ponded -** None of the water added to the soil as precipitation or by flow from surrounding areas escapes as runoff. This condition occurs normally in depressed areas.

b) **Very slow -** Surface water flows away **very slowly** that free water lies on the surface for long periods or enters immediately into the soil. In very slow condition, most of the water either passes through the soil or evaporates into the air. This condition is observed normally in level to nearly level areas or in very porous sandy soils.

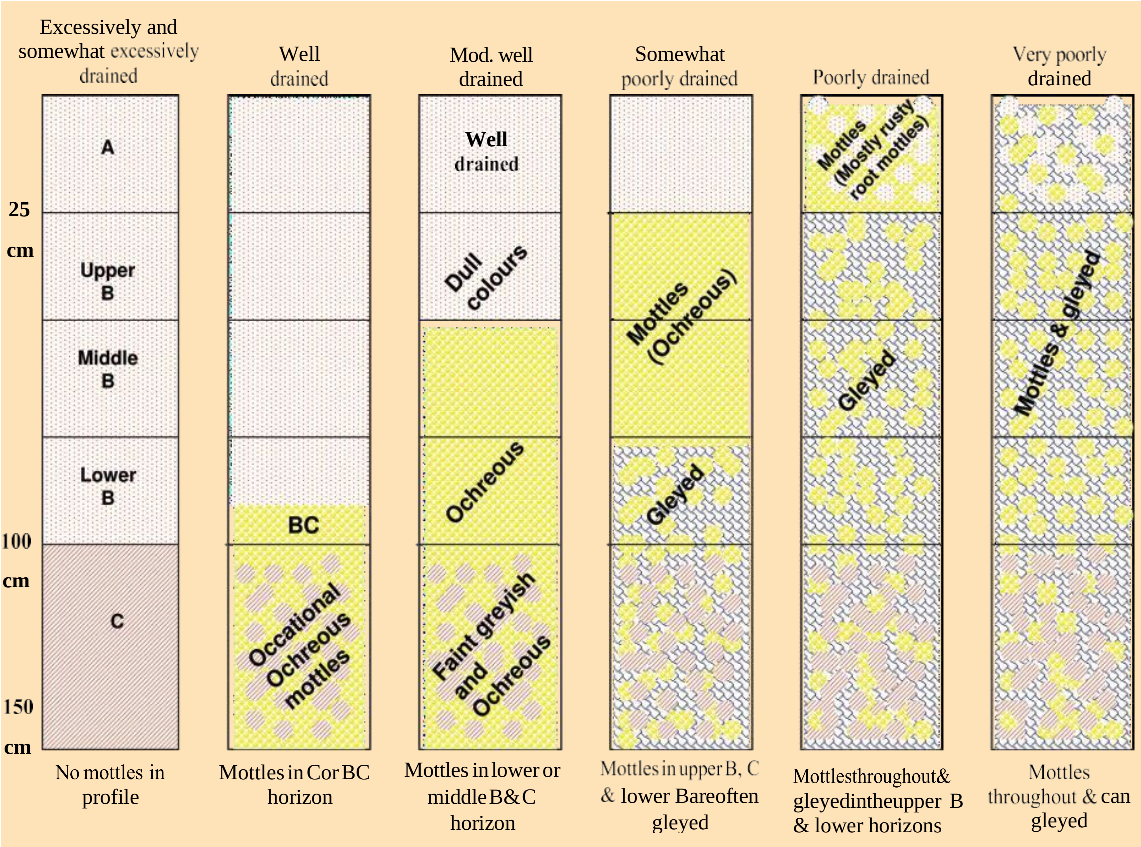
c) **Slow -** Surface water flows away **slowly** that free water lies on the surface for significant periods or enters rapidly into the soil. This condition is observed normally in nearly level or very gently sloping areas or in sandy soils.

d) **Medium -** Surface water flows away at such a rate that a moderate proportion of the water enters the soil and free water lies on the surface for only short periods.

e) **Rapid -** A large part of the rainfall moves rapidly over the surface of the soil and a small part moves through the soil profile. In this condition, water runs off nearly as fast as it is added and occur in moderately steep to steep areas and in soils with low infiltration capacity.

f) **Very rapid -** A very large part of the rainfall moves rapidly over the surface of the soil and a very small part moves through the soil profile. In this condition, water runs off as fast as it is added and are observed in steep to very steep areas and in soils with low infiltration capacity.

Drainage Classes - Natural drainage class refers to the frequency and duration of wet periods under conditions like those under which the soil developed. After completing the profile study, go through the description provided in the table and compare the soil colour and occurrence of mottles with the chart to find out the drainage class.



Morphological changes due to prolonged wetness and poor drainage

Description of various drainage classes of soil

Drainage class	*Characteristics*	*Water table (cm)*	*Mottles/gleying & other features*
Excessively drained	Water is removed from the soil very rapidly	>100	None in profile
Somewhat Excessively drained	Similar to excessively drained, but water table may not be as deep, and the soil may be slightly fine textured	>100	None in profile
Well drained	Water is removed from the soil readily but not rapidly.	at or nearer to 100	Mottles in C or BC horizon
Moderately well drained	Water is removed from the soil somewhat slowly. Soil is wet for a short time have a slowly pervious layer within one metre, periodically receive high rainfall, or both	75 – 100	Mottles in lower or middle B horizon and in C horizon
Somewhat poorly drained	The soil is wet at a shallow depth for significant periods and commonly have a pervious layer, high-water table, and/or nearly continuous rainfall	25-75	Mottles in upper B horizon; C and lower B horizons are often gleyed

Poorly drained	The soil is wet at shallow depths or remains wet for long periods. Needs proper drainage for cultivation.	< 25	Mottles throughout the profile; soil is in the upper B and lower horizons
Very poorly drained	Similar to poorly drained soils except that the soils occur on level or depressed areas and are frequently ponded	At surface or < 15	Entire profile has mottles and soil may be gleyed

Ground water depth - Indicate the depth of the water table and seasonal fluctuations of the profile site area. The water table measurements can be taken from the nearest open or bore wells or by enquiring with the farmers of the area.

Flooding - Wherever records are available they can be collected, and the frequency can be indicated and in other areas, it can be estimated based on the site characteristics and other converging evidence.

Frequency	*Classes Criteria*
None	No possibility of flooding in the area
Rare	1 to 5 times in 100 years
Occasional	5 to 50 times in 100 years
Frequent	>50 times in 100 years, *ie*, once in two years
Very frequent	Every month > 15 day in a year, used for tidal flooding

Salt / alkali (per cent surface coverage) - The presence of salinity or alkalinity can be identified based on the occurrence of barren areas, presence of salt tolerant crops like prosopis and very poor or stunted growth of plants. Presence of white encrustation on the surface of the soil is an indication of salinity and smooth or fluffy feel to the feet indicates alkalinity in the field. Observe the extent of the area covered by the saline or alkali areas and indicate the per cent surface cover in the column provided.

Soil Reaction (pH) - In the field, pH is estimated by using pH indicator papers and portable pH meter. After estimation, tick the appropriate pH values given in the column.

Electrical Conductivity (EC) - It is a measure of the concentration of water-soluble salts in soils. The occurrence of bare spots, salt tolerant crops like prosopis and uneven crop growth are indicators of salinity in the field. Portable field EC meters are used to estimate the salt content.

Surface fragments - This refers to the presence of coarse fragments (>2 mm in size) on the soil surface. The classes used are pebbles, cobbles, stones, and boulders based on their size. Gravel is a collection of pebbles that have diameters ranging from 2 to 75 mm. The size of the cobbles ranges from 75 to 250 mm (3 to 10 inches), stones from 250 to 600 mm (10 to 24 inches) and boulders above 600 mm (>24 inches). Assessment for the surface fragments is done separately for the gravel and for stones and boulders. Indicate the size of the fragments observed in the field. The gravelliness and stoniness classes used are indicated below

Gravelliness class	*% of area covered*
Non gravelly	< 15 per cent
Gravelly	15 to 35 per cent
Very gravelly	35 to 60 per cent
Extremely gravelly	60 to 80 per cent
Considered as part of the top	>80 per cent

Stoniness class	*Percentage of surface covered*
Stony (class 1)	0.01 to 0.1 per cent of the surface
Very stony (class 2)	0.1 to 3 per cent of the surface
Extremely stony (class 3)	3 to 15 per cent of the surface
Rubbly (class 4)	15 to 50 per cent of the surface
Very rubbly (class 5)	>50 per cent of the surface

Rock outcrops - The distance between the rock outcrops and their percentage coverage in the field is to be recorded as indicated below

Per cent coverage	**Description**
< 2	No rocks or very few rocks to interfere with tillage
2 to 10	Fairly rocky, sufficient to interfere with tillage but not to make inter-tilled crops impracticable. Exposures are roughly 35 to 100 m apart
10 to 25	Rocky, sufficient to interfere with tillage of inter-tilled crops impracticable. Exposures are roughly 10 to 35 m apart.
25 to 50	Very rocky, sufficient to make all use of machinery impracticable, except for light machinery. Exposures are roughly 3.5 to 10 m apart
50 to 90	Extremely rocky, sufficient rock outcrops to make all use of machinery impracticable. Exposures are about 3.5 m apart or less
Over 90	Rock outcrops

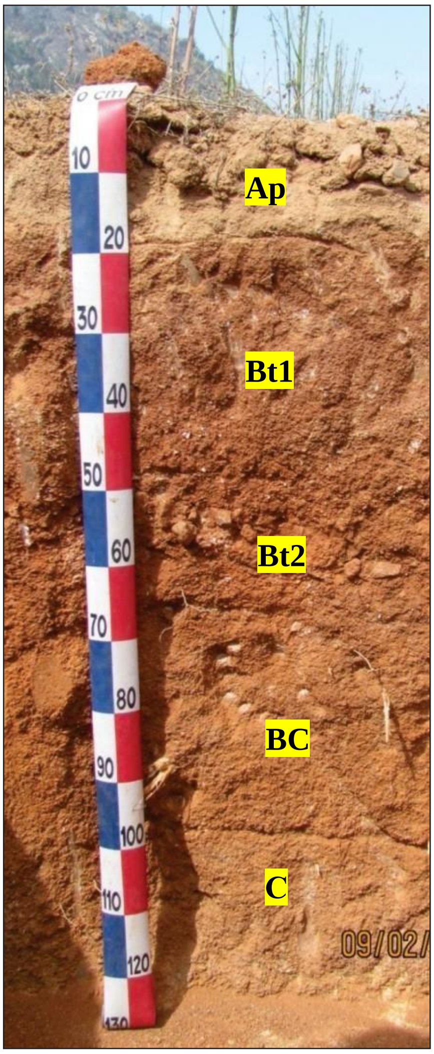
Elevation - Elevation refers to the height of a point on the earth's surface, relative to mean sea level. It can be determined from the contour maps or by using Global Positioning System (GPS). The elevation of the area is to be noted in the box based on the GPS measurement.

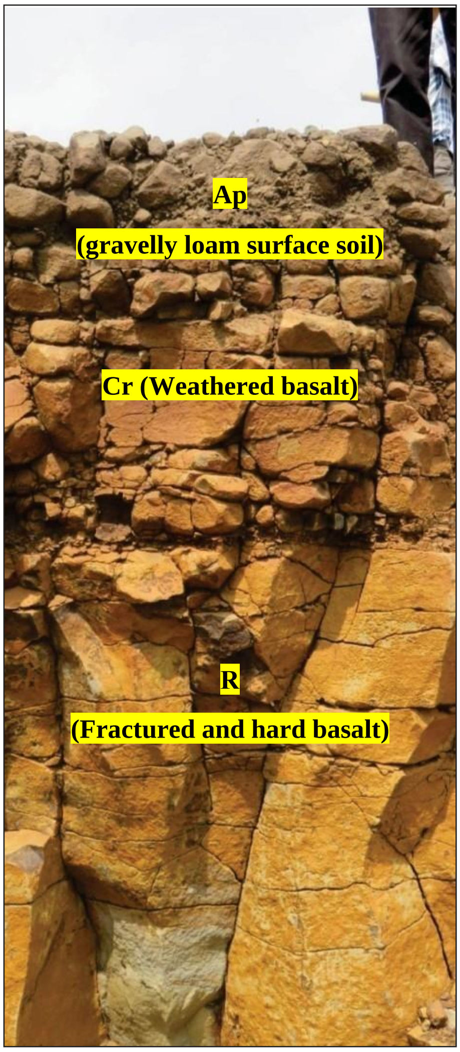
Land Use - Indicate the name of the crop or combination of crops (common names like bajra, ragi *etc*., are preferred) cultivated in the season and crops cultivated in the previous season and major and minor crops if it is a mixed one.

Vegetation - The type of natural vegetation to be described with their common names.

Soil characters

Study and description of soils is important to understand their formation and mapping. Soil properties are studied by opening a profile of 2 m length, 1m width and 2 m depth in a representative area. The profile is cleaned and examined carefully from the surface to identify any change in the morphology or other properties of the soil. Based on the changes observed, layers/horizons are identified and marked. Immediately after marking the layers photographs of the profile and surrounding features are to be completed, followed by estimation of the volume of coarse fragments and any other features that may be destroyed later during the study of the soils. Apart from profile study, road/well cuts, quarries or other fresh cuts can be used to describe the soils of the survey area.





Typical horizon designations used to describe profile development

Soil depth - Soil depth indicates the depth of the solum, which includes A and B horizons, occurring above the parent material or hard rock. Depth is measured from the soil surface. For soils with a cover of 80 per cent or more rock fragments on the surface, the depth is measured from the surface of the rock fragments. Generally, all the four faces of the pit will not be uniform, and care is necessary to select the typical or representative face of the pit for the study of the profile. The depth classes are

Very shallow	25 cm
Shallow	25-50 cm
Moderately shallow	50-75 cm
Moderately deep	75-100 cm
Deep	100-150 cm
Very deep	> 150 cm

Horizon - Horizon development indicates the extent and degree of soil formation. It will be weak in the early stages and exhibit distinct characteristics in well-developed soils.

a. **Designations for horizons -** Layers and horizons of different kinds are identified by symbols. Capital letters (O, A, E, B, C, R and W) are used to designate the master horizons. Lower case letters are used as suffixes to indicate specific characteristics of master horizons. Arabic numerals are used both as suffixes to indicate vertical subdivisions within a horizon or layer and as a prefix to indicate discontinuities.

b. Master Horizons and Layers

O horizons or layers - This layer is dominated by organic material and consist of undecomposed or partially decomposed litter, deposited on the surface of either mineral or organic soils.

A horizons - It is a mineral horizon formed at the surface or below O horizon. They exhibit obliteration of all or much of the original rock structure and show an accumulation of humified organic matter intimately mixed with the mineral fraction.

E horizons - Mineral horizon in which the main feature is loss of silicate clay, iron, aluminium, or some combination of these, leaving a concentration of sand and silt particles. This horizon is usually lighter in colour than B and A horizons. The organic matter is normally less than A horizon and occurs commonly near the surface.

B horizons - Horizons that formed below an A, E, or O horizon and are dominated by obliteration of all or much of the original rock structure and show one or more the following:

1. illuvial concentration of silicate clay, iron, aluminium, humus, carbonates, gypsum, or silica, alone / in combination
2. evidence of removal of carbonates
3. residual concentration of sesquioxides
4. coatings of oxides that makes the horizons lower in value, higher in chroma, or redder in hue than overlying and underlying horizons
5. alteration that forms silicate clay or liberates oxides or both and that forms granular, blocky or prismatic structure
6. brittleness or gleying

C horizons - Horizons, excluding hard bedrock, that are little affected by pedogenic processes and lack properties of O, A, E, or B horizons. The material of C layers may be either like or unlike that from which the solum presumably formed. The C horizon may have been modified even if there is no evidence of pedogenesis.

R layers: Hard Bedrock - The R layer is coherent when moist to make hand digging with a spade impractical, although it may be chipped or scrapped.

Transitional horizons - Horizons dominated by properties of one master horizon but having subordinate properties of another. Two capital letter symbols are used to designate the transitional horizons (AB, EB, BE, BC, CB). The master horizon symbol that is given first designates the kind of horizons whose properties dominate the transitional horizon.

Combination horizons - Horizons in which distinct parts have recognizable properties of the two kinds of master horizons indicated by the capital letters. The two capital letters are separated by a slash as A/B, E/B, B/E, B/C.

Subordinate distinctions within master horizons - Lower case letters are used as suffixes to designate kinds of master horizons and some of the symbols used commonly are indicated below

Horizon suffix	*Criteria*
A	Highly decomposed organic matter. Used with O horizon
C	Concretions or nodules
E	Moderately decomposed org. matter
G	Strong gley
K	Accumulation of (pedogenic) carbonates
N	Pedogenic, exchangeable sodium accumulation
P	Plough layer or other artificial disturbance
R	Weathered or soft bedrock
Ss	Presence of slickensides
T	Illuvial accumulation of silicate clay
V	Presence of plinthite
W	Weak color or structure within B (used only with B)

Conventions for using letter suffices

- Master horizon symbol (capital letter) should be followed by one or more lower case letters.
- Normally up to two suffices are used and more than three suffices are rarely used.
- B horizon with accumulation of clay and also showing evidence of colour or structure, or both, is designated as Bt and not as Btw or Bts or Btws (t has precedence over w, s, and h).

Vertical subdivision - The subdivision of a horizon or layer designated by a single letter, or a combination of letters is indicated at the end using arabic numerals. For example, the subdivision of B horizon can be shown as Bt1-Bt2-Btk1-Btk2 and not as Bt1-Bt2-Btk3-Btk4.

Discontinuities - Arabic numerals are used as prefixes (preceding A, E, B, C, and R) to indicate discontinuities in mineral soils. Discontinuity is indicated by significant or abrupt change in texture, age or mineralogy between the layers or horizons. Examples: A-Bt-C-2R, Ap-Bt1-2Bt2-2Bt3-2BC-C.

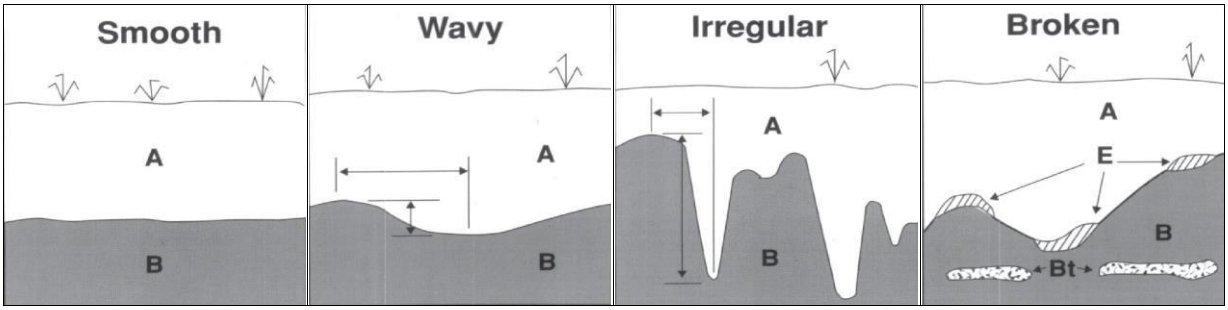
Boundaries of horizons and layers - A transitional area or layer present between two adjoining horizons or layers is known as the boundary. Boundaries vary in **distinctness** (contrast) and in **topography**.

Distinctness - Distinctness is the distance through which one horizon grades into another. It refers to the thickness of the zone within which the boundary can be located. The distinctness depends on the degree of contrast between the layers and thickness of the transitional zone. Distinctness is defined in terms of thickness of the transitional zone.

Distinctness class	*Criteria: transitional zone thickness*
Very Abrupt or sharp	Less than 0.5 cm
Abrupt	0.5 to < 2 cm
Clear	2 to < 5 cm
Gradual	5 to 15 cm
Diffuse	> 15 cm

Topography - Topography is the lateral undulation and continuity of the boundary between horizons. Topography refers to the irregularities of the surface that divides the horizons

Smooth	The boundary is a plane one with few or no irregularities
Wavy	The boundary has undulations in which the width of undulation is more than the Depth
Irregular	Similar to wavy in which the depth of undulation is more than the width
Broken	Discontinuous horizons; discrete but intermingled, or irregular pockets



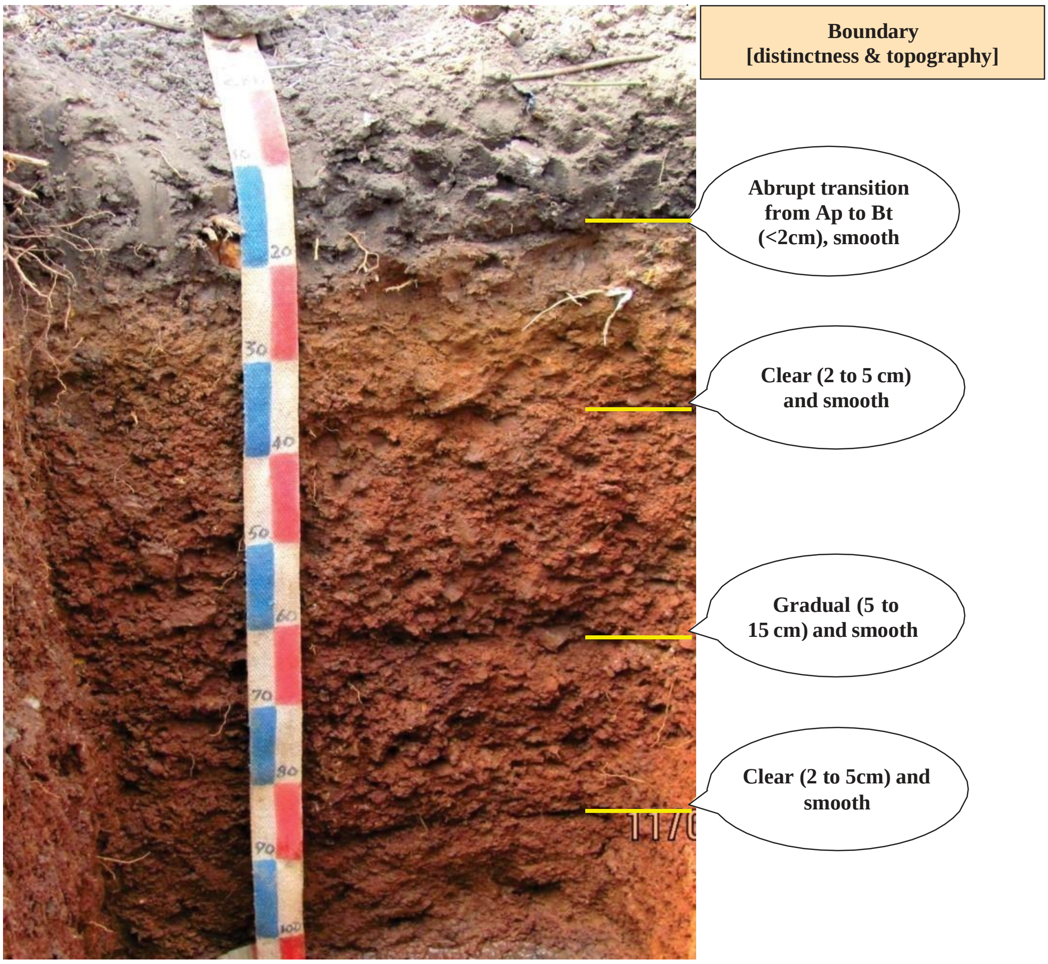
Topography of the soil boundaries as seen in the field

Soil colour - Soil colour is measured by comparing peds with Munsell Colour Chart. The notation is recorded in the form of hue, value and chroma - for example, 5YR 5/3.

1. **Hue** is a measure of the chromatic composition of light that reaches the eye.
2. **Value** indicates the degree of lightness or darkness of a colour in relation to a neutral grey scale. The value is a measure of the amount of light that reaches the eye under standard lighting conditions. **Grey** is perceived as about halfway between black and white and has a value notation of 5/.
3. **Chroma** is the relative purity or strength of the spectral colour. The scales of Chroma for soils extend from /0 for neutral colours to a chroma of /8 as the strongest expression of

colour used for soils.

Distinctness (contrast between two layers) and topography of red soil profile



Typical soil colours in red (5YR 4/6) and black soils (10YR 3/1)

Conditions for measuring soil colour - Measurement of soil colour is affected by the quality and intensity of light, moisture content and roughness of the sample selected. Determination done either early in the morning or late in the evening will not be accurate. Also, when the sun is low or the atmosphere is smoky, the light reaching the sample and the light reflected will be more towards redder colour. Colours also appear different in the subdued light of a cloudy day than in bright sunlight. Hence, determination of soil colour is undertaken in shade by utilising the shadow of the person holding the colour chart.

Mottling - Mottles are spots of different colours which are different from colour variation associated with ped surfaces, worm holes, concretions, nodules, *etc*. Mottles are described by quantity, size, contrast, colour, and shape in that order.

Quantity - Indicates the per cent of horizon area covered by mottles

Few	< 2 % of surface area
Common	2 to 20 % of surface area
Many	> 20 % of surface are

Mottling size - Refers to dimensions as seen on a plane surface. It is measured along the greatest dimension except in linear forms. The size classes used are

Fine	< 2 mm
Medium	2 to < 5 mm
Coarse	5 to < 20 mm
Very Coarse	> 20 mm

Mottling Contrast - Refers to the degree of visual distinction that is evident between associated colours. Record the colour difference between the mottle and the dominant matrix colour and express the contrast as indicated below

Faint	Evident only on close examination. Faint mottles commonly have the same hue as the colour to which they are compared and differ by no more than 1 unit of chroma or 2 units of value
Distinct	Readily seen but contrast only moderately with the colour to which they are compared
Prominent	Contrast strongly with the colour to which they are compared

Soil texture - Soil texture refers to the relative proportion (per cent by weight) of sand, silt and clay present in a soil. Texture is estimated in the field by feel method. The texture classes range from sand to clay and some of the commonly occurring texture classes are briefly described below. Normally, sand particles feel gritty, and the grains can be seen with the naked eye. Silt has a smooth feel to the fingers both in dry and wet conditions. Clayey soils exhibit sticky and plastic characteristics. Guidelines for the assessment of soil texture in the field are indicated in the table below

Modifiers used for describing soil texture - If the soil (fine earth) contains various rock fragments, their quantity and size are recorded and used as a modifier in describing the texture of the soil.

Rock fragments % byvolume	*Modifier used for texture description*
< 15	No texture adjective is used (noun only; e,g., loam)
15 to < 35	Use adjective for appropriate size; e.g., gravelly

35 to < 60	Use "very" with the appropriate size adjective; e.g., very Gravelly
60 to < 90	Use "extremely" with the appropriate size adjective; e.g., extremely gravelly
> 90	No adjective or modifier, If the soil contains < 10 % fine earth, use the appropriate noun for the dominant size class; e.g., gravel (used in lieu of texture)

Guide for assessment of soil texture in the field

Sl. No.	*Texture class*	*Feel*	*Coherence at sticky point*	*Ribbon Length [mm]*	*Other features*	*Clay %*
1	Sand	Very gritty	Nil	Nil	Single sand grains adhere to fingers	<5
2	Loamy sand	Very gritty	Slight	5	Discolor fingers with an organic stain	5-10
3	Sandy loam	Gritty	Just coherent	15-25	Medium sand readily visible	10-20
4	Loam	Neither very gritty nor very smooth	Coherent	about 25	No obvious sandiness	25
5	Silt loam	Smooth or buttery	Coherent	about 25	Silky; very smooth	25 (>25 silt)
6	Sandy clay loam	Moderately gritty	Strong	25-40	Medium sand in fine matrix	20-30
7	Clay loam	Slightly Gritty	Strong	40-50	No obvious sand grains	30-35
8	Silty clay loam	Very smooth	Coherent	40-50	Silky feeling	30-35 (>25 silt)
9	Sandy clay	Sticky	Coherent	50-75	Fine to medium	35-40
10	Silty clay	Sticky	Coherent	50-75	Smooth and Silky	35-40 (>25 silt)
11	Clay	Sticky	Coherent	>75	Smooth with slight to fair resistance to shearing	35-50
12	Heavy Clay	Very sticky	Coherent	>75	Firm resistance to shearing	>50

Rock fragments (described earlier as coarse fragments) **-** The discrete unattached pieces of rock having more than 2 mm in diameter are described by their size as indicated below.

2 - 75 mm diameter	Pebbles
75 – 250 mm	Cobbles
250 – 600 mm	Stones
> 600 mm	Boulders

Soil Structure - The arrangement of primary soil particles into aggregates is known as structure in soils. Clods and fragments in the soil are not considered as structural units. Soils lacking structure are considered as structure less soils and described as single grain or massive. The structure is described based on the shape (type), size and grade of the structural units observed in the soil.

Based on shape (type)

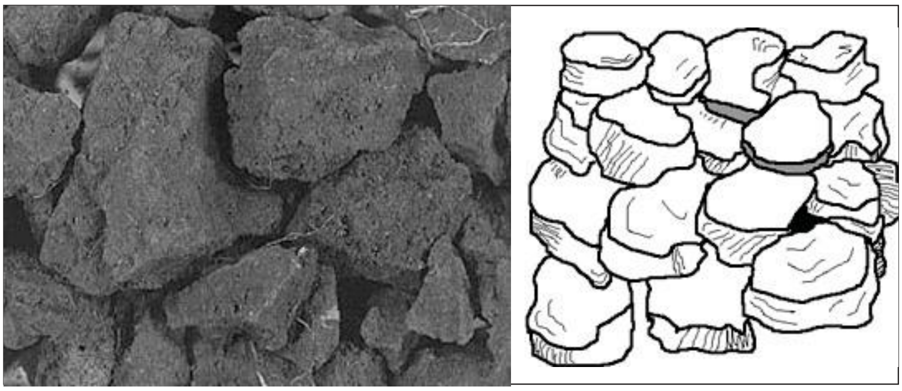
Platy	The units are flat and plate like and horizontally oriented
Prismatic	Vertically elongated units with flat tops, the individual units are bounded by flat to rounded vertical faces
Columnar	The units are like prisms and are bounded by flat or slightly rounded vertical faces and the top of columns are rounded
Blocky	The units are like blocks and considered as angular blocky if the faces intersect at sharp angles; sub angular blocky if the faces are a mixture of rounded and plane faces and the corners are mostly rounded
Granular	The units are approximately spherical or polyhedral and are bounded by curved or very irregular faces

Size - Based on size, the structural units are described as very fine, fine, medium, coarse and very coarse.

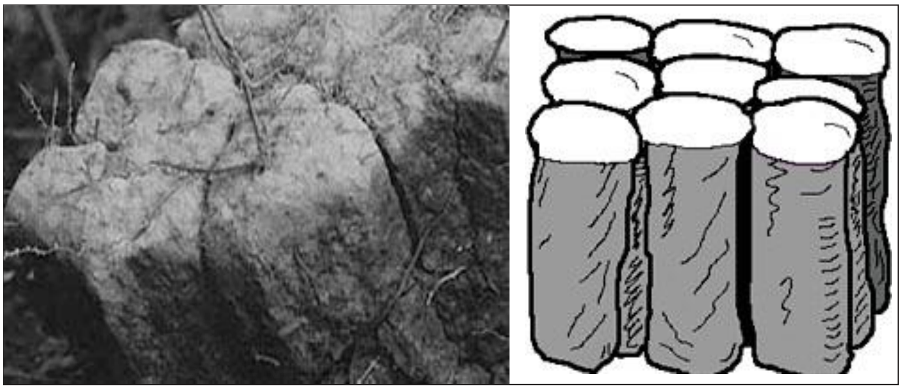
Size classes	*Grannular, Platy (mm)*	*Prismatic & Columnar (mm)*	*Blocky (mm)*
Very fine	< 1	< 10	< 5
Fine	1-2	10-20	5-10
Medium	2-5	20-50	10-20
Coarse	5-10	50-100	20-50
Very Coarse	> 10	> 100	> 50

Grade - Grades describe the degree of ped development in the soil. It is distinguished in the field by the portion of the soil appearing as peds and the ease with which the soil separates into peds and their durability. Three classes are used to describe the grade

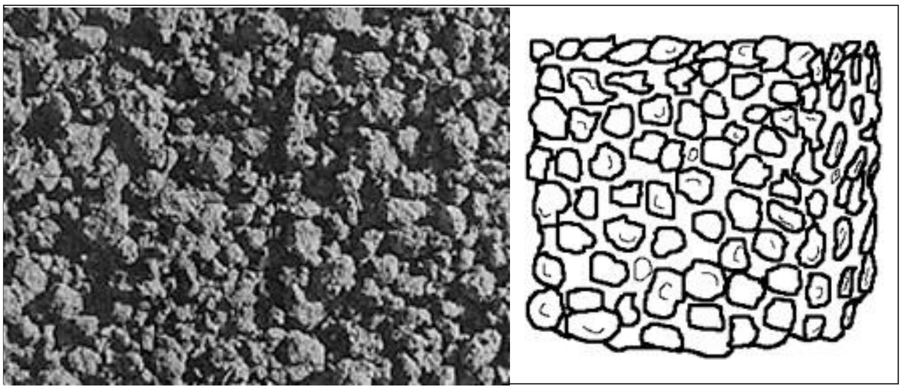
Structureless (0)	No discrete units observable in place or in hand sample
Weak (1)	Units are barely observable in place or in a hand sample
Moderate (2)	Units well-formed and evident in place or in a hand sample
Strong (3)	Units are distinct in place (undisturbed soil) and separate cleanly when Disturbed



Blocky - Irregular blocks that are usually 1.5 - 5.0 cm in diameter



Columnar - Vertical columns found in arid climate



Granular - Resembles crumbs and seen in surface horizons

Consistence - It refers to the degree and kind of cohesion and adhesion and/or the resistance of soil to deformation or rupture when stress is applied. Every soil has this property, irrespective of their nature and moisture status. In the field, consistence is assessed based on resistance of soil material to rupture, resistance to penetration, plasticity, toughness, and stickiness of puddled soil material, and the way the soil material behaves when subject to compression. Consistence is highly dependent on the soil-water state, and it is observed for dry and moist soil in the field separately.

Dry Class	*Moist Class*	*Specimen fails under*
Loose	Loose	Intact specimen not available
Soft	Very friable	Very slight force between fingers
Slightly hard	Friable	Slight force between fingers
Moderately Hard	Firm	Moderate force between fingers
Hard	Very firm	Strong force between fingers
Very hard	Extremely firm	Moderate force between hands
Extremely hard	Slightly rigid	Foot pressure by full body weight
Rigid	Rigid	Cannot be failed underfoot by full body weight

Plasticity is the degree to which puddled or reworked soil can be permanently deformed without rupturing. The evaluation is made by forming a roll (wire) of soil at a water content where the maximum plasticity is expressed

Non plastic (po)	Will not form a roll 6 mm in diameter, or if a roll is formed, it can't support itself if held on end
Slightly Plastic (ps)	6 mm diameter roll supports itself
Moderately Plastic (p)	4 mm diameter roll supports itself; 2 mm diameter roll does not
Very Plastic (vp)	2 mm diameter roll supports its weight

Stickiness - refers to the capacity of a soil to adhere to other objects. The determination is made on puddled soil material at the water content at which the material is stickiest. The sample is crushed in the hand, water is applied while manipulation is continued between thumb and forefinger until maximum stickiness is reached.

Stickiness Class	*Code*	*Criteria-Description*
Non-sticky	so	After release of pressure, practically no soil material adheres to fingers
Slightly sticky	ss	Soil adheres to both fingers, after release of pressure. Soil stretches little on separation of fingers.
Moderately Sticky	ms	Soil adheres to both fingers, after release of pressure. Soil stretches some on separation of fingers.
Very Sticky	vs	Soil adheres firmly to both fingers, after release of pressure. Soil stretches greatly on separation of fingers

Redoximorphic Features (RMF) - Mottles are already described under the section soil colour. RMF mottling is normally associated with wetness. The colour pattern of RMF, is due to depletion or concentration of pigments compared to the matrix colour and formed by oxidation/reduction of Fe and/or Mn coupled with their removal, translocation, or accrual; or a soil matrix colour controlled by the presence of Fe^{2+}. RMF are described separately from other mottles, salt concentrations or clay films.

RMFs include the following:

1. **Redox Concentrations -** Localized zones of enhanced pigmentation, formed due to the accumulation of Fe-Mn minerals in the form of

- **Masses** - Non cemented bodies of enhanced pigmentation that have aredder or blacker color than the adjacent matrix.

- **Nodules or Concretions** - Cemented bodies of Fe-Mn oxides.

2. **Redox Depletions -** Localized zones of “decreased" pigmentation that are greyer, lighter, or less red than the adjacent matrix. Redox depletions (chroma ≤ 2) are used to define aquic conditions and to infer the depth of saturation in soils. Types of redox depletions in the soil are:

- **Iron Depletions** - Localized zones that have a yellower, greener; or bluer hue; a higher value; or a lower chroma than the matrix color. Color value is normally ≥ 4. Loss of pigmentation results from the loss of Fe and/or Mn.

- **Clay Depletions -** Localized zones that have either a yellower, greener or bluer hue, a higher value; or a lower chroma than the matrix color. Color value is normally ≥ 4. Loss of pigmentation results from a loss of Fe and or Mn and clay.

3. **Reduced Matrix -** A soil horizon that has an *in-situ* matrix chroma ≤ 2 due to the presence of Fe^{2+}. Color of a sample becomes redder or brighter (oxidizes) when exposed to air.

RMF are described separately from other color variations, mottles or concentrations. Record Kind, Quantity (% of area covered), Size, Contrast, Color, Shape, Location, Hardness *etc*. in the proforma

Quantity (% of area covered)

Class	*Code*	*Criteria: % of surface area covered*
Few	F	< 2
Common	C	2 to < 20
Many	M	≥ 20

Size (Refer size class under mottles or concentrations)

Size Class	*Code*	*Criteria*
Fine	1	< 2 mm
Medium	2	2 to < 5 mm
Coarse	3	5 to < 20 mm
Very Coarse	4	20 to < 76 mm
Extremely Coarse	5	≥ 76 mm

Contrast - Describe the contrast as faint, distinct or prominent as provided for the mottles

Colour - use the Color chart to describe them

Concentrations - Concentrations are formed by accumulation of material during soil formation due to dissolution, precipitation, oxidation, and reduction and physical and/or biological removal, transport, and accrual. Types of concentrations include

a. **Finely Disseminated Materials** are patches of precipitates (e.g. salts, carbonates) dispersed throughout the matrix of a horizon and can be detected by a chemical reaction (e.g. effervescence of $CaCO_3$ by HCl).

b. **Masses** are non-cemented accumulation that cannot be removed from the soil as discrete units, and consist of calcium carbonate, fine crystals of gypsum or more soluble salts or iron and manganese oxides.

c. **Nodules are** cemented bodies of various shapes that can be removed as discrete units from soil.

d. **Concretions** are cemented bodies like nodules, except for the presence of visible concentric layers of material around a point line or plane.

e. **Crystals** are crystalline forms of relatively soluble salts (e.g. halite, gypsum, carbonates) that form *in situ* by precipitation from soil solution.

f. **Biological Concentrations** are discrete bodies accumulated by a biological process like fecal pellets, or insect casts formed or deposited in soil.

g. **Plinthite** is iron-enriched reddish bodies that are low in organic matter and are coherent enough to be separated readily from the surrounding soil. It is firm or very firm when moist, hard, and very hard.

Field description of concentrations - The description of concentrations is like that of the mottles or redoximorphic features present in the soil.

a. Kind - Identify the composition and the physical state of the concentration in the soil. A rough field guide to identify the materials is given below

- Finely disseminated - Carbonates, salts
- Masses - non-cemented Carbonates, Gypsum, Salts
- Nodules - cemented Carbonates, Gibbsite
- Concretions - cemented Carbonates, Gibbsite, Titanium oxide
- Crystals - Calcite, Gypsum, Salt (NaCl, Na-Mg sulfates)
- Biological concentrations **- f**ecal pellets, insect casts, root sheaths, worm casts

b. Quantity (% area covered) - Refers to the relative volume of a horizon or other specified unit occupied by the bodies. The classes used are the same as that used for estimating the quantity of mottles and redoximorphic in the soil.

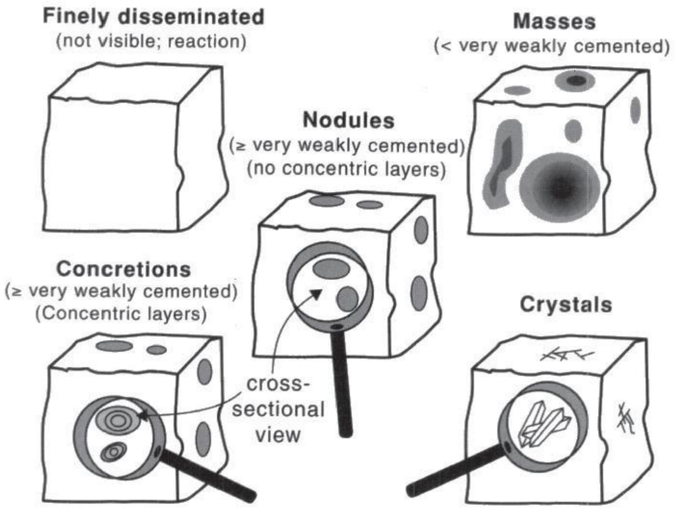
c. Size is like the classes used for describing mottles.

d. Contrast is like describing Mottle or RMF present in the soil.

e. Colour chart to describe the colour.

f. Location is described as on the matrix, ped faces, pores, cracks *etc*.

g. Composition of the material like carbonates, iron, manganese *etc*.



Types of concentrations present in soil

Coats/Films/ Stress Features (Internal Surface Features) - These features include coats/films, or stress features and formed by translocation and deposition, or shrink-swell processes. The kind, amount, continuity, distinctness, location, and thickness of the feature is described.

a. Kind - Includes carbonate coats, clay films, organic stains *etc*.

b. Amount of ped and void surface features - Estimate the relative per cent of the visible surface area that a ped surface feature occupies in a horizon

Amount	*Code*	*Criteria: % of surface area*
Very few	Vf	<5
Few	F	5 to<25
Many	M	25 to<50
Common	C	50 to<90

c. Continuity - It is described as continuous if the feature covers the entire surface, discontinuous if only partially covered and patchy if in isolated patches.

d. Distinctness - The relative extent to which a ped surface feature visually stands out from the adjacent material is known as its distinctness. The classes used are

Distinctness Class	*Code*	*Criteria*
Faint	f	Visible with magnification only (10X hand lens); little contrast between materials.
Distinct	d	Visible without magnification; significant contrast between materials.
Prominent	p	Markedly visible without magnification; sharp visual contrast between materials.

Roots - Quantity, size, and location of roots in each layer are to be recorded. Describe the quantity (number) of roots for each size class. The unit area that is evaluated varies with the size class of the roots being considered. The unit area for different root size classes is: 1 sq cm for very fine and fine roots, 1 sq dm (10 x 10 cm) for medium and coarse roots, and 1 m^2 for very coarse roots.

Quantity Class	**Code**	**Average Count (per assessed area)**
Few	f	<1 per area
Common	c	1 to<5 per area
Many	m	≥ 5 per area

Size of Roots (and Pores)

Size Class	*Code*	*Diameter*	*Soil Area Assessed*
Very Fine	vf	<1 mm	1 cm^2
Fine	f	l to<2 mm	1 cm^2
Medium	m	2 to<5 mm	1 dm^2
Coarse	c	5 to< 10 mm	1 dm^2
Very Coarse	vc	≥ 10 mm	1 m^2

Pores - Pores are the air or water filled voids present in the soil. It is difficult to assess very small size pores (e.g. < 0.05 mm) in the field. So, field observations are limited to those pores that can be seen through a 10X hands lens or larger. Pores are described by their quantity and size. Quantity classes pertain to number of pores per unit $area^{-1}cm^2$ for very fine and fine pores, 1 dm^2 (10 x 10 cm) for medium and coarse pores, and 1 m^2 for very coarse. The quantity and size classes are similar to the classes used for roots.

Cracks - Are fissures primarily associated with clayey soils and are most pronounced in high shrink-swell soils. Record the Relative Frequency **(**estimated average number per m^2) and Depth.

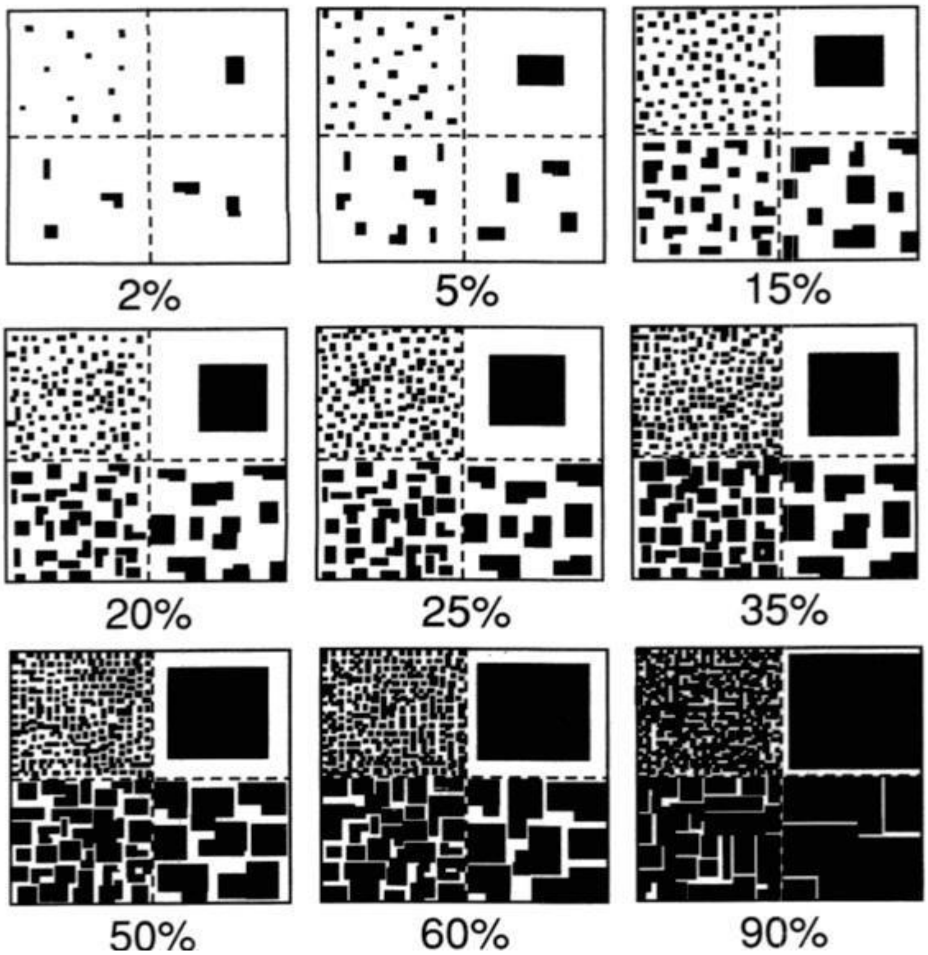
Soil crusts - A soil crust is a thin (e.g. <1 cm up to 10 cm thick) surface layer of soil particles bound together by living organisms and / or by minerals into a horizontal mat or small polygonal plates. Soil crusts form at the soil surface and have different physical and /or chemical characteristics than the underlying soil material. Typically soil crusts change the infiltration rate of the mineral soil and stabilize loose soil particles and aggregates. There are two general categories of soil crusts: Biological crusts, and Mineral crusts. Record the type of (kind) surface crust present in the soil.

Soil reaction (pH) - Both colorimetric and electrometric methods can be used for measuring pH. Colorimetric methods are simple and inexpensive. Record the pH and method of observation.

Effervescence - The gaseous response of soil to cold dilute (about 1:10 dilution) hydrochloric acid is used to test the presence of carbonates in the field. The amount and expression of effervescence is affected by distribution and mineralogy as well as the amount of carbonates present in the soil. The effervescence classes used are very slight, slight, strong, and violent.

Other features - Like presence of small animals, termite mounds, ant hills, heaps of excavated earth, the openings of burrows, paths, feeding grounds, earthworm or other castings *etc*., as special notes to be recorded in the proforma.

For estimation of per cent of area covered in soil



The above graphic can be used to assess the amount or quantity of mottles, concentrations, redoximorphic features and ped and void surface features present in the soil. Within any given box above, each quadrant contains the same total area covered, but with by different sized objects.

PEDON DESCRIPTION FORM – SITE CHARACTERISTICS

NBSS & LUP	Agricultural University	Dept. of Agriculture	Author: Date :

Series Name:	Map unit Symbol:	Soil Classification:

Observation No.:	Topo sheet No.:	Imagery No.:	Base map: Scale:	Cadastral Sheet No.:

Location:	Latitude: ° ′ ″ Longitude: ° ′ ″	Plot (Survey) No.:	Village: Taluk:	Block: District:

Physiographic division:	Geology:	Parent material:

Topography of the surrounding country: Level / Nearly level / Undulating / Rolling / Hilly / Steep / Very steep	Landform:	Microfeatures:	Profile position:

Soil slope															
	Gradient (%)	0-1 A	1-3 B	3-5 C	5-10 D	10-15 E	15-25 F	25-33 G	>33 H	Erosion	Very slight	Slight	Mod.	Sev.	V. Sev
	Length (m)	0-50	50-150	150-300	300-600	>600	Runoff	Ponded	V.Slow	Slow	Med	Rap	V.Rap		

Drainage	V. Pr	Pr	Some what Pr.	M. Well	Well	Some what excessive.	Ex.	**G.Water depth (m)**	<1	1-2	2-5	5-10	10-25	25-50	>50

Flooding	No	Occassional	Frequent	Very Frequent	**Salt/Alkali (% sur. coverage)**	No	<20	20-50	>50	

pH	<4.5	4.5-5.5	5.5-6.5	6.5-7.5	7.5-8.5	8.5-9.5	>9.5	**E.C.**	<2	2-4	4-8	8-15	15-25	25-50	>50

Surface fragments	Dia (cm)	<2	2-7.5	7.5-25	25-60	>60	**Rock out-crops**	Dist. Apart (m)	No	35-100	10-35	3.5-10	<3.5		
Coverage of gravels (<25cm)	(%)	<15	15-35	35-60	>60			Coverage(%)	<2	2-10	10-25	25-50	50-90	>90	
Coverage of stones&boulders	(%)	0.01-0.1	0.1-3	3-15	15-50	50-90	Elevation above MSL(m):								

LAND USE / VEGETATION

Crop	Season	Yield	Management

Vegetation
Nine fold classification
Forests : evergreen / deciduous / shrub
Area put to non agricultural uses
Barren and uncultivable land
Permanent pastures & other grazing land
Land under misc.tree crops and groves
Culturable wasteland
Fallow lands other than current fallows
Current fallows
LCC

FIELD NOTES	SKETCH
	cm
	50
	100
	150
	200

Notes :

1

Observation Method:		Auger	Minipit	Roadcut

	Depth (cm)	Horizon	Bnd [1] D T	Diag. Hori.	Matrix Colour Dry	Matrix Colour Moist	Texture [2]	% clay	Rock Frags [3] Sz Knd Vol	Structure [4] Grade Sz Type	Consistence [5] Dry	Mst	Stk	Pls
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														

	Mottles/ Redox features [6] Qty Sz Cn Col Sp Loc	Coats/Films/Stress Features [7] Amt Dst Cont Kd Loc Col	Concentrations [8] (Conca, Conir, etc.,) Qty Sz Cn Kd Col	Roots [9] Qty Sz Lc	Pores [10] Qty Sz Shp	pH	Effer [11] (dil Hcl)- 1,2,3	Sample bag No.
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

1. **D-Distinctness:** a-abrupt, c-clear, g-gradual, d-diffuse, **T-topography:** s-smooth, w-wavy, i -irregular, b-broken
2. **Texture:** s-sand, ls-loamy sand, sl -sandy loam, l -loam, sil -silt loam, si-silt, scl -sandy clay loam, cl -clay loam, sicl -silty clay loam, sc-sandy clay, sic-silty clay, c-clay.
3. **Size:** fg- fine gravel(<2cm), cg-coarse gravel(2-7.5cm), cb-cobbles(7.5-25cm), st-stones(25-60cm), b-boulders(>60cm).
4. **Grade:** 0-structureless, 1-weak, 2-moderate, 3-strong; **Size:** vf-very fine, f-fine, m-medium, c-coarse, vc-very coarse **Type:** gr-granular, cr-crumb, clr-columnar, pr-prismatic, pl-platy, abk-angular blocky, sbk-subangular blocky, sg-single grain, m-massive, c-cloddy.
5. **Dry:** l-loose, s-soft, sh-slightly hard, h-hard, vh-very hard, eh-extremely hard, **Moist:** l-loose, vfr-very friable, fr-friable, fi-firm, vfi-very firm, efi-extremely firm, **Stickyness:** so-non-sticky, ss-slightly sticky, ms-moderately sticky, vs-very sticky, **Plasticity:** po-non-plastic, sp-slightly plastic, mp-moderately plastic, vp-very plastic.
6. **Quantity(qty):** f-few(<2%), c-common(2-20%), m-many(>20%); **Size(sz):** 1-fine(<2mm), 2-medium(2-<5mm), 3-coarse (5-<20mm), 4-very coarse(>20mm); **Contrast(cn):** f-faint, d-distinct, p-prominent ; **Colour(col); Shape(sp):** c-cylindrical, d-dendritic, i-irregular, p-platy, s-spherical, t-threads, r-reticulate; **Location(Loc)**-matrix/ped/pores/others.
7. **Amount(Amt):** vf-very few(<5%), f-few(5-<25%), c-common(25-<50%), m-many(50-<90%), vm-very many(>90%);**Distinctness(Dst):** f-faint, d-distinct, p-prominent; **Continuity(Cont):** c-continuous, d-discontinuous, p-patchy; **Kind(Kd):** Type of coating/stress features; **Location(Loc)**: on bottom/top or all faces of peds; **Colour(Col)**: Munsell
8. **Concentrations:** Quantity(qty), Size(sz), Contrast(cn) and Colour are to be described similar to that of the mottles; **Kind(Kd)**: Disseminated materials, Masses, Nodules, Concretions, Crystals and Biological concentrations.
9. & .10. **Roots/Pores: Quantity**: f-few(<1 per area), c-common(1-5), m-many(>5); **Size**: vf-very fine, f-fine, m-medium, c-coarse; vc- very coarse; **Location(Loc):** between peds(p), in cracks(c), throughout(t); **Shape(Shp):** tubular/irregular/vesicular/interstitial. 11. **Effervescence:** 1-slight, 2-strong, 3-violent.

2

Soil series establishment and phase map preparation

Grouping of similar kind of soils called soil series and it is a basic mapping unit in detailed soil survey. Soils which are similar in surface characteristics (Texture, Slope, Erosion and gravelliness) are grouped as phases.

Following Institutes are supporting REWARD in Karnataka for generation of data required for scientific planning of watersheds

NBSS&LUP, Regional Centre, Bengaluru	Lead Partner for LRI
University of Agricultural Sciences, Bangalore	Partner for LRI and hydrology
University of Agricultural Sciences, Dharwad	Partner for LRI and hydrology
University of Agricultural Sciences, Raichur	Partner for LRI and hydrology
University of Agricultural Sciences, Bangalore	Partner for LRI and hydrology
University of Agricultural & Horticultural. Science, Shivamogga	Partner for LRI and hydrology
University of Horticultural. Science, Bagalkot	Partner for LRI and hydrology
Indian Institute of Science, Bengaluru	Lead Partner for Hydrology
Karnataka State Remote Sensing and Application Centre, Bangalore	RS and GIS
Karnataka State Natural Disaster Management Centre, Bengaluru	Meteorological aspects

LRI outputs: All the LRI outputs generated, compiled and reproduced in the form of Atlas and reports. The atlas contains basic information on kinds of soils, their geographic distribution, characteristics and classification. The soil map and soil based thematic maps derived from data on soil depth, soil texture, soil gravelliness, slope, erosion, land capability, land suitability for various crops and land use maps are presented. The maps on fertility status *viz*., soil reaction, salinity (EC), organic carbon, nitrogen, phosphorus, potassium, sulphur, exchangeable calcium and magnesium, available copper, manganese, zinc, iron and boron were derived on analysis of surface soils sampled at 320 m grid spacing within the micro watershed. The atlas illustrates maps and tables that depict the soil resources of watershed and the need for their sustainable management.

The user, depending on his/her requirement, can refer this atlas first by identifying his/her field and survey number on the village soil map and by referring to the soil legend which is provided in tabular form after the soil map for details pertaining to his/her area of interest.

The atlas explains in simple terms the different kinds of soils present in the watershed, their potentials and problems through a series of thematic maps that help to develop site-specific plans as well as the need to conserve and manage this increasingly threatened natural resource through sustainable land use management. The Land Resource Atlas contains database collected at land parcel/survey number level on soils, climate, water, vegetation, crops and cropping patterns, socio-economic conditions, marketing facilities etc. helps in identifying soil and water conservation measures required, suitability for crops and other uses and finally for preparing viable and sustainable land use options for each and every land parcel. LRI also helps in grouping together areas where similar land resource exists on ground, which require the same kind of management, the same kind and intensity of conservation treatment and same kind of crops, pasture or forestry species, with similar yield potentials.

Data products of LRI atlas

1. **Location and extent:** Indicate the location of watershed with latitude, longitude along with total area cover and area bounded.
2. **Agro Ecological Sub Region of watershed:** Represent the Agro Ecological Sub regions of watershed among different Agro Ecological Sub regions of India.
3. **Agro-climatic Zone of watershed:** Indicate the Agro-climatic Zone under which the watershed falls along with the total geographical area, total cultivable area under irrigation, mean sea level (MSL), average annual rainfall, major soil types and main cropping season of that particular Agro-climatic Zone.
4. **Base maps, satellite images and cadastral maps:** Before start of an inventory, there is a need for the data resources like base maps, satellite images and cadastral maps to study the location features and existing situation.

a. **Base map:** A base map is the graphic representation at a specified scale of selected fundamental map information; used as a framework upon which additional data of a specialized nature may be compiled (American Society of Photogrammetry, 1980).

b. **Satellite image:** Satellite images are images of earth collected by imaging satellites. At present for survey (inventory), we (Karnataka) are using maps in the False Colour Composite (FCC) form at 1: 8000 scale from Karnataka State Remote Sensing and Application Centre (KSRSAC), Bengaluru.

5. **Cadastral map:** Cadastral Maps are a digital form of land records that show all the boundaries of different parts of land (survey number of land parcels).

   The above said satellite image and cadastral maps overlaid with and without grid are used for the survey.

6. **Rainfall trend in watershed area:** The watershed area temperature, annual rainfall, South West monsoon, North East monsoon and pre monsoon data to be recorded, which will be further useful in suggesting the crop plans and conservation measures.

7. **Geology:**

a. **Geology of State:** Information on the geology of the State helps to know the distribution of different types of rocks and minerals, weathering stages in soil, dominant rocks, minerals and major soil types.

b. **Geology of watershed area:** Study of the geology of the particular watershed area helps to know the predominant rocks and minerals, weathering stages and major soil types.

8. **Current land use map:** The information on present serve (use) of the land (*i,e.,* cultivable land, non-cultivable land (fallow land) and use for construction, *etc*.) under particular watershed will be collected and represented in the map to know the percent usage of land.

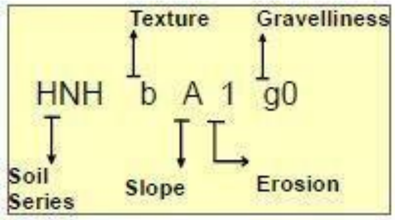
9. **Location of wells map:** The total number of wells (open wells and bore wells) existing in the particular watershed area will be indicated in the maps along with their location.

10. **Existing Structures:** Existing soil and water conservation structures (agronomical and mechanical), water harvesting structures (farm pond, gokatte, *etc.*) will be recorded.

11. **Soil characteristics:** During land resource inventory, data/observations on surface soil features like soil texture, slope, soil erosion, gravelliness and subsurface features like soil depth and profile characteristics as per pedon description form will be recorded and represented in the form of thematic maps.

12. **Mapping unit description:** Mapping units are represented in the form of surface characteristics combined with series code on map, that should be described clearly in the atlas. Also extent of area occurring in the mapping unit to be mentioned.

Ex: HNHbA1: Moderately shallow, non-gravelly (0-15%) loamy sand, derived from granite gneiss, occurring on nearly level land, slope 0-1 per cent and slight erosion.



13. **Soil fertility description:** It represents the status and distribution of different soil fertility parameters like pH, electrical conductivity, organic carbon, available nitrogen, phosphorus, potassium, Sulphur, exchangeable calcium, magnesium, DTPA extractable iron, manganese, copper, zinc and hot water-soluble boron in the particular watershed area, which will be furtherhelpful to correct the deficit nutrient through proper nutrient management techniques.

14. **Land capability classes:** Land capability classification is a system of grouping soils primarily on the basis of their capability to produce common cultivated crops and pasture plants without deteriorating over a long period of time. There are eight land capability classes

    Class I- Class IV: Suitable for cultivation
    Class V- Class VIII: Not suitable cultivation and suitable only for pasture and recreation.

Classification of soils based on their capability helps to know the usefulness of the land

15. **Land suitability for different crops:** Under this section we can assess the suitability of land/soils for cultivation of particular crops *viz*., cereals (paddy, ragi, maize *etc.*), pulses (red gram, black gram, cowpea *etc.*), oilseeds (groundnut, sunflower *etc.*), plantations (tea, coffee, coconut, *etc.*) and commercial crops (sugarcane, cotton *etc.*).

16. **Land management units (LMU):** It is the grouping of different soils into single management unit based on their similar characteristic's features. It helps to propose similar management practices. The number LMUs we can get in a particular watershed area is based on the variability in management requirements of lands. If the variation in the land features is more, more the number land management units.

Ex: LMU-1, LMU-2, LMU-3 *etc*.

17. **Proposed crop plan based on LMU:** After grouping of soils into LMUs, suitable crops for cultivation to that particular watershed area is to be proposed which helps to exploit the yield potentials of the crops. Along with suitable crop plan, suitable interventions like cultivation on raised beds with mulches and irrigation system with suitable soil and water conservation measures and application of amendments if needed is to be proposed.

18. **Economic land evaluation of different land use types:** Economic evaluation of the land is very much important and it will be done based on benefit cost ratio (B:C ratio) and land suitability classes.

The FAO framework defines two suitability orders: 'S' (suitable if Benefit Cost Ratio (BCR) >1) and 'N' (not suitable if BCR< 1), which are divided into five economic suitability classes: 'S1' (highly suitable if BCR >3), 'S2' (moderately suitable if BCR >2 and < 3), 'S3' (marginally suitable if BCR >1 and < 2), 'N1' (not suitable for economic reasons but physically suitable), and 'N2' (not suitable for physical reasons).

19. **Runoff distribution:** Knowing runoff status of the particular watershed area is important to adopt the proper conservation measures.

20. **Conservation plans:** After knowing all the variation in the particular watershed area, suitable conservation plans will be proposed.

21. **Conclusion:** Correction of variation in the particular watershed area with suitable technologies helps to conserve the natural resources effectively and exploit the potentials of the area economically.

Exercise - 1

LRI atlas

1. What criteria are followed in coding the soil phases in the Atlas?

3. Hydrological assessments for watershed planning and management

Importance of agro-hydrological monitoring:

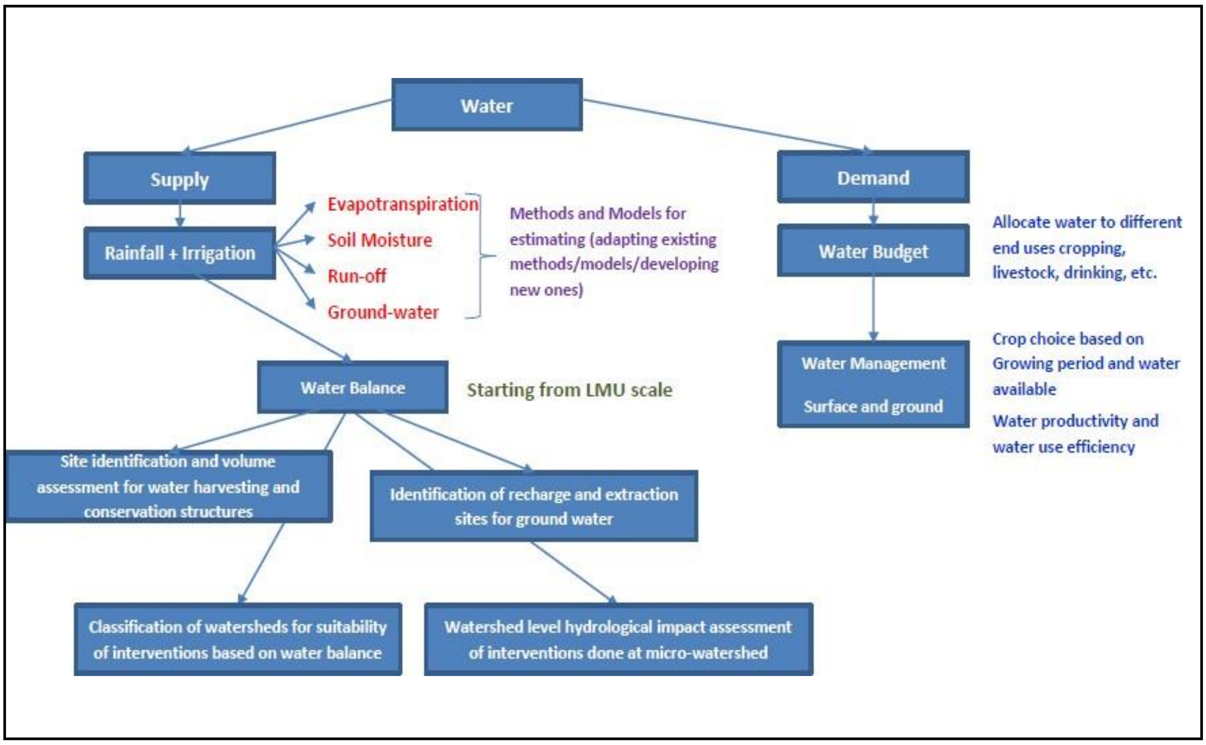
Agro-hydrology can be regarded as the study of hydrological processes and the collection of hydrological data. However, the influences on the production of runoff and the ways that runoff affects the environment within which crops grow are very diverse and agro - hydrological study also includes the collection of information on climate, soils, vegetation, and topography. Rainfall amount and its spatial and temporal distributions determine the quantity of water that reaches the land's surface. Temperature and humidity, its type, amount and distribution of vegetation cover determine what proportion of this water re - evaporates. Vegetation, soil conditions and topography determine how much water infiltrates into the soil, how much runs off the land's surface and where it goes. Knowledge of the hydrological environment is necessary to determine whether or not opportunities to create optimal soil moisture conditions exist, and how these opportunities can be exploited.

The objective is that hydrological monitoring aided by advanced data and innovative models that will be used under this project will aid in producing hydrological budget at relatively higher temporal frequency (e.g. weekly/monthly) and also at the desired spatial granularity in the micro watersheds, for improved sustainable water management.

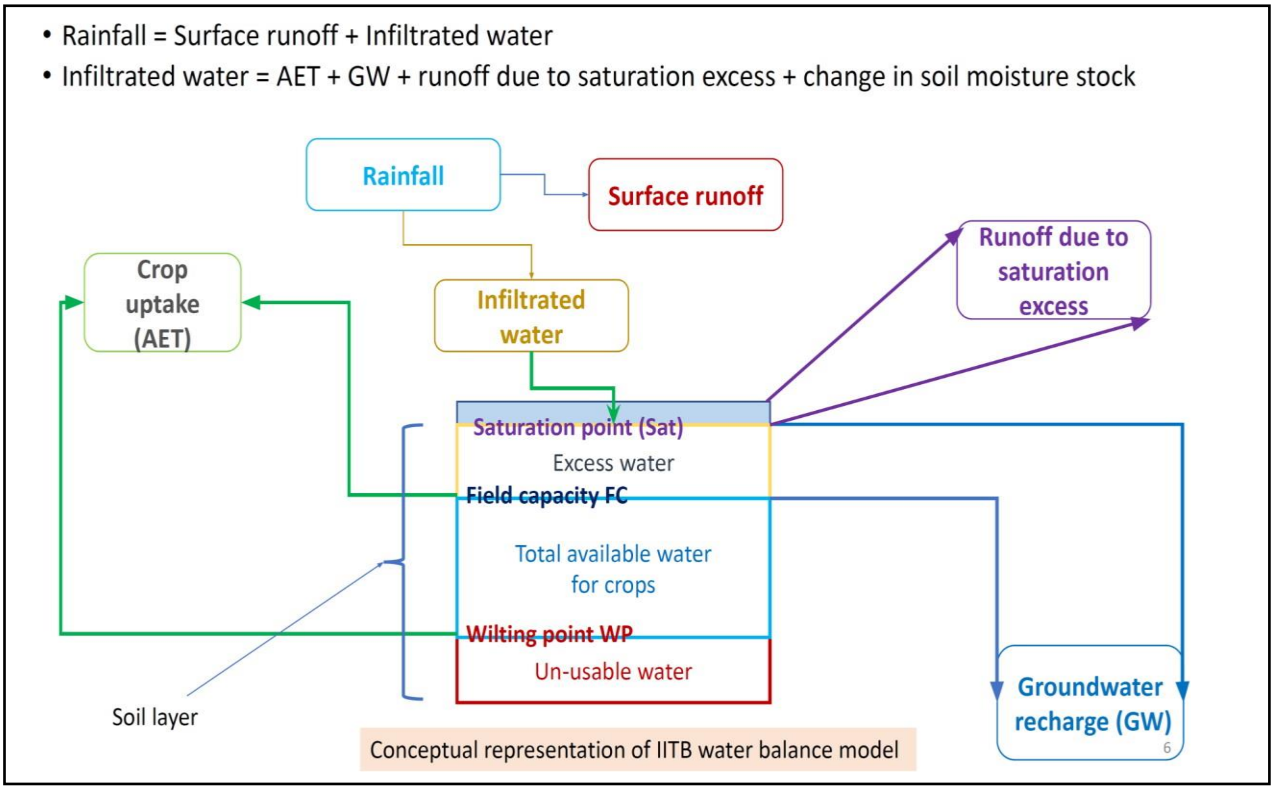
The focus is to

(i) assess the sustainability of the project watersheds for future climate; and
(ii) estimate water budget in the watersheds to facilitate improved design of soil & water conservation measures.

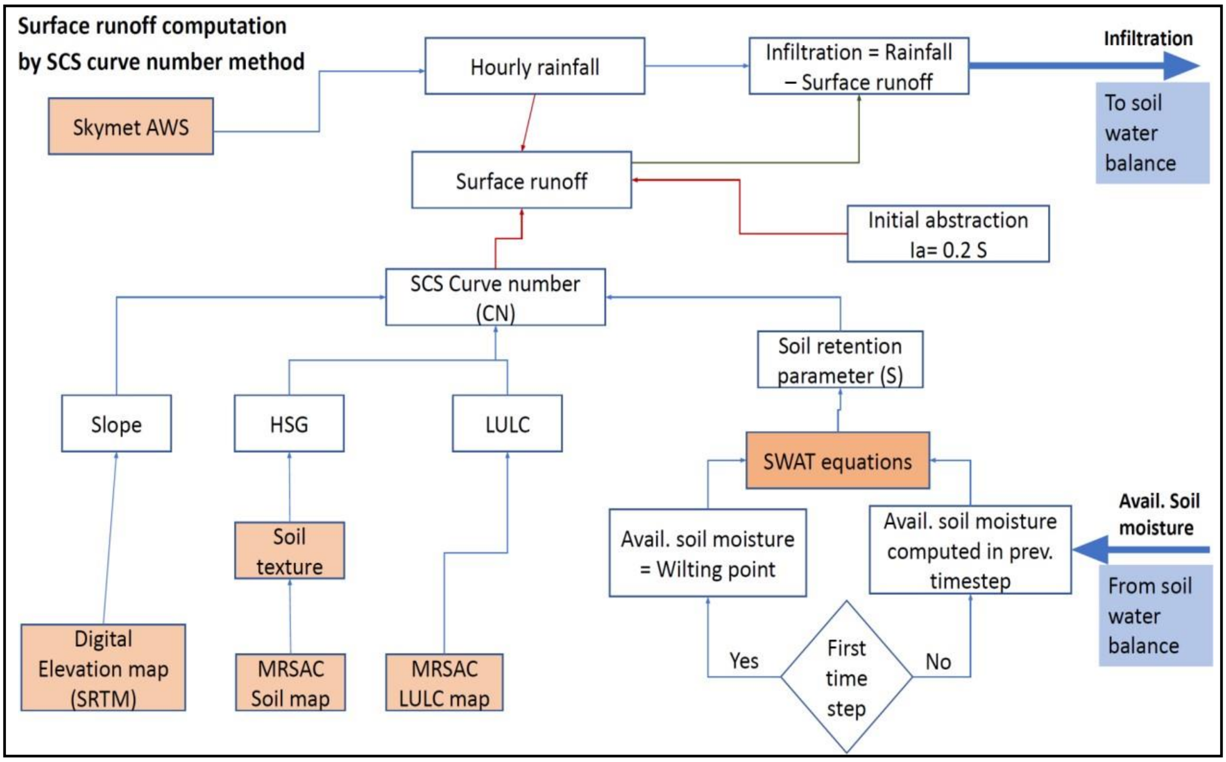
The additional objective is to integrate the hydrological variables with the land resource inventory mapping for developing robust integrated watershed management plans.



Hydrology in REWARD



Conceptual representation of water balance model



Surface runoff computation: SCS curve number method

Study of equipment required for hydrological assessment and interpretation of hydrology atlas

Installation of the equipment:
To provide precise weather-related information, forecast and advisory to the farmers for planning agricultural activities and to minimize crop loss due to adverse weather condition s, automatic weather stations are set up in every model micro watershed. Rainfall information at every 15 minutes time interval will be captured. In addition to this, weekly rainy days, daily temperature, relative humidity, evapotranspiration, mean wind speed, *etc*. are recorded and effectively will be used in the REWARD project. The hydrological instruments (diver for runoff and groundwater measurement) will be installed at model micro watersheds to get periodical hydrological information and to support hydrological studies. The agro-hydrological parameters measured and monitored include soil moisture (surface and profile), groundwater levels, bore wells discharge and yield, water quality surface and groundwater, andcanopy variables (LAI, biomass, crop yield, crop management activities).

In an experimental watershed, the following agro-hydrology components are monitored or measured:

Soil moisture:
Surface Soil Moisture (SSM) plays a vital role in various processes occurring on the soil atmosphere interface. The evaporation is controlled directly by the surface soil moisture; the transpiration is controlled by the soil moisture present in the root zone. The precipitation passes through surface soil moisture to reach the root zone. Hence, surface soil moisture could be able to provide some insight into the root zone soil moisture. This means that surface soil moisture may be a useful variable to predict the hydrological cycle over land. Apart from hydrology, it is also useful in various other applications e.g., agronomy, drought management and in the improvement of disaggregation/downscaling of precipitation *etc*.

Surface soil moisture:
Currently, surface soil moisture is assessed for the following three main reasons:

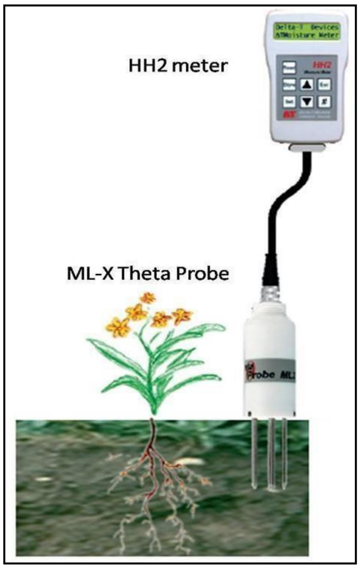
- ✓ To validate the radiometer satellite data
- ✓ To calibrate the STICS crop model
- ✓ Calibration/Validation of SAR satellite data

The two methods for measuring the surface soil moisture are detailed in the following two subsections:

Volumetric soil moisture measurement (Theta Probe):
Surface soil moisture is measured using ML2x theta probe (Delta-T devices, Delta-T Devices Ltd, Cambridge, UK), which measures soil moisture averaged over 0 to 5 cm depth and equipped with a HH2 meter for spot measurements and display. Accuracy of measurements is ± 1 %. The operating principle, steps to be employed during measurements *etc*. of this probe is given below.

Operating principle:

Theta Probe measures soil parameters by applying a 100 MHz signal via a specially designed transmission line whose impedance is changed as the impedance of the soil changes. This impedance has two components; the apparent dielectric constant and the ionic conductivity. The signal frequency has been chosen to minimize the effect of ionic conductivity, so that changes in the transmission line impedance are dependent almost solely on the soil's apparent dielectric constant. These changes cause a voltage standing wave to be produced which augments or reduces the voltage produced by the crystal oscillator, depending on the medium surrounding the measurement prongs. The difference between the voltage at the oscillator and that reflected by the rods is used by Theta Probe to measure the apparent dielectric constant of the soil. A linear correlation exists between the square root of the dielectric constant, (Ve), and volumetric moisture content, (0), which is used to convert the measured dielectric constantto soil moisture.



Theta probe and HH2 meter (Delta T Devices)

Steps to be employed for the measurement:

- ✓ The theta probe needles should be inserted (penetrated) fully into the soil vertically. Take care while inserting the probe in stony soils as it may damage the needle. In such cases if it is difficult to insert the probe in a particular location try a few other locations in the plot where the needles can penetrate without much force being applied.
- ✓ Three readings should be taken for each plot (soil unit), to get the mean value that is representative of the field plot and variability.
- ✓ If the plot is with furrows and ridges (as in the case of turmeric), then take one reading at the top of the furrow, one in the ridge, one at another representative location.
- ✓ If the plot is partially irrigated, take at least two measurements in the irrigated area and mark the reading as irrigated.
- ✓ If the plot is irrigated the previous day of measurement, note it down in the field note. At least one measurement has to be made within the 2 m^2 area adjoining the location where theaccess tube is installed.

- ✓ Note down the label number of the Delta-T probe. (Usually, each Theta probe is given an identification number by the field team, this will help us in calibration) Do not take soil moisture reading too close to a crop, as the probe may penetrate the root and measurements may be misleading.
- ✓ Do not take soil moisture reading in the loose soil as the presence of air gaps may affect themeasurements.
- ✓ If the reading cannot be taken for the dry soil (hard to penetrate the needles), note down that. (This usually occurs in summer season in most soils) Note down the crop type.

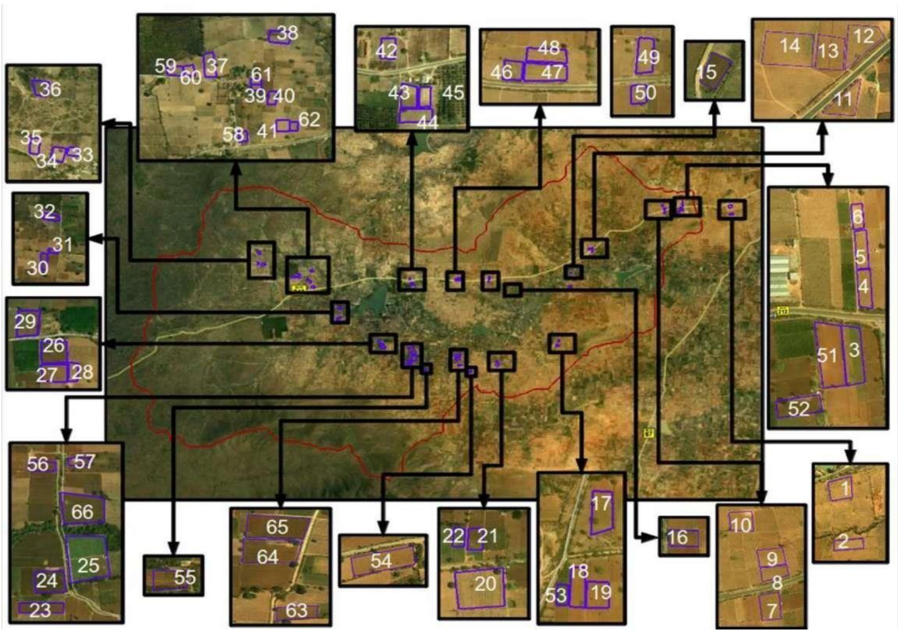
Profile soil moisture:

The procedure for profile soil moisture measurements, the instruments used and their operating principle, calibration techniques are discussed below. Profile soil moisture is being monitored/measured either continuously or intermittently at regular frequency in a watershed for cropped and uncropped areas.

TRIME-PICO IPH soil moisture sensor

Operating principle:

The TRIME device generates a high-frequency pulse (up to 1GHz) which propagates along the metal shells, generating an electromagnetic field around the probe. At the end of the shells, the pulse is reflected back to its source. The resulting transit time (3ps...2ns!) can be measured and enables determination of the propagation velocity, which is primarily dependent on the water content. The volumetric water content is then calculated by the velocity and is shown onthe display panel immediately. The particular probe that is used to depict the procedure is T3/44, which has moisture measuring range from 0 to 60 % (volumetric water content) and an accuracy of ±2%. Measuring volume: The effective penetration depth of the probe T3 is about 15 cm with the highest sensitivity in the immediate vicinity of the access tube, and decreasesexponentially as distance increases.



Map showing a typical layout for soil moisture monitoring field-plots

Installation of access tubes:

Access tube of TRIME contains three parts, the tube (1 m or 2 m long) with a metal ring at the bottom, a rubber cork (to seal the bottom of the tube) and a plastic cap to cover the top of the tube. It is necessary to maintain close contact between the access tube and the soil material for reliable measurements; hence the tubes should be installed as recommended by the manufacturer. Alternatively, the access tubes can be installed by following the steps below.

- ✓ Fix the rubber cork tightly inside the metallic ring at the bottom of the access tube, this can be fixed with the help of the auger provided with the instrument. (The specially designed auger has provision for tightening the rubber cork). Additionally, it is better to seal the bottom with cello tapes to ensure that no water seeps into the tube from the bottom. Close the top of the access tube with the plastic cap.
- ✓ Drill a hole to the required depth (1 mor 2 m) using the auger provided by the manufacturer. Save soil in a small bucket to mix with water to form a well-blended mud. Pour the mud back into the hole until it is full.
- ✓ Insert the Access Tube in an auger hole. Move the tube up and down (inside the hole) a few times to remove all air. Mud should come up to above surface level
- ✓ Fix the access tube in this position and insert the Probe into the access tube, slowly lower it to the bottom and note the readings, since the readings are taken immediately after installation all the readings should be in the high (40 to 50 %) and consistent.
- ✓ Lower readings indicate the presence of air gaps which should be fixed immediately by following step 3.
- ✓ Installation of access tubes can be carried out at least two weeks before the intended start of the experiment, since the newly installed access tube may take at least 10 days to settle.

TRIME-PICO IPH for profile soil moisture measurements

How to measure:

- ✓ Open the cap of the access tube and insert the sensor slowly into the tube till the sensor is fully below the ground level. Note down the reading from the data logger.
- ✓ Now slowly push the sensor further down to the required depth (depth is marked in the cable with a white tape) and continue taking measurements. Continue this process till the whole of the access tube (1 m or 2 m) is covered.
- ✓ Note the reading and depth of measurement each time.
- ✓ Note also the crop type and general condition of the plot (like irrigated or rained *etc*.).
- ✓ In dry soil, sometimes it will be difficult to push the sensor inside the access tube, in such cases it is better to avoid taking measurements since the sensor may get struck inside the access tube and pulling it back by force may damage the connecting wires.
- ✓ Do not make the sensor or the data logger to hang from the cable while taking for field measurements since this will lead to wear and tear in the connecting cable and eventually the sensor unit may be disconnected from the logger. Always support the sensor and logger with hand or use the instrument box each time.

Continuous soil moisture monitoring:

Continuous monitoring of surface and profile soil moisture is essential to understand the controls of soil moisture in the watershed. Such data can help in irrigation scheduling, calibration and validation of satellite soil moisture products and in predicting drought.

HYDRA probe soil moisture sensor:

The Hydra Probe sensor uses the Coaxial Impedance Dielectric Reflectometry method in soil moisture measurement. The Coaxial Impedance Dielectric Reflectometry method of soil moisture measurement employs an oscillator to generate an electromagnetic signal that is propagated through the unit (usually by metal tines or other wave guide) and into the soil. The probe sends electrical signals into the soil, measures the responses, and relays this information to a data collection device known as a data logger. Part of this signal will be reflected back to the unit by the soil, and the sensor will measure the amplitude of this reflected signal and the incident signal in volts. The ratio of these raw voltages is used in a mathematical numerical solution to Maxwell's equations to first calculate the impedance, then both real and imaginary dielectric permittivity which in turn is used to accurately estimate soil water content.

Installation and calibration:

- ✓ Excavate a hole no larger than 25" x 25" square and 25" deep for the sensor installation pit. To best re-create the original soil horizons, these soil layers should be replaced in the pit in the same order they were removed.
- ✓ Trench from the location of the power source and data logger to the sensor installation pit. Assemble rigid or flexible PVC conduit to protect the sensor wires.
- ✓ Check that there is enough cable length to reach up through the soil pit and through the conduit to the data logger. Label sensor wires with sensor depth or position at both ends – the sensor end and the end that will be hooked up to the data logger.

- ✓ Before installing sensors into the soil, connect the wires to data logger and power source. Test each sensor separately in moist soil to make sure that it is working as expected. A small cup with moistened soil works well for testing because each sensor should give very close to the same reading for soil moisture and temperature.
- ✓ Install the 50cm, 5cm, and 5cm sensors along the pit face in a staggered pattern, carefully backfill the soil in the rest of the pit and leave drip loops in all the wires.
- ✓ Gather all the wires together at the surface and seal the end of the conduit with duct seal putty. When all the sensors are in place and the installation is complete, bury the conduit inthe trench


Schematic of HYDRA Probe soil moisture sensor

Measurement of runoff:

The detailed monitoring surface runoff at the outlet of the micro watershed will be measuredusing a CTD diver and analysis will be done by using check dam weir formulae.

Groundwater studies:

The detailed monitoring of hydrological characteristics like water table fluctuation (Monthly) and water yield (seasonal) in the model micro watersheds will be observed. Totally 75 (including function, and defunct) wells will be selected for monitoring the groundwater table. The groundwater samples will be collected seasonally (*Kharif*, *Rabi* and *Summer*) and analysis will be done for different chemical parameters viz., pH, EC, Cl, SAR and RSC to assess its quality for irrigation purposes.

Hydrology outputs: Agro-hydrology can be regarded as the study of hydrological processes and the collection of hydrological data, aimed at increasing the efficiency of crop production, largely by providing beneficial soil moisture conditions. However, the influences on the production of runoff and the ways that runoff affects the environment within which crops grow are very diverse and agro - hydrological study, of necessity, also includes the collection of information on climate, soils, vegetation, and topography. Rainfall amount and its spatial and temporal distributions determine the quantity of water that reaches the land's surface. Temperature and humidity, the type, amount and distribution of vegetation cover determine what proportion of this water re - evaporates. Vegetation, soil conditions and topography determine how much water infiltrates into the soil, how much runs off the land's surface and where it goes. It is the interaction of these complex processes and the volumes of runoff that these processes produce that form the core research of agro- hydrology. Knowledge of the hydrological environment is necessary to determine whether or not opportunities to create optimal soil moisture conditions exist, and how these opportunities can be exploited.

The objective is that hydrological monitoring aided by advanced data & innovative models that will be used under this project will aid in producing hydrological budget at relatively higher temporal frequency (e.g. weekly/monthly) and also at the desired spatial granularity in the micro watersheds, for improved sustainable water management.

Preparation of hydrologic atlas:

Integrated Hydrological Assessment & Monitoring involves hydrological data gathering, behavior mapping & processes understanding at micro-watersheds scale. The focus is to assess the links between groundwater conditions in the watersheds and design of soil & water conservation measures; groundwater level changes & water yields in hard rock aquifers; impacts of water stress on crop productivity; and land management changes and impacts on groundwater recharge & runoff. Further the additional objective is to integrate the hydrological variables & water budgets with the land resource inventory mapping for developing robust integrated watershed management plans.

Once the procedures are implemented for a given watershed and compilation of required primary and secondary data is done, the next step is to use these data to prepare several elements for the hydrological atlas for the watershed. Below section, methodology for computation and analysis associated with the preparation of hydrologic atlas is discussed.

Location and index maps for the study area:

At the very beginning of the study, number of hydrological and other required information are collected about the study area. Some of these are boundary and geographical location, location of monitoring sites, drainage network, habitation, cadastral boundaries, sub-watershed boundaries *etc*. This information is then transformed into several thematic GIS layers and maps.

Rainfall indices:

The first task is to compile a catchment-averaged time series by combining the available rainfall data from several sources with lowest possible frequency and longest possible record. Depending upon data availability and context of the project objectives multiple such rainfall series may be prepared. Once that is done, many types of summary time series are to be prepared for the hydrological Atlas.

Summary time series plots:

For the micro-watershed following four types of summary time series plots are prepared using the available rainfall data

- ✓ Annual Rainfall Time Series: These are prepared by aggregating the available daily (and sub-daily, as the case may be) rainfall over the calendar year for the period of record.
- ✓ *Kharif* Rainfall Series: The period from June to September has been considered as *Kharif* season for a particular calendar year and the corresponding time series is to be prepared in similar way as that of the annual series.
- ✓ *Rabi* Rainfall Series: The period from October to January has been considered as *Rabi* Season for a particular calendar year and the corresponding time series is to be prepared in similar way as that of the annual series.
- ✓ Summer Rainfall Series: The period from February to May has been considered as Summer Season for a particular calendar year and the corresponding time series is to be prepared in similar way as that of the annual series.

Runoff potential:

Mapping unit wise runoff availability with effective interventions and with existing conditions for the target watershed is computed using infiltration intensity method. The runoff potential information is thus generated are then converted into spatial maps.

Evapotranspiration and associated indices:

Several types of indices are developed using available time series of Actual Evapotranspiration (AET). Generally, AET time series are compiled at daily time step and with catchment-averaged values. Using this time series data following summary time series are prepared and presented in graphical & tabular forms as part of the Atlas.

Summary time series plots:

- Annual total AET series over the period of record; from this series Annual Average value of AET for the given catchment is also computed.
- Annual Average AET series for each of the calendar month. In this case, temporal averaging is done over all the years in the period of record. Using this Monthly Average AET series following two types of summary plots are prepared:
  - Month wise comparison of AET and Rainfall over the period of record.
  - Month wise of variation in AET over two consecutive decades, depending upon the length of available time series of AET.

Water budgeting:

The concept of Water Budgeting aims to use water judiciously for people, agriculture and livestock with a view to optimizing benefits in the context of climate variability, erratic rainfall and drought. Water budget studies consider the volumes of water within the various reservoirs of the hydrologic cycle and the flow paths from recharge to discharge. Water budgets need to consider this information on a variety of spatial and temporal scales.

In simple terms a water budget for a given area can be looked at as water inputs, outputs and changes in storage. The inputs into the area of investigation (precipitation, groundwater or surface water inflows, anthropogenic inputs such as waste effluent) must be equal to the outputs (evapotranspiration, water supply removals or abstractions, surface or groundwater outflows) as well as any changes in storage within the area of interest. So, given a watershed under consideration, a water budget equation may be developed over various time periods, Monthly, Seasonal, Annual *etc*., depending upon the context.

For example, using the available concurrent data on Precipitation (P), Runoff (Q), Actual Evapotranspiration (AET) and Ground Water Recharge (R) for the period April-October over the years 2015-2018 following water budget equation has been developed for the Madahalli Watershed,

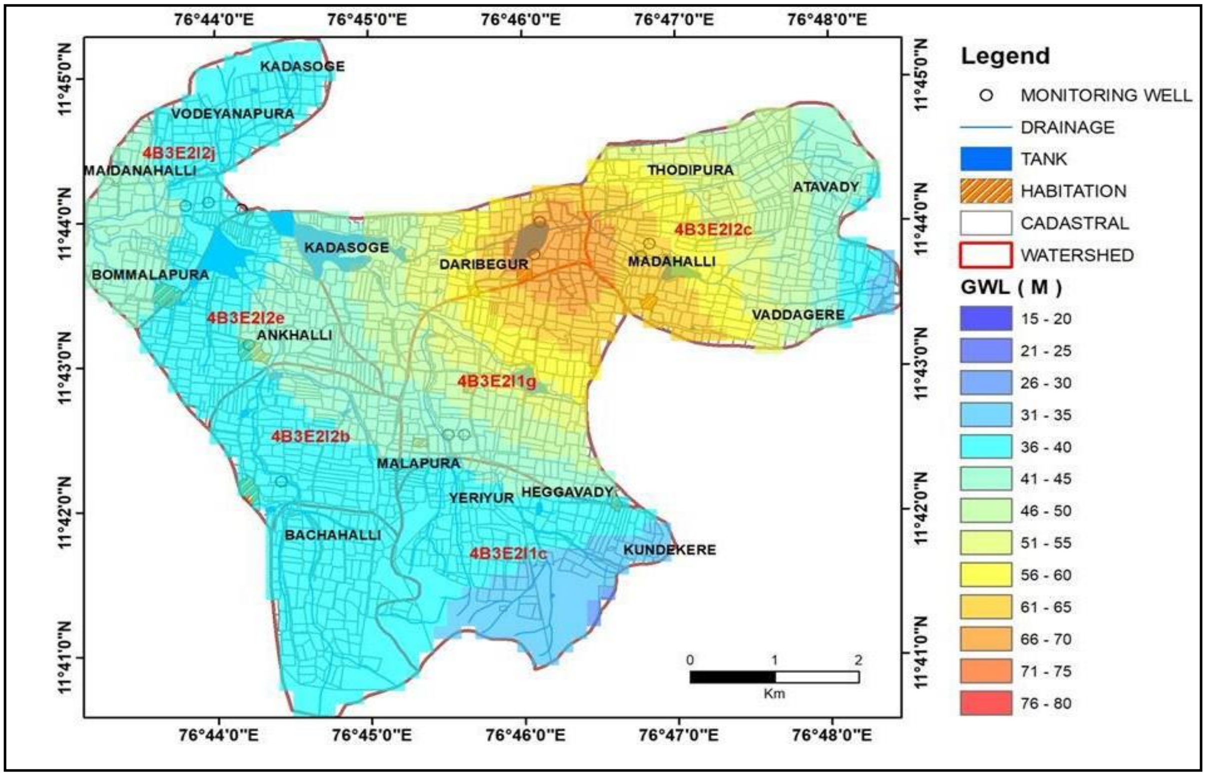
$$P=Q+AET+R+S$$

where all the variables are expressed in mm unit. Inserting following known values, P=501, Q=44, AET=540, R=85 into this equation, we get, S=−168 mm. This implies that over the considered time period, precipitation was lower than evapotranspiration. This negative balance when combined with runoff and recharge results in a net negative soil water store for the *Rabi* season.

Spatial distribution of depth to groundwater:

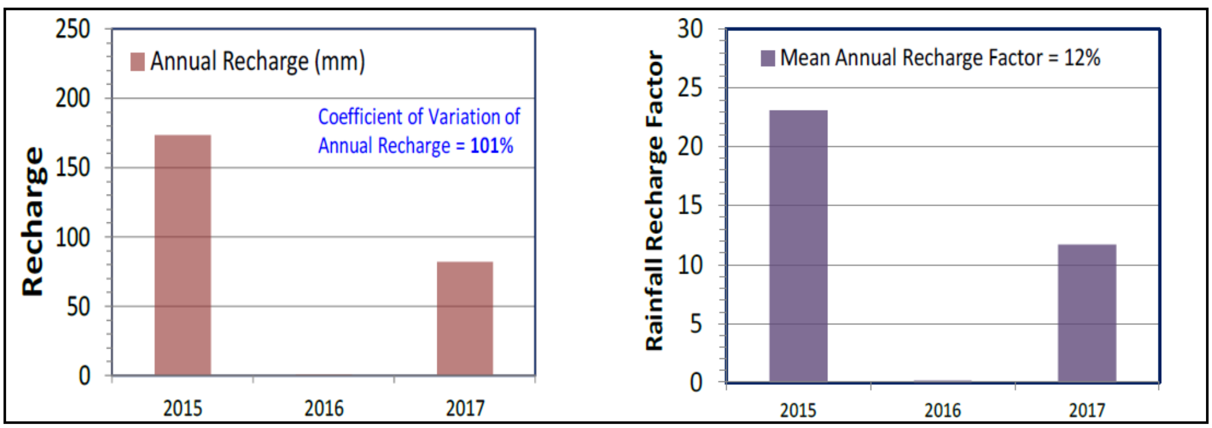
DGW is point data and needs to be interpolated to prepare the spatial maps. Any of the following approaches can be used to convert the point data into spatial maps:

- Inverse Distance Weighted (IDW) Approach: In IDW, the value at an unknown point is estimated by giving weights proportional to the inverse of the distance (between the known locations and the unknown location) raised to the power value p. Typically, a value of p=2 is used; however, care should be taken that it should not result in spurious behavior in any part of the map. In that case, different values of p should be tried.
- Kriging-based Interpolation: Kriging provides the best linear unbiased estimation at an unknown point giving the values at known locations. Before performing the Kriging, variogram analysis is performed to understand the underlying statistical distribution of the process.



Spatially interpolated map of DGW values over the Madahalli micro-watershed

Ground water recharge:



Sample plot showing annual recharge and mean annual recharge factor for Madahalli micro-watershed

Well yield:

The yield of the well should be monitored by filling a container of known volume and measuring the time required to fill the container. By taking the data of each monitoring well, a map of groundwater well yield shall be prepared following the IDW or Kriging method of interpolation.

Water quality maps:

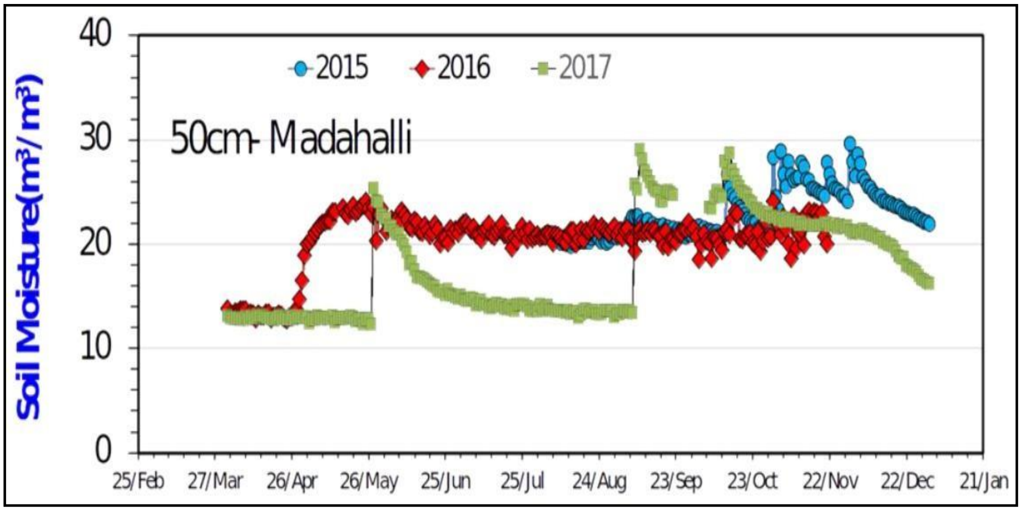
Prepare the map of groundwater quality parameters following the IDW or Kriging method of interpolation.

Depiction of surface soil moisture data:
Surface soil moisture data are generally depicted either as time series plot or as raster maps over the whole watershed.

Spatial maps:
These maps are prepared using satellite remote sensing products. The following facts are to be noted:

- Seasonal maps are prepared by aggregating multiple images over the watershed.
- Cadastral maps are always overlaid on top of soil moisture rasters.

Time series plots:
Aggregating the surface soil moisture data over the study watershed a catchment aggregated soil moisture time series are prepared to assess the temporal variability. Soil moisture comparison plots should also be created to evaluate the coincidence of the field and satellite observations to cross-check the data accuracy from both the sources.
The root zone soil moisture data is observed for dominant field crops in rainfed conditions. Subsistence irrigation may be required for attaining the potential productivity of these crops currently in practice.



Root zone soil moisture time series plot at the particular location in the study watershed

Depiction of profile soil moisture data:
The following two considerations are to be noted for profile soil moisture data,

- Profile soil moisture should be observed every 10 days.
- Depth-wise measurements should be taken for an increment of 10 cm, up to the depth of 80 cm.

4. An overview of DSS modules used in REWARD program

A Key component of Sujala-3 Project is the development of Decision Support System (DSS) along with LRI Digital Library, LRI Portal and Mobile Application for real time dissemination of LRI information and advisories to the farmers, line departments, research institutions and other stakeholders in the state. A DSS is a computerized expert interactive information system developed and integrated in a Geographic Information System environment (GIS) to support decision-making in a particular field or domain. The development of DSS for watershed development/natural resource management depends on the availability of spatial and non-spatial information, like data on soil, water, land use, hydrology, demography, climate, base maps, remote sensing data, and other resource information and models, algorithms and rules that can help to infer the outcome.

The objectives of developing DSS

- To facilitate the project management in planning, execution and monitoring of various watershed development and other programs in the state
- To integrate Land Resource Inventory, Hydrology, and other database with GIS, MIS and other systems for easy retrieval of information and visualization.
- To support dynamic use of MIS and GIS, monitoring and evaluation, seamless integration of online and offline activities, and dynamic updating of the information.
- To facilitate the convergence of various programs implemented by Watershed, Agriculture, Horticulture, Forestry, Animal Husbandry, Rural Development and other line departments at the watershed/village level in the state.
- To develop criteria, algorithms and models, knowledge base and expert systems needed to help the decision makers to access relevant information from a combination of raw data, documents, and personal knowledge, or models to identify and solve problems and make appropriate decisions as and when needed.

The Decision Support System is developed primarily to serve the needs of planning, implementation and monitoring of watershed development programs in the state by Watershed Development Department, Departments of Horticulture, Agriculture, Animal Husbandry, and other line departments, LRI project partners, and other stakeholders. The DSS development is based on the integration of data generated by LRI partners and compiled from other sources (Annexure 1) with criteria, models and algorithms already available or developed under this project. It is critical for the successful implementation of various watershed programs, other line department schemes and for empowering farmers and other stakeholders in the state. As a part of Sujala-3 Project, nine Decision Support Systems are developed in the first phase to facilitate the departments to take up key interventions and to provide advisories to the farmers and other stakeholders at the grassroots level as indicated below.

DSS modules developed as part of Sujala-3 project

Sl. No.	*Decision Support System*
Group 1 (Soil & Water conservation plan, Crop selection, Land Capability Classification and Nutrient management)	
1	DSS for **Soil & water conservation plan**-to identify the type of structures, their design and estimate, for both arable and non-arable lands/areas
2	DSS for **Crop selection** (Based on physical suitability and cost benefit ratio)
3	DSS for delineating prime farmlands/arable and non-arable lands based on **Land Capability Classification**
4	DSS on crop based **Nutrient management** and **soil health**
Group 2 (Surface Runoff, Size and location of Farm Ponds and Check Dams, Crop water requirement, Soil Water balance and Water budgeting)	
5	DSS for estimating **Surface runoff** at farm/MWS/SWS levels
6	DSS for designing the **Size and location of Farm ponds and Check dams** based on runoff model
7	DSS for estimating the **Crop water requirement** at MWS/SWS levels based on the existing land use or crops that are planned to be taken up for cultivation
8	DSS for estimating **Soil water balance** at MWS or higher levels, considering the RF, crop requirement, Runoff, evaporation and other losses, soil moisture and ground water.
9	DSS for **Water budgeting** taking into consideration the needs of various uses/users at MWS/ Village level- crop needs, human needs, livestock needs etc.

The DSS on **Soil & water conservation** helps to identify appropriate conservation structures for the arable and non-arable lands based on site-specific parcel level information generated through Land Resource Inventorisation and available to the users in the form of LRI and Hydrology Reports and Atlases. The user can select the area of his interest from the drop-down menu and run the DSS in the Portal to get the conservation map of the area along with the output showing the type of structures, cost of the main and side bunds with waste weir and conservation practices to be followed. The DSS can also be run for the selected survey number or parcel of land to get the type of structures to be constructed along with the cost and other details.

Similarly, the DSS on **Crop suitability** compares the bio physical characteristics of the land like the soil-site characteristics, climate *etc.*, with the requirements of the crop and generates the suitability map. The suitability map will show the degree of suitability like highly, moderately, or marginally suitable or not suitable for the crop with their limitations and extent. The DSS model can also be run at the field or at any higher levels as per the needs of the users. This model is available for about 73 different crops that are under cultivation in the state at present. The DSS on crop suitability assessment helps the planner to prepare a matrix of suitable and not suitable crops for a given area and the farmer to choose the best suited crop for the farm.

The DSS on **Nutrient management** enables the farmer to choose the type, quantity and time of application of fertilisers to the selected crop under cultivation based on the nutrient status of the soil and the planner to identify the extent of deficient/sufficient areas for taking up appropriate interventions. This model can be run at any levels from the farm, watershed or higher levels based on the availability of information. This helps to supply the required nutrients in a targeted manner and avoids misapplication of fertilisers, thereby reducing the cost of cultivation to the farmer.

The DSS on Land Capability, Runoff, Farm Ponds and Check Dams, Crop water requirement, Soil moisture and water balance and Water budgeting facilitate the departments to take up key interventions and to provide advisories to the farmers and other stakeholders at different levels.

The development of the nine Decision Support Systems was based on the criteria, type of models, algorithms and state of knowledge available at present in the respective domains. The output from the model/DSS may or may not reflect the existing field situations due to various reasons. Hence the outputs generated by using the DSS needs to be verified/validated in the field and recalibrated/modified wherever necessary with inputs/feedbacks received from the stakeholders before they are finally deployed in the Portal.

Exercise - 2

Delineation of arable and prime lands based on land capability assessment

Based on the soil characters presented in the atlas, group each soil phase into various land capability classes and sub classes.

The parameters to be considered are given below and the criterias to be used in grouping the land parcels into land capability units are given in DSS book (Table 4.1, Page: 110). To understand soil characteristics and soil-site characteristics, refer Annexure-2 page: 219.

Climate, soil and site parameters/features affecting LCC		***Land capability ratings***							
		Suitable for Agriculture				***Suitable for forestry, silvipasture, wildlife etc.***			
		Class I	***Class II***	***Class III***	***Class IV***	***Class V***	***Class VI***	***Class VII***	***Class VIII***
Climate	Humid with well distributed rainfall								
	Humid with occasional dry spells								
	Sub humid-yields frequently reduced by droughts								
	Semi-arid								
	Arid								
Slope	**Red soils**								
	A (<1%)								
	B (1-3%)								
	C (3-5%)								
	D (5-10%)								
	E&F (10-25%)								
	G,H&I (25>50%)								
	Black soils								
	A (<1%)								
	B (1-3%)								
	C (3-5%)								
	D (5-10%)								

Climate, soil and site parameters/features affecting LCC		***Land capability ratings***							
		Suitable for Agriculture				***Suitable for forestry, silvipasture, wildlife etc.***			
		Class I	***Class II***	***Class III***	***Class IV***	***Class V***	***Class VI***	***Class VII***	***Class VIII***
Erosion	Slight (e_1)								
	Moderate (e_2)								
	Severe (e_3)								
	Very Severe (e_4)								
Drainage	Excessive								
	Well drained								
	Mod.WD								
	Imperfect								
	Poor								
	Very Poor								
Soil depth	> 100 cm								
	50 –100 cm								
	25-50 cm								
	10-25 cm								
	< 10 cm								
Texture	sl, scl, cl, loam, silty clay loam								
	sandy clay, silty clay								
	clay								
	loamy sand								
	sand								
Gravels	< 15 %								
	15-35 %								
	35-60 %								
	> 60 %								

Climate, soil and site parameters/features affecting LCC		***Land capability ratings***							
		Suitable for Agriculture				***Suitable for forestry, silvipasture, wildlife etc.***			
		Class I	***Class II***	***Class III***	***Class IV***	***Class V***	***Class VI***	***Class VII***	***Class VIII***
Rockout crops (%)	<2								
	2-10								
	10-50								
	50-90								
	>90								
Salinity EC	<2								
	2-4								
	4-8								
	8-16								
pH	Favorable Reaction (6.5-7.5)								
	Unfavorable reaction (easy to modify) (5.5-6.5 & 7.5-8.5)								
	Unfavorable reaction (difficult to modify) (4.5-5.5 & 8.5-9.5)								
	Unfavorable reaction (exceedingly difficult to modify) (<4.5 & >9.5)								
Permeability	Very slow								
	Slow								
	Mod. slow								
	rapid								
	Very rapid								

Final land capability class:

5. Preparation of soil and water conservation plan based on LRI data

Following are some of the treatments suggested for soil and water conservation. Understanding of these activities will be helpful to choose appropriate measures for a given condition in addition to decision criteria indicated for each measures.

A. **Contour Bunding:** The contour represents the envelope of the normal drawn at any given level to the lines of the greatest slope of a given watershed. Since runoff from any given surface is along the lines of the greatest slope and the velocity of runoff increases inter alia with the vertical distance through which it is moved. Contour bunding is the best means for arresting runoff from the watershed (Liu *et al*., 2014). These are applicable in areas receiving an annual rainfall of less than 750 mm and successfully practiced in all soils having infiltration rate of more than 8 mm per hour and slope less than 6 %.

B. **Graded Bunding:** In situations where rainfall is not readily absorbed due to high rainfall or low intake of the soil, graded bunding recommended (Shinde *et al*., 2019). Graded bunds are trapezoidal earthen embankments constructed on a grade across the major slope to lead excess runoff through a wide and relatively shallow channel formed on 0.2 to 0.4 % grade on the upstream side of the bund. These are suitable for areas receiving annual rainfall more than 750 mm, where runoff is high, surplussing are essential and having infiltration rate less than 8 mm per hour Slope is 5 to 10 %.

C. **Contour border strips (CBS):** These are levelled strips of land constructed across the major slope at a vertical interval of 0.3 m with suitable drop structure in the waterways at the end of each strip (Singh *et al*., 2007). Each strip separated from the next bund of 0.24 m^2 cross section. CBS are most suitable in moderately to deep soils with infiltration rate of more than 8 mm per hour and where the rainfall is not more than 750 mm annually.

D. **Broad Base Terrace:** Recommended in deep black soils with high clay content develop deep cracks in summer and bunds in these soils breach extensively during rainy season, especially when the rains are of high intensity (Singh and Meena, 2020). A terrace is a combination of ridge and channel built across the slope on a controlled grade.

E. **Zing terracing:** Adopted in lands with 3 to 10 percent slopes and bench terracing is recommended on steeper slopes (Zingg and Hauser, 1959). Zing terraces are constructed in medium to deep soils in moderate to high rainfall areas. The length of the field is divided into donor area and receiving area in the ratio 2:1 to 5:1, but usually 2:1. The donor area is not levelled whereas the lower receiving area is levelled and provided with bund of cross- section area 0.3 to 1.5 m^2.

F. **Bench terracing:** On steeply sloping and undulated land, intensive farming is possible only with bench terracing (Meena and Meena, 2017). It is usually practicing on slopes ranging from 16 to 33 percent. Bench terracing consists of principally transforming relatively steep land into a series of level strips or platforms across the slope of the land. The field is made into a series of benches by excavating the soil from upper part of the terrace and filling in the lower part. A good soil depth is required to avoid exposure of unproductive soil during levelling. The vertical drop may vary from 60 to 180 cm, depending on the slope and soil conditions and width required for easy cultural operations.

Types of terraces for different soil and rainfall conditions:

Type	Suitability
Level and table-top	Area receiving medium rainfall (750mm) of even distribution with highly permeable deep soils.
Sloping outwards	Low rainfall (<750) area with permeable soil of medium depth.
Sloping inwards	Heavy rainfall areas (>750mm) with soil of poor infiltration rate.

G. Vegetative Barriers: Closely spaced plantations, few rows of grasses or shrubs grown along the contour lines for erosion control in agricultural lands.

H. Grassed waterways: Waterways dug to a shallow depth of 0.15 to 0.5 m with flat side slopes of 4:1. Based on the gradient decided by the existing slope of the land. Suitable perennial grass (not edible by the cattle, deep rooted and of spreading type) established subsequently for the stability of the waterway (*Panicum repens, Brachiaria mutica, Cynodon plectostahyus, Cynodon dactylon and Paspalum notatum*, *etc*.) (Meena *et al*., 2018).

While planning the activities for individual farmers in the micro watershed all the activities like conservation measures in the land owned by them, crop plan, nutrient plan, animal husbandry, livelihood activities *etc*., are to be prepared. To prepare the activities as a first step survey number wise details of farmers to be collected. The farmer details should include identifying information like name, father’s name, gender, land holding and caste category, village *etc*. Referring to LRI and hydrology atlases, the activities proposed to be taken are soil conservation and their technical specifications need to be mentioned along with the unit cost and total cost. Likewise, it should be detailed for all the farmers in the micro watershed.

Exercise - 3

Soil and Water conservation for arable and non-arable lands

Step-by-step execution of Conservation Plan

Steps	***Description***
1	Select two distinct soil phases and study their land characteristics
2	Select treatment for land characteristics based on decision rules (Table 2.6: Page No. 14 of DSS book)
3	Select vertical and horizontal interval based on decision rules (Table 2.9: Page No. 29 of DSS book)
4	Select cross-section of structure based on the decision rules (Table 2.10: Page No. 30 of DSS book)
5	Estimate length of Bunding per hectare (m) = 10000 x S/(VI x 100)
6	Estimate cost of conservation structure based on decision rules (Table-2.11: Page No. 31 of DSS book for Contour Bunding, Table 2.12: Page No. 33 of DSS book for TCB and Table 2.13: Page No. 34 of DSS book for Graded bunds.

6. Preparation of crop suitability plan based on LRI data

The land resources are finite and under stress due to the increased demand for food, fiber, fodder *etc*. from growing population. The population growth is leading to unfavorable man to land ratio. In India, per capita cultivable land holding has been declining from 0.48 ha in 1951 to 0.16 ha in 1991 and it is likely to decline further to 0.11 ha in 2025 and less than 0.09 ha in 2050 (NAAS, 2009). Although, the food production has increased from 52 m tons in 1950's to almost 311 m tons in 2020-21 (GOI, 2022), this increase has been largely as a result of expansion in cultivated and irrigated area and high chemical (fertilizer) inputs. The significant growth of agriculture has been at the cost of decline in soil quality and risk of soil degradation. We are now facing the serious threat of ensuring sustainability in our production systems. In many of the so-called first green revolution areas, a whole range of second-generation problems are posing serious challenges to the sustainable agricultural production. About 57 per cent of soils are under different kinds of degradation and these are getting further deteriorated with risk of jeopardizing our food security (Sehgal and Abrol, 1994). In addition to this, many issues concerning environmental sustainability, carrying capacity of our land resources, *etc*., are also cropping up and adversely affecting soil and human health. These problems demand a systematic appraisal of our soil and climatic resources to recast and implement an effective and appropriate land use plan at local level. Soil survey interpretation and land evaluation precede land use planning. Standard survey information can be interpreted for several purposes like suitability for agriculture through technical classification of soils, hydrological groupings, suitability for sewage disposal, trafficability, building construction, *etc*.

Land evaluation is the process of estimating the potential of land for alternative kinds of use. These uses can be productive such as i) arable farming, ii) livestock production, iii) forestry or other uses such as, a) catchment protection, b) recreation, c) tourism, d) wild life conservation. It involves interpretation of surveys, climate, soils, and vegetation and other aspects of land with the requirements of alternative land use.

Land evaluation procedures

The land evaluation activities undertaken and the order in which the work is done depend on the type of approach adopted, whether parallel or two-stage.

The main activities in a land evaluation are as follows:

- Initial consultations, concerned with the objectives of the evaluation and the data and assumptions on which it is to be based
- Description of the kinds of land use to be considered, and establishment of their requirements
- Description of land mapping units, and derivation of land qualities
- Comparison of kinds of land use with the types of land present
- Economic and social analysis

- Land suitability classification (qualitative or quantitative)
- Presentation of the results of the evaluation

It is important to note that there is an element of iteration, or a cyclic element, in the procedures. Although the various activities are here of necessity described successively, there is in fact a considerable amount of revision to early stages consequent upon findings at later periods. Interim findings might, for example, lead to reconsideration of the kinds of land use to which evaluation is to refer, or to changes in boundaries of the area evaluated.

Data set requirements for land evaluation

The land units and their homogeneity form the basic requirement for proper land evaluation. The land units selected for land evaluation have no scale limitation. The information on the land units is generated through different kinds of soil surveys.

The land characters and land qualities considered in defining the land units are as under:

Land characters: Land characteristics used in land evaluation are measurable properties of the physical environment directly related to land use and are available from the soil survey. These characteristics are

Bio-physical characteristics: factors like topography (t)-slope length and gradient; wetness (w)-drainage and flooding

Physical soil characteristics: Texture, soil depth and intensity of acid sulphate layer and gypsum or kankar layer

Fertility characteristics (f): Cation exchange capacity of the clay as an expression of weathering stage, base saturation and organic matter content

Salinity and alkalinity (n): Salinity status and alkalinity status

Climatic database: Factors such as temperature, potential evaporation, the temporal and spatial variability of rainfall, specific to an area are considered as database for estimation of growing period.

There are a number of other important properties, which co-vary with changes in the property; however, these properties are of great value in interpreting the various uses. Soil classification systems very much rely extensively on quantitative composition of soils and these compositions are selected on their assumed importance in understanding the genesis of the soil.

Land qualities: It is a complex attribute of land which acts in a distinct manner, its influence on the suitability of land for a specific kind of use. They may be positive or negative. They are in fact practical consequences of land characteristics. They could be segregated in to two groups: FAO (1976) suggests three comprehensive land qualities:

Internal qualities: Water holding capacity; oxygen availability; availability of foot hold to roots; tolerance to iron induced chlorosis; nutrient availability; resistance to structural degradation of top soil; absence of salinity and alkalinity.

External qualities: Correct temperature regime; resistance against erosion; ability for layout of farm plan and workability.

Land Evaluation Approaches

Land evaluation is the ranking of soil units on the basis of their capabilities (under given circumstances including levels of management and socio-economic conditions) to provide highest returns per unit area and conserving the natural resources for future use (Van Wambeke and Rossiter, 1987). Several systems of land evaluation have been recognized (Storie, 1954; Requier *et al*., 1970; Sys, 1985; Sehgal *et al*., 1980). There are both qualitative and quantitative approaches in vogue.

A. Qualitative evaluation

i) Land Capability Classification (Klingbiel & Montgomery, 1961).
ii) Land Irrigability Classification (Soil Survey Staff, 1951; USBR, 1953).
iii) Fertility Capability Classification
iv) Crop Suitability Classification (FAO, 1976; Sys, 1985; Sys *et al*. 1993)
v) Prime Land Classification (Ramamurthy *et al*., 2012)

B. Quantitative evaluation

i) Soil index rating (Shome and Raychaudhari, 1960; Storie, 1978)
ii) Actual and potential productivity (Riquier *et al*., 1970)
iii) Soil suitability classification- statistical approach (Sehgal *et al*., 1989)
iv) Land use planning and analysis system (LUPAS) (Laborte *et al*., 2002):
v) Land suitability assessment by parametric approach (Rabia and Terribile, 2013)
vi) Land suitability by fuzzy AHP and TOPSIS methods (Mukhtar Elaalem *et al*., 2010)
vii) Land suitability by integrated AHP and GIS method (Ramamurthy *et al*., 2020)

Land Suitability Evaluation

Each plant species requires specific soil-site conditions for its optimum growth. The land suitability assessment provides the suitability or otherwise of the various land resources occurring in an area for major crops grown. This helps to find out specifically the suitability of the land resources like soil, water, weather, climate and other resources and the type of constraints that affect the yield and productivity of the selected crop.

This assessment is based on the model proposed by the FAO (1976 and 1983) for land evaluation and suggested the classification of land in different categories: Orders, Classes, Sub-classes and Units. The soil-site characteristics are expressed in terms of degree of limitation (0, 1, 2, 3 or 4); the limitation of 2 is considered critical at which the expected yield declined significantly and the cultivation is considered marginally economical. The final soil-site evaluation/suitability is based on the number and degree of limitation (s). Modern approaches involve simulation model predicting yield as a measure of suitability. Although very well refined, yet these approaches are largely based on local experience of farmers or of the researchers.

Land evaluation involves the assessment of land and soils for their potential for different uses involving matching the land qualities and requirements for the land use. For rationalizing land use, soil-site suitability for different crops need to be determined to suggest the models for guiding the farming community to grow most suitable crop(s), depending on the suitability/capability of each soil unit mapped.

The adaptability of crops in one or the other area is the interaction between existing edaphic conditions and fitness of the cultivar under these conditions. Although, lot of data on crop production through experimentation have been generated by the SAU's and Crop Research Institutes, yet it has not been correlated with sufficient data base on the soil-site conditions in order to work out soil-site suitability models for optimizing land use in the country.

In the land evaluation, there are four steps namely (i) characterization of existing soil, climatic and land use conditions (ii) development of soil site criteria or crop requirements (iii) matching of crop requirements with existing soil and climatic conditions and (iv) choosing of the best fit among the crops and the selecting the same as the alternative crop strategy.

Among the above four steps, the formulation of the soil site criteria to meet the crop requirements forms a vital and important step. For the development of crop requirements, one has to do either experimentation at each well characterized growing environment or take the help of published literature. Naidu *et al*. (2006) have compiled the soil-site requirement of major crops of India by reviewing published literature and consulting crop specific researcher teams.

Matching of crop requirements consists of comparing existing climate, soil and physiographic conditions with the soil-site criteria with respect to individual crop. On the basis of the degree and the number of limitations identified, the suitability class is established, *viz*., highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and unsuitable land (N1 & N2) for specific kind of land use. Land suitability subclasses are divided into land suitability units based on specific management requirements. The ratings used for defining each class are based on the number and degree of limitations present. The S1 classes correspond to areas, which have a yield potential above 80% of the maximal attainable harvest within the climatic region of the area. This figure drops to 60% and 40% for classes S2, and S3, respectively.

Simple limitation method: In assigning the overall suitability class to any area, the limitation approach or law of the minimum is followed. According to this approach, even if all other factors are favorable for the crop and only one factor is likely to be a limitation, then that factor is given precedence in assigning the suitability class. The suitability classes and sub-classes are directly assigned to land units based on suitability criteria. A brief description of the orders, classes and subclasses used in the suitability assessment of major crops is given below:

Order S (Suitable)

Class S1	:	(Highly suitable) Land unit having no limitation for sustainable use or with not more than three slight limitations.
Class S2	:	(Moderately suitable) Land with more than three slight limitations but with not more than three moderate limitations.
Class S3	:	(Marginally suitable) Land with more than three moderate limitations but with not more than two severe limitations.

Order N (Not Suitable)

Class N1	:	(Currently not suitable) Land with severe or very severe limitations that may be overcome in time but cannot be corrected with existing knowledge at current acceptable cost
Class N2	:	(Permanently not suitable) Land having limitations that will be very difficult to correct and use

There are no sub-classes within the suitability class S1. Classes S2, S3 and N1 are divided into subclasses based on the specific limitations encountered in an area for the selected land use. The specific limitations that are likely to affect crop production at the watershed or village level are indicated below with their symbols to be used.

Erratic rainfall and its distribution and short growing period	c
Erosion hazard (Slope and erosion)	e
Soil depth (rooting conditions)	d

Soil texture (lighter or heavy texture)	t
Coarse fragments (gravelliness or stoniness)	g
Soil fertility constraints, calcareousness, sodicity hazard, salinity problem etc.	n
Drainage problem	w
Moisture availability	m
calcareousness	z
Topography	l

Limitations are indicated in lower case letters after the suitability class symbol. For example, marginally suitable land with low rainfall or short growing period as a limitation is designated as S3c. Normally two and sometimes three limitations are included at subclass level. Land suitability units are indicated by the Arabic numbers after the limitation symbol.

Based on the suitability classification, land resources of any watershed or area can be evaluated to find out their suitability for various crops, like cereals and millets, oil seeds, pulses, commercial crops like cotton, sugarcane, spices and horticultural crops. The assessment can be done for the existing crops that are under cultivation at present or for some of the promising crops and varieties from other places before they are recommended for cultivation in the area.

The process involved in the crop suitability assessment is elaborated below.

- Selection of the crop and the survey number or land parcel to be assessed for suitability evaluation
- Finalisation of suitability criteria for the crop or crops to be assessed. The criteria table developed for each crop will show the soil-site and other land characteristics on one side and the range of values assigned to each of the land characteristics for different suitability classes like Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3), Currently Not Suitable (N1) and Not Suitable (N2) on the other side
- Run the system to match the crop suitability criteria with LRI, Hydrology and other resource information pertaining to the farm/survey number stored in the system
- After the matching process, the system displays the degree of suitability for the crop with constraints if any as subscripts after considering the following criteria/logic
- Law of Minimum/Limitation approach in assigning the degree of suitability

- Internal prioritization among crops with same rank
- Displaying the suitable crops (on prioritization basis) with all limiting factors as sub-script
- Based on the soil, site, climate and other datasets, the system calculates the number of S1s, S2s and S3s against the parameters provided with each crop matrix. Then the crop is placed into a suitability class/category based on the law of minimum as illustrated below.

Example:

Sorghum: 4S1 + 3S2 + 4S3 ~ will be placed in to S3 (Internal prioritization based on the Law of Minimum approach)

Maize: 1S1 + 10S2 + 0S3 ~ will be placed in to S2 (Internal prioritization based on the Law of Minimum approach)

Red gram: 15S1 + 0S2 + 0S3 ~ will be placed in to S1 (Since there is no limitation for the crop)

Maize S2, Groundnut S2-Selection of the most suitable crop among the two will be based on B:C Ratio as the score for both crops are same.

Benefit cost ratio: is decided based on standard cost of cultivation, yield and dynamic market prices. The standard cost of cultivation for any crop is available with the Department of Agriculture. Market prices can be obtained from Agmarketnet web API. Using the above the B:C Ratio can be calculated as (Yield X Market Price) / Cost of Cultivation.

The Crop suitability choices arrived for an area need to be shared to the concerned agricultural office/stakeholders and vetted before the same is recommended to the farmer. This assessment can help greatly in identifying the best suited areas and the areas having limitations in the watershed area. Similar assessments can be made for other areas and for other crops for the same area.

Exercise - 4

Crop wise soil characteristics for deciding suitability of crops

Description		***Ragi***	***Redgram***	***Mango***	***Areca***
Depth (cm)					
Very shallow	<25	N	N	N	N
Shallow	25-50	S3	N	N	N
Moderately shallow	50-75	S2	S3	N	S3
Moderately deep	75-100	S1	S2	S3	S2
Deep	100-150	S1	S1	S2	S1
Very deep	>150	S1	S1	S1	S1
Gravels (%)					
g0	<15	S1	S1	S1	S1
g1	15-35	S2	S2	S2	S2
g2	35-60	S3	S3	S3	S3
g3	60-80	N	N	N	N
Slope (%)					
A	0-1	S1	S1	S1	S1
B	1-3	S1	S1	S1	S1
C	3-5	S2	S2l	S2	S2
D	5-10	S3	S3l	S3l	S3
E	>10	N	N	N	N
Texture					
Loamy sand (b)	ls	S3	S3	N	S3
Sandy loam (c)	sl	S1	S2	S2	S2
Sandy clay loam (h)	scl	S1	S2	S1	S1
Clay loam (f)	cl	S1	S2	S1	S1
Sandy clay (i)	sc	S1	S1	S1	S1
Clay Red (m)	c	S1	S1	S1	S2
Clay Black (m)	c	S3	S2	S3	S3
Drainage					
Well		S1	S1	S1	S1
Moderately well		S1	S2	S2	S2
Poorly		S3	S3	S3	N
Very poorly		N	N	N	N

Considering the above crop suitability criteria, for the given soil phases indicate suitability of Ragi, Redgram, Areca and Mango as S1/S2/S3/N

Soil Phase	***Characters***					***r***	***t***	***g***	***l***	***w***	***Suitability class***
	Depth	***SSG***	***SST***	***Slope***	***Drainage***	***Depth***	***Texture***	***Gravels***	***Slope***	***Drainage***	
Ragi											
TDHhB1	50-75	0	sc	1-3%	mod. well						
APHiA1St1	<25	33	sl	0-1%	well						
CKMiC1g1	75-100	0	ls	3-5%	poor						
Redgram											
KMHiB1g1	100-150	23	c(r)	1-3%	well						
BPRiB1	25-50	32	scl	1-3%	poor						
JDGcA1	50-75	8	sc	0-1%	mod. well						
Arecanut											
GLRiD1	100-150	40	c(r)	5-10%	well						
NDLhC1	>150	50	s	3-5%	well						
BDKcB1	25-50	14	c(b)	1-3%	very poor						
Mango											
RTRiB2g1	25-50	10	c(b)	1-3%	well						
TSDiA1	75-100	17	scl	0-1%	poor						
TDGiC1	>150	37	s	3-5%	well						

7. Preparation of nutrient management plan based on LRI data

The importance of soil fertility and plant nutrition to the health and survival of all life cannot be understated. As human population continue to increase, human disturbance of the earth's ecosystem to produce food and fiber will place greater demand on soils to supply essential nutrients. The practice of intensive cropping with hybrid varieties for boosting food production in India caused nutrient depletion in soil, consequently macro and micro nutrient deficiencies are reported in soils of India. If we do not improve and/or sustain the productive capacity of our soils, we cannot continue to support the food and fiber demand of our growing population. Maize is gaining importance as a commercial food grain crop in Karnataka. High fertilizer responsiveness together with preference for cultivation under irrigation, maize crop is known to remove nutrients exhaustively. It is therefore important to monitor the nutrients status of soil from time to time with a view to monitor the soil health.

In the recent past, concept of watershed based holistic development has emerged as one of the potential approaches in rainfed areas, which can lead to higher productivity and sustainability in agriculture. Hence, assessing the fertility status and nutrient mapping of soils is needed to identify extent of nutrient deficient area for site specific recommendations. Micronutrient deficiency in soil has become wide spread in recent years and has resulted in low crop yields, more so after the introduction of high yielding crop varieties coupled with the use of high analysis fertilizer and increased cropping intensity. The information regarding the status of available micronutrients and nutrient mapping of soils is needed to realize the concept of watershed approach successfully.

Many of the soils in different ecosystems are fragile and miss management can rapidly lose whatever capability they have for sustained productivity. If we do not improve and/or sustain the productivity capacity of our fragile soils, we cannot continue to support the food and fiber demand of our growing population. Therefore, it is critical that we increase our understanding of the soil nutrient status and relationships in the soil-plant atmosphere continuum that control nutrient availability.

Hence, geo-referenced information on the location, extent, quality of land display of spatial data is a must for advisory purposes. Geographic information system (GIS) is a powerful set of tool for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world. Geographic information system (GIS) can be used in producing a soil fertility map of an area, which will help in formulating site specific balanced fertilizer recommendation and to understand the status of soil fertility spatially and temporally. This is an important technique for formulating site specific recommendation of nutrients.

Available Nutrients mapping

Surface (0-20/30 cm) soil samples are to be drawn in grid sampling from the area at 320-meter grid intervals. Soil samples are to be processed and analyzed for the soil fertility parameters like organic carbon, nitrogen, phosphorous, potassium, calcium, magnesium, Sulphur, copper, iron, zinc, manganese and boron by standard analytical techniques. Thematic maps are to be prepared for the analysis data using GIS tools.

DSS on Nutrient Management

Inputs data required for the DSS: GIS layers of all soil fertility parameters, crop wise NPK fertilizer and micro nutrient recommendations, criteria for adjusting the fertilizer recommendations, information of the farmer and location details of the farmer's field.

Soil fertility criteria for adjusting the recommended fertilizer doses for macro nutrient application (NPK)

<table>
<tr><th>Nutrient</th><th>Very Low</th><th>Low</th><th>Medium</th><th>High</th><th>Very High</th></tr>
<tr><td>Nitrogen</td><td rowspan="3">Recommended dose x 1.67</td><td rowspan="3">Recommended dose x 1.33</td><td rowspan="3">Recommended dose x 1.00</td><td rowspan="3">Recommended dose x 0.67</td><td rowspan="3">Recommended dose x 0.33</td></tr>
<tr><td>P_2O_5</td></tr>
<tr><td>K_2O</td></tr>
</table>

Note: For example, if the recommended dose of N for irrigated maize is 150 kgs/ha and if the nutrient content of the soil is very low, then we need to add 250 kg/ha (150 x 1.67), for low 200 kgs/ha (150 x1.33), for medium 150 kgs/ha (150 x 1.0), for high 100 kgs/ha (150 x 0.67; 2/3 general recommendation as per POP) and for very high 50 kgs/ha (150 x 0.33; 1/3 general recommendation as per POP). Similarly, for phosphorus and potassium, the fertilizer requirements are calculated using the above formula.

Step by Step Process

Step	*Description*
1	Read farmers information (Contact number, land parcel, crop sown, area, ACZ, dry or irrigated)
2	Read soil fertility status with respect to land parcel from LRI information
3	Select nutrient recommendation from selected crop
4	Adjust nutrient recommendation with respect to soil fertility status
5	Read nutrient content in fertilizers
6	Estimate amount of fertilizer required for the crop
7	Estimate the dose at different stages of plant growth (Basal dos and top dressing)
8	Send the advisory to the farmer-dosage of fertilizer and cost at different stages of growth along with package of practices to be followed
9	Based on the nutrient status of the soil in the watershed/sub watershed area estimate the amount of fertilizers required for the area.

Apart from the display of the nutrient status maps, the amount of nutrients required for the Micro watershed/sub watershed area can be estimated and shown as an output as per the requirement.

Exercise - 5

Nutrient Management Plan

1	Select a micro watershed atlas
2	Select three crops suggested for a particular survey number in a soil phase
3	Study the soil fertility status for major nutrients of the survey number in a soil phase
4	Select nutrient recommendation for the selected crops
5	Adjust nutrient recommendation considering soil fertility status and RDF of selected crop
6	Select the suitable combination of fertilizers and estimate the quantity of fertilizers required for the crop
7	Estimate the dose at different stages of plant growth (Basal dose and top dressing)
8	Workout the cost per hectare

Status of nutrients for a particular survey number in a soil phase (refer the atlas)

Soil phase	Survey number	Nutrient status (low/medium/high)		
		N	P	K

Select Two crops and Two combinations of fertilizers, workout the per hectare nutrient requirement and the cost

Item	Crops	
	1.	2.
Nutrients recommendation (RDF) (table - 5.3a to 5.3h Page No. 119-142 of DSS book)		
Adjusted nutrient as per soil nutrient status (table - 5.4: Page 143 of DSS book)		
Type and quantity of fertilizers recommended		
Combination 1		
Urea		
SSP		
MOP		
Combination 2		
DAP		
17-17-17		
Urea		
MOP		
Cost of fertilizers (Rs.) (table - 5.7: Page 148 of DSS book)		

8. Automation tools for preparation of SWC, LCC, Crop selection, and Nutrient management plan

Preamble:

The technical consortium partners, as continuous part of LRI and hydrological assessments have to prepare the atlas covering proposed site-specific SWC, LCC, Crop selection, and Nutrient management plans. This will be migrated to digital library for its applications in the geoportal. Presently, the process of preparation of these plans are done manually which is laborious and time consuming. To improve the efficiency (time saving and improved accuracy) of the staff working on these tasks, the Centre of Excellence on Watershed Management has developed a set of automation tools. The effective application of these automation tools is described below.

Need for automation tools:

- For a SWS of 5-10 MWS, it may take more than a month's time for a skilled person. Hence, by using this automation DSS tool the task taking a month's time can be achieved in less than an hour.
- Human validation of the input data and cleaning the dataset for possible errors, so that typographical mistakes are addressed properly. For example, the soil phase, soil depth, etc., are being entered manually, which is leading to unseen errors, so to bring them to a standard platform, the ArcGIS tool could be used, or else there is an option in the google sheet tool for data validation.
- Furthermore, the output can be joined with soil phase shapefile to get the area statistics, Estimated Length of Bund (ELOB), and the Standard Operating Rates (SOR) for calculating the total costs of the SWCS being considered.

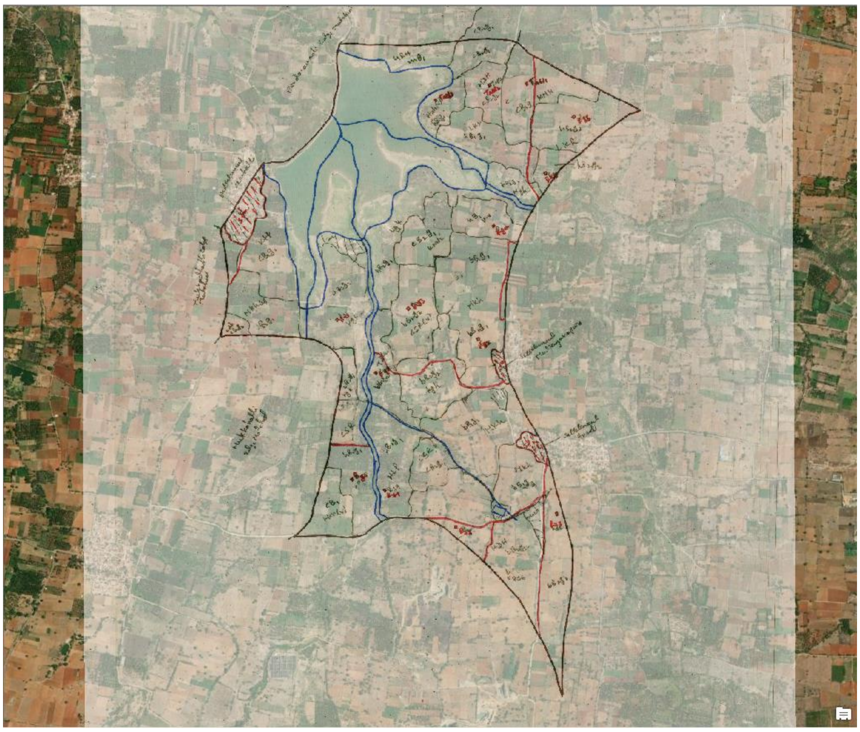
Precautions while using automated DSS tool:

The important cautions to be taken before using the DSS tool. There are several sheets available in that google workbook, but the sheets that are named with serial order are the only sheets to be used for working. Because, all the sheets are interlinked with one another and with formulae, so if any deletion or changes made with formulae may affect the final results. Therefore, for ease of use the supporting sheets are hidden. Unless a skilled person, trained on this complete methodology, one should not tamper with the hidden sheets or any formulae, unless otherwise officially directed.

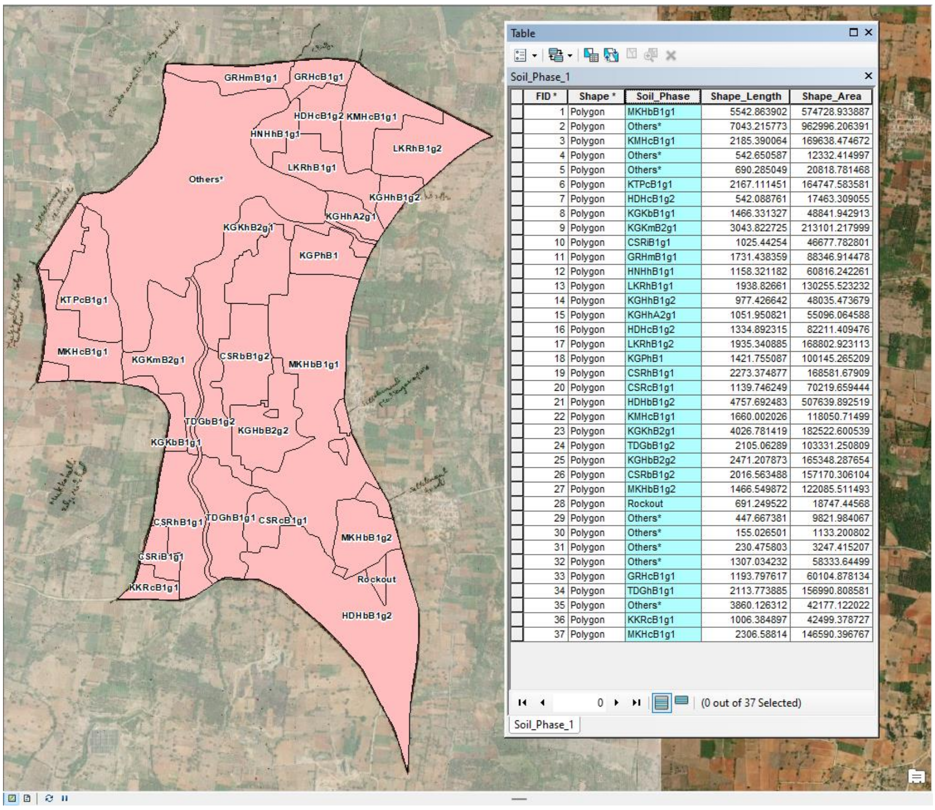
The google workbook is accessible for any number of people at a time just by clicking on the provided link, therefore any changes made by multiple users at a time will be reflected in the output. Hence, each user should create separate google workbook for individual user access. The detailed step-by-step methodology on how to use this DSS tool is given below.

Step-01-A:

Firstly, we need LRI data for soil surface and subsurface characteristics. Before working with the said data, let's get a background on the procedure of the same data being prepared. The field verified and traced Soil Phase data will be scanned and digitized into a Feature class (or a shapefile). This feature class should be a geometry type of "polygon"



Then the corresponding soil phase attributes are added to that Feature class or a shapefile as shown in the image.



FID *	Shape *	Soil_Phase	Shape_Length	Shape_Area
1	Polygon	MKHbB1g1	5542.863902	574728.933887
2	Polygon	Others*	7043.215773	962996.206391
3	Polygon	KMHcB1g1	2185.390064	169638.474672
4	Polygon	Others*	542.650587	12332.414997
5	Polygon	Others*	690.285049	20818.781468
6	Polygon	KTPcB1g1	2167.111451	164747.583581
7	Polygon	HDHcB1g2	542.088761	17463.309055
8	Polygon	KGKbB1g1	1466.331327	48841.942913
9	Polygon	KGKmB2g1	3043.822725	213101.217999
10	Polygon	CSRiB1g1	1025.44254	46677.782801
11	Polygon	GRHmB1g1	1731.438359	88346.914478
12	Polygon	HNHhB1g1	1158.321182	60816.242261
13	Polygon	LKRhB1g1	1938.82661	130255.523232
14	Polygon	KGHhB1g2	977.426642	48035.473679
15	Polygon	KGHhA2g1	1051.950821	55096.064588
16	Polygon	HDHcB1g2	1334.892315	82211.409476
17	Polygon	LKRhB1g2	1935.340885	168802.923113
18	Polygon	KGPhB1	1421.755087	100145.265209
19	Polygon	CSRhB1g1	2273.374877	168581.67909
20	Polygon	CSRcB1g1	1139.746249	70219.659444
21	Polygon	HDHbB1g2	4757.692483	507639.892519
22	Polygon	KMHcB1g1	1660.002026	118050.71499
23	Polygon	KGKhB2g1	4026.781419	182522.600539
24	Polygon	TDGbB1g2	2105.06289	103331.250809
25	Polygon	KGHbB2g2	2471.207873	165348.287654
26	Polygon	CSRbB1g2	2016.563488	157170.306104
27	Polygon	MKHbB1g2	1466.549872	122085.511493
28	Polygon	Rockout	691.249522	18747.44568
29	Polygon	Others*	447.667381	9821.984067
30	Polygon	Others*	155.026501	1133.200802
31	Polygon	Others*	230.475803	3247.415207
32	Polygon	Others*	1307.034232	58333.64499
33	Polygon	GRHcB1g1	1193.797617	60104.878134
34	Polygon	TDGhB1g1	2113.773885	156990.808581
35	Polygon	Others*	3860.126312	42177.122022
36	Polygon	KKRcB1g1	1006.384897	42499.378727
37	Polygon	MKHcB1g1	2306.58814	146590.396767

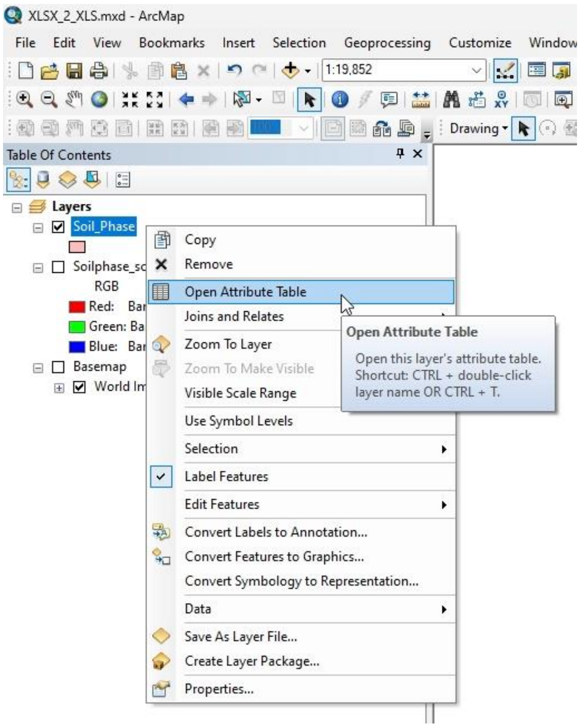
This feature class or the shapefile having soil phase polygons is the input required. For this feature class we have to add other soil parameters like sub-surface parameters as the fields. Using these parameters the LCC, SWCS, and CS are being generated using appropriate decision criteria.

Step-01-B:

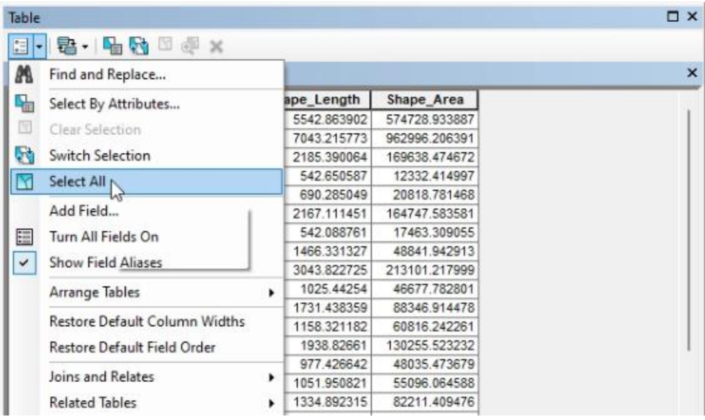
Initial information required about the location/SWS/MWS are to be collected. This information is not available in the attribute table, therefore to be collected separately. The taluk name provides the Agro-Climatic Zone (ACZ), which in turn provide the climate parameter classes for LCC. The MWS code is important to index the location of that MWS. The rainfall amount is required either as minimum-maximum value or average rainfall value (in millimeters).

Taluk	Chamarajanagara
Type	MWS
MWS_Code	**4B3E1H2d**
MWS_Name	Mallainupura
Rainfall_MIN (mm)	730
Rainfall_MAX (mm)	730

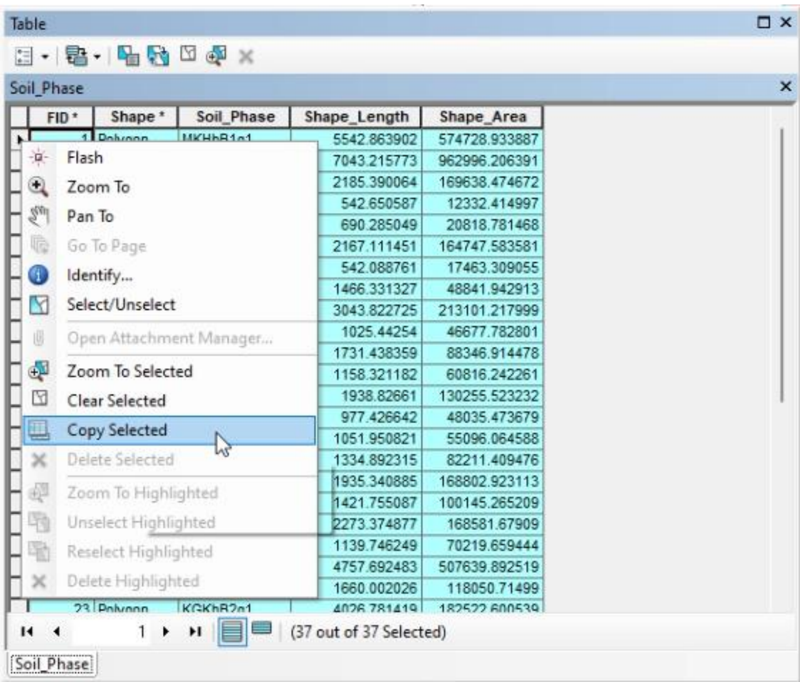
This attribute table of the feature class or shapefile is copy-pasted to a excel workbook, for further analysis.



In ArcGIS desktop Table of Contents (ToC), right-click on the layer associated with the Soil phase data, and click on "Open Attribute Table". On the top-left corner, click on the "Table Options"  as shown in the image below and click on "Select All". This will select all the records available in the attribute table.



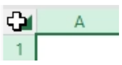
Once the records are selected, a bluish tinge will appear as the background for all the records. Then, to the left of first row first column, there is an empty space. Right click on that space as shown in the image, then click on the "Copy Selected".



Observe the bottom-center of the attribute table for "Show all records" 

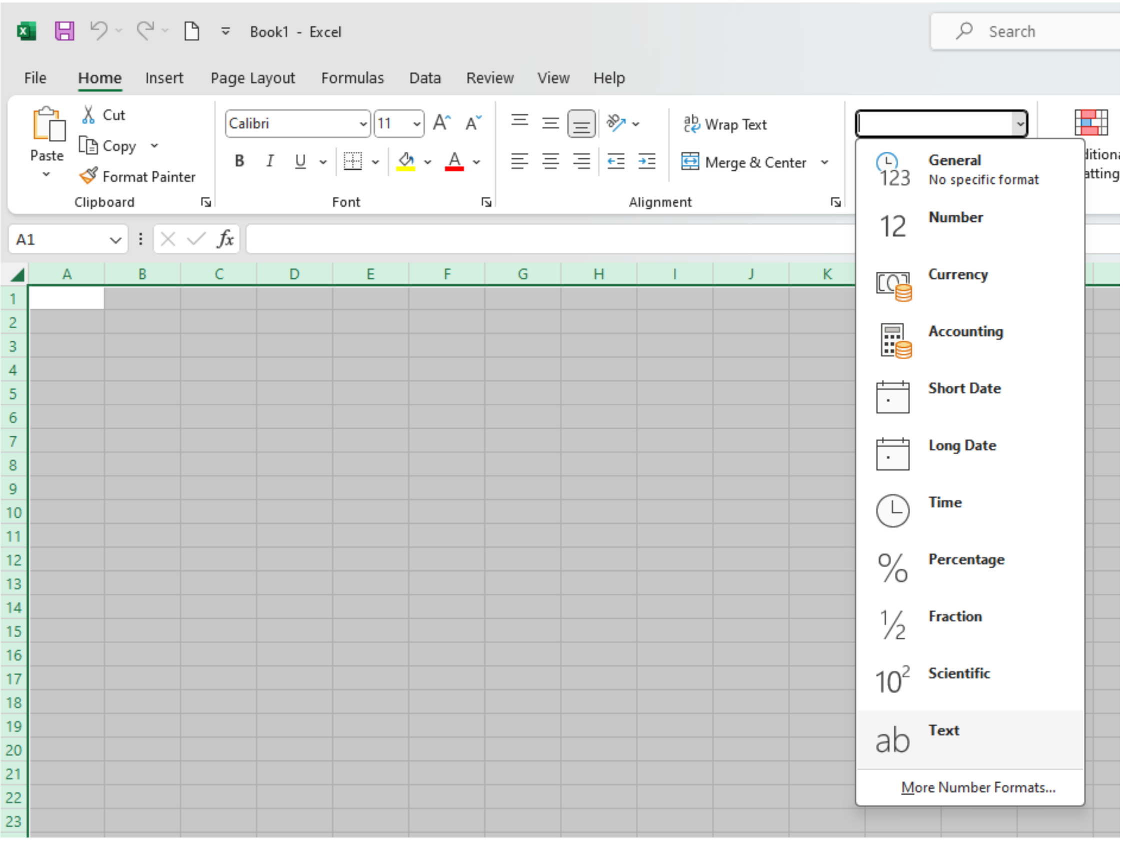
, and make sure all records are being selected. Here 37 out of 37 records are selected. This will copy all the records available in the attribute table.

Before pasting the data, the number format of the data to be pasted should have "Values or text", because otherwise the formulas may also be copied which may result in errors, or the values may be converted into date format (which is unintentional). This can be achieved in two methods

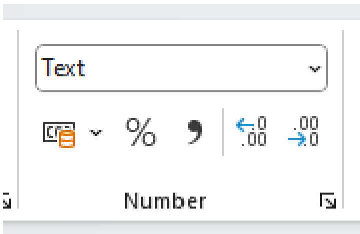
<u>Method-01:</u> In the excel workbook, select all the cells in the sheet 

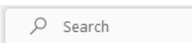
by clicking on the top-left corner which is the starting point of Column-A and Row-01. Also, the same can be done by using shortcut "Ctrl+A", which selects all the records in the excel sheet.

Then, go to "Format Cells > Number Format > Text" as shown in the image. But if you are not able to follow, then simply search for "Format Cells" in the search bar.



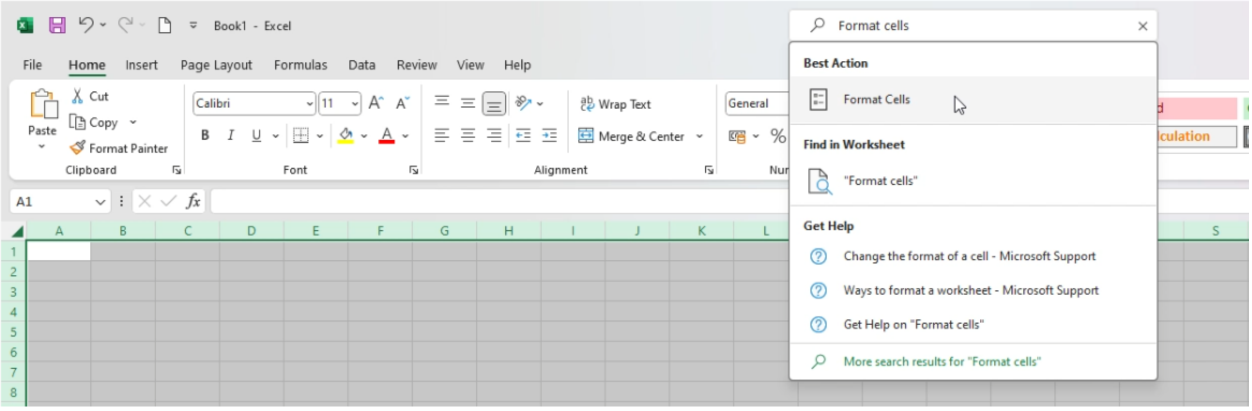
Now all the cells are considered as just text and not any other data formats, so that the numbers are not automatically converted to date format or decimal format.



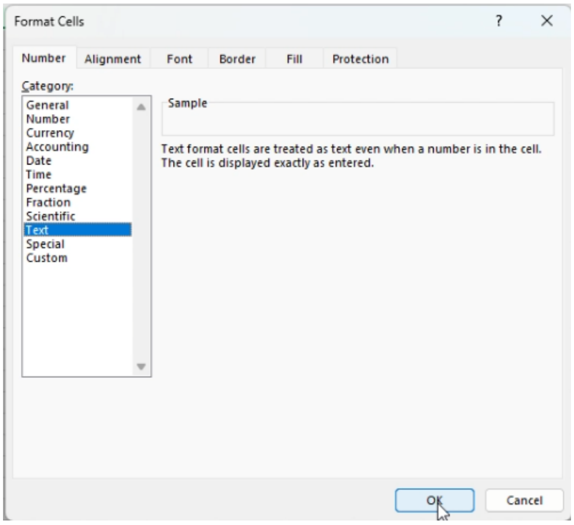
<u>Method-02:</u> By using the 

"search box" one can achieve the same goal. If the method-01 is slight confusing, then this would be a easy method to use.

In the search box at the top-center of the excel sheet, type the words "Format cells", a option will appear as shown in the image, click on it.

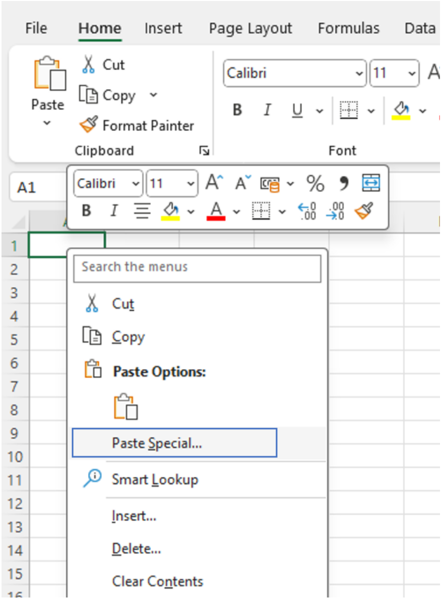


A new pop-up window for format cells will open. In that click on the "Number" tab, click on the "text" item in category section, and click OK.

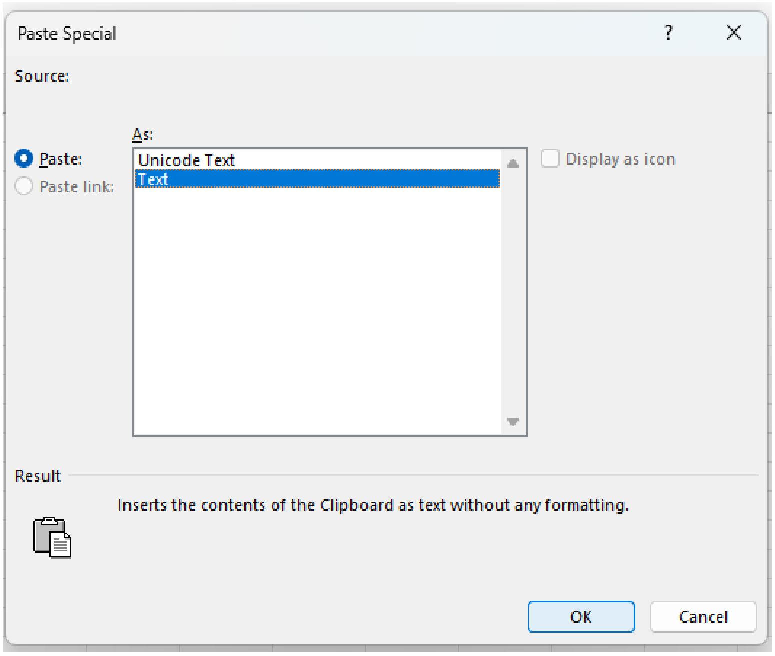


Once all the cells in the excel workbook are modified appropriately, and are converted into a "TEXT" format. Then the nest step is to paste the values.

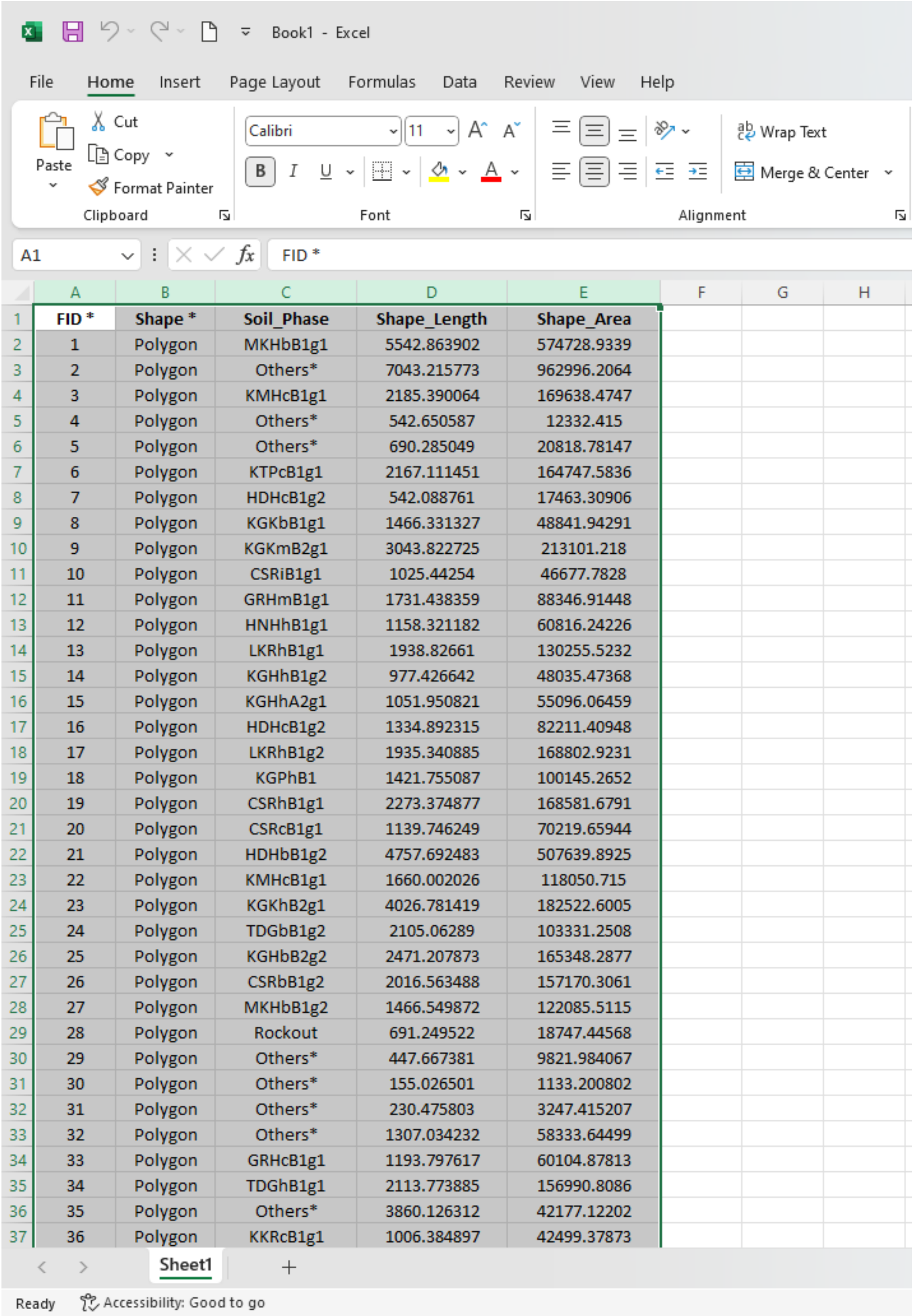
Now open a blank excel workbook and right click on the A1 cell (top-left 1st cell). Click on the "Paste Special… (Ctrl + Alt + v)" button as shown in the image below. Right-click on the A1 cell at the top-left corner, then click on "Paste Special…" button.



Then a pop-up window will appear as shown in the image below, click on the “text” for ‘Paste As’, and then OK.

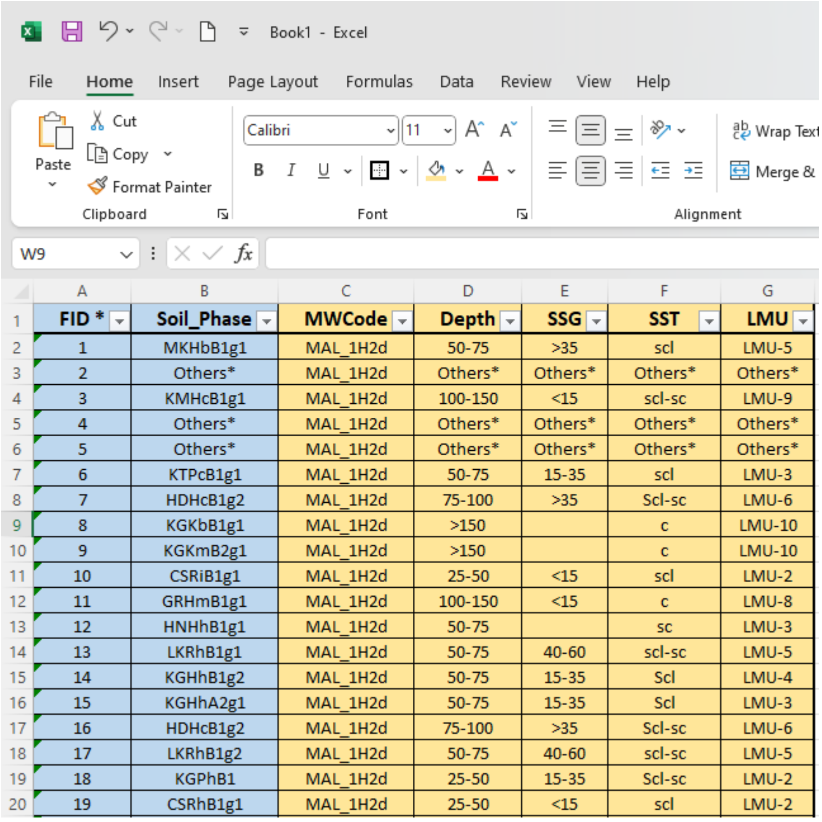


The attribute table data is now successfully copy-pasted into a excel sheet as shown in the image below.



FID *	Shape *	Soil_Phase	Shape_Length	Shape_Area
1	Polygon	MKHbB1g1	5542.863902	574728.9339
2	Polygon	Others*	7043.215773	962996.2064
3	Polygon	KMHcB1g1	2185.390064	169638.4747
4	Polygon	Others*	542.650587	12332.415
5	Polygon	Others*	690.285049	20818.78147
6	Polygon	KTPcB1g1	2167.111451	164747.5836
7	Polygon	HDHcB1g2	542.088761	17463.30906
8	Polygon	KGKbB1g1	1466.331327	48841.94291
9	Polygon	KGKmB2g1	3043.822725	213101.218
10	Polygon	CSRiB1g1	1025.44254	46677.7828
11	Polygon	GRHmB1g1	1731.438359	88346.91448
12	Polygon	HNHhB1g1	1158.321182	60816.24226
13	Polygon	LKRhB1g1	1938.82661	130255.5232
14	Polygon	KGHhB1g2	977.426642	48035.47368
15	Polygon	KGHhA2g1	1051.950821	55096.06459
16	Polygon	HDHcB1g2	1334.892315	82211.40948
17	Polygon	LKRhB1g2	1935.340885	168802.9231
18	Polygon	KGPhB1	1421.755087	100145.2652
19	Polygon	CSRhB1g1	2273.374877	168581.6791
20	Polygon	CSRcB1g1	1139.746249	70219.65944
21	Polygon	HDHbB1g2	4757.692483	507639.8925
22	Polygon	KMHcB1g1	1660.002026	118050.715
23	Polygon	KGKhB2g1	4026.781419	182522.6005
24	Polygon	TDGbB1g2	2105.06289	103331.2508
25	Polygon	KGHbB2g2	2471.207873	165348.2877
26	Polygon	CSRbB1g2	2016.563488	157170.3061
27	Polygon	MKHbB1g2	1466.549872	122085.5115
28	Polygon	Rockout	691.249522	18747.44568
29	Polygon	Others*	447.667381	9821.984067
30	Polygon	Others*	155.026501	1133.200802
31	Polygon	Others*	230.475803	3247.415207
32	Polygon	Others*	1307.034232	58333.64499
33	Polygon	GRHcB1g1	1193.797617	60104.87813
34	Polygon	TDGhB1g1	2113.773885	156990.8086
35	Polygon	Others*	3860.126312	42177.12202
36	Polygon	KKRcB1g1	1006.384897	42499.37873

The data here is having only soil phase values which constitutes of soil series code and surface soil parameters. It is imperative to note that, the surface soil parameters like surface texture, slope, erosion, gravels, and sometimes stoniness and rockiness can be extracted from the soil phase code. But, most of the sub-surface soil parameters are not provided directly. In fact, the soil series code associated with soil phase, must have all those information. Some of the important sub-surface soil parameters are landform, sub-surface texture, sub-surface gravelliness, soil depth, available water content (water holding capacity), etc. If these sub-surface parameters are not provided as soil series code, then they have to be manually entered with corresponding soil phases, as shown in the image below.



FID *	Soil_Phase	MWCode	Depth	SSG	SST	LMU
1	MKHbB1g1	MAL_1H2d	50-75	>35	scl	LMU-5
2	Others*	MAL_1H2d	Others*	Others*	Others*	Others*
3	KMHcB1g1	MAL_1H2d	100-150	<15	scl-sc	LMU-9
4	Others*	MAL_1H2d	Others*	Others*	Others*	Others*
5	Others*	MAL_1H2d	Others*	Others*	Others*	Others*
6	KTPcB1g1	MAL_1H2d	50-75	15-35	scl	LMU-3
7	HDHcB1g2	MAL_1H2d	75-100	>35	Scl-sc	LMU-6
8	KGKbB1g1	MAL_1H2d	>150		c	LMU-10
9	KGKmB2g1	MAL_1H2d	>150		c	LMU-10
10	CSRiB1g1	MAL_1H2d	25-50	<15	scl	LMU-2
11	GRHmB1g1	MAL_1H2d	100-150	<15	c	LMU-8
12	HNHhB1g1	MAL_1H2d	50-75		sc	LMU-3
13	LKRhB1g1	MAL_1H2d	50-75	40-60	scl-sc	LMU-5
14	KGHhB1g2	MAL_1H2d	50-75	15-35	Scl	LMU-4
15	KGHhA2g1	MAL_1H2d	50-75	15-35	Scl	LMU-3
16	HDHcB1g2	MAL_1H2d	75-100	>35	Scl-sc	LMU-6
17	LKRhB1g2	MAL_1H2d	50-75	40-60	scl-sc	LMU-5
18	KGPhB1	MAL_1H2d	25-50	15-35	Scl-sc	LMU-2
19	CSRhB1g1	MAL_1H2d	25-50	<15	scl	LMU-2

Along with these parameters, we also require important parameters like landform, soil colour, pH, AWC, drainage, permeability, EC, etc., would greatly improve the accuracy of the output. Now these parameters and records are the input for generating LCC, SWCS, and CS.

Step-02-A:

Click on the below link to open the automation tool in the google workbook named "Input DSS".

https://docs.google.com/spreadsheets/d/1YQj-1jruL3jnGUG9sBHTtrtcADNvps8K15_2qi04L40/edit?gid=272717352#gid=272717352

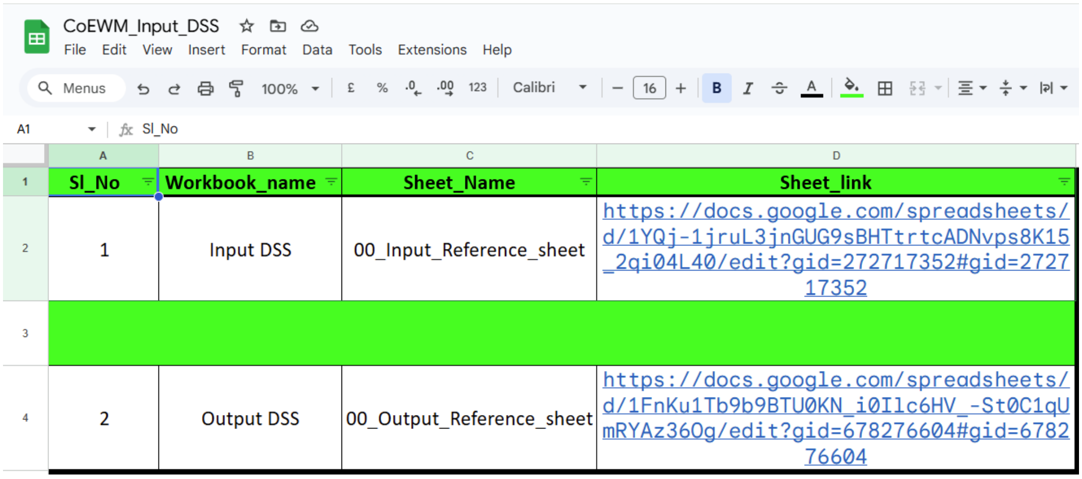
All the process will happen in the "Output DSS" google workbook. But there is no need to access the "Output DSS" workbook, because the input data and the output data are both available in the "Input DSS" workbook itself. Here the "Output DSS" workbook is just being referenced by the "Input DSS" google workbook. Unless a skilled person trained on this complete methodology, one should not tamper with the "Output DSS" or any formulas, unless otherwise officially directed. If such is the case then the "Output DSS" google workbook can be accessed by clicking on this link.

https://docs.google.com/spreadsheets/d/1FnKu1Tb9b9BTU0KN_i0Ilc6HV_-St0C1qUmRYAz36Og/edit?gid=678276604#gid=678276604

The methodology on creating separate DSS workbooks for individual users will be explained in detail at the later stage.

Step-02-B:

Do not work with the DSS available at the given link as it can be edited by several users at a time, which may yield unexpected or wrong results. Therefore, create a dedicated DSS google sheets for individual user before working with the DSS. Firstly, open the google sheet "**00_Input_Reference_sheet**" from the "Input DSS" and copy the sheet page link (from the address bar) and paste the link in the **cell D2** of the "**00_Input_Reference_sheet".** Secondly, open the **"00_Output_Reference_sheet"** sheet from the "Output DSS" google workbook, copy the link page link (from the address bar) and paste the link in the **cell D4** of the "**00_Input_Reference_sheet"**. The result should look similar to the image given below,

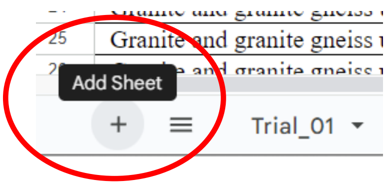


Sl_No	Workbook_name	Sheet_Name	Sheet_link
1	Input DSS	00_Input_Reference_sheet	https://docs.google.com/spreadsheets/d/1YQj-1jruL3jnGUG9sBHTtrtcADNvps8K15_2qi04L40/edit?gid=272717352#gid=272717352
2	Output DSS	00_Output_Reference_sheet	https://docs.google.com/spreadsheets/d/1FnKu1Tb9b9BTU0KN_i0Ilc6HV_-St0C1qUmRYAz36Og/edit?gid=678276604#gid=678276604

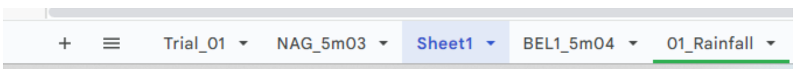
Thirdly, copy the cells from A2:D4 and paste into the **"00_Output_Reference_sheet"** sheet from the "Output DSS" google workbook. Now, both the google workbooks are in sync and can reference each other.

Step-03:

Close the "Output DSS" workbook, and open only the "Input DSS" workbook. At the bottom-left of the google workbook, click on the + symbol to add a new sheet.



Open the new google sheet named "Sheet1"



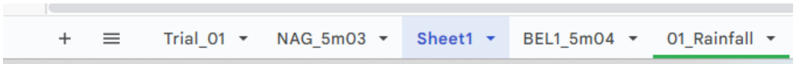
Copy-paste the important data from the attribute table of the shapefile, or the excel sheet. The input parameters required are Landform/Reach, Soil phase, MWS code, Soil colour, Soil depth, SST, SSG, Drainage, pH, Salinity/EC, Permeability, AWC, LMU, etc. Most importantly, the Soil surface and sub-surface parameters are required. The sample data should be similar to the image given below.

Landform	Soil_Phasel	Depth_Code	SST	SSG	AWC	Drainage	Colour	Eff	LMU
Granite and granite gneiss uplands	JLDbB1	25-50	ls	15-35%	Very low (< 50 mm/m)	WD	Red		LMU-1
Granite and granite gneiss uplands	MKHhC1g1	50-75	sc	35-60%	Very low (< 50 mm/m)	WD			LMU-2
Granite and granite gneiss uplands	TDHhB1	50-75	sc	<15%	Low (51-100 mm/m)	WD			LMU-2
Granite and granite gneiss uplands	BDGcC1g1	75-100	c	35-60%	Very low (< 50 mm/m)	WD			LMU-3
Granite and granite gneiss uplands	CKMcC1	75-100	sc	<15%	Low (51-100 mm/m)	WD			LMU-3
Granite and granite gneiss uplands	CKMhB1	75-100	sc	<15%	Low (51-100 mm/m)	WD	Red		LMU-3
Granite and granite gneiss uplands	CKMhC1	75-100	sc	<15%	Low (51-100 mm/m)	WD	Red		LMU-3
Granite and granite gneiss uplands	CKMiC1	75-100	sc	<15%	Low (51-100 mm/m)	WD	Red		LMU-3
Granite and granite gneiss uplands	GHTcC1	75-100	scl	15-35%	Low (51-100 mm/m)	WD	Red		LMU-4
Granite and granite gneiss uplands	HDHcD1	75-100	sc	35-60%	Very low (< 50 mm/m)	WD	Red		LMU-5
Granite and granite gneiss uplands	HDHhB1	75-100	sc	35-60%	Very low (< 50 mm/m)	WD	Red		LMU-3

If some of the parameters are not provided, then also the output will be generated, but the accuracy of the output will be diminished. For example, if “pH” or “EC” data is not available, still the output will be generated for LCC and crop Selection. But, if the “Soil depth” parameter is missing then the output generated may not be reliable. Therefore, the user has to take a call on the required parameters and their importance as input data, which greatly affects the reliability of the output.

Step-04:

Open the “01_Rainfall” from the available google sheets at the bottom of the workbook.



The “01_Rainfall” sheet looks similar to the image given below,

Sl_no	Taluk	Type	MWS_Code	MWS_Name	Rainfall_MIN (mm)	Rainfall_MAX (mm)	District	Agro Climatic Zones	Rainfall AVG (mm)	Remark
1	Afzalpura	MWS	MUK_3M1c	Makenahalli	950	950.05	Kalaburagi	North Eastern Dry Zone	950.025	First two reco reference
2	Select Taluk	MWS	DOD_3M2d	Doddatimmanapaly a	700	800			750	4B3D3
3	Arasikere	MWS	BEL1_5m04	Belagumba1	750	750	Hassan	Central Dry Zone	750	
4	Arasikere	MWS	NAG_5m03	Nagenahalli	550	550	Hassan	Central Dry Zone	550	
5	Select Taluk									
6	Select Taluk									
7	Select Taluk									
8	Select Taluk									
9	Select Taluk									
10	Select Taluk									
11	Select Taluk									
12	Select Taluk									
13	Select Taluk									
14	Select Taluk									
15	Select Taluk									
16	Select Taluk									
17	Select Taluk									
18	Select Taluk									
19	Select Taluk									
20	Select Taluk									

Update the sheet with the information collected in step-01.

- The Taluk name should be selected from the drop-down available as shown here. This will automatically generate the corresponding ACZ and District of that taluk.

5	Select Taluk

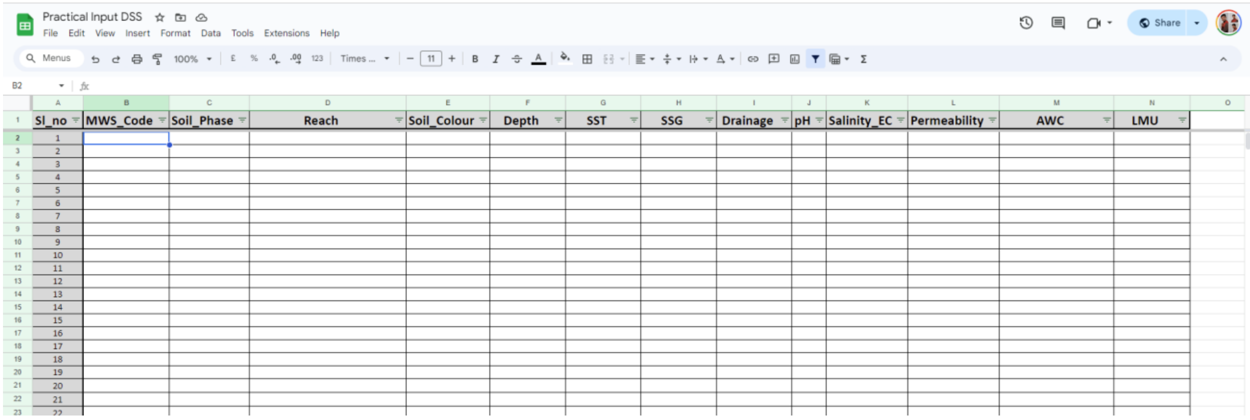
- The column named “Type” is to know whether the given input data is of a MWS, SWS, Village etc. This should be filled manually by typing. Here the type is “MWS” as we are using the MWS dataset.

- Provide the code of the MWS for "MWS_Code" column. Copy-paste the MWS code from the step-01.
- Provide the name of the MWS for "MWS_Name" column. Copy-paste the MWS name from the step-01.
- Provide the rainfall amount (in mm) of the MWS. Copy-paste the rainfall amount from the step-01. If the rainfall amount is in minimum-maximum, then provide in the appropriate columns, but if the rainfall amount is average value, then provide the same value for minimum and maximum rainfall value.

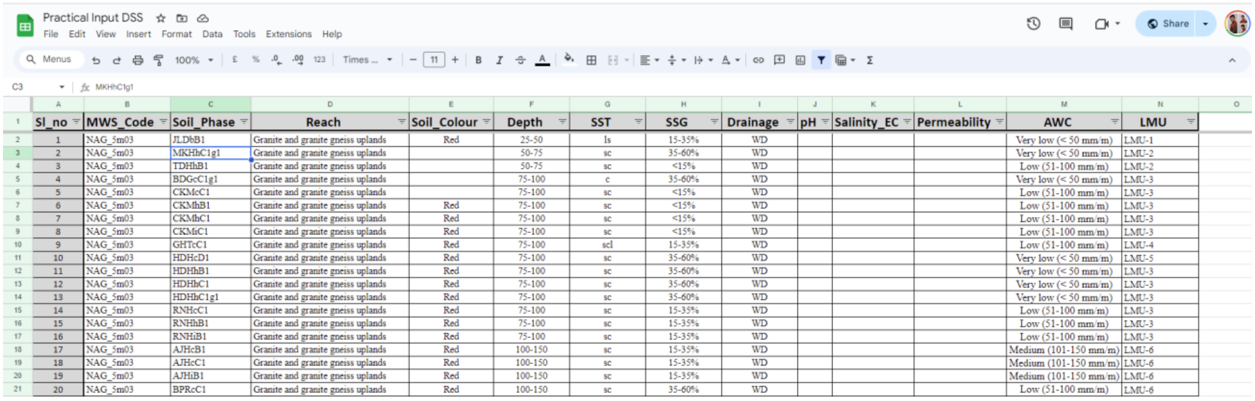
Step-05:

Open the "02_Input_data" sheet from the available google sheets at the bottom of the workbook.

The "02_Input_data" sheet looks similar to the image given below, before pasting the data.



Now, observe the column headings, and copy-paste the relevant values from the "Sheet1". Note that copy only the values and not the headings. Do not replace or alter the headings available in the "02_Input_data" sheet. The resulting "02_Input_data" sheet should look similar to this.



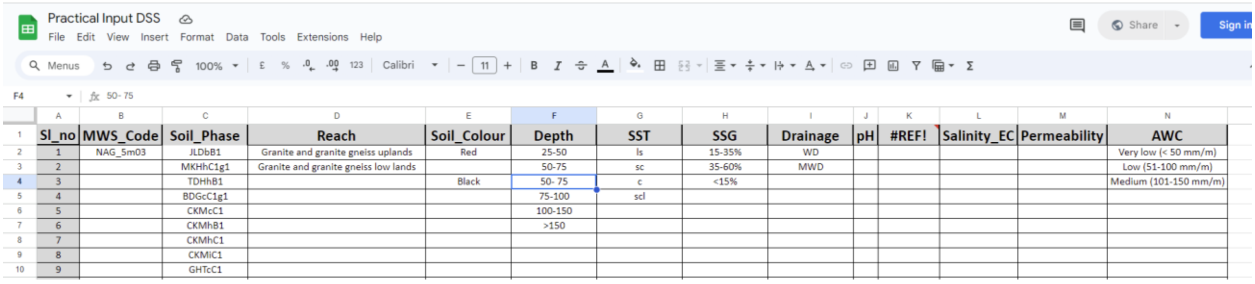
Sl_no	MWS_Code	Soil_Phase	Reach	Soil_Colour	Depth	SST	SSG	Drainage	pH	Salinity_EC	Permeability	AWC	LMU
1	NAG_5m03	JLDbB1	Granite and granite gneiss uplands	Red	25-50	ls	15-35%	WD				Very low (< 50 mm/m)	LMU-1
2	NAG_5m03	MKHhC1g1	Granite and granite gneiss uplands		50-75	sc	35-60%	WD				Very low (< 50 mm/m)	LMU-2
3	NAG_5m03	TDHhB1	Granite and granite gneiss uplands		50-75	sc	<15%	WD				Low (51-100 mm/m)	LMU-2
4	NAG_5m03	BDGcC1g1	Granite and granite gneiss uplands		75-100	c	35-60%	WD				Very low (< 50 mm/m)	LMU-3
5	NAG_5m03	CKMcC1	Granite and granite gneiss uplands		75-100	sc	<15%	WD				Low (51-100 mm/m)	LMU-3
6	NAG_5m03	CKMhB1	Granite and granite gneiss uplands	Red	75-100	sc	<15%	WD				Low (51-100 mm/m)	LMU-3
7	NAG_5m03	CKMhC1	Granite and granite gneiss uplands	Red	75-100	sc	<15%	WD				Low (51-100 mm/m)	LMU-3
8	NAG_5m03	CKMiC1	Granite and granite gneiss uplands	Red	75-100	sc	<15%	WD				Low (51-100 mm/m)	LMU-3
9	NAG_5m03	GHTcC1	Granite and granite gneiss uplands	Red	75-100	scl	15-35%	WD				Low (51-100 mm/m)	LMU-4
10	NAG_5m03	HDHcD1	Granite and granite gneiss uplands	Red	75-100	sc	35-60%	WD				Very low (< 50 mm/m)	LMU-5
11	NAG_5m03	HDHhB1	Granite and granite gneiss uplands	Red	75-100	sc	35-60%	WD				Very low (< 50 mm/m)	LMU-3
12	NAG_5m03	HDHhC1	Granite and granite gneiss uplands	Red	75-100	sc	35-60%	WD				Very low (< 50 mm/m)	LMU-3
13	NAG_5m03	HDHhC1g1	Granite and granite gneiss uplands	Red	75-100	sc	35-60%	WD				Very low (< 50 mm/m)	LMU-3
14	NAG_5m03	RNHcC1	Granite and granite gneiss uplands	Red	75-100	sc	15-35%	WD				Low (51-100 mm/m)	LMU-3
15	NAG_5m03	RNHhB1	Granite and granite gneiss uplands	Red	75-100	sc	15-35%	WD				Low (51-100 mm/m)	LMU-3
16	NAG_5m03	RNHiB1	Granite and granite gneiss uplands	Red	75-100	sc	15-35%	WD				Low (51-100 mm/m)	LMU-3
17	NAG_5m03	AJHcB1	Granite and granite gneiss uplands	Red	100-150	sc	15-35%	WD				Medium (101-150 mm/m)	LMU-6
18	NAG_5m03	AJHcC1	Granite and granite gneiss uplands	Red	100-150	sc	15-35%	WD				Medium (101-150 mm/m)	LMU-6
19	NAG_5m03	AJHiB1	Granite and granite gneiss uplands	Red	100-150	sc	15-35%	WD				Medium (101-150 mm/m)	LMU-6
20	NAG_5m03	BPRcC1	Granite and granite gneiss uplands	Red	100-150	sc	35-60%	WD				Low (51-100 mm/m)	LMU-6

Some of the parameters' data is not available, therefore only available information is provided here.

Step-06-A:

Open the "03_Uniq_values" sheet from the available google sheets at the bottom of the workbook.

The "03_Uniq_values" sheet looks similar to the image given below, after the "02_Input_data" sheet is provided with the data.



Sl_no	MWS_Code	Soil_Phase	Reach	Soil_Colour	Depth	SST	SSG	Drainage	pH	#REF!	Salinity_EC	Permeability	AWC
1	NAG_5m03	JLDbB1	Granite and granite gneiss uplands	Red	25-50	ls	15-35%	WD					Very low (< 50 mm/m)
2		MKHhC1g1	Granite and granite gneiss low lands		50-75	sc	35-60%	MWD					Low (51-100 mm/m)
3		TDHhB1		Black	50- 75	c	<15%						Medium (101-150 mm/m)
4		BDGcC1g1			75-100	scl							
5		CKMcC1			100-150								
6		CKMhB1			>150								
7		CKMhC1											
8		CKMiC1											
9		GHTcC1											

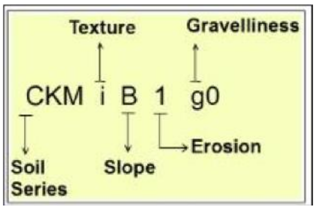
Here all the unique values of each parameter are available automatically. Possibilities are there might be typographical errors, or they data provided is not in the standard format as being approved and used by all the partners. Therefore, it is important to rectify these errors, and bring it into a standard format. Thus, this step is very important as validation is being done by the user.

Step-06-B:

Check if there is only one MWS code. Here it is "NAG_5m03" which is a unique value for the MWS Nagenahalli. In this case, we are using only one MWS.

Step-06-C:

Check if the "Soil phase" code is in the standard format. For example, observe the image given below.

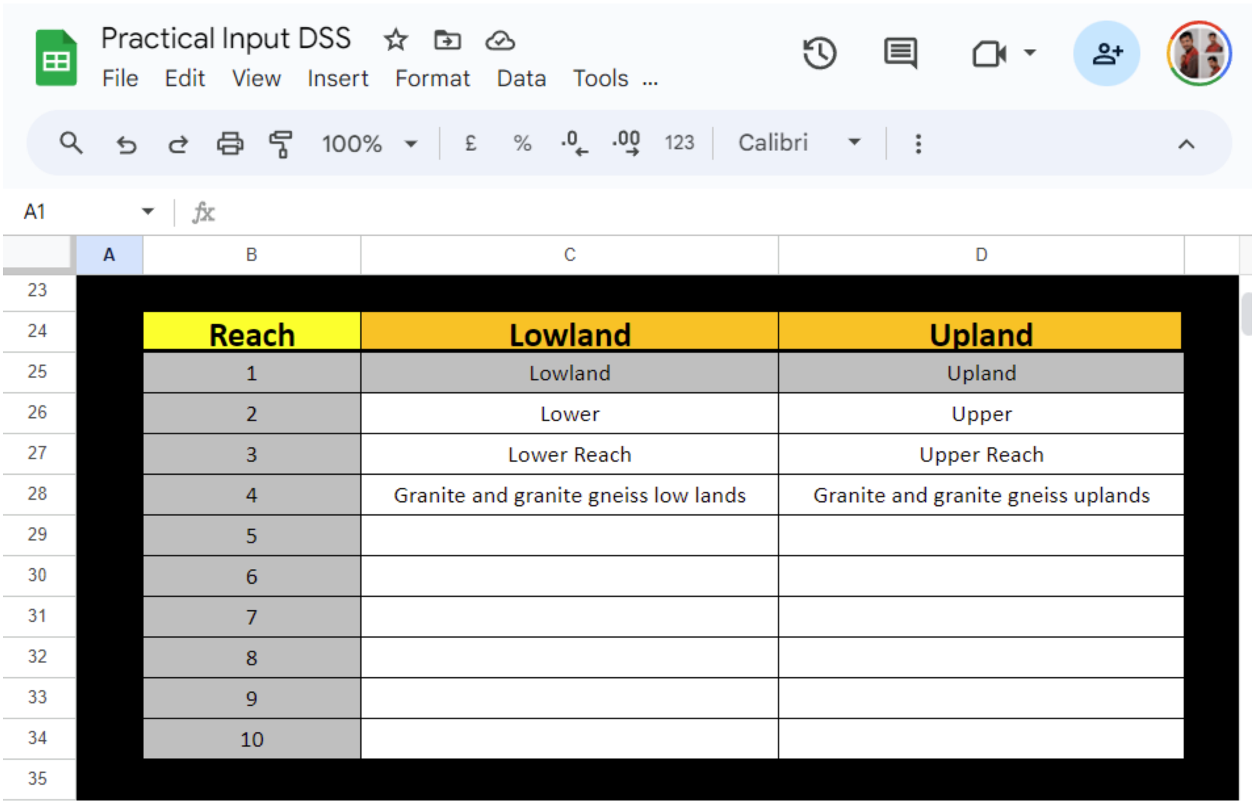


The first three characters are soil series (CKM), 4th character is Texture (i), 5th character is Slope (B), 6th is Erosion (e1) are mandatory characters in the soil phase code, whereas, the gravelliness (g0), stoniness (St), and rockiness (R) can be shown if data is available, either in the same order, or the one which is available. For more information on soil phase coding, refer LRI manual.

Step-06-D:

Check the Landform / Reach column, which is having two values namely "Granite and granite gneiss uplands" and "Granite and granite gneiss low lands" which is supposed to be landform as "Granite and granite gneiss" and reach as "Upland or Lowland". Therefore, to bring this to the standard format, let us follow these steps.

Firstly, consider two google sheets namely "03_Uniq_values" and "04_Master_Classes". The "04_Master_Classes" is having several small tables. These tables are provided to map the unique values of the classes of each parameter. Consider, the cells B24:D34 of the google sheet "04_Master_Classes" for validating the "Landform/Reach" parameter classes. The "Landform/Reach" parameter is having only two classes namely "Upland" and "Lowland". But here the input data is given as "Granite and granite gneiss uplands" and "Granite and granite gneiss low lands", which needs to be converted to standard format as "Upland" and "Lowland". Therefore, copy the "Granite and granite gneiss uplands" value from the "03_Uniq_values" sheet's reach column (D3 cell), and paste as values to the "04_Master_Classes" sheet's cell (anywhere in D26:D34) having "Upland" heading as shown in the image. Here we can give up to 10 unique values for class of the parameter. Repeat the same process for "Lowland". Copy the "Granite and granite gneiss low lands" value from the "03_Uniq_values" sheet's reach column (D4 cell), and paste as values to the "04_Master_Classes" sheet's cell (anywhere in C26:C34) having "Lowland" heading as shown in the image. Note for each class of a parameter, one can give up to 10 similar names, for example for "Lowland" or "Upland" one can give 10 different variations at a time.



Reach	Lowland	Upland
1	Lowland	Upland
2	Lower	Upper
3	Lower Reach	Upper Reach
4	Granite and granite gneiss low lands	Granite and granite gneiss uplands
5		
6		
7		
8		
9		
10		

Step-06-E:

Check the depth column, which is having six unique values namely "25-50, 50-75, 50- 75, 75-100, 100-150, and >150”. All these classes are to be are to be placed into the “04_Master_Classes” sheet’s cell (anywhere in cells C65:I74) against the depth master classes. Here, there should be only one value for “50-75”, but due to a additional space in the value the other might be an error. Therefore, to bring this to the standard format, both values of “50-75”, “50- 75” are to be placed into the “04_Master_Classes” sheet’s cell (anywhere in cells F65:F74) with the heading “50-75”.

Depth	<10	10-25	25-50	50-75	75-100	100-150	>150
1	<10	10-25	25-50	50-75	75-100	100-150	>150
2			25-50	50-75	75-100	100-150	>150
3				50- 75			
4							
5							
6							
7							
8							
9							
10							

Once the depth classes are mapped, the same procedure is to be carried out for all other parameters like “Soil_Colour, SST, SSG, Drainage, pH, Salinity_EC, Permeability, AWC”.

Step-07:

After all the parameter values are mapped with the master classes, next open the google sheet named “Processed_Input”. This sheet will have all the unique values validated, and brought the parameters and their master classes to the standard format. The parameters and values available in this sheet (Processed_Input) are considered for all further process in the DSS and decision criteria.

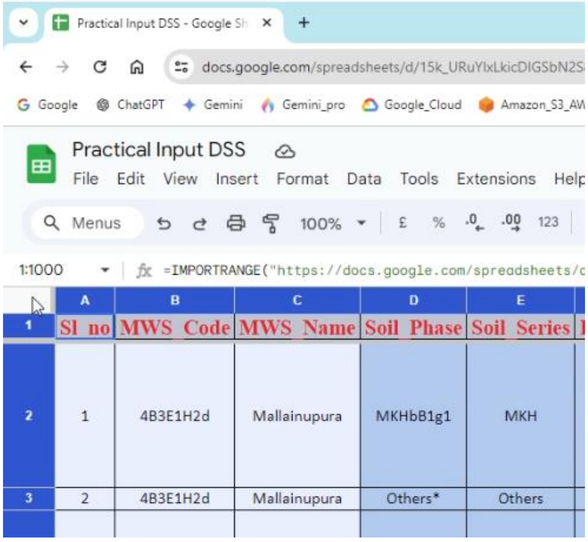
Sl_no	MWS_Code	Soil_Phase	Reach	Soil_Colour	LMU	AWC	Depth	SST	SSG	Rainfall	Rainfall_class	Drainage	pH
1	NAG_5m03	JLDbB1	Upland	Red	LMU-1	<=50	25-50	ls	15-35	550	<=750.00	Well drained	
2	NAG_5m03	MKHhC1g1	Upland	Black	LMU-2	<=50	50-75	sc	35-60	550	<=750.00	Well drained	
3	NAG_5m03	TDHhB1	Upland	Black	LMU-2	51-100	50-75	sc	<15	550	<=750.00	Well drained	
4	NAG_5m03	BDGcC1g1	Upland	Black	LMU-3	<=50	75-100	c	35-60	550	<=750.00	Well drained	
5	NAG_5m03	CKMcC1	Upland	Black	LMU-3	51-100	75-100	sc	<15	550	<=750.00	Well drained	
6	NAG_5m03	CKMhB1	Upland	Red	LMU-3	51-100	75-100	sc	<15	550	<=750.00	Well drained	
7	NAG_5m03	CKMhC1	Upland	Red	LMU-3	51-100	75-100	sc	<15	550	<=750.00	Well drained	
8	NAG_5m03	CKMiC1	Upland	Red	LMU-3	51-100	75-100	sc	<15	550	<=750.00	Well drained	
9	NAG_5m03	GHTcC1	Upland	Red	LMU-4	51-100	75-100	scl	15-35	550	<=750.00	Well drained	
10	NAG_5m03	HDHcD1	Upland	Red	LMU-5	<=50	75-100	sc	35-60	550	<=750.00	Well drained	
11	NAG_5m03	HDHhB1	Upland	Red	LMU-3	<=50	75-100	sc	35-60	550	<=750.00	Well drained	
12	NAG_5m03	HDHhC1	Upland	Red	LMU-3	<=50	75-100	sc	35-60	550	<=750.00	Well drained	
13	NAG_5m03	HDHhC1g1	Upland	Red	LMU-3	<=50	75-100	sc	35-60	550	<=750.00	Well drained	
14	NAG_5m03	RNHcC1	Upland	Red	LMU-3	51-100	75-100	sc	15-35	550	<=750.00	Well drained	
15	NAG_5m03	RNHhB1	Upland	Red	LMU-3	51-100	75-100	sc	15-35	550	<=750.00	Well drained	
16	NAG_5m03	RNHiB1	Upland	Red	LMU-3	51-100	75-100	sc	15-35	550	<=750.00	Well drained	
17	NAG_5m03	AJHcB1	Upland	Red	LMU-6	101-150	100-150	sc	15-35	550	<=750.00	Well drained	
18	NAG_5m03	AJHcC1	Upland	Red	LMU-6	101-150	100-150	sc	15-35	550	<=750.00	Well drained	
19	NAG_5m03	AJHiB1	Upland	Red	LMU-6	101-150	100-150	sc	15-35	550	<=750.00	Well drained	

The image above shows the sample of how the data values look like after validation. Also, the validation process is not required, if the same values are being used for other MWS. Because, those values are already mapped, the output will be directly generated.

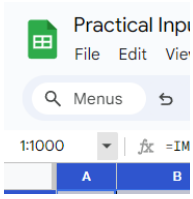
Step-08:

Open the google sheet named “05_Final_results”. This is the last step in DSS generation, copy the complete sheet and paste as values into a new excel sheet. To do that, let’s follow these steps.

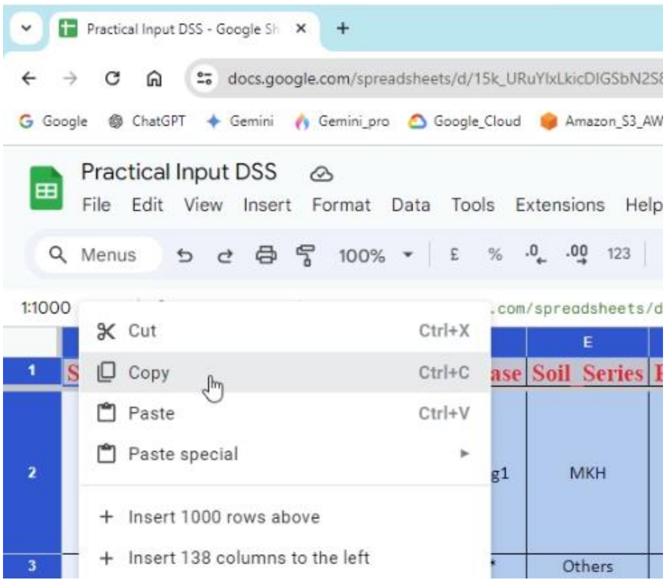
Click on the top-left corner where the column alphabets and rows numbers start, this will select the complete table in the "05_Final_results" sheet.



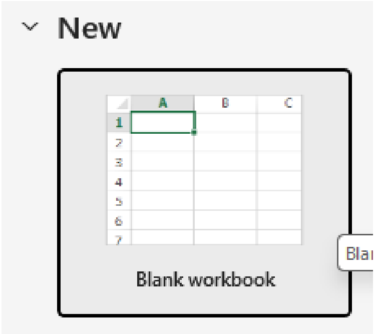
On the top-left corner, in the "Name box" we can see the total cells selected as 1:1000 as shown in the image below.



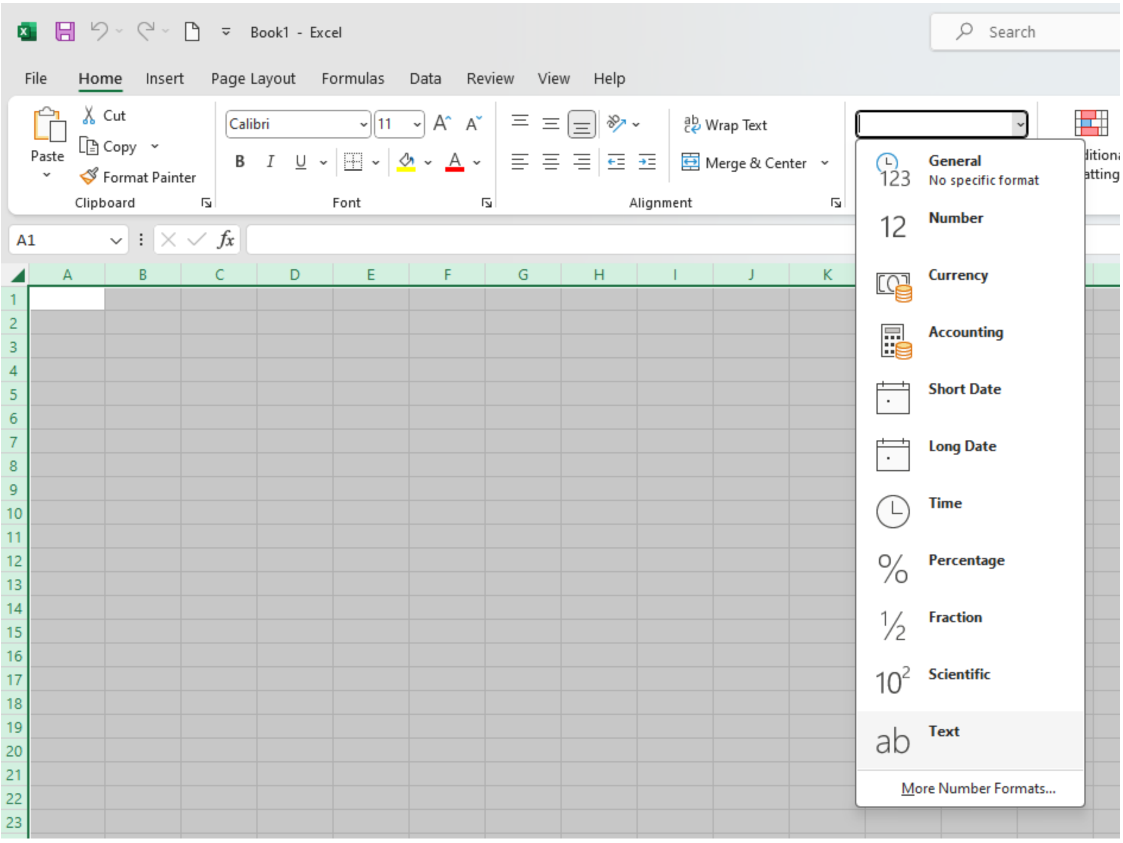
Right-click on the same top-left corner and click on "Copy" to copy all the cells. This can also be achieved by using shortcut as "Ctrl+A" to select all the cells, and "Ctrl+C" to copy all the cells.



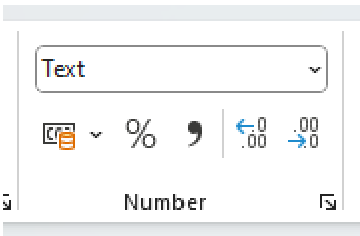
Now open a blank excel workbook (do not open an already existing workbook, as we are going to save it into a compatible format). Select the complete excel sheet by clicking on the top-left corner. The same can be achieved with the shortcut "Ctrl+A".



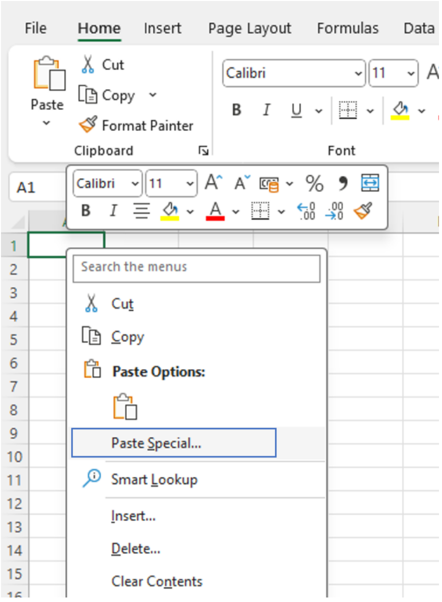
In the "Number Format" box of the blank excel sheet, click on the "Text" format as shown in the image.



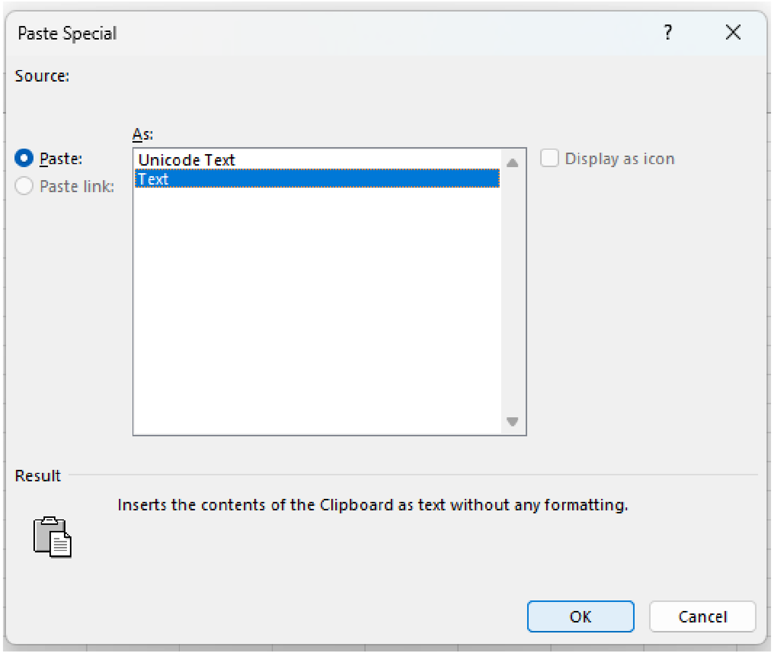
Now all the cells are considered as just text and not any other data formats, so that the numbers are not automatically converted to date format or decimal format.



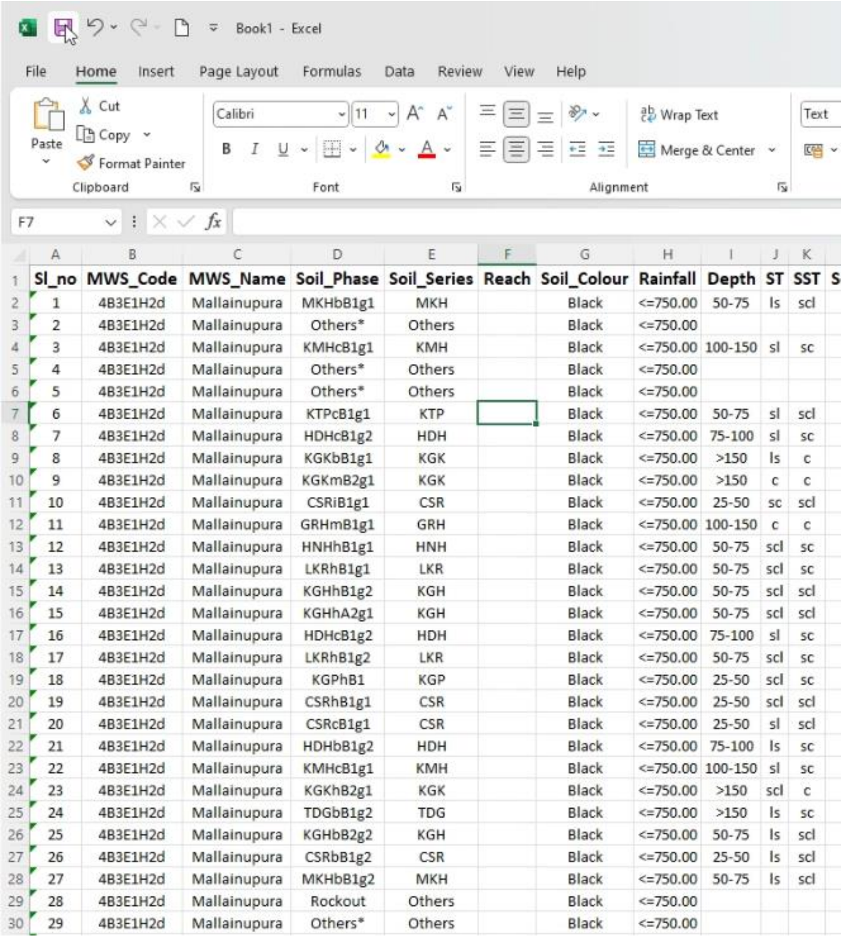
Right-click on the A1 cell at the top-left corner, then click on "Paste Special…" button.



A new pop-up will appear, in which click on "Text" and then "OK", to paste the complete table as values. If it is a normal paste rather than "Paste Special…", then the formulas and data type will also appear, which may lead to erroneous data.

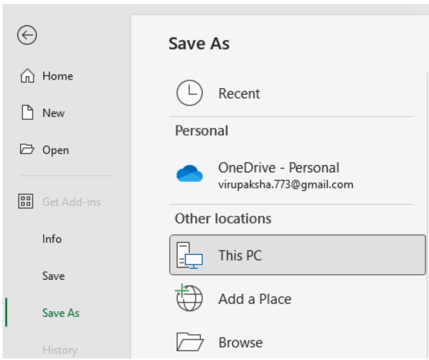


The excel sheet should look like the image below, once the Copy-Paste process is completed. It should include parameters like surface and sub-surface parameters, LCC, SWCS, and CS for 99 crops.

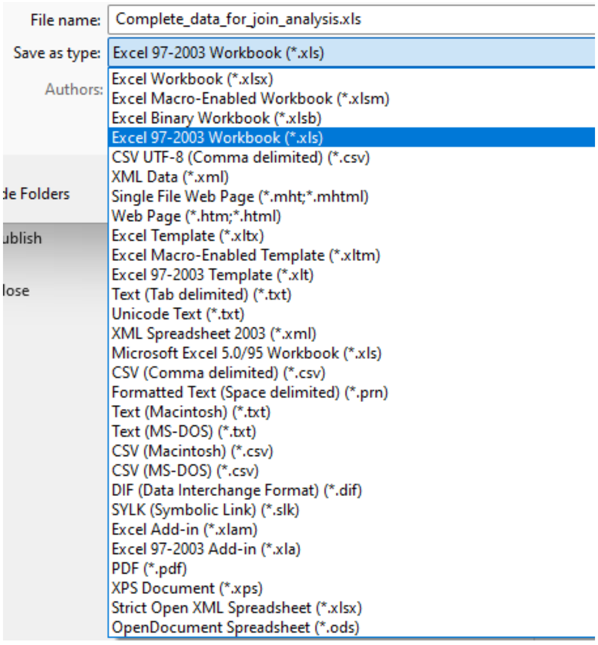


Sl_no	MWS_Code	MWS_Name	Soil_Phase	Soil_Series	Reach	Soil_Colour	Rainfall	Depth	ST	SST
1	4B3E1H2d	Mallainupura	MKHbB1g1	MKH		Black	<=750.00	50-75	ls	scl
2	4B3E1H2d	Mallainupura	Others*	Others		Black	<=750.00			
3	4B3E1H2d	Mallainupura	KMHcB1g1	KMH		Black	<=750.00	100-150	sl	sc
4	4B3E1H2d	Mallainupura	Others*	Others		Black	<=750.00			
5	4B3E1H2d	Mallainupura	Others*	Others		Black	<=750.00			
6	4B3E1H2d	Mallainupura	KTPcB1g1	KTP		Black	<=750.00	50-75	sl	scl
7	4B3E1H2d	Mallainupura	HDHcB1g2	HDH		Black	<=750.00	75-100	sl	sc
8	4B3E1H2d	Mallainupura	KGKbB1g1	KGK		Black	<=750.00	>150	ls	c
9	4B3E1H2d	Mallainupura	KGKmB2g1	KGK		Black	<=750.00	>150	c	c
10	4B3E1H2d	Mallainupura	CSRiB1g1	CSR		Black	<=750.00	25-50	sc	scl
11	4B3E1H2d	Mallainupura	GRHmB1g1	GRH		Black	<=750.00	100-150	c	c
12	4B3E1H2d	Mallainupura	HNHhB1g1	HNH		Black	<=750.00	50-75	scl	sc
13	4B3E1H2d	Mallainupura	LKRhB1g1	LKR		Black	<=750.00	50-75	scl	sc
14	4B3E1H2d	Mallainupura	KGHhB1g2	KGH		Black	<=750.00	50-75	scl	scl
15	4B3E1H2d	Mallainupura	KGHhA2g1	KGH		Black	<=750.00	50-75	scl	scl
16	4B3E1H2d	Mallainupura	HDHcB1g2	HDH		Black	<=750.00	75-100	sl	sc
17	4B3E1H2d	Mallainupura	LKRhB1g2	LKR		Black	<=750.00	50-75	scl	sc
18	4B3E1H2d	Mallainupura	KGPhB1	KGP		Black	<=750.00	25-50	scl	sc
19	4B3E1H2d	Mallainupura	CSRhB1g1	CSR		Black	<=750.00	25-50	scl	scl
20	4B3E1H2d	Mallainupura	CSRcB1g1	CSR		Black	<=750.00	25-50	sl	scl
21	4B3E1H2d	Mallainupura	HDHbB1g2	HDH		Black	<=750.00	75-100	ls	sc
22	4B3E1H2d	Mallainupura	KMHcB1g1	KMH		Black	<=750.00	100-150	sl	sc
23	4B3E1H2d	Mallainupura	KGKhB2g1	KGK		Black	<=750.00	>150	scl	c
24	4B3E1H2d	Mallainupura	TDGbB1g2	TDG		Black	<=750.00	>150	ls	sc
25	4B3E1H2d	Mallainupura	KGHbB2g2	KGH		Black	<=750.00	50-75	ls	scl
26	4B3E1H2d	Mallainupura	CSRbB1g2	CSR		Black	<=750.00	25-50	ls	scl
27	4B3E1H2d	Mallainupura	MKHbB1g2	MKH		Black	<=750.00	50-75	ls	scl
28	4B3E1H2d	Mallainupura	Rockout	Others		Black	<=750.00			
29	4B3E1H2d	Mallainupura	Others*	Others		Black	<=750.00			

Now "Save as" the excel workbook in the compatible format "Excel 97-2003 Workbook.xls" format. Because the ".xls" format is the only excel format accessible by ArcGIS desktop 10.8.2 software. Also, the table can be saved in ".csv" format, which is also accessible by ArcGIS desktop 10.8.2 software.



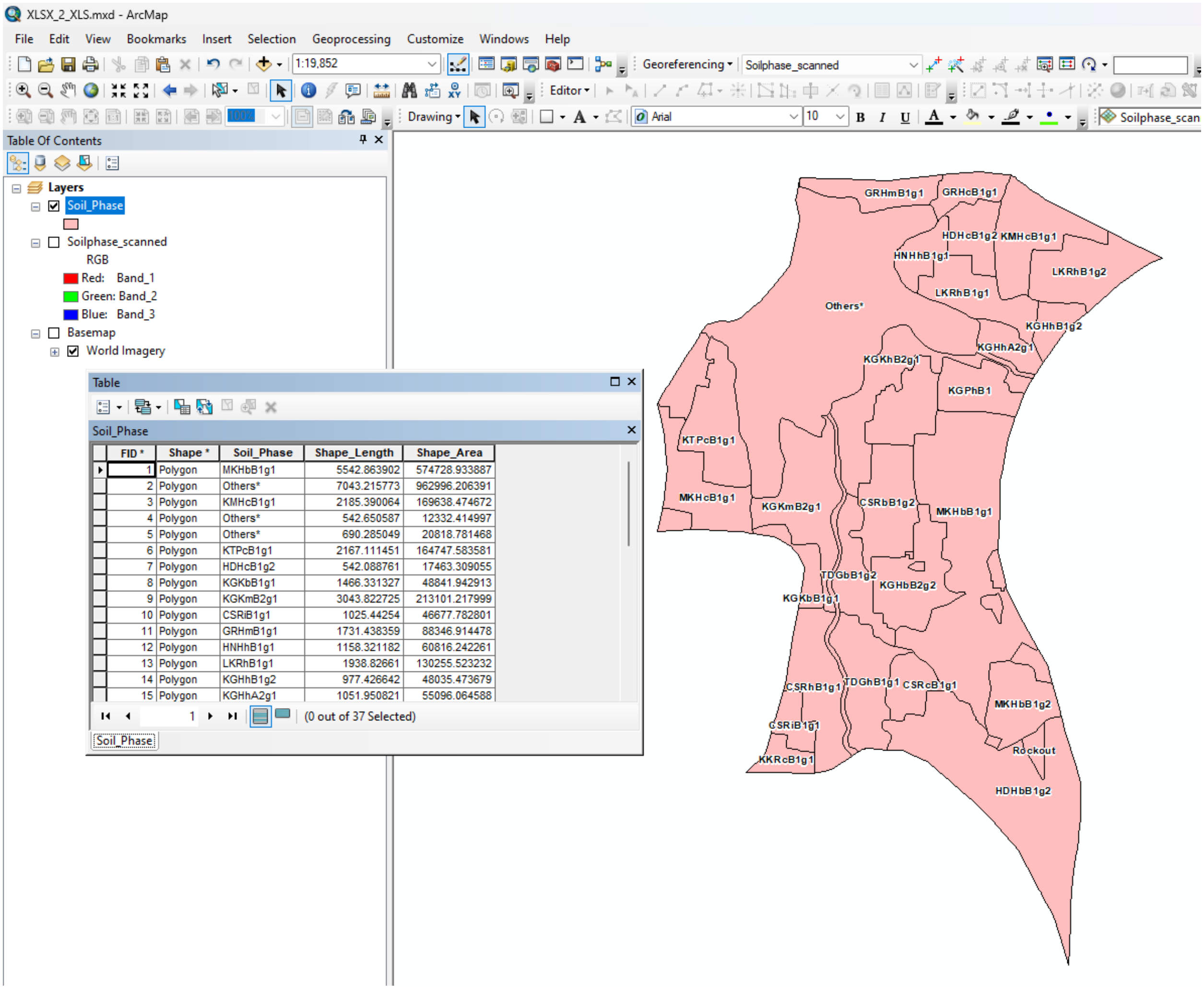
Preferably, the ".xls" format is better for later editing (if any).



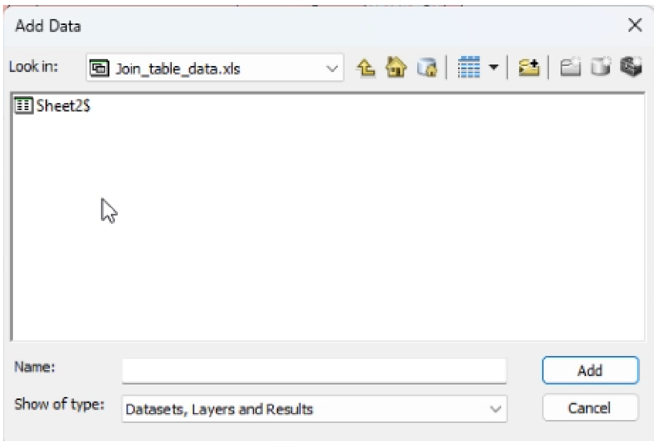
Once the excel sheet is ready, the next step is to join this excel sheet to the feature class or the shapefile having the soil phase polygon features. The index column would be the "Soil_Phase" field which is available in both the tables.

Step-10:

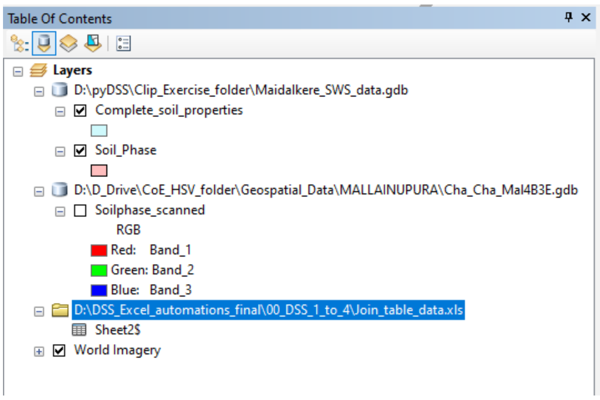
Open the feature class "Soil_Phase" having the soil phase (polygon geometry) data in the ArcGIS desktop 10.8.2 software.



Now add the excel sheet (.xls) having the complete table of LCC, SWCS, and CS data. Click the “Add data” button , browse to the excel workbook, then the excel sheet and click on “Add” as shown in the image below.

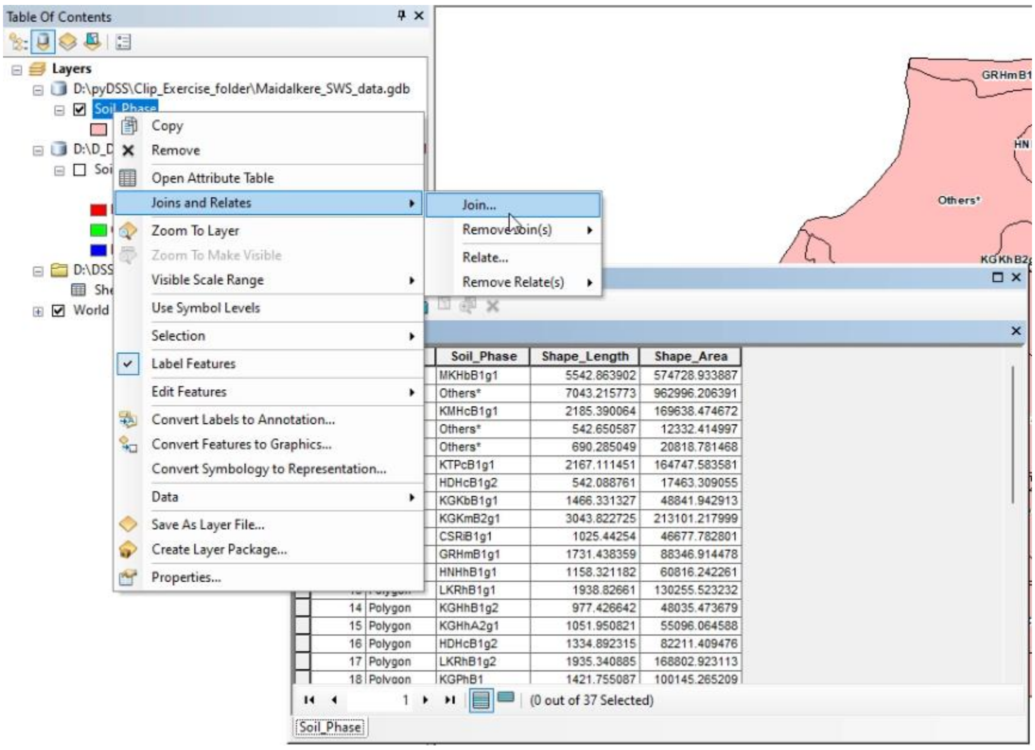


The ArcGIS ToC automatically changes to “List by Source” in which the complete path of the excel sheet and other layers can be seen.

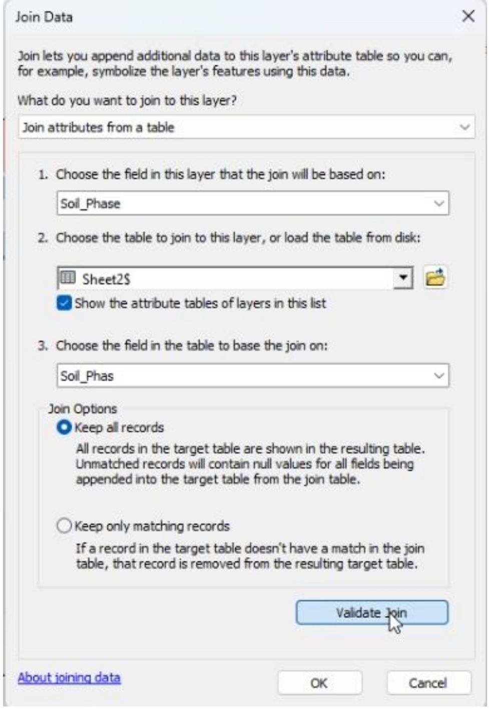


Right-click on the excel sheet name in this case "Sheet2$", and click open to see the table with complete records same as in the excel sheet.

Right-click on the feature class with soil phase, hover on the "Joins and Relates" to expand "Join…" and click on it to open a new pop-window of "Join Data".

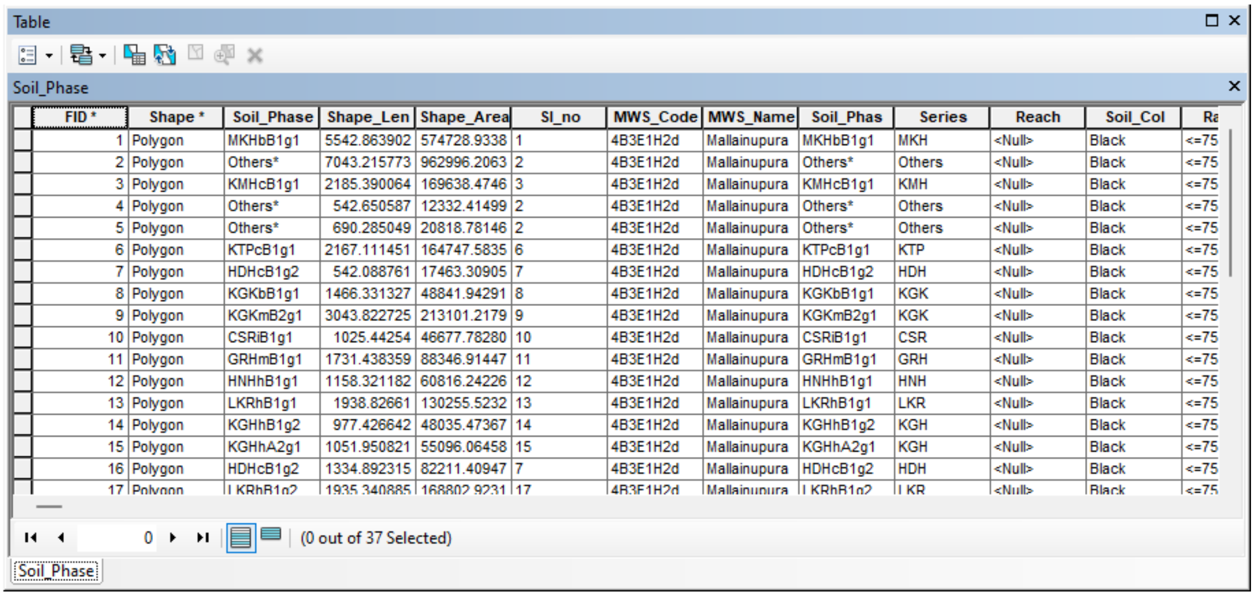


There are five important steps in using the join data tool.



a. What do you want to join to this layer?
   - Select “Join attribute from a table” in the first drop-down list.
b. Choose the field in this layer that the join will be based on
   - Select the field which is having soil phase information, in this case it is “Soil_Phase”.
c. Choose the table in this layer, or load the table from disk
   - Select the excel sheet name which needs to be joined with the feature class.
d. Choose the field in the table to base the join on
   - Select the column name of the excel sheet, having the soil phase. In this case, it is “Soil_Phas”.
e. Join options
   - Click on the button “Keep all records” and validate the join.
f. Click OK to complete the joining process.

Once the join data process is completed, the resultant attribute table will be similar to this, having all the fields, and not just “Soil phase”.



Table

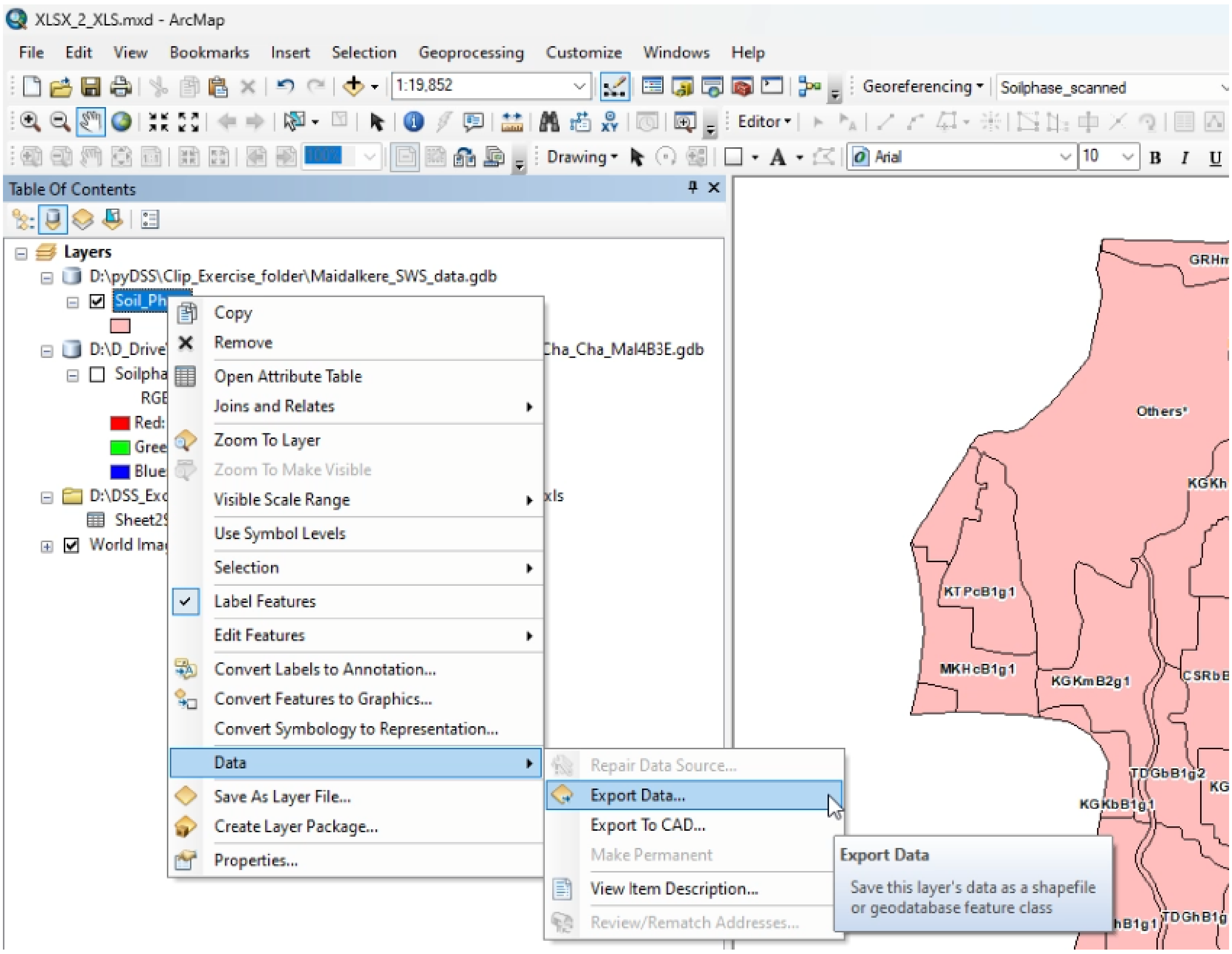
Soil_Phase

FID *	Shape *	Soil_Phase	Shape_Len	Shape_Area	Sl_no	MWS_Code	MWS_Name	Soil_Phas	Series	Reach	Soil_Col	Ra
1	Polygon	MKHbB1g1	5542.863902	574728.9338	1	4B3E1H2d	Mallainupura	MKHbB1g1	MKH	<Null>	Black	<=75
2	Polygon	Others*	7043.215773	962996.2063	2	4B3E1H2d	Mallainupura	Others*	Others	<Null>	Black	<=75
3	Polygon	KMHcB1g1	2185.390064	169638.4746	3	4B3E1H2d	Mallainupura	KMHcB1g1	KMH	<Null>	Black	<=75
4	Polygon	Others*	542.650587	12332.41499	2	4B3E1H2d	Mallainupura	Others*	Others	<Null>	Black	<=75
5	Polygon	Others*	690.285049	20818.78146	2	4B3E1H2d	Mallainupura	Others*	Others	<Null>	Black	<=75
6	Polygon	KTPcB1g1	2167.111451	164747.5835	6	4B3E1H2d	Mallainupura	KTPcB1g1	KTP	<Null>	Black	<=75
7	Polygon	HDHcB1g2	542.088761	17463.30905	7	4B3E1H2d	Mallainupura	HDHcB1g2	HDH	<Null>	Black	<=75
8	Polygon	KGKbB1g1	1466.331327	48841.94291	8	4B3E1H2d	Mallainupura	KGKbB1g1	KGK	<Null>	Black	<=75
9	Polygon	KGKmB2g1	3043.822725	213101.2179	9	4B3E1H2d	Mallainupura	KGKmB2g1	KGK	<Null>	Black	<=75
10	Polygon	CSRiB1g1	1025.44254	46677.78280	10	4B3E1H2d	Mallainupura	CSRiB1g1	CSR	<Null>	Black	<=75
11	Polygon	GRHmB1g1	1731.438359	88346.91447	11	4B3E1H2d	Mallainupura	GRHmB1g1	GRH	<Null>	Black	<=75
12	Polygon	HNHhB1g1	1158.321182	60816.24226	12	4B3E1H2d	Mallainupura	HNHhB1g1	HNH	<Null>	Black	<=75
13	Polygon	LKRhB1g1	1938.82661	130255.5232	13	4B3E1H2d	Mallainupura	LKRhB1g1	LKR	<Null>	Black	<=75
14	Polygon	KGHhB1g2	977.426642	48035.47367	14	4B3E1H2d	Mallainupura	KGHhB1g2	KGH	<Null>	Black	<=75
15	Polygon	KGHhA2g1	1051.950821	55096.06458	15	4B3E1H2d	Mallainupura	KGHhA2g1	KGH	<Null>	Black	<=75
16	Polygon	HDHcB1g2	1334.892315	82211.40947	7	4B3E1H2d	Mallainupura	HDHcB1g2	HDH	<Null>	Black	<=75
17	Polygon	LKRhB1g2	1935.340885	168802.9231	17	4B3E1H2d	Mallainupura	LKRhB1g2	LKR	<Null>	Black	<=75

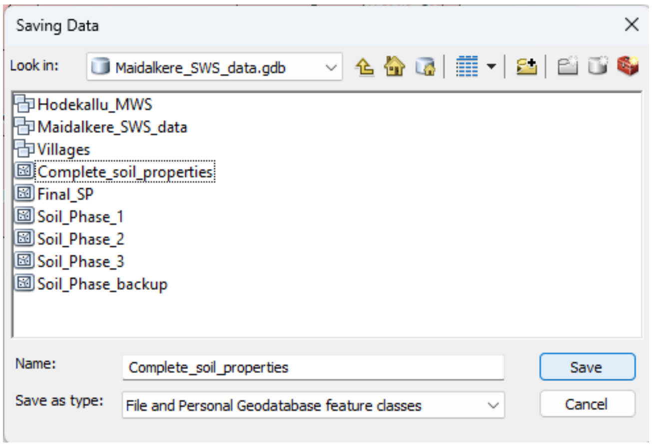
(0 out of 37 Selected)

Soil_Phase

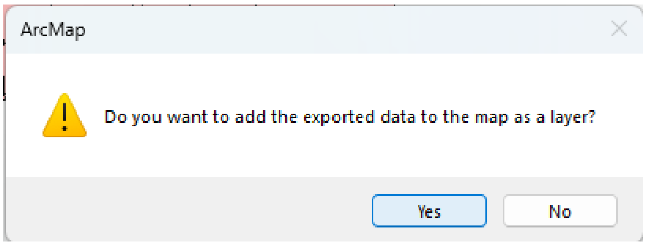
To save the changes export the “Soil Phase” feature class into a new feature class as the image below,



Another pop-up window will appear, browse the folder/geodatabase and provide the name. In this case it is “Complete_soil_properties”. Click “save” and then OK.



If asked to add the feature class into the map, click "Yes", and verify the attribute table of the feature class (Complete_soil_properties) for all the fields.



This completes the process of utilizing the DSS tool.

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